Handbooks for Genebanks: No. 3

HANDBOOK OF SEED TECHNOLOGY FOR GENEBANKS

Volume II. Compendium of Specific Germination Information and Test Recommendations

International Board for Plant Genetic Resources

CHAPTER 16. INTRODUCTION TO VOLUME II: THE ORGANIZATION OF CHAPTERS AND AN EXPLANATION OF ABBREVIATIONS

Volume I of Handbook of Seed Technology for Genebanks dealt with many of the principles of seed testing which need to be understood when monitoring the viability of seed accessions maintained in gene banks. It will have become clear that one of the main problems facing those who have the responsibility for monitoring seed viability in gene banks is that seed dormancy can often interfere with the results of germination tests designed to estimate the percentage viability of accessions. The extent of the problem varies between species and between accessions within species, and the techniques which are most appropriate for minimising dormancy in germination tests also vary. In some species the problems are sufficiently understood so that prescriptions for germination tests have been developed which enable dormancy to be removed completely. In other species sufficient is known to minimise the problem of dormancy so that it is no longer a serious problem. However, there are still many species where existing techniques for dormancy removal are unsatisfactory, and yet others where the information on dormancy is meagre.

This volume provides general approaches, detailed information, guidance and, where available, prescriptions for removing dormancy and germinating the seeds. Since completely satisfactory prescriptions are relatively rare, Chapter 17 deals with general approaches which may help staff in gene banks develop their own techniques for solving dormancy problems.

The subsequent chapters (Chapters 18 to 75) provide information, family by family, on the germination of individual species of crop plants and sometimes their wild relatives. These chapters are essentially for consultation and, since the amount of information is large, considerable use is made of abbreviations. The final chapter (Chapter 76) summarises the germination test recommendations which are available for species outside the 58 families covered by Chapters 18 to 75.

The rest of this chapter is essential to understanding Volume II since it explains the structure and abbreviations used. It also provides guidance on the preparation of solutions commonly used in dormancy-breaking treatments.

THE STRUCTURE OF CHAPTERS 18 TO 75 AND ABBREVIATIONS USED IN THIS VOLUME

Each chapter which deals with a single family begins with a short introduction which includes, where available, the algorithm for devising dormancy-breaking techniques developed by staff at the Wakehurst Place Gene Bank (see Chapter 17). A comment is also provided on seed morphology if this is considered to be of help in devising appropriate treatments to promote germination. Prescriptions for germination test procedures and recommendations for dormancy-breaking treatments from various sources, but primarily the ISTA and AOSA rules, are tabled for species within genera where more detailed information is not provided within the chapter. Most alternating temperature regimes are diurnal cycles of 16h/8h and, to save space, only exceptions to this general rule are noted in these tables. The following abbreviations are used within these tables, and also Chapter 76, to describe the source of information.

AOSA AOSA (1981). Rules for testing seeds. Journal of Seed Technology, 6, 1-126.

Atwater Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technology, 8, 523-573.

Ballard Ballard, L.A.T. (1972). High sensitivity to temperature of the germination responses of seeds of Townsville stylo (Stylosanthes humilis H.B.K.). Proceedings of the International Seed Testing Association, 37, 779-791.

B&B Ballard, L.A.T. and Buchwald, T. (1971). A viability test for seeds of Townsville stylo using thiourea, Australian Journal of Experimental Agriculture and Animal Husbandry, 11, 207-210.

Butler Butler, J.E. (1975). Germination of Stylosanthes humilis (Townsville stylo) in short cycles of alternating temperature. Seed Science and Technology, 3, 523-528.

Cameron Cameron, D.F. (1967). Hardseededness and seed dormancy of Townsville lucerne (Stylosanthes humilis) selections. Australian Journal of Experimental Agriculture and Animal Husbandry, 7, 237-240.

CHML Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

Everson Everson, L. (1949). Preliminary studies to establish laboratory methods for the germination of weed seed. Proceedings of the Association of Official Seed Analysts, 39, 84-89.

Fornerod Fornerod, C. (1975). Remarques sur la germination des semences potageres en laboratoire. Revue Horticole Suisse, 48, 6-9.

G&R Gordon, A.G. and Rowe, D.C.F. (1982). Seed Manual for Ornamental Trees and Shrubs. Forestry Commission Bulletin 59, 132pp., HMSO, London.

Heit Heit, C.E. (1948). Laboratory germination test results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

Holm Holm, A. McR. (1973). Laboratory procedures for germinating Townsville stylo seed pods. Journal of the Australian Institute of Agricultural Science, 39, 75-76.

ISTA ISTA (1985). International rules for seed testing. Seed Science and Technology, in press. (We are most grateful to Dr. S. Cooper for providing draft copies of the new rules prior to publication.)

M&O Maguire, J.D. and Overland, A. (1959). Laboratory germination of seeds of weedy and native plants. Washington Agricultural Experiment Station Circular 349, 15pp.

McIvor McIvor, J.G. (1976). Germination characteristics of seven stylosanthes species. Australian Journal of Experimental Agriculture and Animal Husbandry, 16, 723-728.

M&M Mott, J.J. and McKeon, G.M. (1979). Effect of heat treatments in breaking hardseededness in four species of Stylosanthes. Seed Science and Technology, 7, 15-25.

Oakes Oakes, A.J. (1984). Scarification and germination of seeds of Leucaena leucocephala (Lam.) De Wit. Tropical Agriculture (Trinidad), 61, 125-127.

O&W Olvera, E. and West, S.H. (1985). Aspects of germination of leucaena. Tropical Agriculture (Trinidad), 62, 68-72.

Riley Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

R&S Rogers, B.J. and Stearns, F.W. (1955). Preliminary studies on the germination of weed seeds. Proceedings of the North Central Weed Control Conference, 12, 7.

SGCF Steinbauer, G.P., Grigsby, B., Correa, L. and Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-51.

Most chapters then go on to provide a more detailed summary and analysis of seed germination responses to treatments, genus by genus, for the more important species where information is available. This information is restricted mainly to orthodox species, but information on a few recalcitrant species is provided where dormancy is known to be a potential problem. The layout of information within each genus is as follows.

At the beginning of each genus a catalogue is provided of those species for which some information is given. The catalogue includes botanical synonyms and common names. It

should be noted that sometimes identical synonyms may be given for species within another genus. Where this occurs and information is provided for the second genus the reader should consider the information provided for both genera. The information on dormancy-breaking techniques and germination test regimes for each genus is divided into seven sections. Note that although the term dormancy is used in the titles below information on factors other than dormancy per se (see definition in Chapter 5, Volume I), particularly hardseededness (Chapter 4, Volume I), is also included.

I. Evidence of dormancy

This section simply provides evidence of whether dormancy can be a problem and attempts to place it in context - often by giving details of how long after harvest 'post-harvest' dormancy typically remains a problem under ambient conditions. Differences in the degree of dormancy between species within the genus are sometimes noted. Other problems may be noted in this section. For example, it is sometimes necessary to draw attention to the classification of seed storage behaviour (see Chapter 1, Volume I) where this has been in some doubt.

II. Germination regimes for non-dormant seeds

In the majority of cases this section provides details of the prescribed germination test conditions for species within the genera given by the ISTA and the AOSA - where these are available. The ISTA and AOSA rules are divided into three parts here.

The first information is the method (or methods) of providing the medium for the germination test. The abbreviations used and their meanings are:

TP test on top of paper, that is, place the seed on filter papers, blotting papers or paper towels in a petri-dish or similar container.

BP test between paper, including rolled paper towels and pleated papers.

S test in (sterilized) sand.

TS test on top of (sterilized) sand.

Often more than one medium is suggested. In this case choose whichever is the more suitable for your laboratory.

The information after the first colon gives the prescribed temperature regime for the germination test. An alternating temperature regime is denoted by A°/B°C (xh/yh), where A°C is provided for x hours per day and B°C provided for the remaining y hours per day; e.g. 20°/30°C (16h/8h) means germinate in a continuous alternating temperature regime in which the seeds are subjected to 20°C for 16 hours followed by 30°C for 8 hours each day. Often alternative temperature regimes are provided. The alternative regimes are separated by semi-colons.

The final information provided (after the second colon) is the total germination test period in days, but of course seedlings may have to be removed and counted at more frequent intervals. Moreover, it is likely that in many cases gene banks will have to continue germination tests beyond these periods.

The provision of both the ISTA and the AOSA prescriptions for germination test regimes (where these are available for a species) allows the reader to compare and contrast the two sets. In the main these are quite similar, but where they occur the differences of detail should be noted.

In addition to the ISTA and AOSA rules this section also includes other published information,

where available, on germination test procedures which are satisfactory for non-dormant seeds.

III. Unsuccessful dormancy-breaking treatments

The third section gives details of treatments that have been applied to seeds in attempts to break dormancy, but which have either failed to increase germination more than marginally or may have even led to a reduction in germination - either by inducing dormancy in the seeds or by damaging the seeds in some way. Although at first sight the reader may consider this information to be of no interest - after all the requirement is to promote germination - it is important to be aware of those treatments which should be avoided. Moreover, the reader will begin to notice that similar treatments may appear in more than one section. These apparent inconsistencies and contradictions, often between different reports, are nevertheless probably indicative of the real situation: a treatment which greatly promotes the germination of seeds of one accession, may fail to promote the germination of seeds of another accession, whilst in a third accession germination may be reduced by the treatment. Hence the inclusion of this information here.

IV. Partly-successful dormancy-breaking treatments

Treatments detailed in this section have promoted the germination of some dormant seeds, but have either failed to promote the germination of all the dormant seeds within a single accession, or within a report they may have promoted full germination in some accessions but not promoted full germination in other accessions.

V. Successful dormancy-breaking treatments

The ISTA and/or the AOSA recommendations for breaking dormancy are provided first of all in this section (where available for a species). The style of layout is different from, and less detailed than, that given for other sources of information. The reasons for this are to highlight the ISTA and AOSA recommendations and to avoid repetition of the treatment details, which are given below.

Pre-chill: Seeds are placed in contact with the moist substratum and kept at a low temperature for an initial period before being moved to the germination test temperature. With the exception of tree seeds, the pre-chill temperature is between 5° and 10°C and the initial treatment period up to 7 days, although in some cases - particularly the more dormant of the grasses - this may be extended to 14, or, rarely, 28 days. Tree seeds are kept at 3°-5°C for between 7 days and a year.

Pre-dry: Before imbibition the dry seeds are heated at a temperature not exceeding 40°C with free air circulation for up to 7 days.

Potassium nitrate: The germination test paper is moistened with a 0.2% solution of potassium nitrate (see below for details of solution preparation).

GA_3: The germination test paper is moistened with 200-1000 ppm of gibberellic acid (see below for details of solution preparation).

Pre-wash: Seeds are soaked and washed in running water at between 20° to 25°C for 2 hours or so to remove substances in seed (or fruit) coats which may inhibit germination.

Test at: An alternative germination test regime is suggested if difficulties are encountered at the prescribed germination test temperatures (given in II. Germination regimes for non-dormant seeds).

The information which follows the ISTA and AOSA recommendations (where available) provides details of those treatments which have been reported to be fully effective in promoting the germination of all, or nearly all, dormant seeds within accessions. Note, however, that these treatments may on occasion be the same as those given in the preceding sections: that is a treatment found to be successful for one seed lot may not have been successful when applied by another worker to a different seed lot.

VI. Comment

This section may point out problems with the ISTA/AOSA prescriptions and recommendations, conflicts between various reports in the literature and attempt to provide a guide to devising appropriate germination test regimes. In a few cases germination test prescriptions may be given; in rather more cases the more suitable techniques will be suggested with alternatives in the event of failure. The symbol A in this section indicates unpublished work by the authors of this report.

VII. References

Within each genus the numbers in brackets refer to the references provided in the last section. These are numbered in alphabetical order with the exception of those references added in final revisions of this manuscript. It is envisaged that gene bank staff will consult only a very few of these references, if at all. Most, if not all, of the relevant information has been extracted and summarised in the sections I to VI.

Shorthand used to describe treatments

A shorthand notation has been devised to present the information in as concise a form as possible. A description of the treatment is given before the colon; the information following the colon gives precise treatment details - where available. Some examples follow.

Alternating temperatures: (4); 20°/30°C, 20°/35°C (16h/8h) (8)

Potassium nitrate: pre-applied, 24h, 0.1-1% (7); co-applied, 0.1, 0.2%, at 25°C (6)

Light: (10); dark, continuous (12); red, 15 min/d (3)

These have the following meaning:

Reference 4 reported that alternating temperatures were used but no treatment details were given. Reference 8 applied alternating temperatures of either 20°C for 16 hours per day and 30°C for 8 hours per day or 20°C for 16 hours per day and 35°C for 8 hours per day. Reference 7 treated the seeds to potassium nitrate solutions between 0.1 and 1% - with several intermediate concentrations - for one day before beginning the germination test which was then carried out on a substrate moistened with water - hence pre-applied. Reference 6 moistened the germination test substratum - hence co-applied - with either 0.1% or 0.2% potassium nitrate (but at no intermediate concentrations) and the germination test was at a constant temperature of 25°C. Reference 10 reported that a light treatment was given but no details were reported. Reference 12 carried out the germination test in the dark. Reference 3 exposed the seeds to red light, but only for 15 minutes per day.

Often incomplete treatment details are provided. References 4 and 10 above provide examples of the layout in such cases. Incompleteness is usually because the information was not provided by the paper referred to, but sometimes we have omitted information that appears to us to be mistaken or misleading.

It is possible that mistakes in interpretation or transcription may have been made. We apologise to the authors of any papers cited if this has occurred and would welcome

correspondence pointing out any errors or omissions, and particularly welcome further details of successful dormancy-breaking treatments.

In passing it should be noted that certain regimes are referred to very frequently. For example, diurnal alternating temperature regimes of 20°/30°C, where the higher temperature is applied for 8 hours per day combined with co-application of 0.2% potassium nitrate are often mentioned. This is because it is a germination test regime recommended by ISTA/AOSA for a large number of species and a large number of workers have tested the response of seed germination to this regime as a consequence. However, often this regime appears superior by default - since other regimes will not necessarily have been tested. Consequently the reader is reminded that the information reported here is in that sense limited: other, more favourable, germination test regimes and dormancy-breaking treatments may exist which have not yet been the subject of investigation.

Abbreviations

The following abbreviations have been used to provide treatment details.

cm^{-2}	per square centimeter
°C	degrees Celsius
d	day
g	gramme
GA	gibberellins, the subscript denoting the particular gibberellin; GA_3 is the most commonly applied gibberellin.
h	hour
j	joule
kc	kilocycles, that is 1000 cycles
l	litre
m	month
m^{-2}	per square metre
M	Molar, that is the molecular weight in grammes dissolved in a litre
min	minute
ml	millilitre, that is 10^{-3} litre
mol	$6.02x10^{23}$ photons - see Chapter 6, Volume I
N	normal, that is the number of gramme-equivalents of the substance dissolved in a litre of solution where one gramme equivalent equals the gramme-molecular weight of the substance divided by its hydrogen equivalence.
nm	nanometre, that is 10^{-9} meteres - see Chapter 6, Volume I
pH	concentration of hydrogen ions given as the negative logarithm of hydrogen ion activity
ppm	parts per million, equivalent to 0.0001% (see below)
R	Roentgen, a unit of ionizing radiation
s	second
s^{-1}	per second
W	watt - see Chapter 6, Volume I
/	between two temperatures or time period indicates an alternating regime (usually alternating temperature)
/	followed by another symbol indicates per, e.g./d = per day
%	percentage concentration, usually in terms of weight per volume (w/v), that is g/100 ml of solution

How to utilise the information provided for each genus

It is not intended that all seven sections of the information on seed germination provided for each genus should necessarily be read in sequence. The following approach is suggested.

After reading the introduction to the family - and Table 17.1 or Table 17.2 if either is referred to - read sections I (Evidence of dormancy) and VI (Comment).

In most cases these sections will provide sufficient information to decide upon a suitable germination test procedure and whether to apply one or more dormancy-breaking treatments - and, if so, the details of these treatments. Reference to sections II (Germination regimes for non-dormant seeds) and V (Successful dormancy-breaking treatments) may help to clarify the details of these treatments and procedures.

The information provided in sections III (Unsuccessful dormancy-breaking treatments) and IV (Partly-successful dormancy-breaking treatments) should help the reader to understand why certain dormancy-breaking treatments and germination test procedures are to be preferred and why others are best avoided. This information, however, will probably be of more use to those attempting to devise and develop improved germination test procedures and dormancy-breaking treatments if the advice presently available (Comment) is found to be inadequate or inappropriate for an accession.

For gene banks handling comparatively few genera Section VII (References) could form the basis of a reference library of articles on seed germination and dormancy. However this is not essential in view of the information summarised in this manual. More useful will be the information generated from the results of germination tests on material maintained within the gene bank.

Commencing an alternating temperature germination test

If seeds are to be tested in an alternating temperature regime it must be decided which of the two temperatures the seeds are exposed to first. There are three main possibilities:

(1) Initially expose the seeds to the first stated temperature of the alternating temperature regime. For example, in the case of the regime 20°/35°C (16h/8h) the seeds would be exposed to 20°C for 16 hours before their first exposure to 35°C.

(2) Expose the seeds to the lower of the two temperatures first. For example, in the above alternating temperature regime 20°C is the lower temperature and the seeds are thus exposed to 20°C for 16 hours before their first exposure to 35°C.

(3) Expose the seeds to the longer duration of the two phases first. In the above example 20°C is applied for the longer duration and thus the seeds are exposed to 20°C for 16 hours before their first exposure to 35°C.

Where a regime is described as, for example, 30°/10°C (16h/8h) it will be seen that it is not possible to satisfy all three possible rules. We suggest that it is logical for the first stated temperature to be the initial temperature to which the seeds are exposed and that, therefore, the first rule should take priority over all others. It is important that the protocol to describe alternating temperature regimes be explicitly stated and consistently applied in gene banks.

Application of light during part of alternating temperature cycles

When light is applied during part of an alternating temperature cycle it is the usual practice for the light treatment to coincide with the higher temperature phase (as would occur in a natural environment). If the light is applied once a day for a lengthy period, it is also convenient for the duration of any light treatment to be the same as that for the higher temperature phase of the alternating temperature cycle. This is because the heat generated by the lights (even

fluorescent tubes) will affect the maintenance of temperature. Thus if the periods of exposure to the higher temperature and to light coincide throughout then the higher temperature of the germination environment can be set taking into account the heat generated by the lights. It is important that the protocol adopted for the provision of light during alternating temperature regimes be explicitly stated and adhered to. For more information on light and seed germination see Chapter 6, Volume I.

MAKING UP SOLUTIONS

Two of the more common dormancy-breaking treatments pre-applied or co-applied to seeds are potassium nitrate and gibberellic acid. The preparation of solutions of these and other compounds will be required in most, if not all, gene banks. Consequently some notes on the preparation of solutions are provided below.

To make up a 0.2% solution of potassium nitrate, 2 g of potassium nitrate is dissolved in one litre of distilled or deionised water. (It is not essential to make up a whole litre of solution. For example, 1 g dissolved in 500 ml would also provide a 0.2% solution.) To make up a 500 ppm solution of GA_3 dissolve 0.5 g GA_3 in one litre of distilled or deionised water. GA_3 generally takes a long time to dissolve in water and considerable stirring; with a glass rod, may be required before all the GA_3 has dissolved. Strong concentrations of GA_3, above 800 ppm, will reduce pH. To avoid this it is generally advised to use a buffer solution of 0.01 M di-sodium hydrogen orthophosphate dihydrate/di-sodium hydrogen orthophosphate monohydrate for GA_3 concentrations of 800 ppm and above. This solution is prepared by dissolving 1.7799 g of di-sodium hydrogen orthophosphate di-hydrate ($Na_2HPO_42H_2O$) and 1.3799 of di-sodium hydrogen orthophosphate monohydrate ($Na_2HPO_4H_2O$) in distilled or deionised water and making up to one litre. The GA_3 is then dissolved in this buffer solution.

Solution concentrations

Throughout the report the concentrations of solutions of potential dormancy-breaking agents are expressed in the style given by the reference. To enable the reader to convert between these different forms of presentation, Figure 16.1 has been provided. In particular the grammes per litre scale (g/1, or g 1^{-1}) provides sufficient information to enable the reader to make up the required concentrations of solutions. The only additional information required to use Figure 16.1 is the molecular weight of the potential dormancy-breaking agent. These are usually provided on the labels of chemical containers. Some values are provided here in Table 16.1, but more comprehensive information is available from chemical company catalogues and Merck's Index. The latter is particularly recommended. The use of Figure 16.1 is described in the caption.

ADDITIONS AND AMENDMENTS

The chapters which follow are very much a first attempt at pooling practical information concerning methods of overcoming seed dormancy and promoting germination. It is intended that this report should be referred to on a day to day basis. Readers might like to use the space after the information on each genus to append their own notes of any additional information they consider useful. Perhaps the most striking point illustrated by the format used here is how little is known of satisfactory treatments to break dormancy in seed of so many species. Note that whilst the literature on seed dormancy is considerable, that concerned with regimes capable of promoting full germination for many accessions is extremely limited. The authors hope that this realisation will spur readers on to add to this knowledge. We welcome reports of successful dormancy-breaking treatments which can be included in subsequent revisions or amendments to this handbook.

TABLE 16.1. The molecular weights of selected compounds which have been applied to seeds as putative dormancy-breaking agents.

	Molecular Weight
Abscisic acid	264
Acetaldehyde	44
Acetamide	59
Acetic acid	60
Alanine	89
Ammonium bisulphide	51
Ammonium bisulphite	99
Ammonium chloride	53
Ammonium nitrate	80
Ammonium phosphate, dibasic	132
Ammonium phosphate, monobasic	115
Ammonium sulphate	132
Ammonium sulphide	68
Ammonium sulphite	116
Ascorbic acid	176
Boric acid	62
Calcium hypochlorite	143
Calcium nitrate	164
Diethyl dithiocarbanate, sodium	171
Dimercaprol (Dithioglycerol)	124
Dinitrophenol	184
Dithiothreitol	154
Ethrel (Ethephon or CEPA)	144
Gibberellic acid	346
Hydrogen peroxide	34
Hydrogen sulphide	34
Hydroxylamine hydrochloride	70
Indoleacetic acid	186
Ketoglutaric acid	146
Kinetin	215
Mercaptoethanol	78
Methylene blue	374
Napthaleneacetic acid	186
Nitric acid	63
Potassium cyanide	65
Potassium nitrate	101
Potassium nitrite	85
Potassium permanganate	158
Potassium sulphate	174
Potassium thiocyanate	97
Potassium thiosulphate	190

Sodium azide	65
Sodium fluoride	42
Sodium hydroxide	40
Sodium hypochlorite	74
Sodium nitrate	85
Sodium nitrite	69
Sodium sulphide	78
Sodium thiocarbonate	154
Sodium thiocyanate	81
Sodium thiosulphate	158
Sucrose	342
Sulphuric acid	98
Thiourea	76
Uranyl nitrate	394
Urea	60

How to use Figure 16.1

The first three scales of the nomograph differ by factors divisible by ten. To convert between these values place a ruler on the diagram perpendicular to these axes and read off the values. To determine molarity connect up the concentration in grammes per litre with the molecular weight of the compound (see Table 16.1) with the straight edge of a ruler. The point where the ruler crosses the molarity scale gives the value of the molarity of the solution. Alternatively if it were required to make up a solution of a given molarity, connect up this value with the molecular weight of the compound with the straight edge of a ruler and note the point on the grammes per litre scale where the straight edge crosses.

Two examples of the use of the nomograph are shown by broken lines. The uppermost broken line is for potassium nitrate - molecular weight 101. A 0.2% solution is the same as a 2000 ppm solution and is made by dissolving 2 grammes of potassium nitrate in one litre. The resultant solution can also be described as 0.02 M or as $2x10^{-2}$ M. The lower broken dotted line is for GA_3 - molecular weight 346. Thus, for example, a 500 ppm GA_3 solution is 0.0015 M ($1.5x10_{-3}$ M) and can be obtained by dissolving 0.5 grammes of GA_3 in one litre of solution.

CHAPTER 17. GENERAL APPROACHES TO PROMOTING SEED GERMINATION

Deciding appropriate germination test regimes for accessions so that germination tests reflect true viability with minimum interference from dormancy (and other factors which limit germination, such as hardseededness) can be one of the more difficult decisions which gene bank staff need to make. In the following chapters we have summarised useful information on the germination response of seeds of various genera to very many test regimes and dormancy-breaking treatments together with advice on suggested test procedures. In many cases, however, the information available is far from complete and accordingly much of the advice is very tentative. In such cases it is hoped that gene bank staff will be able to improve on the suggestions made. In order to help in this endeavour, in this chapter we discuss four different types of approach to determining appropriate germination environments.

ECOLOGICAL GUIDELINES TO DEVELOPING APPROPRIATE GERMINATION ENVIRONMENTS

A consideration of the ecology of a species may sometimes help to provide some guidance as to appropriate germination test conditions. At the simplest level tropical species generally require higher temperatures for germination than temperate species. However, there are other more subtle responses which relate to the strategy of the plant in relation to its natural environment and a consideration of these may help in the development of germination test conditions which minimise dormancy.

Dormancy may prevent seeds from germinating in the wrong place at the wrong time

As mentioned in Chapter 5 (Volume I) the majority of mature seeds show innate (or inherent or primary) dormancy - a condition necessary to prevent germination on the mother plant before the seed is shed. Innate seed dormancy in most species tends to be gradually lost with time (except in some tree species), often at a rate depending on temperature and moisture content. But induced (or secondary) dormancy, in many respects similar to innate dormancy, may subsequently be induced by conditions which signal that the current environment is inappropriate for germination - e.g. high temperatures or anaerobic conditions. Furthermore enforced dormancy may be temporarily imposed by conditions which again appear to play a role in ensuring that the seed only germinates when there is a reasonable probability of the seedling growing to maturity. Dormancy in all its forms (see Chapter 5, Volume I) therefore tends to prevent seeds from germinating in the wrong place at the wrong time.

Field environment

For example, many annual or ephemeral species produce large numbers of small seeds. At any one time it is common for there to be more dormant seeds in the soil waiting for appropriate conditions than there are growing plants. Since small seeds only contain small food reserves, only a small amount of seedling growth can occur before the seedling needs to start photosynthesising. Thus germination more than a few centimetres below the soil surface or beneath dense vegetation could lead to seedling destruction. It would seem that many species have evolved dormancy mechanisms which avoid these problems. The seed needs to be able to respond to environmental factors that signal when it is at or near the soil surface. There seem to be two major environmental factors which many species use as indicators - light and alternating temperatures; and in most cases the seeds respond to both. Light is obviously only present at or near the soil surface; and diurnal temperature alternations have a maximum amplitude (or diurnal range) at the soil surface: the range rapidly diminishes with depth in the soil profile. Furthermore even at the soil surface the amplitude is diminished by the presence of vegetation. Since vegetation contains chlorophyll which absorbs strongly in the red region of the spectrum, the quality of light beneath vegetation may be inhibiting since far-red light penetrates much more and thus the light quality tends to affect the balance of phytochrome in the seeds in favour of the inactive Pr form (see Chapter 6, Volume I).

Accordingly it is very common for small seeds of annuals and ephemerals to be light-sensitive and to germinate in response to white (or red) light and alternating temperatures. In many cases neither of these factors on their own has a major effect and both are necessary for a maximum response. Both these factors also often interact with nitrate ions.

Maternal environment

It may be worth considering the maternal environment in which the seeds develop as a further guide to distinguishing those species likely to require light treatments in order to promote seed germination. The light-filtering properties of the maternal tissues which surround the developing seeds, whilst they remain moist, can affect the sensitivity of seed germination to light in subsequent environments. Where the maternal tissues have a high chlorophyll content (that is are green) the seeds tend to require a light stimulus for germination (in subsequent tests). In contrast those seeds which have developed within maternal tissues where the chlorophyll content declined whilst the seeds remained moist tend to be able to germinate subsequently in light or darkness (that is are light insensitive). This is because the seeds developing within green maternal tissues would have received light filtered by the chlorophyll. This light would have a low red/far red ratio and most of the phytochrome would be in the inactive Pr form. In the latter case, however, the light would not have been filtered to such an extent; the red/far red ratio of the light received by the seeds would have been greater and thus more of the phytochrome would be in the active Pfr form which promotes germination. This Pfr would remain after desiccation and subsequent imbibition and accounts for the insensitivity of these seeds to light.

Large-seeded species of arid environments

As mentioned in Chapter 6 (Volume I), sustained and/or high-intensity light can also inhibit the germination of some seeds. This response is more common amongst somewhat larger seeds of species of arid environments, where it is more important

for seeds to germinate below the soil surface where short-term severe water shortage is less likely, and the probability of the shoot not reaching the soil surface before food reserves are reduced is lessened by the larger food reserves of the seed.

In desert regions where rains are infrequent and of limited duration, ephemeral plants have short life cycles and it is important for them to germinate only after a substantial fall of rain (and not after a minor shower which would not provide sufficient water for survival). In such cases seeds of some species appear to have their own 'rain gauge' which depends on the fact that it takes a certain minimal amount of rain to leach germination inhibitors. Thus in such cases germination may be stimulated by washing the seeds in running water.

Probability of plant establishment and survival

Dormancy mechanisms often also tend to ensure that the seeds do not germinate at times when the probability of the survival of the plant to maturity is poor. For example, many seeds in temperate latitudes tend to germinate after the winter, i.e. at the beginning of the main growing season. These seasonal considerations are often independent of seed size and thus many temperate species germinate best after a period of stratification (i.e. cool temperatures applied to moist seeds). Such a response ensures that seeds do not germinate at the beginning of winter. In contrast, seeds of species from Mediterranean climates tend to avoid germination at the beginning of the hot, dry summer and germination at the beginning of the cool moist winter is more common. In such cases it would be less likely to find marked responses to stratification. This would also be generally true of tropical plants, but see the note below.

In tropical rain forests the temperature and water supply is always adequate for growth and so seeds of such species often show little dormancy. Seeds of many of the woody perennial species are also recalcitrant. Such seeds do not have to survive long periods in the dry conditions, and fresh supplies of short-lived seeds are produced regularly by the mature plants. Many seeds of this type show little dormancy, and many are killed by cool temperatures (e.g. less than 10° to 15°C) which they would never normally experience. However, even in tropical forests some species are not recalcitrant, and some may show light responses to ensure that they only germinate when a gap arises in the forest canopy and/or the soil is disturbed after clearance, thus ensuring that early growth is not inhibited by low light intensity.

There are, of course, exceptions to these general principles. In particular it should be noted that laboratory treatments which emulate environments which the seeds would never experience in their natural habitat may sometimes promote germination. For example, low temperatures applied to moist seeds of some species of tropical and sub-tropical ecotypes can promote germination. Nevertheless the few examples above may be sufficient to indicate that a consideration of the ecology of the species may give useful clues as to the type of laboratory germination techniques which may be most appropriate.

Further reading

Cresswell, E.G. and Grime, J.P. (1981). Induction of a light requirement during seed development and its ecological significance. Nature, 291, 583-585.

Grime, J.P., Mason, G., Curtis, A.V., Rodman, J., Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. Journal of Ecology, 69, 1017-1059.

THE ANATOMICAL APPROACH TO DEVELOPING APPROPRIATE GERMINATION ENVIRONMENTS

This approach has been developed largely by B.R. Atwater from long experience of attempting to germinate seeds of flower and ornamental species. Atwater's observations suggest that dormancy and germination requirements in these species are closely related to the maturity of the embryo and the structure and permeability of the seed coat coverings in the mature seed.

Atwater has described eight basic forms of seed structure. These categories have been described in Chapter 3 (Volume I). Within each of these categories it is suggested that the seeds have similar dormancy and germination patterns, but it should be emphasised that the mechanisms suggested are hypotheses rather than established facts.

I. Seeds with dominant endosperm (ENDOSPERMIC SEEDS) and immature dependent embryos (that is embryos not ready to germinate)

A. BASAL RUDIMENTARY EMBRYOS

The rudimentary embryos are the principal cause of delayed germination in this group. Inhibitors found in the endosperm may also contribute to the delay. Treatment consists of neutralization of the inhibitors with leaching, or with extra oxygen at low temperature followed by higher temperatures favourable to rapid embryo growth. Gibberellic acid increases the rate of embryo development if added to the substrate.

B. AXILLARY LINEAR EMBRYOS

Linear embryos are similar to the above. An additional block is added by the seed coats which may limit oxygen entry, but seed coat permeability may be increased when the seeds are exposed to light. Gibberellic acid added to the substrate increases the rate of embryo development.

C. AXILLARY MINIATURE EMBRYOS

Miniature seeds having minimal embryos are protected by thin seed coats showing a light requirement for oxygen permeability. Germination is prompt. Gibberellic acid is an aid, but not a substitute for light.

D. PERIPHERAL LINEAR EMBRYOS

Peripheral embryos which surround the food storage organ rather than being contained within it have multiple seed coverings which contain inhibitors, and which form barriers to both oxygen and water. Treatment is primarily leaching of the inhibitor but

cold or light treatments may be required to increase permeability. Removal of the seed covering structures is also effective.

Summaries of seed anatomy, blocks to germination, successful germination test regimes and families exhibiting these characteristics are provided in Table 17.1 for endospermic seeds.

TABLE 17.1 ENDOSPERMIC SEEDS: Anatomy and Germination

		A. BASAL RUDIMENTARY EMBRYO	B. AXILLARY LINEAR EMBRYO	C. AXILLARY MINIATURE EMBRYO	D. PERIPHERAL LINEAR EMBRYO
SEED ANATOMY	embryo	small, show little differentiation,	linear in a central axillary	linear-spatulate in a central	curved in a peripheral position
		basal location	Position	axillary position	surrounding the perisperm or endosperm
	cotyledons	obscure and limited to a few cells	minimal: thin, narrow and shorter than the stalk	not expanded and equal to the stalk	thin, narrow and equal to the stalk
	endosperm	occupies most of seed and surrounds embryo	occupies half or more of seed and surrounds the central embryo	occupies half or less of the seed and surrounds the central embryo	centrally placed within the curved envelope
	seed coat	permeable and fibrous or reticulated	thin, reticulous or fibrous: may be semi-permeable	thin and fragile	thin testa, leathery outer coat and often parts of the calyx
	seed size	medium, 2-4 mm long	medium-large, 3-10 mm long	small, 1 mm long or less	medium-large, 2-6 mm diameter
	example	Anemone coranaria	Cyclamen persicum	Nemesia strumosa	Portulaca grandiflora
	embryo	must develop before germination, hence delay	must develop before germination, hence delay		
BLOCKS TO GERMINATION	endosperm	inhibitors to germination may be present			
	seed coat	permeable, no block to germination	may be semi-permeable	permeable if light provided	may be impermeable and contain inhibitors
	temperature	temperate species 15°C; others 20°C, 20°/30°C	15° to 20°C; 10°/30°C or 20°/30°C	10°, 15° or 20°C; 20°/30°C, 10°/20°C or 5°/30°C	10°, 15° or 20°C (rarely 3°-6°C); 20°/30°C
	test duration	14-28d; in extreme cases 100-155d	14-28d; in extreme cases 40-60d	10-28d; in extreme cases 40-60d	5-28d; in extreme cases 65-75d
	KNO_3	*0.2%	*0.2%	*0.2%	0.2%
SUCCESSFUL GERMINATION TEST	GA_3	*100-400 ppm	*400-800 ppm	120-400 ppm	
	pre-chill	2w at 3°-5°C, or (rarely) test throughout at 5°-8°C	8w at 5°C	2-4w at 5°C	
REGIMES (*most widely applied treatments)	light	probably insensitive	*insensitive or sensitive (promotory, may aid imbibition)	*sensitive (promotory); supply red light for up to 70h either continuously or 12h per day	*may be insensitive or sensitive (promotory)
	seed coats	partial removal of pericarp	may be necessary to remove endosperm over radicle		*remove (calyx and) outer coats; pierce, chip (clip)
	pre-soak	hot water; 0.5h in 1N KOH or other alkaline solutions			pre-wash in water
PLANT FAMILIES WITH SPECIES EXHIBITING THESE CHARACTERISTICS		ARALIACEAE, FUMARIACEAE, PAPAVERACEAE, RANUNCULACEAE	ERICACEAE, GENTIANACEAE, PRIMULACEAE, RESEDACEAE, SOLANACEAE, TROPAEOLACEAE, UMBELLIFERAE	BEGONIACEAE, CAMPANULACEAE, CRASSULACEAE, HYPERICACEAE, LOBELIACEAE, SAXIFRAGACEAE, SCROPHULARIACEAE, SOLANACEAE	AIZOACEAE, AMARANTHACEAE, CACTACEAE, CAPPARIDACEAE, CARYOPHYLLACEAE, CHENOPODIACEAE, MESEMBRYANTHACEAE, NYCTAGINACEAE, POLYGONACEAE, PORTULACACEAE

TABLE 17.2 NON-ENDOSPERMIC SEEDS: Anatomy and Germination

		A. AXILE FOLIAR EMBRYOS WITH HARD SEED COATS	B. AXILE FOLIAR EMBRYOS WITH THIN, MUCILAGINOUS, SEED COATS	C. AXILE FOLIAR EMBRYOS WITH WOODY SEED COATS AND INNER SEMI-PERMEABLE LAYER	D. AXILE FOLIAR EMBRYOS WITH FIBROUS SEED COAT AND

					SEPARATE INNER SEMI-PERMEABLE MEMBRANOUS LAYER
SEED ANATOMY	embryo	spatulate, bent or folded and fills seed cavity	spatulate or bent and fills most of seed cavity	fills most of seed cavity	spatulate and fills most of seed cavity
	cotyledons	large, thickened and dominant over the stalk	large, thickened and dominant over the stalk	expanded and dominant	large and dominant embryo
	endosperm	reduced to a thin layer or lacking	thin layer around embryo or lacking	surrounds axillary embryo forming a lining of the seedcoat or none	thin layer(s) lining the membranous testa
	seed coat	hard	thin, may exude mucilage when wet, or contain a mucilaginous layer within	woody, usually achenes with fused or separate membranous testa	
	seed size	medium-large; 2-15 mm long	small-medium; 1-6 mm long	medium-large; 2-10 mm long	wedge-shaped achenes; 1-10 mm long
	example	Ipomoea purpurea	Iberis amara	Verbena x hybrida	Dimorphotheca sinuata
	embryo				inhibitors present in cotyledons
BLOCKS TO GERMINATION	endosperm	possibility of inhibitors in residual endosperm			impermeable to oxygen, gibberellins and inhibitors
	seed coat	impermeable when desiccated; imbibition through specialized valves or after scarification	becomes impermeable to oxygen and other gases as it absorbs water	permeable to moisture, but impermeable to some gases and inhibitors may be present within the seed coat	inhibitors may be present
	temperature	20°C; 20°/30°C	15°C, 20°C; 15°/25°C or 10°/30°C	15°, 20°, 25°C; 20°/30°C, 25°/35°C, 15°/25°C or 15°/30°C	15°,20°C; 15°/25°C or 20°/30°C
	test duration	14-28d; in extreme cases 40-50d	10-28d; in extreme cases 56-90d	9-28d; in extreme cases 40-60d (but excised embryos 2-4d only)	5-14d; in extreme cases 21-40d
	KNO_3		*0.2%	*0.2%	0.2%
	GA_3		*100-400 ppm	5 ppm	5-10 ppm
	pre-chill				60d at 2°-5°C with high oxygen conc.
SUCCESSFUL GERMINATION TEST	light	insensitive	*insensitive or sensitive (promotory)	*insensitive or sensitive (promotory)	insensitive or sensitive (promotory)
REGIMES (*most widely applied treatments)	seed coat	*file; chip (clip); excise embryo	excise embryo	*excise embryo; pierce, remove over radicle	*excise embryo from endosperm and seed coat; chip (clip) radicle end
	scarification	*mechanical; conc H_2SO_4 for 15 min to 4 h; absolute ethyl alcohol for 20-72 h; percussion (shake)			
	pre-soak	water at 50°-90°C for 30 sec-24h		400 ppm GA_3 or warm water for 24h	*in water or 5% chlorox or leach (even with excised embryos) away inhibitors with water
	after-ripen	dry at 95°C for 6 mins; dry over $CaCl_2$		2-3m dry storage	
PLANT FAMILIES		ANACARDIACEAE, CONVOLVULACEAE, GERANIACEAE, LEGUMINOSAE,	BALSAMINACEAE, CRUCIFERAE, LABIATAE, LINACEAE,	ACANTHACEAE, APOCYNACEAE, BALSAMINACEAE, BORAGINACEAE, CISTACEAE, DIPSACEAE, EUPHORBIACEAE, HYDROPHYLLACEAE,	COMPOSITAE (only)

WITH SPECIES EXHIBITING THESE CHARACTERISTICS		MALVACEAE, RHAMNACEAE, SAPINDACEAE	PLANTAGINACEAE, VIOLACEAE	LABIATAE, LIMNANTHACEAE, LOASACEAE, ONAGRACEAE, PASSIFLORACEAE, PLUMBAGINACEAE, POLEMONIACEAE, ROSACEAE, VALERIANACEAE, VERBENACEAE, ZYGOPHYLLACEAE	

II. Seeds with only residual or no endosperm (NON-ENDOSPERMIC SEEDS) and mature independent embryos (that is embryos ready to germinate)

A. HARD SEED COAT

Hard (impermeable) seed coats are present which limit the entry of water for imbibition. Treatment for allowing water entry is necessary and may be mechanical scarification, acid treatment, percussion, high temperature treatment or soaking. (See Chapter 7, Volume I, for more information on treatments to overcome hardseededness.)

B. THIN SEED COAT WITH MUCILAGINOUS LAYER

Mucilaginous seed coats limit oxygen availability to the embryo after imbibition. Gibberellic acid is the most effective additive but light and potassium nitrate are also helpful, particularly when treatment with the two agents is combined.

C. WOODY SEED COAT WITH INNER SEMI-PERMEABLE LAYER

Woody-textured and membranous multi-layered seed coverings cause blocks to germination which are most difficult to overcome. They readily admit water for imbibition but contain strong inhibitors which do not leach readily. Some of these are probably located in the thin residual endosperm surrounding the embryo or within the cotyledons of the embryo and are blocked from leaching by the semi-permeable membranous testa incorporated in the coverings. Excised embryos germinate promptly.

D. FIBROUS SEED COAT WITH SEPARATE SEMI-PERMEABLE MEMBRANOUS COAT

The Compositae family forms a specialised group which is similar to the preceding section. Embryos contain inhibitors in their cotyledons. Testa and thin endosperm form a separate membranous semi-permeable coat. An outer fibrous coat offers various dispersal forms. Extracted embryos grow promptly if leaching is complete.

Summaries of seed anatomy, blocks to germination, successful germination test regimes and families exhibiting these characteristics are provided in Table 17.2 for non-endospermic seeds.

Atwater has developed her ideas and experience almost to the stage of providing species prescriptions. Much of this information is summarised in subsequent chapters, but the problems inherent in species prescriptions are discussed below. Note also that certain plant families have species in more than one category of seed anatomy (e.g. Solanaceae, see Tables 17.1 and 17.2). If Tables 17.1 and 17.2 are used to develop germination test environments and dormancy-breaking treatments, it should be remembered that combinations of different dormancy-breaking agents are more likely to be successful than treatment with a single agent alone.

Further reading

Atwater, B.R. (1978). Dealing with stop-go germination in flower seeds. Acta Horticulturae, 83, 175-179.

Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technology, 8, 523-573.

Mullet, J.H. (1981). Germinating those problem seeds. Australian Horticulture, December 1981, 61-67.

PRESCRIPTIONS FOR GERMINATING ALL ACCESSIONS OF A GIVEN SPECIES

This approach to determining germination test environments is exemplified by the Rules of the International Seed Testing Association (ISTA) and the Association of Seed Analysts of North America (AOSA). Commercial seed testing has evolved over the past 130 years to provide a certain degree of assurance to farmers, growers and foresters that any seeds of agricultural, horticultural or arboreal crops that they may purchase are capable of germinating under normal field conditions, emerging above the soil surface and developing into plants which yield an adequate crop. Thus, by assessing the quality of seed lots before they are sown, commercial seed testing minimises the risk to the farmer, grower or forester of sowing seed lots which do not have the ability to produce an abundant crop. Since this assessment will be done by only one of many laboratories and since there is also considerable international trade in seed of many species, assessments by different seed testing laboratories must give similar results.

Compatibility between seed testing stations

To achieve compatibility of germination test results between different laboratories ISTA and AOSA co-ordinate and produce agreements between seed testing laboratories on the procedures to be applied for each species. We have discussed in Chapters 4 and 5 (Volume I) how the proportion of seeds which will germinate in a germination test can be affected by the test environment. Thus if seed testing laboratories used very different germination test conditions the results obtained in different laboratories could differ substantially. To aid compatibility ISTA and AOSA seek agreement between laboratories as to the most appropriate environment for testing the germination of a given species. In theory this implies agreement upon a single germination test environment. In practice alternative environments are often specified for a given species. This is either because of disagreement between laboratories as to the single most appropriate environment, or because of the need to provide alternative procedures for certain seed lots, or because of practical difficulties in providing certain environments (for

example, alternating temperatures) in some laboratories.

The rules of the ISTA and AOSA list the prescribed germination test conditions for each species. These prescriptions specify the substrata, temperatures and test duration which seed testing laboratories must adhere to, Additional directions are provided for special treatments which may be required for certain species together with recommendations for breaking dormancy. These prescriptions and directions are summarised in the chapters which follow.

Now, these rules and directions are intended to give the most regular, rapid and complete germination for the majority of samples of seed of a particular species. To that end we presume the rules are successful, but how closely does the above aim coincide with the problems facing those testing seeds within gene banks?

Prescriptions are not available for all species

First, ISTA and AOSA tend to only provide rules for those species in which certian individual seed testing stations have knowledge of the germination behaviour of a large number of seed samples. Thus the species listed in the ISTA and AOSA rules are those in which there is considerable trade in the sees; the seed-propagated crops. In contrast gene banks will often need to germinate seeds of species which are not yet in substantial trade in the developed world (e.g. the tropical pasture species), true seeds of vegetatively propagated crops (e.g. potato, Solanum tuberosum), and seeds of species which do not have crop status such as wild and weedy relatives of modern crop species (e.g. teosinte, Euchlaena mexicana). Thus the first drawback for gene banks of the ISTA/AOSA rules is that for many species on which gene banks require advice on germination test conditions no information is provided.

Prescriptions developed for modern cultivars

Secondly, within those species for which ISTA and AOSA prescribe test conditions the range of seed lots which seed testing stations test for germination, and upon the results of which ISTA precriptions are based, are generally limited to relatively non-dormant, high quality, modern, genetically homogeneous cultivars. That is in most cases the cultivars with which the rules have been developed are likely to have been subjected to considerable selection pressures. In contrast gene banks will be testing seeds of primitive cultivars and genetically heterogeneous landraces which may also show considerable dormancy and/or be of poor quality. Thus the second drawback for gene banks of the ISTA/AOSA rules is that the prescribed conditions for a particula species will not necessarily be suitable for those acessions within gene banks which are dissimilar to modern cultivars - or of poor quality.

Relative priorities of the aims of seed testing

Thirdly, for some crops seed testing stations may operate under considerable pressure at harvest time. For example, in temperate countries autumn sown cereal seeds are sown only five or six weeks after harvest. Thus seed testers may need to complete germination tests in as short a time as possible. Hence seed testing stations' aim of providing conditions which give rapid germination. Now in at lest one group of species - the temperate cereals - although the conditions prescribed by the rules may give rapid germination this is only achieved in our experience by using supra-optimal temperatures at the cost of the parallel aims of achieving regular and complete germination which are better achieved at much lower temperatures. In contrast to seed testing stations, gene banks are not under any pressure to give priority to rapid germination over achieving regular and complete germination. Thus the third drawback for gene banks of the ISTA/AOSA rules is that the aims of rapid and complete germination may not always be compatible. Note that this criticism does not apply to the rules for all crops. In the case of tree species, for example, considerable periods are allowed for dormancy-breaking and germination test treatments by ISTA and AOSA rules, and the requirement for complete germination takes precedence over the requirement for rapid germination.

Field planting value

The purpose of commercial testing is to provide information on the comparative field planting value of different seed lots. In general the ISTA and AOSA prescriptions make no attempt to enable those viable seeds which will not germinate under field conditions to germinate in the laboratory test. If, for example, dormancy is a problem in laboratory tests, but not in field sowings (for example, due to differences in temperature between the two regimes) then directions to break dormancy must be provided in the rules - otherwise the field planting value may be underestimated. However, where dormancy is a problem in both laboratory tests and field sowings then to obtain an indication of field planting value the rules may not necessarily provide dormancy-breaking directions - since the removal of dormancy in laboratory tests may result in an overestimate of field planting value.

Again whether or not this objective of ISTA or AOSA prescriptions and recommendations makes them unsuitable for viability testing in gene banks depends on the species. For example, in tree species directions for dormancy removal are suggested to enable viability to be estimated in laboratory tests and these directions must also be followed in field sowings if laboratory results are to provide a reasonable estimate of field planting value. In contrast in some species where hardseededness prevents germination no recommendation is made to render the seed coat permeable. Instead the proportion of hard seeds is reported. Thus the fourth drawback of ISTA/AOSA rules is that no attempt may be made to overcome a wide range of physiological phenomena which may prevent the germination of viable seeds under both laboratory and field conditions. Of these phenomena the most important are hardseededness and strong dormancy. In contrast to seed testing stations, gene banks aim to provide conditions which will enable all viable seeds to germinate both in laboratory tests and in subsequent field or glasshouse sowings.

Other sources of prescriptions

Numerous groups of workers have attempted to provide prescriptions for germination tests of species for which no ISTA/AOSA rules are available or which overcome certain of the deficiencies of the ISTA and AOSA prescriptions for species where rules are available. Particular emphasis has been placed on overcoming dormancy since this can be an important problem for plant breeders, and also for seed testers if considerable dormancy is experienced when the seeds are tested but which is likely to be lost during storage before sowing.

However, much of this information is also of limited use in gene banks. This is because the majority of such information relates to the application of single dormancy breaking agents alone. In Chapter 5 (Volume I) it was explained that if this approach is used then the treatment concentration (if a chemical agent) or duration (if another form of treatment) required to break dormancy in the most dormant seeds would be likely to damage less dormant seeds, particularly if these are also of poor quality.

The aim of developing a species prescription for use in gene banks

We believe that the ultimate desirable aim of a prescriptive test for a given species is to be able to provide within one test environment or procedure those conditions which enable all viable seeds of that species - whether strongly dormant, moderately dormant, weakly dormant or non-dormant, and of high or low quality - to be able to germinate. This means that any stimulus or combination of stimuli used to promote the germination of dormant seeds must not be damaging to other non-dormant seeds in the sample or to intolerant genotypes.

Developing a prescription for a species

Whether this aim can in fact always be achieved is a matter for debate, but two considerations are important in attempting to achieve it. The first is to ensure that the germination test temperature is suitable for poor quality seeds; within this range attempts can then be made to determine the most suitable temperature regime which will minimise the expression of dormancy. In certain species this first step may result in an adequate single germination test environment without any need for further treatment. In temperate cereals this appears to be the case, where a single low constant temperature is appropriate for both purposes. However, in other species simple solutions of this type may not be available and so it is necessary to take a second step and provide further stimuli to break dormancy which do not impair the germination of less dormant seeds. In our opinion this is often best attempted by combining more than one additional stimulus with all stimuli being applied at relatively low dose-levels. This is an attempt to utilise the positive interactions observed between many dormancy-breaking agents (see Chapter 5, Volume I). The treatments developed for Oryza spp. and Vitis spp. provide examples of this type of procedure (these and other prescriptions are described in the appropriate chapters of this volume).

Gene banks considering developing their own germination test prescriptions may be discouraged by the wide range of different treatments - and the even wider range of different treatment combinations - which may be of potential benefit in promoting the germination of viable seeds. Consequently it is worthwhile considering which factors should receive priority in any investigation. We believe that the three most important factors to consider first are to ensure that the seeds have imbibed moisture without damage (see Chapter 7, Volume I) and then to attempt to determine the most suitable temperature (probably alternating temperature, see Chapter 5, Volume I) and light (see Chapter 6, Volume I) regimes for germination.

Provided a prescription is already available for a species which is suitable for application in a gene bank then this would be the simplest approach for gene banks to use. However, even where a prescription is well-tried, gene banks will still need to be alert to the possibility that some accessions may be discovered for which the prescription does not appear to work. Furthermore, for many years to come, there will continue to be a large number of species for which there are no adequate prescriptions. Accordingly alternative approaches to providing suitable germination test environments are also considered in this handbook.

Use of tetrazolium test to determine efficacy of a prescription

Although a gene bank can never be absolutely certain about the efficacy of any approach to germinating seeds, do not forget that the efficacy of a species prescription on a particular accession can be tested by comparing the results of the germination test with that of the topographical tetrazolium test (see Chapter 11, Volume I) on a sub-sample of the seed lot and by also applying a tetrazolium test to the seeds remaining ungerminated at the end of the test. In this way one can determine the proportion (if any) of viable seeds which are either killed by the germination test procedure or remain dormant at the end of the germination test procedure.

In the above we have detailed objections to the wholesale and unquestioning adoption of either ISTA or AOSA prescribed germination test procedures as gene bank germination tests. However, this certainly does not mean that such prescriptions should be ignored by gene banks. The ISTA and AOSA rules summarise a wealth and depth of expertise and experience which is unmatched. Thus where available, the prescribed conditions represent a control against which any proposed alternative should be tested; and, despite our earlier comments, certain of these prescriptions will be suitable for gene bank use.

TAXONOMIC ALGORITHMS TO DETERMINE APPROPRIATE GERMINATION TEST ENVIRONMENTS

As mentioned above, germination test prescriptions are available for only a small proportion of seed-producing species. What environment should be chosen to test the germination of seed accessions of species for which no prescription or no acceptable prescription is available? This is exactly the problem which faced staff at the Royal Botanic Gardens Kew, Wakehurst Place Gene Bank, for almost all their accessions, because this gene bank deals entirely with seed collections of species which do not have great commercial significance. The method that they developed to answer the question posed above provides another approach to developing appropriate germination test regimes for seed accessions maintained in gene banks.

Algorithm: the shortest series of tests to define a suitable test environment

This approach acknowledges that the most suitable environment for testing each accession is unknown. Thus, instead of a single prescription, an attempt has been made to develop the shortest series of tests which is likely to give a solution to the problem of defining a suitable test environment. The decision as to which test to try next depends on the results obtained in the previous test(s), and so we call this series of tests an algorithm. For gene banks a truly universal algorithm would be one appropriate to all seed-producing species, irrespective of taxonomy. However, such an approach would be rather unwieldy and

require a large number of tests. Certain similarities in the response of seed germination to environment for species within a family can be recognised. Consequently this approach provides a separate algorithm for each family where sufficient knowledge has been accumulated.

Where available, the algorithms developed by the staff at the Wakehurst Place Gene Bank are presented according to family in Chapters 18 to 75. However, it is necessary here to provide some explanation of how the algorithms were developed, their possible faults, and how they should be applied.

The development of the RBG Kew Wakehurst Place algorithms

Storage at the Wakehurst Place Gene Bank began in 1974. Since then all accessions entered into storage have been tested for germination as soon as possible thereafter. In many cases accessions were tested in more than one germination test environment, the reason for this being an inadequate proportion (less than 85%) of seeds germinating in the first test. Thus for many accessions it was possible to compare germination test results over a number of different environments with and without the imposition of various additional dormancy-breaking treatments. For each accession the best germination test regime was noted, and this regime was then used for all subsequent germination tests of that accession. In addition the results of all the different germination tests carried out on each accession were filed according to species to provide a growing information bank on the response of seed germination to different test conditions. Table 17.3 provides an example of the information generated and filed from such tests for a single accession of Veronica verna.

TABLE 17.3 Example of germination test results recorded by staff at the Wakehurst Place Gene Bank used in subsequent analyses to determine algorithms for determining suitable test regimes: germination (%) and classification of non-germinating seeds after testing seeds of a 1977 collection of Veronica verna under four different regimes (100 seeds per test).

Test Date	Germination Test regime	Total Test Duration (days)	Cumulative Germination (%) at end of test	Non-germinated seeds at end of test[1]		
				Fresh	Mouldy	Empty
16/12/77	21°C	42	0	100	0	0
16/12/77	21°/11°C (12h/12h)	157	48	52	0	0
18/4/78	26°C for 28 days (imbibed) then 11°C	48	100	0	0	0
18/4/78	2°C	73	88	12	0	0

[1] expressed as the percentage of the original number of seeds tested

The two original tests on seeds from this accession, begun on 16/12/77, demonstrated a high proportion of dormant seeds (those designated as fresh at the end of the test - see Chapters 10 and 11, Volume I). At 21°C all seeds exhibited dormancy (Table 17.3). The alternating temperature 'regime of 21°/11°C was only partly successful in breaking this dormancy (Table 17.3). Therefore towards the end of the latter test, a decision was made to sample more seeds from the accession and begin two additional germination tests in different conditions (which are known to promote germination in several species). One of these additional regimes - consisting of a preliminary period during which the imbibed seeds were exposed to 26°C (sometimes described as a warm stratification treatment) followed by subsequent exposure to 11°C - was entirely successful at breaking dormancy, enabling all the seeds tested to germinate (Table 17.3). Consequently this regime will be used for any subsequent germination tests to monitor the viability of this accession.

Over the past ten years or so a considerable amount of information on the response of seed germination to various test regimes (similar to that described above for Veronica verna) has been generated by staff at Wakehurst Place. This raw information has subsequently been analysed, principally by Mr. S. Linington, in the following manner. For a particular family all the routine test data for all accessions (each similar in form to that provided in Table 17.3) were examined. It was (arbitrarily) decided that test regimes in which 85%, or more, of the full seeds germinated would be classified as successful. For each accession all the successful regime(s) (if there were any) were listed. For example, two regimes would be listed as successful for the accession shown in Table 17.3: 2°C constant; and 28 days at 26°C followed by 11°C constant.

When this first stage of analysis was completed a pattern of successful regimes within each family was sought. Emphasis was placed on determining those simpler regimes (that is those employing few dormancy-breaking agents) which were successful for the greatest number of accessions. These regimes are those which are now used as the first step in the algorithms which have been developed. More complicated regimes (involving the use of many dormancy-breaking treatments) which are successful for fewer accessions are then provided as subsequent alternatives (later steps) in the algorithm if the first step does not provide a suitable environment for germination testing.

Possible limitations of the algorithms

There are a number of possible faults inherent in this method of analysis. First, by excluding from the analysis all accessions which failed to reach 85% germination under any test regime, the response of accessions which are either very dormant, or very poor quality and vulnerable in certain germination test environments may have been ignored. Secondly, it is based on tests of accessions within the Wakehurst bank which, at least in the past, were biased towards collecting in temperate regions. Not only may this result in an algorithm more suited to temperate collections, but it may also result in algorithms more suited to certain tribes within each family. For example, the algorithm for the Leguminosae was based largely on accessions of the Papilionoideae tribe and little data was available for accessions from either the Caesalpinoideae or Mimosoideae tribes. Finally it should be noted that the analysis was based on data obtained over only a limited range of treatments. Other, untested, treatments may be superior and there is as yet no way of knowing whether this will be the case.

Success of the algorithms may vary between families

Despite these reservations, the algorithm approach to determining germination test environment works well at Wakehurst and

is likely to be useful in other gene banks. Tests at Wakehurst on previously untested accessions using the algorithms for the Amaranthaceae, Gramineae, Leguminosae and Solanaceae families (provided in Chapters 20, 39, 43 and 67 respectively) have shown that 100%, 50%, 90% and 75% of accessions within each family reached 85% germination or greater. In view of the importance of the Gramineae in food production the limited success of the algorithm for this family is disappointing. One group of species within the Gramineae whose seed is particularly difficult to germinate is the tropical pasture species. Unfortunately tests on five seed lots of tropical pasture species at Reading (Table 17.4) confirm that the present algorithm for the Gramineae (Chapter 39) is not particularly helpful for determining germination test environment in these species.

Demonstration of the use of an algorithm

Nevertheless, Table 17.4 can be used to explain the method of applying the algorithm. Table 17.4 should be studied together with the Gramineae algorithm provided in Chapter 39. In Table 17.4 every feasible combination of dormancy-breaking agents within the algorithm was applied to the seeds, amounting to some 24 separate test environments. Note, however, that only a few of these tests would have been applied if the algorithm had been followed. The pathway through the tests which would have been followed if the Gramineae algorithm had been applied is shown by the boxed values in Table 17.4, the sequence being from the top of the table to the bottom.

Table 17.4 Normal germination (expressed as percentage of full seeds tested) after 28 days in germination test [lower figures in square brackets after 56 days] for five tropical grass seed lots. If the Gramineae algorithm (Chapter 39) had been followed in the manner intended only the tests in square boxes would have been investigated (see text).

Treatment	SPECIES																			
	Brachiaria decumbens				Brachiaria humidicola				(Gatton Panic) Panicum maximum				(Green Panic) Panicum maximum				(Riversdale Guinea) Panicum maximum			
	Temperature, °C				Temperature, °C				Temperature, °C				Temperature, °C				Temperature, °C			
	20	25	35/20	(15/30,10/30)	20	25	35/20	(15/30,10/30)	20	25	35/20	(15/30,10/30)	20	25	35/20	(15/30,10/30)	20	25	35/20	(15/30,10/30)
Control (constant temperature)	[4]	[1]			[0]	[4]			[39]	[25]			[18]	[18]			[2]	[0]		
	[5]	[3]			[0]	[4]			[39]	[26]			[18]	[18]			[3]	[0]		
Alternating temperature			[19]	(10,10)			[21]	(74,73)			[46]	(90,92)			[18]	(13,7)			[31]	(57,69)
			[22]	([10],[15])			[57]	([75],[77])			[49]	([92],[93])			[18]	([15],[8])			[44]	([58],[70])
10^{-3} M KNO_3	3	3	[28]	(13,17)	0	1	[18]	(66,-)	61	31	[59]	(93,82)	14	14	[13]	(14,14)	3	0	[40]	(64,79)
	[4]	[3]	[30]	([13],[19])	[1]	[2]	[64]	([67],-)	[61]	[31]	[64]	([97],[90])	[16]	[14]	[13]	([17],[14])	[6]	[0]	[51]	([64],[80])
Dehusk	15	14	65		0	2	[14]		11	8	7		14	15	[18]		1	2	35	
	[17]	[15]	[66]		[0]	[2]	[45]		[12]	[10]	[12]		[14]	[15]	[19]		[10]	[2]	[41]	
Dehusk + KNO_3	14	15	[63]		4	3	12		17	11	[9]		14	21	13		18	3	[61]	
	[15]	[16]	[63]		[4]	[4]	[40]		[19]	[13]	[26]		[14]	[22]	[14]		[19]	[3]	[69]	
8 week pre-chill	0	0	0		0	0	[3]		33	21	16		0	0	[2]		35	54	59	
	[0]	[0]	[0]		[0]	[0]	[4]		[34]	[21]	[18]		[0]	[0]	[2]		[35]	[54]	[62]	
Dehusk + pre-chill	1	7	38		0	0	5		11	27	25		0	2	2		35	31	46	
	[2]	[7]	[38]		[1]	[0]	[12]		[11]	[27]	[26]		[0]	[3]	[4]		[38]	[31]	[49]	
KNO_3 + pre-chill	1	1	1		1	0	4		8	20	[25]		2	2	2		49	62	59	
	[1]	[1]	[1]		[1]	[0]	[5]		[8]	[20]	[25]		[2]	[2]	[2]		[49]	[62]	[62]	
Dehusk + KNO_3 + pre-chill	0	9	[35]		0	0	6		24	18	30		4	2	7		31	45	[62]	
	[0]	[10]	[35]		[2]	[0]	[9]		[24]	[18]	[30]		[5]	[3]	[9]		[33]	[45]	[62]	
Viability (tetrazolium test)		[94]				[75]				[97]				[25]				[76]		

Three details of the work reported in Table 17.4 differ from the Gramineae algorithm provided by the Wakehurst Place Gene Bank. First the germination test temperatures are not identical, but are within 1°C - except for the upper limit of the alternating temperature regime where the difference is 2°C. These minor differences are unimportant and result from differences in the standard temperatures available at Reading and Wakehurst. Secondly the comment in the algorithm to test at constant temperatures either below 20°C or above 25°C depending upon which gave the higher test result was not followed, since previous experience with dormant seed lots of these species indicated that alternating temperatures were essential to promote germination. Thirdly, following on from the last point, seeds were also tested for germination at the two additional alternating temperature regimes of 15°/30°C and 10°/30°C.

To enable the reader to understand fully the use of the algorithm, an explanation is provided below of the sequence of tests and decisions that would have been applied for tests on the accession of Brachiaria decumbens. The first stage in the algorithm was to test the seeds at constant temperatures of 20°C and 25°C. These test results were inadequate (less than 85% germination).

Now, according to the algorithm (Chapter 39) the next step would have been to look for trends in the results of these two tests (i.e. was germination greater at the higher or lower temperature?) and test for germination at either a more extreme higher or a more extreme lower constant temperature accordingly. This, however, was not done for the reasons given above and we proceeded to the second step of the algorithm which was to test a fresh sample of the seeds in an alternating temperature regime of 35°/20°C (the nearest regime available to the standard 33°/19°C Wakehurst regime). The germination obtained in this test was substantially greater than at either of the two constant temperatures, but again inadequate as a germination test regime. Consequently further tests were required.

The third step according to the algorithm was to test a fresh sample of the seeds in a medium containing 10^{-3} M KNO_3 at, in view of the difference observed between the results at steps 1 and 2, an alternating temperature of 35°/20°C. Again the result of this test at step 3 was an improvement on the result at step 2 but inadequate as a germination test regime since 85% germination was not achieved.

Thus the fourth step was to remove the seed covering structures from a fresh sample of the seeds and test in a medium containing 10^{-3} M KNO_3 (since the result at step 3 was greater than the result at step 2) at an alternating temperature of 35°/20°C. Once again the result of the test at this step was an improvement on the previous test result (suggesting that dehusking was a worthwhile treatment), but the percentage of seeds germinating was still unsatisfactory.

Consequently the final step in the algorithm was applied. Namely dehusked imbibed seeds were pre-chilled at 3°-5°C for 8 weeks and then transferred to an alternating temperature regime of 35°/20°C in a medium containing 10^{-3} M KNO_3. Unfortunately this test resulted in substantially fewer seeds germinating than the previous test. Thus the conclusion reached by using the algorithm is that dehusked seeds of this accession of Brachiaria decumbens should be tested on a substrate containing 10^{-3} M KNO_3 in an alternating temperature regime of 35°/20°C.

Note that the decision making procedure at each step in the algorithm did not result in the algorithm missing more favourable treatment combinations. For example, if the algorithm had been followed dehusked seeds would not have been tested at 35°/20°C without 10^{-3} M KNO_3 in the germination medium. In fact this treatment gave a very similar result (that is there was no significant difference) to the treatment with dehusked seeds which did include 10^{-3} M KNO_3 in the germination medium. Thus it appears that the use of 10^{-3} M KNO_3 in the medium is in fact not necessary, but its use (apparently necessary if the algorithm had been followed) does not result in a significantly lower proportion of seeds germinating. In that sense we can regard the decision-making procedure within the algorithm as being successful, but unfortunately the algorithm itself was not successful since the level of viability indicated by the tetrazolium test was not achieved in these germination tests.

Sensitivity of germination to the temperature regime

In addition to all the possible germination test regimes according to the Gramineae algorithm, Table 17.4 also presents results of tests carried out in two additional alternating temperature environments (15°/30°C and 10°/30°C) and also in combination with 10^{-3} M KNO_3 (where sufficient seeds were available). These results suggest that, for some seed lots at least, those gene banks testing tropical grass species would be well advised to include additional alternating temperature regimes as the second step of the algorithm. For three of the seed lots tested here small differences in the alternating temperature regime greatly influenced the proportion of seeds which germinated (Table 17.4). Not only did this result in almost full germination of viable seeds, but it would have avoided the need for several stages of the algorithm in the case of Gatton Panic. (See the section on the genus Panicum, Chapter 39, for advice on an appropriate alternating temperature regime for this species.)

In passing note that the results shown in Tables 17.3 and 17.4 emphasise that seed germination can be particularly sensitive to the temperature regime in which the seeds are tested. It cannot be overemphasised that gene bank staff must make strenuous efforts to get this right first before embarking on investigations as to the efficacy of other dormancy-breaking agents.

Possible use of ungerminated seeds from prior step in algorithm for the current test

In the algorithms provided here additional tests are carried out by drawing a fresh sample of seeds from the accession bulk in storage. In some cases, for example if the supply of seeds is severely limited, it is possible to test the response to additional treatments by applying these to those ungerminated seeds which remain fresh and firm at the end of a previous test. This is particularly suitable for scarification, dehusking or puncturing treatments since it may avoid the need to apply these time-consuming procedures to all seeds tested (see Chapter 7, Volume I). For example, if 70% of seeds tested of a legume accession germinate without scarification it is easier to scarify the remaining proportion of seeds and to return these to the germination environment than to draw a fresh sample of seeds from storage and scarify all of the seeds to be tested.

Duration of germination tests

During each step of the algorithm it is necessary to decide when to terminate the germination test and whether to pursue the next step in the algorithm. Since both aged and dormant seeds may only begin to germinate in a test after a substantial delay (see Chapters 4 and 5, Volume I) it is not possible to provide categorical advice. In Chapter 10, Volume I, an example is provided of how to decide when to terminate a germination test by constructing a germination progress curve. This technique can be used for each step in the algorithm, but each test should not be continued for an excessive period because the next step in the algorithm might result in a more suitable and more rapid procedure. That is if the progress of germination is very slow it might be better to pursue the next step in the algorithm.

A minimum germination test period of 28 days is suggested. A comparison of results after 28 and 56 days in test (Table 17.4), for example, shows substantial germination after 28 days in test for only the Brachiaria humidicola accession tested at 35°/20°C. Consequently it is suggested that the decision to test a further sample of seeds in the next step of the algorithm can generally be made once the 28-day test result is known, but that the current test be continued for a further period dependent

upon the shape of the germination progress curve. In tests at a very low temperature (e.g. 6°C), however, it may be better to delay a decision as to whether to continue through the algorithm until the 56-day test result is known.

Use of algorithms at accession receipt

It is suggested that the algorithms could be applied soon after an accession is received if the standard advice on germination test procedures and dormancy-breaking treatments is unsatisfactory or if no advice is available. The number of seeds tested in each of the regimes required by the algorithm need not exceed 100 (and 50 seeds may well be sufficient), but the seeds should be sampled from the accession at random (see Chapter 13, Volume I) and replication in each test is advisable (which will allow the use of the tolerance tables, Chapter 14, Volume I).

Once a suitable test procedure has been developed a further sample of 200 seeds can be withdrawn from the accession and tested by this procedure in order to 'estimate initial accession viability (discussed in more detail in Chapter 15, Volume I). Subsequent monitoring tests of accession viability will also apply the same germination test procedure, but may be either fixed sample size tests (see Chapter 14, Volume I) or sequential tests (see Chapter 15, Volume I). Note that it is envisaged that the algorithms would only be applied once, i.e. when the accession is first received: the subsequent monitoring tests would employ the most appropriate regime already determined.

CHAPTER 18. ACTINIDIACEAE

The Actinidiaceae, formerly called Dilleniaceae, comprise about 300 tree and shrub species within four genera. Fruits are either hard dehiscent capsules, or are fleshy and berry-like and indehiscent as is the case in Actinidia, the only genus in this family for which information is provided here on seed dormancy and germination.

ACTINIDIA

A. arguta
A. chinensis Planch. kiwifruit, Chinese gooseberry, yangtao
A. kolomikta

I. Evidence of dormancy

Germination of A. Chinensis seeds is generally poor and erratic and can be a considerable problem for growers (2,5), although there are reports where seeds were germinated without difficulty (1,4). After-ripening for three months is unable to promote the subsequent germination of seeds at constant temperatures (5).

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

A. chinensis

Constant temperatures: 21°C (2,3); 4.5°-26.5°C (5) Pre-chill: 4.5°C, 2w, germinate at 4.5°-26.5°C (5); 4°C, 37d, germinate at 20°C (3)

IV. Partly-successful dormancy-breaking treatments

A. chinensis

Alternating temperatures: 21°/10°C, 10°/21°C (16h/8h) (2,3); 4.5°/21°C, 10°/21°C, 15.5°/21°C, 26.5°/21°C (16h/8h) (5)

Pre-chill: 4°C, 37d (2,3); 4.5°C, 5w (5); 4.5°C, 4-12w, germinate at 10°-26.5°C (5); 4°C, 37d, then GA_3, pre-applied, 24h, 10-500 ppm (2)

GA_3: pre-applied, 24h, 10, 100, 500, 2500 ppm (2); pre-applied, 6-25h, 2000 ppm (2); pre-applied, 6,23,25h, 5000 ppm, then pre-dry, 24h (2); pre-applied, 6-23h, 2000 ppm (3); pre-applied, 6,23h, 5000 ppm (3)

A. kolomikta

Pre-chill: 3°-5°C, 5m (6)
GA_3: 500 ppm (6); 500 ppm, plus kinetin, 50 ppm (6)

V. Successful dormancy-breaking treatments

A. arguta

Scarification: abrade with sharp sand (7); file or nick seed coat (7)

A. chinensis

Pre-chill: 4.5°C, 2-12w, germinate at 10°/21°C (16h/8h) (5); 4°C, 37d, then GA_3, pre-applied, 24h, 2500 ppm, germinate at 21°/10°C (16h/8h) (2)

GA_3: pre-applied, 17h, 5000 ppm, germinate at 21°/10°C (16h/8h) (2); pre-applied, 17h, 5000 ppm, germinate at 21°C (3); pre-applied, 17-24h, 2500 ppm (3)

A. kolomikta

Scarification: abrade with sharp sand (7); file or nick seed coat (7)

VI. Comment

The germination of seeds of A. chinensis is promoted greatly by alternating temperatures (2,3,5). Thermoperiod appears to be relatively unimportant - 10°/21°C being equally promotory at both 16h/8h and 8h/16h cycles (2). The regime 4.5°/21°C (16h/8h) is, however, superior to 10°/21°C (16h/8h) (5). Alternating temperatures alone generally provide insufficient stimulus to promote the germination of all dormant seeds (2,3,5). Pre-chill and gibberellin treatments also promote germination (1,2,3,5). Consequently the following combined procedure has been suggested: pre-chill, 3°-5°C, for 37 days, then pre-treat in 2500 ppm GA_3 for 24 hours (on filter paper in petri dishes) and subsequently test for germination at 21°/10°C (16h/8h) (2). Whilst this is satisfactory it might be worth investigating whether testing at 5°/20°C (16h/8h) could enable the pre-chill period, and thus the total test period, to be reduced.

VII. References

1. Bailey, F.L. (1961). Chinese gooseberries, their culture and uses. New Zealand Department of Agriculture, Bulletin 349.

2. Lawes, G.S. and Anderson, D.R. (1980). Influence of temperature and gibberellic acid on kiwifruit (Actinidia chinensis) seed germination. New Zealand Journal of Experimental Agriculture, 8, 277-280.

3. Lawes, G.S. and Sim, B.L. (1980). An analysis of factors affecting the propagation of kiwifruit. Orchardist of New Zealand, 53, 88 -90.

4. Rivals, P. (1964). Notes biologiques et culturales sur 1'Actinidia de chine (Actinidia sinensis Planchon). Journal d'Agriculture Tropicale et de Botanique Appliquee, 11, 75-83.

5. Smith, R.L. and Toy, S.J. (1967). Effects of stratification and alternating temperatures on seed germination of the Chinese gooseberry, Actinidia chinensis Planch. Proceedings of the American Society for Horticultural Science, 90, 409-412.

6. Kolotova, G.K. and Nikolaeva, M.G. (1981). [Effect of stratification and phytohormones on seed germination of Schisandra chinensis and Actinidia kolomikta.] Rastitel'nye Resursy, 17 (4), 544-550. (From Seed Abstracts, 1982, 5, 1584.)

7. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 19. AGAVACEAE

The Agavaceae comprise about 600 species in 20 genera. Certain species are sometimes classified in the Liliaceae (see Chapter 44) and the remainder in the Amaryllidaceae (see Chapter 76).

The genera Agave, Furcraea, Phormium, Sansevieria and Yucca yield hard fibres. For example Agave sisalana Perrine (sisal), Furcraea gigantea Vent. (Mauritius hemp), Phormium tenax Forst. (New Zealand flax or hemp) and Sansevieria guineensis (L.) Willd. (bowstring hemp). Although it can be difficult to produce seeds from vegetatively propagated plants, the seeds are reported to store well and seeds of Agave and Yucca spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

Germination is reported to be epigeal, at least in Agave spp. Seed dormancy can be problematic with poor germination being reported for freshly harvested seeds. Detailed information on seed germination and dormancy-breaking treatments is limited (Table 19.1), but the algorithm below may be helpful in developing suitable germination test procedures for other species in the Agavaceae.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test the seeds at a constant temperature of 16°C with light applied for 12h/d.

If this is not successful in promoting full germination then the second step is to test the seeds in an alternating-temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

TABLE 19.1 Summary of germination test recommendations for species within the Agavaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Cordyline australis (G. Forst.) Hook. f.	TP	20°/30°C	30d	light, pre-soak fruit balls, 1-2d, then extract seeds and test	AOSA
Yucca filamentosa L.	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 21-28d	AOSA

CHAPTER 20. AMARANTHACEAE

The Amaranthaceae comprise about 500 species within 40 genera. The most important genus is Amaranthus which is cultivated for grain and as a leaf vegetable. The seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

The fruits are usually surrounded by a persistent perianth. B.R. Atwater classifies seed morphology as endospermic seeds with peripheral linear embryos (see Table 17.1, Chapter 17). Light, alternating temperatures, pre-washing and removal of the seed covering structures can promote germination, but some care may be required in defining promotory treatments in detail. Detailed information on seed germination is provided for the genera Amaranthus and Celosia in this chapter. A limited number of other recommended germination test procedures is provided in Table 20.1 and the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step of the algorithm is to test three samples of the seeds at constant temperatures of 26°C, 31°C, and 36°C with light applied for 12h/d. If full germination has not been promoted and there is a trend in germination response to constant temperatures, then test further samples of seeds at more extreme constant temperatures. That is: if germination was greatest at 26°C then test at constant temperatures of 16°C and 21°C with light applied for 12h/d; but if germination was greatest at 36°C then test at a constant temperature of 41°C with light applied for 12h/d. If, however, germination was greatest at 31°C then go to the next step of the algorithm.

If full germination has not been promoted, the second step of the algorithm is to test a further sample of seeds in an alternating temperature regime of 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If full germination has not been promoted, the third step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided in this chapter for the genera Amaranthus and Celosia and from Table 20.1.

TABLE 20.1 Summary of germination test recommendations for species within the Amaranthaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Gomphrena globosa L.	TP; BP	20°/30°C; 20°C	14d	Potassium nitrate	ISTA
	TP	20°/30°C	14d	light, potassium nitrate	AOSA

		20°/30°C'	10d	Light	Atwater

AMARANTHUS

A. albus L.	tumble pigweed
A. blitoides Wats.	prostrate pigweed
A. caudatus L. [A. paniculatus L.; A. cruentis L.]	grain amaranth, pigweed, love-lies-bleeding, tassel flower
A. graecizans L.	tumbleweed, prostrate pigweed
A. hybridus L.	edible amaranth, smooth pigweed
A. hypochondriacus L.	
A. lividus L.	
A. palmeri Wats.	Palmer amaranth
A. powellii Wats.	Powell's pigweed
A. retroflexus L.	green amaranth, redroot pigweed
A. spinosus L.	spiny amaranth
A. tricolor L.	

I. Evidence of dor mancy

Almost without exception seeds of Amaranthus spp. show considerable dormancy. This is possibly because the majority of references cited here concern seeds from weedy plants of Amaranthus spp. Only in a minority of papers has the dormancy of seeds from cultivated plants within the genus Amaranthus been investigated. Nevertheless it is clear that dormancy can also be considerable in seeds from cultivated plants - e.g. (16).

After-ripening treatment periods required to remove dormancy from the majority of seeds can be considerable: 180 days (4,22), 300 days (20) or as many as 4 years (28) for seeds of A. retroflexus; and 6 months for seeds of A. blitoides and A. graecizans (22).

II. Germination regimes for non-dormant seeds

A. caudatus, A. hybridus, A. hypochondriacus

TP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

A. retroflexus

Constant temperatures: 21°-42°C, 5d (8); 25°C in light, 12h/d, 2.3 x 10^{-3} W cm^{-2} (5); 35°C in light, 10d (9)

Amaranthus spp.

TP: 20°/30°C (16h/8h): 8d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light, 10d (1)

III. Unsuccessful dormancy-breaking treatments

A. albus

Constant temperatures: 29°-38°C (26)

Alternating temperatures: 20°/32°C, 22°/43°C (12h/12h) (26)

Potassium nitrate: co-applied, 1%, at 20°/30°C (12h/12h) (26)

Acetone: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Sodium hypochlorite: pre-applied, 1-5 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 4,8 min, germinate at 20°/30°C (12h/12h) (26)

Catechol: co-applied, 10^{-4}-10^{-2} M, at 30°C in dark (13)

Pyrogallol: co-applied, 10^{-4}, 10^{-3}-10^{-2} M, at 30°C in dark (13)

Hydroxylamine hydrochloride: co-applied, 10^{-5}, $5x10^{-5}$, $5x10^{-3}$ M, at 30°C in dark (13)

A. blitoides

Constant temperatures: 24°-30°C in light, 125 fc, or dark (17); 42°-44°C in dark (17); 25°C (22)

Pre-chill: 5°C, 6m (22)

A. caudatus

Constant temperatures: 40°C (19)

Pre-soak: (25)

Sodium azide: pre-applied, 10^{-3} M (25)

Ammonium hydroxide: pre-applied, 10^{-3} M (25)

Light: white, 2100 ergs cm^{-2} s^{-1}, at 10°-20°C (19)

A. graecizans

Constant temperatures: 15°C, 20°C (22)

Alternating temperatures: 15°/28°C in light or dark (10)

Pre-chill: 5°C, 6m (22)

Potassium nitrate: co-applied, 0.125-1%, at 20°/30°C (12h/12h) (26)

Sodium hypochlorite: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Acetone: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 2,8 min, germinate at 20°/30°C (12h/12h) (26)

A. hybridus

Constant temperatures: 29°-38°C (26)

Alternating temperatures: 15°/28°C in light or dark (10); 15°/13°C, 20°/15°C (day/night) in light, 15d (16); 19°/23°C, 20°/32°C, 22°/43°C (12h/12h) (26)

Potassium nitrate: co-applied, 0.125-1%, at 20°/30°C (12h/12h) (26)

Sodium hypochlorite: pre-applied, 1-5 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 2,4,8 min, germinate at 20°/30°C (12h/12h) (26)

A. palmeri

Constant temperatures: 29°-38°C (26)

Alternating temperatures: 19°/23°C, 20°/32°C, 22°/43°C (12h/12h) (26)

Potassium nitrate: co-applied, 0.125-1%, at 20°/30°C (12h/12h) (26)

Acetone: pre-applied, 2,20 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 2-8 min, germinate at 20°/30°C (12h/12h) (26)

A. retroflexus

Constant temperatures: 15°C in light, 12h/d, $2.3x10^{-3}$ W cm^{-2} (5); 15°-30°C, dark, 7d (28); 20°C (2,3,4); 20°C, 25°C, 30°C, dark or light, red, 5 min after 3d (35); 25°C, 30°C, 14d, dark (6); 29°-38°C (26); 30°C, dark (21); 30°C (31)

Alternating temperatures: 19°/23°C, 20°/32°C, 22°/43°C (12h/12h) (26)

Pre-chill: 5°C, 6m (22)

Warm stratification: 15°C, germinate at 35°C, both in light, 12h/d, $2.3x10^{-3}$ W cm^{-2} (5); 20°C, 35°C, 3d, dark, then 20°-30°C, dark (35)

Abscisic acid: co-applied, 10^{-4}M, at 23°C in dark (15)

Potassium nitrate: co-applied, 0.125-1%, at 20°/30°C (12h/12h) (26)

Acetone: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Sodium hypochlorite: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 4,8 min, germinate at 20°/30°C (12h/12h) (26)

A. spinosus

Constant temperatures: 29°-38°C (26)

Alternating temperatures: 19°/23°C, 20°/32°C, 22°/43°C (12h/12h) (26)

Potassium nitrate: co-applied, 0.125-1%, at 20°/30°C (12h/12h) (26)

Acetone: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Sodium hypochlorite: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 4,8 min, germinate at 20°/30°C (12h/12h) (26)

IV. Partly-successful dormancy-breaking treatments

A. albus

Alternating temperatures: 19°/23°C (12h/12h) (26); 20°/30°C, 20°/35°C (16h/8h) in dark (14)

Light: red, 5 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark (34)

Ethylene: co-applied, 1-100 ppm, at 30°C in dark (34); co-applied, 1, 10 ppm, at 30°C in red

light, 5 min, 1.9x10 W cm , after 24h dark (34)

Potassium nitrate: co-applied, 10^{-2} M, at 30°C in dark (12); co-applied, 0.125-0.5%, at 20°/30°C (12h/12h) (26)

Sodium nitrite: co-applied, 10^{-3} M, at 30°C in dark (12)

Ammonium chloride: co-applied, 10^{-2} M, at 30°C in dark (12)

Potassium cyanide: co-applied, 10^{-4} M, at 30°C in dark (12)

Potassium azide: co-applied, 10^{-5} M, at 30°C in dark (12)

Pyrogallol: co-applied, $3x10^{-4}$ M, at 30°C in dark (13)

Hydroxylamine hydrochloride: co-applied, 10^{-4}-10^{-3} M, at 30°C in dark (13)

Thiourea: co-applied, 10^{-3}-10^{-2} M, at 30°C in dark (13)

Sodium hypochlorite: pre-applied, 20 min, germinate at 20°/30°C (12h/12h) (26)

Scarification: concentrated sulphuric acid, 2 min, germinate at 20°/30°C (12h/12h) (26)

A. blitoides

Constant temperatures: 30°-37°C in dark (17); 40°-44°C in light, continuous, 125 fc, or dark (17)

Warm stratification: 14°C, 6m (22)

Removal of seed covering structures: then germinate at 25°C (22)

A. caudatus

GA_3: co-applied, 10-100 mg/l (19)

Thiourea: co-applied, 0.25%, at 27°C in light (23)

Potassium cyanide: pre-applied, 10^{-3} M (25)

A. graecizans

Constant temperatures: 25°-35°C (22)

Warm stratification: 14°C, 6m (22)

Removal of seed covering structures: then germinate at 15°-35°C (22)

Scarification: concentrated sulphuric acid, 4 min, germinate at 20°/30°C (12h/12h) (26)

A. hybridus

Alternating temperatures: 30°/25°C (day/night) in light, 15d (16); 20°/15°C (day/night) in dark, 15d (16); 15°/13°C (day/night) in dark, 15d (16); 25°/20°C (day/night) in light or dark, 15d (16)

Light: dark, at 25°/20°C, 20°/15°C (day/night), 15d (16); 2h, after 60-150h imbibition in dark (7)

Potassium nitrate: co-applied, 0.2%, at 24°C (7)

Acetone: pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

Sodium hypochlorite: pre-applied, 20 min, germinate at 20°/30°C (12h/12h) (26)

A. lividus

Alternating temperatures: 20°/30°C (32)

A. palmeri

Acetone: pre-applied, 1 min, germinate at 20°/30°C (12h/12h) (26)

Sodium hypochlorite; pre-applied, 1-20 min, germinate at 20°/30°C (12h/12h) (26)

A. powellii

Alternating temperatures: 30°/18°C, light/dark (day/night), 100d (11)

A. retroflexus

Constant temperatures: 25°-28°C (35); 30°C (3,4); 35°C (31); 35°C, dark (6); 35°C, 40°C, dark, 7d (28)

Alternating temperatures: 23°/35°C (12h/12h) (31); 25°/8°C (18h/6h) (24)

Pre-chill: 5°C, 3d, germinate at 30°C in dark (20,21); 5°-20°C, 3-15d, germinate at 35°C (35)

Warm stratification: 14°C, 6m (22); 15°C, 7d, germinate at 30°C (30); 25°C, 8-31d, germinate at 35°C (30); 40°C, dark, 1,5d, germinate at 35°C, dark (29)

Light: dark (24); white, $2x10^{-5}$, $3x10^{-5}$ mol m^{-2} s^{-1}, 1,5d, at 35°C (29); fluorescent, $5x10^{-5}$ mol m^{-2} s^{-1}, at 30°C, 35°C (28); fluorescent, 5 min, $4x10^{3}$ ergs cm^{-2} s^{-1}, after 24h imbibition at 30°C in dark, germinate at 30°C in dark (20); red, 5 min (4); red, $6x10^{-4}$ W cm^{-2}, 5 min, after 3d at 35°C in dark, germinate at 35°C in dark (33); red, $1.5x10^{-11}$-$1.7x10^{-9}$ mol cm^{-2} s^{-1}, after 24-140h in dark at 35°C (36); red, $3.5x10^{-10}$-$1.4x10^{-9}$ mol cm^{-2} s^{-1}, after 96h in dark at 35°C (36)

Ethylene: co-applied, 0.00001-0.1%, at 30°C in dark (6); co-applied, 1-100 ppm, at 30°C in dark, 7d (28); co-applied, 0.001%, at 35°C in light, continuous, $2x10^{-5}$-$3x10^{-5}$ mol m^{-2} s^{-1} (29); co-applied, 0.001%, at 35°C in dark (29); co-applied, 0.51, 51 cm^{3} m^{-3}, at 30°C, after 8-31d at 30°C (30); co-applied, 0.51 cm^{3} m^{-3}, at 35°C, after 8-31d at 25°C (30); co-applied, 51 cm^{3} m^{-3}, at 35°C, after 8,16d at 25°C (30); co-applied, 0.05-51 cm^{3} m^{-3}, at 23°/35°C (12h/12h) (31); co-applied, 1, 10 ppm, at 30°C in dark or red light, 5 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark (34)

GA_3: co-applied, $2.6x10^{-5}$ M, at 30°C (3); co-applied, $2.6x10^{-5}$ M (4)

Scarification: abrasive sand, 4-9w (8); concentrated sulphuric acid, 2-3 min (8); concentrated sulphuric acid, 2 min, germinate at 20°/30°C (12h/12h) (26)

Ultrasonics: 20 kc/s, 1 min, germinate at 23°C in dark (15) 2-Chloroethyl phosphonic acid: co-applied, 10 ppm, at 23°C in dark (15)

Napthaleneacetic acid: co-applied, 10^{-6} M, at 23°C in dark (15)

A. spinosus

Light: red, 5 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark (34)

Ethylene: co-applied, 1-100 ppm, at 30°C, in dark or red light, 5 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark (34)

Scarification: concentrated sulphuric acid, 2 min, germinate at 20°/30°C (12h/12h) (26)

A. tricolor

Constant temperatures: 30°C in light (27)

V. Successful dormancy-breaking treatments

A. albus

Ethylene: co-applied, 100 ppm, at 30°C in red light, 5 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark (34)

Hydroxylamine hydrochloride: co-applied, $3.2x10^{-3}$ M, at 30°C in dark (12)

A. blitoides

Constant temperatures: 30°-37°C in continuous light, 125 fc (17); 30°-37°C, 48h dark, then light, 5 min, 125 fc, then dark (17)

A. caudatus

Pre-chill, Potassium nitrate (ISTA)

Constant temperatures: 10°-40°C, dark (19); 25°-40°C in white light, 2100 ergs cm^{-2} s^{-1} (19)

Alternating temperatures: 15°/28°C in light (10)

A. hybridus, A. hypochondriacus

Pre-chill, Potassium nitrate (ISTA)

A. powellii

Alternating temperatures: 30°/18°C (day/night) in dark, 7d, then light/dark (day/night), 34d (11)

A. retroflexus

Constant temperatures: 35°C (2)

Alternating temperatures: 30°/18°C, light/dark (day/night), 100d (11); 30°/18°C (day/night) in dark, 7d, then light/dark (day/night), 34d (11)

Warm stratification: 20°C, 35°C, 3d, dark, then red light, 5 min, then 35°C in dark (35); 25°C, 4d, dark, then 35°C in light, continuous, $2x10^{-5}$-$3x10^{-5}$ mol m^{-2} s^{-1}, with ethylene, co-applied, 0.001% (29)

Light: red, $6x10^{-4}$ W cm^{-2}, 5 min, after 24h at 35°C in dark, germinate at 35°C in dark (33); red, $2.8x10^{-9}$, $4x10^{-9}$, $5.6x10^{-9}$ mol cm^{-2} s^{-1}, after 96h at 35°C in dark (36)

Pre-dry: 3h-3d (2)

Ethylene: co-applied, 51 cm^3 m^{-3} at 35°C, after 24,31d at 25°C (30); co-applied, 51 cm^3 m^{-3} at

40°C, after 7d at 25°C, 30°C (30); co-applied, 100 ppm, at 30°C in dark or red light, 5 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark (34)

GA_3: co-applied, 10^{-2} M, at 23°C, dark (15)

Thiourea: co-applied, 10^{-2} M, at 23°C, dark (15)

Pre-soak: 40°C, 2h, germinate at 23°C, dark (15)

Amaranthus spp.

Light (AOSA)

VI. Comment

Comparatively few treatments have been reported which are able to break the dormancy of all seeds within accessions of Amaranthus spp. Light is a factor of critical importance. At first sight the literature may appear confusing, since the effect of light on germination has been reported as both stimulatory (2,4,7,11,17,18,29,32,33) and inhibitory (16,19,24). Inhibitory action occurs when the light is of the wrong wavelength - for example, far red (19) - or the dosage is too high. To obtain the maximum promotion from light additional parameters are important: these include temperature, the timing of the light application, and - more occasionally - the presence of other dormancy-breaking agents.

At constant temperatures, high temperatures are required for the germination of dormant seeds: above 30°C (18), 30°-37°C (17), 35°C (22), 35°-40°C (28), or 40°C (14). Alternating temperatures can promote germination: 20°/35°C (16h/8h) is reported to be superior to 20°/30°C (16h/8h) - the AOSA prescribed regime - whilst both are better than high constant temperatures (14); 30°/25°C (day/night) is superior to 25°/20°C, 20°/15°C, or 15°/30°C (day/night) (16); 25°/8°C (18h/6h) is reported to be better than constant temperatures between 25° and 28°C (24); and 23°/35°C (12h/12h) is superior to constant temperatures of 30°C or 35°C (31), but to obtain maximum promotion the initial imbibition temperature should be 23°C, not 35°C - that is 23°/35°C, not 35°/23°C (31). However, neither constant nor alternating temperatures alone can be regarded as satisfactory. For example, testing dormant seeds from five Amaranthus spp. at constant temperatures between 29°C and 38°C, or alternating temperatures of 19°/23°C, 20°/32°C or 22°/43°C in the dark resulted in no more than 10% germination in any one environment, with no significant difference in germination between the various germination test regimes (26).

At high constant temperatures the germination of dormant seeds is promoted by only a very short duration light treatment, for example in A. blitoides (17) and A. retroflexus (18). As little as 45-60 seconds can be sufficient to promote the germination of the majority of dormant seeds - for example, promoting germination from 25% to 92% (17). However, the timing of the light treatment in relation to the start of imbibition is critical: in A. hybridus the maximum promotion is reported after 80-150 hours (7); in A. blitoides after 48 hours (17); and in A. retroflexus after 96 hours (36). Moreover, the response to light can be considerably increased in the presence of other dormancy-breaking agents - particularly potassium nitrate (7). Although the above times appear to vary - probably due to differences of irradiance reaching the seeds (36) - once the maximum sensitivity to light has been achieved during imbibition, delaying the light treatment does not reduce the germination of seeds of Amaranthus spp. (7,18).

Given the wide differences in the level of seed dormancy between accessions within the genus Amaranthus it is difficult to make precise recommendations. Nevertheless, the following regime is tentatively suggested: imbibe seeds in the dark at 35°C for four days with 0.2% potassium

nitrate co-applied; expose briefly to red light - $1x10^{-9}$ mol cm^{-2} is probably sufficient (36). Although one exposure is probably satisfactory, it might be worthwhile to provide this daily in case some individual seeds require a longer period of imbibition before they reach maximum sensitivity to light. It is likely that an alternating temperature regime would be preferable to a constant temperature of 35°C; 20°-25°/35°C (12h/12h) is suggested, again with potassium nitrate and red light as described above, but this must be regarded as untested as yet. Finally, if it is difficult to provide a suitable light environment it is worth noting that pre-chill treatments can reduce the need for light in subsequent germination tests (35); try 14 days at 3°-5°C and then transfer to 35°C in the dark for the germination test.

VII. References

1. Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technology, 8, 523-573.

2. Barton, L.V. (1962). The germination of wed seeds. Weeds, 10, 174-182.

3. Chadoeuf-Hannel, R. and Barralis, G. (1982). Comportement germinatif des graines d'Amaranthus retroflexus L. récoltées dans les conditions naturelles. Weed Research, 22, 361-369.

4. Chadoeuf-Hannel, R. and Barralis, G. (1983). Evolution de l'aptitude à germer des graines d'Amaranthus retroflexus L. récoltées dans différentes conditions, au cours de leur conservation. Weed Research, 23, 109-117.

5. Chakrabarti, A.G. (1977). Effects of temperature shift on weed seed germination. Castanea, 42, 279-285.

6. Egley, G.H. (1980). Stimulation of common cocklebur (Xanthium pensylvanicum) and redroot pigweed (Amaranthus retroflexus) seed germination by injections of ethylene into soil. Journal for Weed Science, 28, 510-514.

7. Engelhardt, M., Vicente, M. and Silberschmindt, K. (1962). Ação da luz e do nitrato de potàssio sôbre a germinacao de sementes de "Amarantus hybridus" L. Revista Brasileira Biologia, 22, 1-7.

8. Evans, C.R. (1922). Effect of temperature on germination of Amaranthus retroflexus. Botanical Gazette, 73, 213-225.

9. Everson, L. (1949). Preliminary studies to establish laboratory methods for the germination of weed seed. Proceedings of the Association of Official Seed Analysts, 39, 84-89.

10. Fenner, M. (1980). Germination tests on thirty-two East African weed species. Weed Research, 20, 135-138.

11. Frost, R.A. and Cavers, P.B. (1975). The ecology of pigweeds (Amaranthus) in Ontario. I. Interspecific and intraspecific variation in seed germination among local collections of A. powellii and A. retroflexus. Canadian Journal of Botany, 53, 1276-1284.

12. Hendricks, S.B. and Taylorson, R.B. (1974). Promotion of seed germination by nitrate, nitrite, hydroxylamine and ammonium salts. Plant Physiology, 54, 304-309.

13. Hendricks, S.B. and Taylorson, R.B. (1975). Breaking of seed dormancy by catalase inhibition. Proceedings of the National Academy of Science, USA, 72, 306-309.

14. Hendricks, S.B. and Taylorson, R.B. (1976). Variation in germination and amino acid leakage of seeds with temperature related to membrane phase change. Plant Physiology, 58,

7-11.

15. Holm, R.E. and Miller, M.R. (1972). Weed seed germination responses to chemical and physical treatments. Weed Science, 20, 150-153.

16. Huang, H. (1981). [Effects of temperature on germination, growth and dry matter contents of two tropical vegetables with high nutritive value - edible amaranth and water convolvulus.] Memoirs of the College of Agriculture, National Taiwan University, 21, 88-105.

17. Kadman-Zahavi, A. (1955). The effect of light and temperature on the germination of Amaranthus blitoides seeds. Bulletin of the Research Council of Israel, 4, 370-374.

18. Kadman-Zahavi, A. (1960). Effect of short and continuous illumination on the germination of Amaranthus retroflexus seeds. Bulletin of the Research Council of Israel, Series D, 9, 1-20.

19. Kendrick, R.E. and Frankland, B. (1969). Photocontrol of germination in Amaranthus caudatus. Planta, 85, 326-339.

20. Kigel, J., Gibly, A. and Negbi, M. (1979). Seed germination in Amaranthus retroflexus L. as affected by the photoperiod and age during flower induction of the parent plants. Journal of Experimental Botany, 30, 997-1002.

21. Kigel, J., Ofir, M. and Koller, D. (1977). Control of the germination responses of Amaranthus retroflexus L. seeds by their parental photothermal environment. Journal of Experimental Botany, 28, 1125-1136.

22. Martin, J.N. (1943). Germination studies of the seeds of some common weeds. Proceedings of the Iowa Academy of Science, 50, 221-2 28.

23. Moursi, M.A., Rizk, T.Y. and El-Deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

24. Popova, D. (1979). [Effect of light at constant and variable temperature conditions on the germination of green amaranth (Amaranthus retroflexus L.) and barnyard grass (Echinochloa crusgalli L.) seeds.] Plant Science, Sofia, 16, 39-48.

25. Roberts, E.H. (1964). The distribution of oxidation-reduction enzymes and the effects of respiratory inhibitors and oxidising agents on dormancy in rice seed. Physiologia Plantarum, 17, 14-29.

26. Santelmann, P.W. and Evetts, L. (1971). Germination and herbicide susceptibility of six pigweed species. Weed Science, 19, 51-54.

27. Sakanishi, Y. (1957). Studies on the germination behavior of some annual and biennial flower seeds. Bulletin of the University of Osaka Prefecture, Series B, 7, 23-28.

28. Schonbeck, M.W. and Egley, G.H. (1980). Redroot pigweed (Amaranthus retroflexus) seed germination responses to afterripening, temperature, ethylene, and some other environmental factors. Weed Science, 28, 543-548.

29. Schonbeck, M.W. and Egley, G.H. (1981). Phase-sequence of redroot pigweed seed germination responses to ethylene and other stimuli. Plant Physiology, 68, 175-179.

30. Schonbeck, M.W. and Egley, G.H. (1981). Changes in sensitivity of Amaranthus retroflexus L. seeds to ethylene during preincubation. I. Constant temperatures. Plant, Cell and Environment, 4, 229-235.

31. Schonbeck, M.W. and Egley, G.H. (1981). Changes in sensitivity of Amaranthus retroflexus L. seeds to ethylene during preincubation. II. Effects of alternating temperature and burial in soil. Plant, Cell and Environment, 4, 237-242.

32. Takabayashi, M. and Nakayama, K. (1981). [The seasonal change in seed dormancy of main upland weeds.] Weed Research, Japan, 26, 249-253.

33. Taylorson, R.B. (1970). Changes in dormancy and viability of weed seeds in soils. Weed Science, 18, 265-269.

34. Taylorson, R.B. (1979). Response of weed seeds to ethylene and related hydrocarbons. Weed Science, 27, 7-10.

35. Taylorson, R.B. and Hendricks, S.B. (1969). Action of phytochrome during pre-chilling of Amaranthus retroflexus L. seeds. Plant Physiology, 44, 821-825.

36. Taylorson, R.B. and Hendricks, S.B. (1971). Changes in phytochrome expressed by germination of Amaranthus retroflexus L. seeds. Plant Physiology, 47, 619-622.

CELOSIA

C. argentea L.
C. cristata L. [C. argentea L. var cristata (L.) Kuntze] cockscomb

I. Evidence of dormancy

Seeds of Celosia spp. exhibit dormancy (2,3), even after 70 or 80 days' storage at 30°C (3).

II. Germination regimes for non-dormant seeds

C. argentea

TP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

TP: 20°/30°C (16h/8h): 28d (AOSA)

C. cristata

TP: 20°/30°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

C. cristata

Constant temperatures: 15°C, 21°C, light, 12h/d, 80-100 W cm^{-2} (2); 20°C in light or dark (3)

Alternating temperatures: 41°/15°C (day/night) in light, 12h/d, 80-100 W cm^{-2} (2)

IV. Partly-successful dormancy-breaking treatments

C. argentea

Constant temperatures: 28°C in light, continuous, 1000 lux (4)

C. cristata

Constant temperatures: 30°C in light or dark (3); 31°C, 41°C, light, 12h/d, 80-100 W cm^{-2}, 25d (2)

Alternating temperatures: 33°/21°C (day/night), light, 12,24h/d, 80-100 W cm^{-2}, 30d (2); 31°/21°C, 41°/21°C, 41°/31°C (day/night) in light, 12h/d, 80-100 W cm^{-2}, 25d (2) Light: (3)

V. Successful dormancy-breaking treatments

C. argentea

Pre-chill (ISTA)

Light (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light, 10d (1)

C. cristata

Light (AOSA)

VI. Comment

High temperatures and light promote the germination of dormant seeds of Celosia spp. (2,3). An alternating temperature regime of 31°/21°C is better than 41°/21°C, 41°/31°C or 41°/15°C (day/night) (2), and better than constant temperatures between 15° and 41°C (2). If it is not possible to provide an alternating temperature regime then 30°C or 31°C is the most suitable constant temperature for germination tests within this range (2,3). At 31°/21°C some germination occurs after 15 days in test (2). Consequently it is suggested that AOSA rules, rather than ISTA rules, be followed since the former prescribe a longer test duration. In addition AOSA directions indicate that the seeds are sensitive to drying - presumably because secondary dormancy is induced - and so germination test substrata should be checked regularly and re-wetted if necessary.

VII. References

1. Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technology, 8, 523-573.

2. Okusanya, O.T. (1980). Germination and growth of Celosia cristata L., under various light and temperature regimes. American Journal of Botany, 67, 854-858.

3. Sakanishi, Y. (1957). Studies on the germination behavior of some annual and biennial flower seeds. Bulletin of the University of Osaka Prefecture, Series B, 7, 23-28.

4. Bansal, R.P. and Sen, D.N. (1981). Differential germination behavior in seeds of the Indian Arid Zone. Folia Geobotanika et Phytotaxonomica, 16, 317-330.

CHAPTER 21. ANACARDIACEAE

The Anacardiaceae comprise some 400 species of trees and shrubs in 60 genera which provide edible fruits (e.g. Mangifera indica L., mango) and nuts (e.g. Anacardium occidentale L., cashew), tannin (e.g. Schinopsis lorentzii (Griseb.) Engl., quebracho), lacquers (e.g. Rhus verniciflua Stokes) and mastics (e.g. Pistacia lentiscus L.). The fruits are usually indehiscent drupes - but with important exceptions, e.g. cashew. The seeds have fleshy cotyledons and little or no endosperm and the seed covering structures are usually hard. For example, mango seeds are surrounded by a stony endocarp.

Seed storage characteristics appear to differ within the Anacardiaceae. Some species show orthodox seed storage behaviour: for example cashew; and seeds of Schinus spp. are maintained in the long-term seed store of the Wakehurst Place Gene Bank. But other species, of which the best known example is the mango, are reported to exhibit recalcitrant seed storage characteristics.

SEED DORMANCY AND GERMINATION

B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos contained within hard seed coats (see Table 17.2, Chapter 17). Consequently a major improvement to the proportion of seeds germinating can generally be achieved by scarification or removal of the seed covering structures. Detailed information on seed germination is provided for the genera Anacardium and Pistacia in this chapter. A limited number of other recommended germination test procedures is provided in Table 21.1 and the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

In this algorithm the seed covering structures are chipped before any germination test is begun. The first step of the algorithm is to test one sample of the chipped seeds at a constant temperature of 21°C with light applied for 12h/d and a second sample in an alternating temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If neither regime promotes full germination then the second step of the algorithm is to test a further sample of chipped seeds in the more successful of the two regimes applied in the first step, but with 7×10^{-4} M GA_3 co-applied to the germination test substrate.

TABLE 21.1 Summary of germination test recommendations for species within the Anacardiaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Harpephyllum caffrum Bernh.			21d	complete removal of seed covering structures	Riley
Mangifera indica L.	S	25°-30°C	28d	light, continuous	CHML
			21d	complete removal of seed covering structures, then pre-soak, 24h	Riley
Rhus integrifolia Benth. & Hook.	soil		11d	scarify, concentrated sulphuric acid, 4h	Atwater

Rhus ovata Wats.				scarify, concentrated sulphuric acid, 3h, or drill a hole	Atwater

ANACARDIUM

A. occidentale L. cashew

I. Evidence of dormancy

Seed dormancy per se in A. occidentale - an orthodox species (5,7) - has not been reported, but germination is often low and delayed (2,10).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 10°C, 15°C (6)

Pre-soak: 2h (9); 6h (3)

Sodium bicarbonate: pre-applied, 2h, 5% (7)

Chloroform: pre-applied, 10+h (9)

Acetone: pre-applied, 10+h (9)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 20°-40°C (6)

Pre-soak: 12-24h (3); 24,48h (5)

Sodium hydroxide: pre-applied, 2h, 1.6% (7)

Light: 12h/d, at 35°C (7)

V. Successful dormancy-breaking treatments

GA_3: pre-applied, 48h, 100-500 ppm (8)

Chloroform: pre-applied, 2h (9)

Acetone: pre-applied, 2h (9)

Pre-soak: 24h (11)

VI. Comment

Slow imbibition of dry intact seeds is the main cause of delayed germination in cashew (9). The problem is greatest in the larger seeds (2,3,10). Pre-soaking for 1 or 2 days (3,5) or the removal of the waxy layer of the pericarp by treatment with chloroform or acetone (9) promote imbibition and thus reduce the time taken to germinate and increase the proportions of seeds germinating. Light (7) and gibberellins (8) are also reported to promote germination. If sand is used as the germination test medium it should be kept moist and well aerated (6); the seeds should be sown shallow with the concave side up or on one side, but not with the convex side up (1,3,4). The optimum constant temperature for germination is 35°C (6,7); germination at

30°C is similar to that at 35°C, but is substantially reduced at 40°C (6). It is suggested that the seeds be tested for germination in moist sand or between paper towels at about 32°C, that is between 30°-35°C, for at least 42 days, after pre-soaking for 24 hours.

VII. References

1. Adams, B.R. (1975). Container production of cashew seedling rootstocks. Seed germination in beds as an alternative to direct sowing. Acta Horticulturae, 49, 99-108.

2. Auckland, A.K. (1961). The influence of seed quality on the early growth of cashew. Tropical Agriculture, Trinidad, 38, 57-67.

3. Ibikunle, B.O. and Komolafe, D.A. (1973). Some experiments on the germination of cashew nuts (Anacardium occidentale Linn.). Nigerian Journal of Science, 7, 19-29.

4. Rao, V.N.M., Rao, I.K.S. and Hassan, M.V. (1957). Studies on certain aspects of germination of seeds in cashew (Anacardium occidentale Linn.). Indian Journal of Agricultural Science, 27, 25-34.

5. Rao, V.N.M., Rao, I.K.S. and Hassan, M.V. (1957). Studies on seed viability in cashew. Indian Journal of Agricultural Science, 27, 289-294.

6. Rocchetti, G. and Panerai, L. (1968). [The effect of temperature on the germination of cashew nuts.] Rivista di Agricoltura Subtropicale e Tropicale, 62, 228-235.

7. Rocchetti, G. and Panerai, L. (1970). [Further studies on the germination of the cashew nut.] Rivista di Agricoltura Subtropicale e Tropicale, 64, 151-160.

8. Shanmugavelu, K.G. (1970). Effect of gibberellic acid on seed germination and development of seedlings of some tree plant species. Madras Agricultural Journal, 57, 311-314.

9. Subbaiah, C.C. (1982/1983). Effect of presoaking in organic solvents on seed germination and seedling growth of cashew. Scientia Horticulturae, 18, 137-142.

10. Turner, D.J. (1956). Some observations on the germination and grading of cashew nut. East African Agricultural Journal, 22, 35-39

11. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

PISTACIA

P. atlantica Desf.

P. chinensis Bunge

P. integerrima Ste. [P. khinjuk Stock]

P. lentiscus L.

P. terebinthus L.

P. vera L. [P. trifolia L.; P. narbonnencis L.] pistachio

I. Evidence of dormancy

Seeds of Pistacia spp. can show considerable dormancy (1,2,3,4,6,12,13). After-ripening for 1.5 years is required to remove dormancy (8).

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

P. atlantica

Pre-soak: 10°-13°C, 1-21d (1)

Scarification: sand paper (3)

P. chinensis

Pre-chill: 3°C, 10°C, 90d (5)

P. integerrima

Scarification: concentrated sulphuric acid, 30 min (13); sulphuric acid, 10%, 12,24h (12)

P. terebinthus

Pre-soak: 7d (2); 3°-6°C, 7d, with or without epicarp (2) GA_3: pre-applied, 7d, 50, 500 ppm (2)

Scarification: sand paper (3); concentrated sulphuric acid, 30 min, with or without epicarp, then pre-soak, 24h (2); concentrated sulphuric acid, 2h, then pre-soak, 24h (3)

P. vera

Removal of seed covering structures: epicarp, then GA_3, pre-applied, 1d, 10°-13°C, 10 ppm (1); endocarp (2); endocarp, then GA_3, pre-applied, 7,15d, 50, 500 ppm (2); endocarp, then pre-soak, 3°-6°C, 7, 15d (2)

IV. Partly-successful dormancy-breaking treatments

P. atlantica

Pre-soak: 2-3h, then remove epicarp and endocarp (10)

GA_3: pre-applied, 7-21d, 100 ppm, 10°-13°C (1)

Removal of seed covering structures: epicarp, then pre-soak, 10°-13°C, 3-21d (1); epicarp, then pre-chill, 10°-13°C, 3-21d (1); epicarp, then GA_3, pre-applied, 3-21d, 10-1000 ppm, 10°-13°C (1)

Scarification: concentrated sulphuric acid, 1.5h, then pre-soak, 24h (3)

P. chinensis

Pre-chill: 0°C, 30-90d (5); 3°C, 30d (5); 5°C, 30,90d (5)

Pre-soak: 1-2h (7)

Removal of seed covering structures: epicarp, then pre-soak, 10°-13°C, 1-21d (1); epicarp, then GA_3, pre-applied, 1-21d, 500 ppm, 10°-13°C (1)

P. integerrima

Pre-chill: 3°-5°C, 15,30,45d (12)

Pre-soak: 100°C, then cool (13)

GA_3: pre-applied, 24h, 50, 100 ppm (4)

Vitamin B_9: pre-applied, 24h, 50 ppm (4)

Scarification: sand paper (4); sulphuric acid, 10%, 6h (12); sulphuric acid, 10%, 6,12,24h, then pre-chill, 3°-5°C, 15,30,45d (12); concentrated sulphuric acid, 15 min (13); concentrated sulphuric acid, 5,10,20 min, then pre-chill, 3°-5°C, 15d (12); concentrated sulphuric acid, 5,10 min, then pre-chill, 3°-5°C, 45d (12); concentrated sulphuric acid, 10 min, then pre-chill, 3°-5°C, 30d (12)

P. terebinthus

Pre-soak: 3°-6°C, 15d, with or without epicarp (2)

GA_3: pre-applied, 7,15d, 50, 500 ppm (2)

Removal of seed covering structures: epicarp, then pre-soak, 10°-13°C, 1-21d (1); epicarp, then GA_3, pre-applied, 1-21d, 500 ppm, 10°-13°C (1)

Scarification: concentrated sulphuric acid, 1.5h, then pre-soak, 24h (3)

P. vera

Pre-soak: 3°-6°C, 7,15d (2)

GA_3: pre-applied, 3,7,14,21d, 100 ppm, 10°-13°C (1); pre-applied, 7,15d, 50, 500 ppm (2)

Removal of seed covering structures: epicarp, then pre-soak, 10°-13°C, 3-21d (1); epicarp, then GA_3, pre-applied, 1-21d, 100, 1000 ppm, 10°-13°C (1); epicarp, then GA_3, pre-applied, 7-21d, 10 ppm, 10°-13°C (1); epicarp, split endocarp, then pre-soak, 10°-13°C, 1,3,7,21d (1); epicarp, split endocarp, then GA_3, pre-applied, 1,3,7,21d, 10-1000 ppm, 10°-13°C (1); epicarp, split endocarp, then pre-chill, 10°-13°C, 3-21d (1)

V. Successful dormancy-breaking treatments

P. atlantica

Pre-soak: (14); 1-2h (7); 2-3h (6); 2-3h, then remove epicarp and endocarp, then pre-chill, 2°-3°C, 4w, germinate at 20°C (10) Removal of seed covering structures: epicarp, then pre-soak, 10°-13°C, 1d (1); epicarp, then GA_3, pre-applied, 1d, 10-1000 ppm, 10°-13°C, germinate at 21°/32°C (night/day) (1)

P. chinensis

Pre-chill: 3°C, 5°C, 60d (5); 10°C, 30d (5)

Pre-soak: 2-3h (6)

Removal of seed covering structures: epicarp, then pre-soak (14)

P. Integerrima

Pre-soak: 2-3h (6)

Vitamin B_9: pre-applied, 24h, 100, 150 ppm (4)

GA_3: pre-applied, 24h, 150 ppm (4)

Scarification: sand paper, then vitamin B_9, pre-applied, 24h, 50-150 ppm (4); concentrated sulphuric acid, 5,20 min, then pre-chill, 3°-5°C, 30d (12); concentrated sulphuric acid, 20 min, then pre-chill, 3°-5°C, 45d (12)

P. lentiscus

Pre-soak: 2-3h (6)

P. terebinthus

Pre-chill: 5°C, 6w, germinate at 21°C (7)

Pre-soak: 2-3h, then warm stratification, 22°C, 2w (6, 14); 2-3h, then remove epicarp and endocarp, then pre-chill, 2°-3°C, 4w, germinate at 20°C (10)

P. vera

Pre-soak: 5°C, 2w (6,7,14); 2d, then remove epicarp and endocarp (11); 2-3h, remove epicarp and endocarp, then pre-chill, 2°-3°C, 4w, germinate at 20°C (10)

Pre-wash: 1-2d, then warm stratification, 22°C, 2w (6)

Removal of seed covering structures: epicarp, split endocarp, then pre-soak, 10°-13°C, 14d (1); epicarp, split endocarp, then GA_3, pre-applied, 14d, 10-1000 ppm, 10°-13°C (1)

Pistacia spp.

Pre-soak: 15°-17°C, 24h (8); warm, 24h, then warm stratification, 1-2w (9)

VI. Comment

Pistacia spp. show orthodox seed storage characteristics (1,6,7,14). The seeds can be tested for germination on top of paper, between paper or in sand (4, 12). Non-dormant seeds germinate well at 21°C or below, poorly at 27°C, whilst no seeds germinate at 33°C (7) - with the exception of seeds of P. terebinthus which germinate well at 27°C (7). Consequently it has been suggested that non-dormant seeds of Pistacia spp. be tested for germination at a constant temperature of 20°C, between moist paper towels (7,10).

The seed covering structures can, however, represent a formidable barrier to embryo growth: the epicarp (the soft outer hull) can inhibit germination (6), and the endocarp can reduce the rate of imbibition (3); removal or careful scarification of these covering structures can promote germination (3,4,6,10,11,12,13,14), but removal of the endocarp can also damage seeds, reducing the proportion which germinates (2). Warm stratification (6,9), pre-soaking (1,2,6,7,14), or pre-chilling treatments (1,5,7,10,12) can be promotory, but soaking for more than 21 days reduces germination (1). Treatment with gibberellins can be promotory, particularly where the seeds have first been scarified (1,2,4). A 10 minute scarification treatment with concentrated sulphuric acid appears to be safe and can be combined with advantage with subsequent gibberellin or pre-chilling treatments (12).

It is suggested that dormant seeds of Pistacia spp. be pre-treated as follows before the germination test. Scarify the seed: either by hand, by first removing the epicarp and then chipping the endocarp or rubbing it with sandpaper, or by a 10 minute treatment in concentrated sulphuric acid followed by through rinsing in running water. Then pre-treat the seeds with GA at 500-1000 ppm for 24 hours, followed by a 2 to 4 week pre-chill at 3°-5°C.

3

Test the seeds for germination as already described for non-dormant seeds: the test duration should be at least 6 weeks (2).

VII. References

1. Ayfer, M. and Serr, E.F. (1961). Effects of gibberellin and other factors on seed germination and early growth in Pistacia species. Proceedings of the American Society for Horticultural Science, 77, 308-315.

2. Casini, E. and Conticini, L. (1979). [The germinability of seeds of Pistacia vera and Pistacia terebinthus.] Rivista di Agricoltura Subtropicale e Tropicale, 73, 233-240.

3. Crane, J.C. and Forde, H.I. (1974). Improved Pistacia seed germination. California Agriculture, 28, 8-9.

4. Dahab, A.M.A., Shafiq, Y. and Al-Kinany, A. (1975). Effects of gibberellic acid, B-nine and scarification on the germination of seeds of Pistacia khinjuk Stock. Mesopotamia Journal of Agriculture, 10, 13-19.

5. Hartmann, H.T. (1967). Effects of various treatments on seed germination of several tree species. Plant Propagator, 12, 10-12.

6. Joley, L.E. (1960). Experiences with propagation of the genus Pistacia. Proceedings of the Plant Propagators' Society, 10, 287-292.

7. Joley, L.E. and Opitz, K.W. (1971). Further experiences with propagation of Pistacia. Combined Proceedings of the International Plant Propagators' Society, 21, 67-76.

8. Kravchenko, V.I. (1961). [The effect of the duration of pistachio seed storage on their germinating power in the ground.] Izvest. Akad. Nauk Turkmen SSR Ser. Biol. Nauk, 5, 83-87. (From Biological Abstracts, 1963, 42, 7667.)

9. Lemaistre, J. (1959). Le pistachier. Etude bibliographique. Fruits, 2, 57-77.

10. Maggs, D.H. (1973). The pistachio as an Australian crop. Journal of the Australian Institute of Agricultural Science, 39, 10-17.

11. Nimadzhanova, K.N., Abdurakhmanov, N.A. and Rafieva, M.G. (1977). [The effect of seed covers on the germination of some nut crops.] Subtropicheskie Kul'tury, 1/2, 129-132. (From Horticultural Abstracts, 1978, 48, 7017.)

12. Shafiq, Y. and Kettaneh, M.S. (1971). The effect of stratification, sulphuric acid and combination treatments on germination percentage of seeds of wild pistacia (Pistacia khinjuk). Mesopotamia Journal of Agriculture, 7, 37-43.

13. Sheikh, M.I. (1979). Tree seeds respond to acid scarification. Pakistan Journal of Forestry, 29, 253-254.

14. Whitehouse, W.E. (1957). The pistachio nut. A new crop for the Western United States. Economic Botany, 11, 281-321.

15. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 22. ANNONACEAE

The Annonaceae comprise roughly 600 species of trees and shrubs in 40 to 50 genera which provide edible fruits (e.g. Annona squamosa L., sugar apple). In some genera the fruits are fleshy, but in others the fruits are dry. The seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

Seed dormancy can be a considerable problem. Detailed information on seed germination is provided for the genus Annona in this chapter. A limited number of other recommended germination test procedures is provided in Table 22.1.

TABLE 22.1 Summary of germination test recommendations for species within the Annonaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Asimina triloba Dunal			90d	scarify, abrade with sharp sand, or file or nick seed coat, then pre-chill, 1°-5°C, 30-60d	Riley
Rollinia deliciosa			21d	pre-soak, 24h	Riley

ANNONA

A. cherimola Mill. [A. cherimolia Mill.]	cherimoya
A. crassiflora Mart.	
A. diversifolia Safford	ilama
A. muricata L.	soursop, guanabara
A. reticulata L.	common custard-apple, bullocks-heart
A. squamosa L.	sweetsop, sugar-apple

I. Evidence of dormancy

Seeds of A. muricata, A. reticulata and A. squamosa are reported not to exhibit dormancy (3,4,5), but may, nevertheless, take up to 3 months to germinate (3). However, freshly harvested seeds of A. cherimola, A. crassiflora and A. diversifolia may exhibit considerable dormancy (1,2,4,6): several months after-ripening at room temperature may be required for full germination (1).

II. Germination regimes for non-dormant seeds

A. cherimola

Constant temperatures: 25°C, 75d (6)

A. reticulata, A. squamosa

Constant temperatures: 30°C, 100d (4)

III. Unsuccessful dormancy-breaking treatments

A. cherimola

Scarification: mechanical (6); mechanical, then pre-soak, 24h (6)

Pre-soak: 24h (2,6); 100°C, then allow to cool, 24h (2)

GA_3: pre-applied, 24h, 10-1000 ppm (2)

A. crassiflora

Constant temperatures: 35°C (4); 30°C, 200d (4)

Scarification: (4)

Pre-soak: 7d (4)

Hydrogen peroxide: pre-applied, 7,14d, 1% (4)

Glucose: (4)

A. squamosa

Scarification: (3)

A. diversifolia

Pre-soak: 24h (1)

IV. Partly-successful dormancy-breaking treatments

A. cherimola

GA_3: pre-applied, 24h, 10000 ppm, test for 3m (2); pre-applied, 24h, 20, 200, 750, 1000 ppm, test for 10w (6)

A. diversifolia

GA_3: pre-applied, 24h, 3.5, 35, 350, 3500, 35000 ppm (1)

V. Successful dormancy-breaking treatments

A. cherimola

GA_3: pre-applied, 24h, 500 ppm, test for 75d (6)

A. crassiflora

Constant temperatures: 30°C, in diffuse light, 300d (4)

A. muricata

Alternating temperatures: 25°/30°C, light, 24h/d, 46d, after heat treatment, 40°C, 5d (7)

VI. Comment

Despite the seed coats of Annona spp. being thick and heavily lignified the seeds imbibe without difficulty (3,4,6). Consequently scarification or pre-soaking treatments are not beneficial (2,3,4,6). The major germination problems appear to result, in A. squamosa at least, from the fact that the embryo is small, only partly developed, and embedded in a large

endosperm (3); the embryo continues to develop after being shed from the mother plant (3). It has been suggested that non-dormant seeds of Annona spp. be tested for germination in moist sand or between moist paper towels at a constant temperature of 30°C for 100 to 300 days (4). It is suggested here that, in addition, GA_3 be pre-applied for 24 hours at 350 to 500 ppm to promote the germination of dormant seeds. Pre-application of GA_3 for 1 day at concentrations between 3.5 and 35000 ppm showed maximum promotion of germination at 350 ppm for 5 lots of A. diversifolia (1). Do not exceed 350 to 500 ppm because GA_3 at higher concentrations, 1000 ppm (6), 3500 ppm (1), may reduce germination and, moreover, affect seedling growth: treatment at 350 ppm did not cause abnormal seedling development whereas treatment at 3500 ppm and higher did (1).

VII. References

1. Campbell, C.W. and Popenoe, J. (1968). Effect of gibberellic acid on seed dormancy of Annona diversifolia Saff. Proceedings of the Tropical Region, American Society for Horticultural Science, 11, 33-36.

2. Duarte, O., Villagarcia, J. and Franciosi, R. (1974). [The effect of different treatments on the propagation of cherimoya by seeds, cuttings and grafting.] Proceedings of the Tropical Region, American Society for Horticultural Science, 18, 41-48.

3. Hayat, M.A. (1963). Morphology of seed germination and seedlings in Annona squamosa. Botanical Gazette, 124, 360-362.

4. Rizzini, C.T. (1973). Dormancy in seeds of Annona crassiflora Mart. Journal of Experimental Botany, 24, 117-123.

5. Stephens, S.E. (1936). Some tropical fruits. No. 11. The soursop. Queensland Agricultural Journal, 46, 409-412.

6. Toll-Jubes, T., Martinez, H., Padilla, E. and Oste, C.A. (1975). [Effects of mechanical scarification, substrate, seed position and gibberellic acid on germination in cherimoya.] Revista Agronomica del Noroeste Argentino, 12, 161-172.

7. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436

CHAPTER 23. AQUIFOLIACEAE

The Aquifoliaceae comprise more than 300 species of trees and shrubs within three genera. The fruits are drupes and contain several bony seeds or nutlets. The seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

Dormancy can be a major problem: successful dormancy-breaking treatments are available but can require substantial treatment periods. Effective dormancy-breaking treatments consist of alternating between warm stratification and pre-chill treatment regimes. Detailed information on seed germination and dormancy-breaking treatments is limited (Table 23.1), but the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to imbibe two samples of seeds at 26°C for 4w (i.e. a warm stratification treatment) with light applied for 12h/d. One sample is then moved to a constant temperature regime of 2°C and the other sample moved to a constant temperature regime of 6°C. In both cases light is applied for 12h/d.

If these treatments are not successful in promoting full germination then the second step of this algorithm is to alter these regimes slightly. For example, increase or reduce the period of warm stratification. Also test further seed samples in alternating temperature regimes of 23°/9°C (12h/12h) and 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature after the initial warm stratification (26°C)/pre-chill (2°-6°C) treatment.

TABLE 23.1 Summary of germination test recommendations for species within the Aquifoliaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Ilex aquifolium L.				warm stratification, 25°C, 40w, then pre-chill, 1°-5°C, 24w	G&R

CHAPTER 24. ARACEAE

The Araceae comprise roughly 1500 species, mainly herbaceous, within more than 100 genera. The aroids provide edible roots (e.g. Amorphophallus campanulatus. (Roxb.) Blume, elephant yam), edible fruits (e.g. Monstera deliciosa Liebm., ceriman) and oils (e.g. Acorus calamus L., sweet flag). The fruits are usually berries. Seed storage behaviour is orthodox, at least in Colocasia and Xanthosoma spp.

SEED DORMANCY AND GERMINATION

The seeds are usually endospermic and can exhibit dormancy, although the problem may not be pronounced. Detailed information is provided for the genera Colocasia and Xanthosoma in this chapter.

caracu Koch & Bouché

cocoyam

X. sagittifolium (L.) Schott

cocoyam, tannia, tanier, yautia

I. Evidence of dormancy

Xanthosoma spp. show orthodox seed storage behaviour and can be stored at low moisture contents and temperature, but longevity is reported to be comparatively short (4). We have found no evidence of dormancy in the literature.

II. Germination regimes for non-dormant seeds

X. caracu

Agar: Hoagland's nutrient agar medium, room temperature, 18d (3)

X. sagittifolium

Constant temperatures: 28°-30°C, 4w, in sand or on top of paper (1,2)

Xanthosoma spp.

Constant temperatures: 25°-28°C in light, 12h/d (4)

III. Unsuccessful dormancy-breaking treatments

IV. Partly-successful dormancy-breaking treatments

V. Successful dormancy-breaking treatments

VI. Comment

Flowering in Xanthosoma spp. is sporadic and consequently seeds are only produced infrequently (1,4). Flowering can be promoted by foliar application of gibberellic acid at 250 ppm (1) or between 500 and 1500 ppm (4); pollination by hand is then required (1,4).

It is suggested that the seeds be tested for germination on top of filter papers at 25°C in light: a 28 day test should be adequate. For seedling production the seeds can be germinated on top of sterile soil (4), but do not let the temperature fall below 22°C (4). The seedlings can be transplanted between 14 and 21 days after sowing (4).

The apparent absence of dormancy in freshly harvested seeds of cocoyam may have been the result of the earlier foliar applications of gibberellic acid which were used to promote flowering in references (1) and (2). If this were to be the case then it would suggest that seed treatment with gibberellic acid is likely to be an effective dormancy-breaking treatment where seed dormancy is encountered in accessions of X. sagittifolium.

VII. References

1. Alamu, S., McDavid, C.R. and Duncan, E.J. (1982). Production of viable seed in gibberellic acid-treated tannia (Xanthosoma sagittifolium (L.) Schott) plants. Tropical Agriculture (Trinidad), 59, 333-334.

2. McDavid, CR. (1984). University of the West Indies, Trinidad (Personal communication).

3. Volin, R.B. and Zettler, F.W. (1976). Seed propogation of cocoyam, Xanthosoma caracu Koch & Bouché HortScience, 11, 459-460.

4. Wilson, J.E. (1980). Cocoyam breeding by flower induction, pollination and seed germination. Manual Series No. 4, 15pp., International Institute of Tropical Agriculture Ibadan, Nigeria.

COLOCASIA

C. esculenta (L.) Schott. [C. antiquorum var esculenta Schott.; Arum esculentum L.; Caladium esculentum Vent.] taro, eddo, dasheen, coco yam

C. gigantea (B1.) Hook. f.

I. Evidence of dormancy

Orthodox seed storage characteristics are shown by C. esculenta (4) and C. gigantea (3), although in the former seed longevity under ambient conditions is short (5). Seed dormancy can be exhibited in C. esculenta, for example after-ripening the seeds for 60 weeks at room temperature has been reported to result in the germination of a greater proportion of seeds (8), but tends to be less of a problem than is the case for freshly harvested seeds of C. gigantea which show considerable dormancy (3).

II. Germination regimes for non-dormant seeds

C. esculenta

Constant temperatures: 22°C in light, 18h/d (4,8); 25°C (5); 25°-28°C in light, 12h/d (9)

C. gigantea

Constant temperatures: 28°C (3)

III. Unsuccessful dormancy-breaking treatments

C. gigantea

Constant temperatures: 15°C, 28°C (3)

Warm stratification: 15°C, 6d, germinate at 28°C (3)

IV. Partly-successful dormancy-breaking treatments

C. esculenta

Constant temperatures: 22°C in light, 18h/d (8)

C. gigantea

Warm stratification: 40°C, 1,2d, germinate at 28°C (3); 15°/28°C, 15°/40°C, 28°/40°C (8h/16h), 6d, germinate at 28°C (3)

V. Successful dormancy-breaking treatments

C. gigantea

Warm stratification: 40°C, 3-20d, germinate at 28°C (3)

VI. Comment

Seeds of C. esculenta are reported to be easy to germinate (2,7) and can be tested in soil (5), between moist rolled paper towels (5), on top of paper (7,8), in agar (4,5,8,9) or in embryo culture (1); testing on top of paper is a more suitable germination test medium than either agar or soil (8). Immature seeds, however, show low germination (7). Seeds of C. gigantea can be more difficult to germinate. It is suggested that non-dormant seeds of Colocasia spp. be tested for germination on top of filter paper at 25°C. Dormant seeds can be tested in this way after the imbibed seeds have first received a 6 day warm stratification treatment at 40°C.

VII. References

1. Abraham, A. and Ramachandran, K. (1960). Growing Colocasia embryos in culture. Current Science, 29, 342-343.

2. Barrau, J. (1959). Fruits et graines du taro, Colocasia esculenta (L.) Schott. Journal d'Agriculture Tropicale et de Botanique Appliquee, 6, 436-438.

3. Hanson, J. and Imamuddin, H. (1983). Germination and storage behaviour of seeds of Colocasia gigantea Hook.f. Proceedings of the 6th Symposium of the International Society for Tropical Root Crops, Peru, February 1983.

4. Jackson, G.V.H., Ball, E.A. and Arditti, J. (1977). Seed germination and seedling proliferation of taro, Colocasia esculenta (L.) Schott. in vitro. Journal of Horticultural Science, 52, 169-171.

5. Kikuta, K., Whitney, L.D. and Parris, G.K. (1938). Seeds and seedlings of the taro, Colocasia esculenta. American Journal of Botany, 25, 186-188.

6. Pardales, J.R. Jr. (1981). Floral morphology and biology, fruit and seed set, seed germination and seedling development of taro. Annals of Tropical Research, 3, 169-176.

7. Shaw, D.E. (1975). Illustrated notes on flowering, flowers, seed and germination in taro (Colocasia esculenta). Research Bulletin, Department of Agriculture, Stock and Fisheries, Papua New Guinea, 13, 39-59.

8. Strauss, M.S., Michaud, J.D. and Arditti, J. (1979). Seed storage and germination and seedling proliferation in taro, Colocasia esculenta (L.) Schott. Annals of Botany, 43, 603-612.

9. Wilson, J.E. (1980). Cocoyam breeding by flower induction, pollination and seed germination. International Institute of Tropical Agriculture, Manual Series No. 4, 15 pp.

CHAPTER 25. BIGNONIACEAE

The Bignoniaceae comprise more than 600 species of trees, shrubs, woody vines and, rarely, herbaceous plants in about 100 genera. Cultivated species include Crescentia cujete L. (calabash), the woody shells of the fruits providing domestic utensils, and Parmentiera edulis DC. (cauchilote), the flesh of the fruits being edible. The fruits are large and, usually, dehiscent capsules. Where known, seed storage behaviour is orthodox. For example, seeds of Incarvillea spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

The seeds are usually winged. Seed dormancy does not appear to be a great problem and it appears that most species are easily grown from seed. The information on seed germination provided here is limited to that summarised in Table 25.1, but as a first step in developing suitable germination test procedures RBG Kew Wakehurst Place suggests testing the seeds at a constant temperature of 21°C with light applied for 12h/d.

TABLE 25.1 Summary of germination test recommendations for species within the Bignoniaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Catalpa bignonioides Walt.	TP	20°/30°C	21d		AOSA
Catalpa speciosa Warder	TP	20°/30°C	21d		AOSA
Catalpa spp.	TP	20°/30°C	21d		ISTA

CHAPTER 26. BIXACEAE

The Bixaceae comprise several species of trees and shrubs within two genera. Bixa orellana L. (annatto) provides a dye. The fruits are dehiscent capsules and seed storage behaviour is orthodox. Detailed information on seed germination is provided here for Bixa orellana only.

BIXA

B. orellana L. achiote, annatto

I. Evidence of dormancy

Without treatment some seeds of B. orellana may take more than a year to germinate (2). Hardseededness, induced by drying seeds below 40% moisture content, is the main cause of this slow germination (2).

II. Germination regimes for non-dormant seeds

Constant temperatures: 30°C, 15d (2)

Alternating temperatures: 25°/30°C, light, 24h/d, 23d (1)

III. Unsuccessful dormancy-breaking treatments

-

IV. Partly-successful dormancy-breaking treatments

-

V. Successful dormancy-breaking treatments

Removal of seed covering structures: chip at radicle end (2)

VI. Comment

B. orellana shows orthodox seed storage behaviour - tolerating desiccation to 10% moisture content (2), but problems have arisen with seeds dried to 4% or stored at low temperatures (5°C, -20°C) when subsequently tested for germination at 30°C in a 15 day test after chipping the testae (2). Further investigations with very dry seeds are required. It is suggested that the dry seeds be humidified for several days after chipping to avoid the possibility of imbibition injury and that before storing seeds at low temperatures moisture should be allowed to equilibrate throughout each seed. Further work may show advantage in testing the seeds for germination in alternating temperature environments. In the meantime it is suggested that chipping, humidification and testing at 25° to 30°C be practised but note that the seeds - particularly the very dry seeds - may require considerably more than 15 to 23 days to germinate.

VII. References

1. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

2. Goldbach, H. (1979). Germination and storage of Bixa orellana seeds. Seed Science and Technology, 7, 399-402.

CHAPTER 27. BROMELIACEAE

The Bromeliaceae comprise about 1500 species of herbaceous plants in about 60 genera which provide edible fruits (Ananas comosus (L.) Merr., pineapple) and fibres (e.g. Neoglaziovia variegata Mez, caroa). The fruits are either berries or capsules, but in some genera the production of seeds may be comparatively rare. Seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

It can be difficult to germinate the seeds: light treatments generally promote seed germination and scarification can be helpful. Detailed information on seed germination is provided in this chapter for the genera Aechmea and Ananas; for information on Bromelia spp. see Ananas. As a first step in developing suitable germination test procedures for species of unknown characteristics, RBG Kew Wakehurst Place suggests testing in an alternating temperature regime of 23°/9°C (12h/12h), with light applied for 12h/d during the period spent at the upper temperature.

AECHMEA

A. coelestis

A. fasciata

A. nudicaulis

I. Evidence of dormancy

Seeds of Aechmea spp. show orthodox seed storage behaviour, that is they can be dried and then stored at low temperatures (1). The seeds can exhibit dormancy (1).

II. Germination regimes for non-dormant seeds

A. A. coelestis, A. fasciata, A. nudicaulis

Constant temperatures: 20°C (1)

III. Unsuccessful dormancy-breaking treatments

A. coelestis, A. fasciata

Light: dark, at 20°C (1)

A. nudicaulis

Constant temperatures: 15°C, 30°C in light, 200 fc, 1 min-8h/d (1)

Light: dark, at 20°C (1)

IV. Partly-successful dormancy-breaking treatments

A. coelestis

Light: 200 fc, 1,8h/d, at 20°C (1)

A. fasciata, A. nudicaulis

Constant temperatures: 20°C, 25°C in light, 200 fc, 1 min-8h/d (1)

V. Successful dormancy-breaking treatments

A. coelestis

Light: light/dark, 5 min/2h, at 20°C (1)

A. fasciata

Light: red, 2 min, at 20°C (1)

VI. Comment

Light is required for the germination of seeds of Aechmea spp. (1). It is suggested that the seeds be tested for germination on top of filter paper at a constant temperature of 20°C in light - see Chapter 6.

VII. References

1. Downs, R.J. (1964). Photocontrol of germination of seeds of the Bromeliaceae. Phyton, 21, 1-6.

ANANAS

A. comosus (L.) Merr. [A. sativus Schult.f.; Bromelia comosa L.] pineapple

I. Evidence of dormancy

The seeds of pineapple are orthodox, that is they can be stored dry (1,6). Seed germination can be slow (1,2,4,6), the delay being caused by the seed coat (1,2,4-6).

II. Germination regimes for non-dormant seeds

Constant temperatures: 30°-35°C (1,3,6)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 20°-28°C (2)

IV. Partly-successful dormancy-breaking treatments

Scarification: concentrated sulphuric acid, 30s (2); concentrated sulphuric acid, 30-60s (4)

V. Successful dormancy-breaking treatments

Scarification: concentrated sulphuric acid, dip, germinate at 35°C (5); concentrated sulphuric acid, 30-60s, germinate at 30°-35°C (1); concentrated sulphuric acid, 1 min, germinate at 32°C (6)

VI. Comment

Seeds of pineapple can be tested for germination on sand or on top of filter papers. Whichever germination test substrate is used it should be sterile, kept moist throughout the test (intermittent mist sprays may be helpful) and well aerated (1-6). It is quite likely that light is

required for germination since it has been recommended that the seeds be sown on top of sand (1,3). In addition many other genera within the Bromeliaceae require light for germination. Although very short acid scarification treatments can promote germination, a 30 second treatment in concentrated sulphuric acid can also be detrimental to pineapple seed germination (2).

It is suggested that the seeds be germinated on top of moist (sterile) sand or on top of filter paper at 30°C' in light with regular mist spraying to maintain moisture. Seeds which fail to imbibe within four or five days can be scarified by hand. Alternating temperature regimes may prove to be beneficial.

VII. References

1. Collins, J.L. (1968). The Pineapple. Leonard Hill, London.

2. Gopinomy, R., Balakrishnan, S. and Kannan, K. (1976). A note on germinating seeds of pineapple (Ananas comosus, Merr.). Agricultural Research Journal of Kerala, 14, 194-195.

3. Higgins, J.E. (1916). Germination of pineapple seeds. Hawaii Agricultural Experiment Station Report, pp. 15-17.

4. Iyer, C.P.A., Singh, R. and Subramanyam, M.D. (1978). A simple method for rapid germination of pineapple seeds. Scientia Horticulturae, 8, 39-41.

5. Kerns, K. (1927). Pineapple seed germination. Pineapple News, 1, 38-39.

6. Purseglove, J.W. (1972). Bromeliaceae. In Tropical crops. Monocotyledons, pp. 75-91. Longmans, London.

CHAPTER 28. CARICACEAE

The Caricaceae comprise roughly 30 species of small trees and shrubs within four genera: Carica spp. provide edible fruits. The fruits are generally large berries. The seeds possess fleshy arils and show orthodox seed storage behaviour.

SEED DORMANCY AND GERMINATION

Germination is epigeal and dormancy can be a severe problem. Information is provided in this chapter for the genus Carica only.

CARICA

C. papaya L.

papaya, papaw, pawpaw

I. Evidence of dormancy

The germination of seeds of C. papaya is frequently reported to be slow, erratic, and incomplete (2,5,7). For example, in one investigation freshly harvested seeds gave only 6% germination (4). The seed is enclosed within a gelatinous sarcotesta (aril, or outer seed coat) which is formed from the outer integment. Whilst this sarcotesta can prevent germination (5,10,11), dormancy is also observed in seeds from which the sarcotesta has been removed (5,10,11).

II. Germination regimes for non-dormant seeds

Constant temperatures: 28°-29°C (2); 28°-30°C (3); 30°C, 30d (10)

Alternating temperatures: 20°/30°C (15h/9h), 90d (1)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 30°C, in dark, after arils removed, 30d (11)

Pre-chill: 11°C, 3d (8); 15°C, 10-40d (10)

Warm stratification: 40°C, 50°C, 1-4d (10)

Pre-soak: 24h (8)

QA3: dust (7); pre-applied, 50-100 ppm (2)

Napthaleneacetic acid: pre-applied, 10-10000 ppm (5); pre-applied, 24h, 100, 200 ppm (8)

Indoleacetic acid: pre-applied, 1-10000 ppm (5)

Maleic hydrazide: pre-applied, 10, 10000 ppm (5)

Dimethyl aminosuccinamic acid: pre-applied, 24h, 10000 ppm (8) 2-Chloroethyl trimethyl ammonium chloride: pre-applied, 24h, 10000 ppm (8)

Ethylenediaminetetraacetic acid: pre-applied, 24h, 100, 200 ppm (8)

Benzyladenine: pre-applied, 20h, 1-1000 ppm, after arils removed, germinate at 30°C in dark, 30d (11)

IV. Partly-successful dormancy-breaking treatments

Pre-chill: 5°C, 30,40d, arils removed, germinate at 30°C (10); 11°C, 3d, then pre-soak, 24h (8); 15°C, 50d (10); 15°C, 10-40d, arils removed, germinate at 30°C (10)

Warm stratification: 25°C, 10-40d, arils removed, germinate at 30°C (10)

Pre-soak: 12h (9); 24h (6); 70°C, 15s (6)

GA_3: (4); pre-applied, 100 ppm (5); pre-applied, 24h, 100, 200 ppm (8); pre-applied, 20h, 10-1000 ppm, after arils removed, germinate at 30°C in dark, 30d (11)

Removal of seed covering structures: arils (5,6,10); arils, then pre-soak (5); arils, then pre-wash (5); arils, then GA_3 pre-applied, 10-1000 ppm (5)

Potassium nitrate: pre-applied, 24h, 1.5%, plus potassium phosphate, 1.5% (6)

Sodium phosphate: pre-applied, 12h, 200 ppm (9)

Ethylenediaminetetraacetic acid: pre-applied, 12h, 200 ppm (9)

V. Successful dormancy-breaking treatments

Pre-chill: 15°C, 50d, arils removed, germinate at 30°C (10)

VI. Comment

The flesh of papaya fruit contains an inhibitor which can prevent germination (5), the sarcotesta can prevent germination (5,6,10), but drying freshly extracted seeds results in increased germination in subsequent tests (10,11). Consequently it is suggested that, as a general practice at harvest, the freshly extracted seeds are rubbed to remove the gelatinous sarcotestae and thoroughly washed in running water before being dried for storage. Pre-soaking the seeds in water for 24 hours is reported to promote germination in seven Carica spp. (12).

Treatment with gibberellins may (4,5,8,11) or may not (2,7) promote germination, but even where it does not promote the germination of a greater proportion of seeds the time taken to germinate is reduced (2). Indeed the major effects of both gibberellin treatments and removal of the sarcotestae is a reduction in the time taken to germinate (5,11). Pre-application for 24 hours with 500 ppm GA_3 is suggested.

Temperature is reported to affect greatly the percentage of seeds which will germinate (5), but unfortunately no details have been provided. On the basis of the evidence available at present, it is suggested that the seeds be tested for germination at 30°C or 20°/30°C (16h/8h), but the temperature requirements for germination require further work. If a combination of aril removal, washing and drying prior to storage, followed by pre-treatment with GA_3 at 500 ppm and testing at either 30°C or 20°/30°C for 30-42 days is insufficient to promote germination, then a pre-chill treatment should also be considered: 15°C for 40 or 50 days was extremely promotory in one case (10), and is suggested as a possible standard procedure.

VII. References

1. Bass, L.N. (1975). Seed storage of Carica papaya L. HortScience, 10, 232.

2. Chacko, E.K. and Singh, R.N. (1966). The effect of gibberellic acid on papaya seeds and subsequent seedling growth. Tropical Agriculture, Trinidad, 43, 341-346.

3. Chacko, E.K. and Singh, R.N. (1971). Studies on the longevity of papaya, phalsa, guava and mango seeds. Proceedings of the International Seed Testing Association, 36, 147-158.

4. Koyamu, K. (1951). A preliminary note on the germination of papaya seed. Madras Agriculture Journal, 38, 348-349.

5. Lange, A.H. (1961). Effect of the sarcotesta on germination of Carica papaya. Botanical Gazette, 122, 305-311.

6. Pérez, A., Reyes, M.N. and Cuevas, J. (1980). Germination of two papaya varieties: effect of seed aeration, K-treatment, removing of the sarcotesta, high temperature, soaking in distilled water, and age of seeds. Journal of Agriculture of the University of Puerto Rico, 64, 173-180.

7. Ramirez, O.D. (1961). Effects of gibberellic acid on germination of papaya (Carica papaya L.) seed. Journal of Agriculture of the University of Puerto Rico, 45, 188-190.

8. Sen, S.K. and Ghunti, P. (1976). Effect of pre-sowing seed treatments on the germination and seedling growth in papaya. Orissa Journal of Horticulture, 4, 38-43.

9. Veeraragavathatham, D., Vadivelu, K.K. and Ranganathan, T.B. (1980). Seed invigoration in Co2 papaya. South Indian Horticulture, 28 69-71. (From Seed Abstracts, 1981, 4, 2822.)

10. Yahiro, M. (1979). Effects of seed-pretreatments on the promotion of germination in papaya, Carica papaya L. Memoris of the Faculty o Agriculture, Kagoshima University, 15, 49-54.

11. Yahiro, M. and Oryoji, Y. (1980). Effects of gibberellin and cytokinin treatments on the promotion of germination in papaya, Carica papaya L., seeds. Memoris of the Faculty of Agriculture, Kagoshima University, 16, 45-51.

12. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 29. CHENOPODIACEAE

The Chenopodiaceae comprise about 1400 species of herbaceous plants in more than 100 genera which provide edible roots (e.g. Beta vulgaris L., beetroot), leaf vegetables (e.g. Spinacia oleracea L., spinach), oils (e.g. Chenopodium ambrosioides L., wormseed) and grain (e.g. Chenopodium quinoa Willd., quinoa). The fruits are utricles (see Chapter 3, Volume I) and the seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

The seeds can show considerable dormancy and, in addition, the presence of the fruit structures may also hinder seed germination. B.R. Atwater classifies seed morphology as endospermic seeds with peripheral linear embryos (see Table 17.1, Chapter 17). Light can be particularly promotory. Detailed information on seed germination is provided in this chapter for the genera Beta, Chenopodium and Spinacia. Additional information on germination test regimes for the Chenopodiaceae is summarised in Table 29.1, and the algorithm below may be helpful in developing germination test procedures for difficult accessions.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test four samples of seeds at constant temperatures of 6°C, 16°C, 21°C and 31°C; in each environment light is applied for 12h/d. If the results of these germination tests appear to show a trend in response to constant temperatures then test at either more extreme temperatures (e.g. if germination is greatest at 31°C then test a further group of seeds at 36°C) or at intermediate constant temperatures (e.g. if germination is greatest at 6°C and 16°C then test a further sample of seeds at 11°C). In all cases apply light for 12h/d.

If none of the above constant-temperature regimes is successful in promoting full germination then the second step of this algorithm is to test in an alternating-temperature regime. The alternating-temperature regime used depends upon the comparative results obtained in the first step: if the greatest proportion of seeds germinated in the test at constant temperatures of 16°C or below, the alternating temperature regime 23°/9°C (12h/12h) is used for the second step; if the greatest proportion of seeds germinated in tests at 31°C or above, the alternating temperature regime 33°/19°C (12h/12h) is used for the second step; if the greatest proportion of seeds germinated in tests at constant temperatures between 17° and 30°C, or if there was little difference between the results at different constant temperatures, then two samples of seeds are drawn and tested at 23°/9°C (12h/12h) and 33°/19°C (12h/12h) for the second step of the algorithm. Whether one or both alternating temperature regimes is used, light is applied for 12h/d during the period spent at the upper temperature.

If an alternating temperature regime is not successful in promoting full germination then the third step of the algorithm is to pre-chill a fresh sample of seeds at 2° to 6°C for 8w and then test for germination in the most successful regime determined from a comparison of the results of steps one and two.

If this is not successful in promoting full germination then the fourth step of the algorithm is to co-apply 10^{-3} M potassium nitrate to the germination test substrate and test a fresh sample of seeds in the most successful regime determined from the tests carried out in steps one to three. If this includes a requirement for pre-chilling then the potassium nitrate is co-

applied to the pre-chill as well as the germination test substrate.

If full germination has not been promoted, the fifth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

TABLE 29.1 Summary of germination test recommendations for species within the Chenopodiaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Atriplex hortensis L.	TP; BP	20°/30°C	28d		ISTA
Atriplex semi-baccata R. Br.		20°C	14d	pre-soak and remove calyx	Atwater
Atriplex polycarpa (Torr.) Wats.		20°C	5d	pre-wash, test in light	Atwater
Corispermum hyssopifolium	TP	20°/30°C		pre-chill, 2-3w	M&O
Kochia scoparia (L.) Schrad.	TP; BP	20°/30°C; 20°C	14d	pre-chill, GA	ISTA
	TP	20°/30°C	6d	light	AOSA
		20°/30°C	7d	light	Atwater
	TP	20°/30°C		light	M&O
	TP; S	15°/30°C	5d	light	Everson

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided in this chapter for the genera Beta, Chenopodium and Spinacia, from Table 17.1 and from Table 29.1.

BETA

B. vulgaris L.

beet, beetroot, sugar-beet, mangel, swiss chard

I. Evidence of dormancy

Seed germination can be erratic (6, 13, 16, 32) and dormancy can create severe problems for seed testing (4-6, 13, 15,36). The seed is contained within a fruit structure and this is the cause of most problems: germination inhibitors are present within this structure (4-6, 13, 17), and the tight ovary cap can act as a physical barrier to germination (17,24,29). In seed testing stations fungal infections can affect the reliability of germination tests and consequently fungicides may be applied: see Chapter 9 for details.

II. Germination regimes for non-dormant seeds

BP; TP; S: 20°C: 14d (ISTA)

BP; S: 20°/30°C (16h/8h); 20°C: 10d (AOSA)

BP; S: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Pre-chill: 4°C, 1-3w (15); 12°C, 3d (22)

Pre-dry: 16h, after 8h imbibition (15)

Pre-soak: 24h (37)

GA_3: pre-applied, 1.5,3h, 250 ppm (31); pre-applied, 4h, 100, 1000 ppm (12); pre-applied, 4h, 100-10000 ppm (31); pre-applied, 18h, 125, 250 ppm (31)

Hydrochloric acid: pre-applied, 8h, 1 N (2); pre-applied, 3-8h, 2 N (2)

Scarification: rub (9, 17); shake, 45 min (9)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 8°/25°C, 11°/25°C, 25°/4°C, 25°/8°C (16h/8h) (23)

Pre-soak: 2h (29); 2-15h, 25°C (25); 4-24h (13); 12h (34); 24h (30, 35); 8h, then pre-dry, 16h, 1-10 cycles (15); 1h, then pre-dry, 1h, 3,4 cycles (29)

Pre-wash: 2h, 20°C (4); 2h, 25°C, with or without pre-dry (28); 2h, then pre-dry (19); 3.5h, 25°C, germinate at 10°C (27); 6-7h (25); 8h, 20°C (36); 20h (15); 1.5-24h, 25°C, germinate at 15°C (26); 4-24h (13); 1-24h, 15°C, germinate at 20°C (37)

Scarification: rub (4,11,28,36); chip (29); notch (32); concentrated sulphuric acid, 20 min, then pre-wash, 20 min (15); concentrated sulphuric acid, 20 min, then pre-wash, 30 min, then pre-chill, 4°C, 1-3w (15); sulphuric acid, 3%, 2h, then pre-wash, 2h (24); hydrochloric acid, 3%, 2h, then pre-wash, 2h (24,29); phosphoric acid, 2h (29)

Hemicellulase: pre-applied, 2h, 0.01-1% (29)

Pectinase: pre-applied, 2h, 0.01-1% (29)

GA_3: co-applied, 10-1000 ppm (30); pre-applied, 24h, 100, 500 ppm (30,35)

Kinetin: co-applied, 10-100 ppm (30); pre-applied, 24h, 40, 80 ppm (30,35)

6-Benzylaminopurine: co-applied, 10 ppm (30); pre-applied, 24h, 10, 40 ppm (30,35)

Magnesium sulphate: pre-applied, 2h, 0.5% (11)

Removal of seed covering structures: (32)

V. Successful dormancy-breaking treatments

Pre-wash (AOSA, ISTA)

Pre-chill: 5°C, 5°/7°C (20h/4h), 3m, germinate at 20°C (7)

Pre-wash: 2h, germinate at 20°/30°C (16h/8h) (3); 2h, then pre-dry (9); 2h, 25°C, then pre-dry, 30°C, 16h, germinate at 20°/30°C (16h/8h) (28); 3.5h, 25°C (26); 4h, germinate at 20°C or 20°/30°C (16h/8h) (11); 1-8h, germinate at 20°/30°C, 15°/25°C (16h/8h) (22); 20h (16, 17)

Pre-soak: then pre-dry (18); then germinate at 20°/30°C (18h/8h) (14)

Removal of seed covering structures: pericarp (2); ovary cap (17); excise seed (17,37)

GA_3: pre-applied, 4 ppm (9)

Cytokinin: pre-applied, 12h, 1%, germinate at 15°C (34)

Oxygen: (17)

Hydrochloric acid: pre-applied, 0.5-8h, 0.5 N (2); pre-applied, 0.5-6h, 1 N (2); pre-applied, 0.5-2h, 2 N (2); pre-applied, 2,3h, 26%, then pre-wash, then pre-dry, 2-3h (29); pre-applied, 2h, 1 N, then pre-wash, 5 min, then hydrochloric acid, pre-applied, 2h, 1 N plus either GA_3, 10, 100 ppm, or kinetin, 10, 100 ppm, germinate at 20°/30°C (8h/16h), 9°C, -10, -15 bar (1)

Hydrogen peroxide: co-applied, 2% (9, 10); co-applied, 1-3% (17); co-applied, 1% (18); pre-applied (21)

VI. Comment

Pre-wash or pre-soak treatments are the most effective method of removing germination inhibitors from the fruit. Percentage germination in subsequent tests increases with increase in the duration of either treatment (13,22,25,26), until maximum promotion is reached after 8 to 16 hours for pre-wash or 16 to 20 hours for pre-soak treatments (13). Drying, subsequent to either pre-wash or pre-soak treatments, may also further improve germination (22,28).

The ISTA recommend 2 or 4 hour pre-wash treatments at 25°C for multigerm and genetically monogerm fruits respectively, with subsequent pre-drying at 25°C. The AOSA recommendations vary between the various crops: 2 hours' pre-soaking at 20°C (250 ml of water per 100 fruits) or 3 hours' pre-washing at 20°C is recommended for beet, mangel and swiss chard; but for sugar beet 16 hours' pre-soaking at 25°C may be necessary, followed by rinsing and 2 hours' drying at room temperature.

Despite the removal of germination inhibitors by pre-washing or pre-soaking, successive germination tests may produce erratic results. The major difficulty remaining is the moisture of the germination test substrate (14): dry seeds require a moist substratum, whilst pre-soaked or pre-washed seeds require a relatively dry substratum (9,16-19,22,33). For the more dormant seeds hydrogen peroxide, co-applied at 1%, can be beneficial (9,10,17,18,21).

Optimum constant temperatures for germination of 11°-25°C (23), 15°-25°C (8), 15°C (20,34), 20°C (7,11,20), and 25°C (15,25) have been reported, as have optimum alternating temperatures of 20°/30°C (16h/8h) (1,3,11,14,19,20,22,28), 15°/25°C (16h/8h) (22), 5°/30°C, 5°/25°C (16h/8h) (15), 25°/11°C and 4°/25°C (16h/8h) (23). It is unlikely that there is any advantage to testing in alternating temperature rather than constant temperature regimes (11,15,20,22,23).

It is suggested that the AOSA prescriptions and recommendations be followed, but with an additional hydrogen peroxide treatment (see above) for the most dormant seeds. However, one of the problems with pre-soak treatments of 16 hours for seeds of sugar beet is that treatments of such length may be damaging to some accessions. One way for gene banks to avoid this is to extract the seed from the fruits by hand and thus avoid the requirement for a pre-soaking treatment. (The ovary caps can be lifted with a scalpel and the seed dropped out.) This has further advantages in easing the scoring of seedlings during subsequent seedling evaluation (which can be difficult with multigerm fruits) and avoiding ovary caps hindering seedling emergence.

VII. References

1. Akeson, W.R., Freytag, A.H. and Henson, M.A. (1981). Improvement of sugar beet seed emergence with dilute acid and growth regulator treatments. Crop Science, 21, 307-312.

2. Akeson, W.R., Henson, M.A., Freytag, A.H. and Westfall, D.G. (1980). Sugar beet fruit

germination and emergence under moisture and temperature stress. Crop Science, 20, 735-739.

3. Andersen, A.M. (1948). The effect of pretreatment and substrata on the germination of sugar beet (Beta vulgaris L.) seedballs. Proceedings of the American Society of Sugar Beet Technologists, 5, 95-99.

4. Barthodeiszky, A. and Gáspár, S. (1965). Studies on the possibility to terminate the lability of germination in the seeds of beet (Beta vulgaris L.). Proceedings of the International Seed Testing Association, 30, 677-688.

5. Battle, J.P. and Whittington, W.J. (1968). Genetic and environmental control of germination in sugar beet. University of Nottingham School of Agriculture, Report of the School of Agriculture 1967-1968, 111-114.

6. Battle, J.P. and Whittington, W.J. (1971). Genetic variability in time to germination of sugar-beet clusters. Journal of Agricultural Science, Cambridge, 76, 27-32.

7. Brown, S.J. (1980). Variation in germination and seedling emergence of sugar beet at sub-optimal temperatures. Annals of Applied Biology, 95, 143-150.

8. Chamberland, E. (1974). [Germination tests of sweet sorghum and sugar beet cultivars.] Canadian Journal of Plant Science, 54, 855-857.

9. Chetram, R.S. and Heydecker, W. (1967). Moisture sensitivity, mechanical injury and gibberellin treatment of Beta vulgaris seeds. Nature, 215, 210-211.

10. Coumans, M. (1974). [Action of perhydrol on the germination of sugarbeet.] Bulletin de la Societé Royale de Botanique de Belgique, 107, 27-31.

11. Cuddy, T.F. (1960). Studies on the germination of sugarbeet seed. Proceedings of the Association of Official Seed Analysts, 49, 98-102.

12. Doxtator, C.W. (1958). Gibberellic acid effects on seed and seedlings of sugarbeet. Journal of the American Society of Sugar Beet Technologists, 10, 117-123.

13. El-Gharbawy, A.-H.A. and Moustafa, S.M.A. (1975). Some physiological studies on germination of sugarbeet seeds. Agricultural Research Review, 53, 87-97.

14. Gadd, I. (1939). On methods for the elimination of seed dormancy in seed control work. Proceedings of the International Seed Testing Association, 11, 96-118.

15. Heide, O.M., Juntilla, O. and Samuelsen, R.T. (1976). Seed germination and bolting in red beet as affected by parent plant environment. Physiologia Plantarum, 36, 343-349.

16. Heydecker, W. and Chetram, R.S. (1971). Water relations of beetroot seed germination. I. Microbial factors, with special reference to laboratory germination. Annals of Botany, 35, 17-29.

17. Heydecker, W., Chetram, R.S. and Heydecker, J.C. (1971). Water relations of beetroot seed germination. II. Effects of the ovary cap and of the endogenous imhibitors. Annals of Botany, 35, 31-42.

18. Heydecker, W., Orphanos, P.I. and Chetram, R.S. (1969). The importance of air supply during seed germination. Proceedings of the International Seed Testing Association, 34, 297-304.

19. Hibbert, D. and Woodwark, W. (1965). The effect of various analytical factors on the germination test results obtained on some British sugar-beet seeds. Proceedings of the International Seed Testing Association, 30, 689-704.

20. Hibbert, D. and Woodwark, W. (1970). Germination testing of sugar beet seed on different types of paper substrate. Journal of the International Institute of Sugar Beet Research, 4, 169-174.

21. Jensen (1962). [Contribution to discussion.] Proceedings of the International Seed Testing Association, 27, 756.

22. Klitgard, K. (1978). Report of the germination committee working group on germination methods of Beta vulgaris. Seed Science and Technology, 6, 215-224.

23. Kotowski, F. (1927). Temperature alternation and germination of vegetable seed. Acta Societatis Botanicorum Poloniae, 5, 71-78.

24. Lackey, C.F. (1948). Chemical loosening of seed caps in relation to germination of sugar-beet seed. Proceedings of the American Society of Sugar Beet Technologists, 5, 66-69.

25. Lexander, K. (1980). Seed composition in connection with germination and bolting of Beta vulgaris L. (sugar beet). In Seed Production (ed. P.D. Hebblethwaite), pp. 271-291, Butterworths, London.

26. Longden, P.C. (1974). Washing sugar-beet seed. Journal of the International Institute of Sugar Beet Research, 6, 154-162.

27. Longden, P.C. (1976). Seed treatments to lengthen the sugar-beet growing period. Annals of Applied Biology, 83, 87-92.

28. MacKay, D.B. (1961). The effect of pre-washing on the germination of sugar beet. Journal of the National Institute of Agricultural Botany, 9, 99-103.

29. Peto, F.H. (1964). Methods of loosening tight seed caps in monogerm seed to improve germination. Journal of the American Society of Sugar Beet Technologists, 13, 281-286.

30. Scott, R.K., Wood, D.W. and Harper, F. (1972). Plant growth regulators as a pretreatment for sugar beet seeds. Proceedings of the 11th British Weed Control Conference, 2, 752-759.

31. Snyder, F.W. (1959). Effect of gibberellin on germination and early growth of sugar beet. Journal of the American Society of Sugar Beet Technologists, 10, 394-396.

32. Snyder, F.W. (1959). Influence of the seedball on speed of germination of sugar beet seeds. Journal of the American Society of Sugar Beet Technologists, 10, 513-520.

33. Snyder, F.W. and Zielke, R.C. (1973). Water requirement for maximum germination and emergence of sugar beet seeds. Journal of the American Society of Sugar Beet Technologist, 17, 323-331.

34. Wilczek, C.A. and Ng, T.J. (1982). Promotion of seed germination in table beet by an aqueous seaweed extract. HortScience, 17, 62 9-630.

35. Wood, D.W. (1973). Agronomic effects of fruit size and fruit treatment of sugar beet. In Seed Ecology (ed. W. Heydecker), p. 546, Butterworths, London.

36. Wood, D.W., Scott, R.K. and Longden, P.C. (1980). The effect of mother-plant temperature on seed quality in Beta vulgaris L. (sugar beet). In Seed Production (ed. P.D.

Hebblethwaite), pp. 257-270, Butterworths, London.

37. Morris, P.C., Grierson, O. and Whittington, W.J. (1984). Endogenous inhibitors and germination of Beta vulgaris. Journal of Experimental Botany, 35, 994-1002.

CHENOPODIUM

C. album L.	lambsquarters, common pigweed, fat hen
C. ambrosioides L.	American wormseed, Mexican tea
C. berlandieri Moq.	
C. bonus-henricus L.	good King Henry, mercury
C. botrys L.	feather geranium, Jerusalem-oak
C. capitatum Aschers.	
C. glaucum L.	oakleaf goosefoot
C. humile L.	
C. hybridum L.	
C. murale L.	
C. paganum Reichb.	
C. polyspermum L.	
C. quinoa Willd.	quinoa
C. rubrum L.	red goosefoot
C. strictum Roth.	
C. urbicum L.	

I. Evidence of dormancy

Seeds of C. quinoa (A) and C. glaucum (5) generally exhibit little or no dormancy and germinate satisfactorily over a wide range of conditions. However, seeds of C. humile (8) and the remaining species listed above can show considerable dormancy (5) and may require, for example, up to 2 years after-ripening at room temperature before dormancy is removed from all seeds (5). Secondary dormancy may be induced if the seeds are prevented from germinating, for example if tested in darkness with insufficient moisture, and this dormancy may be more difficult to remove than primary (innate) dormancy (14).

C. album is rarely cultivated and all citations here to seed dormancy in this and the other Chenopodium spp. concern investigations with seeds collected from plants growing wild or as weeds. Since the literature on the weed seed dormancy of Chenopodium spp. is large only the more important information has been summarised here.

II. Germination regimes for non-dormant seeds

C. album

Constant temperatures: 25°C (15)

Alternating temperatures: 20°/30°C (16h/8h), light, 14d (3)

III. Unsuccessful dormancy-breaking treatments

C. album

Alternating temperatures: 25°/15°C, 15°/25°C, 25°/1°C, 1°/25°C, 15°/1°C, 1°/15°C (8h/16h) in dark (19)

Pre-chill: 6m, germinate in light (6)

C. botrys

Light: dark, at 10°-35°C, 10°/20°C, 10°/30°C, 15°/25°C, 15°/35°C, 20°/30°C, 25°/35°C (16h/8h) (2)

C. polyspermum

Constant temperatures: 1°C, 15°C, 25°C, with or without potassium nitrate, co-applied, 10^{-2} M, in light or dark (20)

Alternating temperatures: 25°/15°C, 15°/25°C, 25°/1°C, 1°/25°C, 15°/1°C, 1°/15°C (8h/16h) in dark (19)

IV. Partly-successful dormancy-breaking treatments

C. album

Alternating temperatures: 30°/10°C, 25°/3°C (16h/8h) in light, diffuse, with potassium nitrate, co-applied, 10^{-2} M, 6w (17)

Pre-chill: 3°C, 3-5m (5); 4°C, 4,7d, in dark, germinate at 25°C in light, brief exposure, diffuse, with potassium nitrate, co-applied, 10^{-3} M, 28d (18)

Light: fluorescent, continuous, 5.25×10^{-4} W cm^{-2}, at 23°C (10); red, 200s, 5×10^{-2}, J cm^{-2}, after 24h at 23°C in dark, germinate at 23°C in dark (9); dark, 24-40h, at 23°C, then red light, 15 min, 0.18 J cm^{-2}, germinate at 23°C in dark (11)

Removal of seed covering structures: perianth (1)

Pre-wash: 8,24,70h, 20°C (1)

Thiourea: co-applied, 0.2%, at 27°C in light (16)

GA_3: co-applied, 10^{-3} M, at 23°C in dark (7)

2-Chloroethylphosphonic acid: co-applied, 500 ppm, at 23°C in dark (7)

C. ambrosioides, C. berlandieri, C. bonus-henricus,

C. botrys, C. capitatum

Pre-chill: 3°C, 3-5m (5)

C. humile

Pre-wash: 24h (8)

Pre-soak: 30 min (8)

Ethanol: pre-applied, 3h, 2%, shaken (8)

Scarification: sulphuric acid, 20%, 30 min (8)

C. hybridum, C. murale, C. paganum, C. polyspermum, C. rubrum, C. strictum, C. urbicum

Pre-chill: 3°C, 3-5m (5)

V. Successful dormancy-breaking treatments

C. album

Alternating temperatures: 1°/25°C, 15°/25°C (8h/16h) in light, brief exposure, diffuse, with potassium nitrate, co-applied, 10^{-2} M (19); 15°/25°C in light, 14h/d, 17120 lux, with potassium nitrate, co-applied, 10^{-1} M (4)

Pre-chill: 6m, germinate in dark (6)

Light: fluorescent, 120 fc, 0.5,0.75,8,16,24h/d at 30°C, 7d (2) Removal of seed covering structures: then germinate at 20°-35°C (15); seed coat and endosperm (12)

$GA_{4/7}$: co-applied, $3x10^{-4}$ M, with red light, 32 min, $1.9x10^{-4}$ W cm^{-2}, after 24h dark imbibition (13)

Thiourea: co-applied, 10^{-2} M, at 23°C in dark (7)

Potassium nitrate: co-applied, 10^{-2} M, at 20°C, with or without pre-chill, 5°C, 4w (22)

C. bonus-henricus

Alternating temperatures: 22°/12°C (12h/12h), light, 12h/d (14)

Pre-chill: 4°C, 28d (14)

C. botrys

Light: fluorescent, 8h/d, 300 fc, at 30°C, 35°C, 10°/30°C, 15°/35°C, 20°/30°C, 25°/35°C (16h/8h) (2); fluorescent, continuous, 300 fc, at 25°C, 30°C, 35°C, 15°/35°C, 20°/30°C, 25°/35°C (16h/8h) (2); dark, 20d, then fluorescent light, 1 min, 300 fc, then dark, at 10°/30°C (16h/8h) throughout (2); fluorescent, 300 fc, 16h/d, at 25°-35°C (2)

C. humile

Removal of seed covering structures: pericarp, germinate at 30°/13°C, light/dark (16h/8h) (8)

Scarification: sandpaper (8)

GA_3: pre-applied, 24h, 1000 ppm, germinate at 30°C, dark (8)

Thiourea: pre-applied, 24h, 1000 ppm, germinate at 30°C, dark (8)

Ethanol: co-applied, 50%, at 30°C, dark (8); co-applied, 50%, at 30°/13°C, light/dark (16h/8h or 8h/16h) (8)

C. polyspermum

Pre-chill: 1°C, 4w, in light, germinate at 25°C in light, with potassium nitrate, co-applied, 10^{-2} M (20); 1°C, 4w, germinate at 25°/1°C (8h/16h) in light, brief exposure, diffuse, with potassium nitrate, co-applied, 10^{-2} M (19)

VI. Comment

The four most important factors in the promotion of germination of dormant seeds of Chenopodium spp. are light, (potassium) nitrate, alternating temperatures, and pre-chill. In the absence of the other three, pre-chill treatments generally appear promotory (17,21,22), though

not in all cases (18, 19). However, in the presence of some, or all, of the other stimulatory agents the benefit from pre-chill is only marginal (17,22). The principal stimulatory agents are light, potassium nitrate, alternating temperatures, and particularly interactions between the latter two (17). Very short duration light treatments are sufficient (2). Diffuse laboratory light reaching the seeds from irregular opening of germination cabinet doors is sufficient (17), although a regular intermittent, treatment with red light as described in Chapter 6 can be provided if this is possible. Potassium nitrate treatments should be co-applied at 10^{-2} M (17,19,20,22) or possibly 10^{-1} M (4). Stimulatory alternating temperature regimes are 10°/30°C, 15°/35°C, 20°/30°C, 25°/35°C (16h/8h) (2), 20°-30°/5°C (day/night) (21), 25°/3°C and 30°/10°C (16h/8h) (17). The alternating temperature regime 25°/3°C (16h/8h) is recommended for germination tests with seeds of Chenopodium spp.

VII. References

1. Chu, C.C., Sweet, R.D. and Ozbun, J.L. (1978). Some germination characteristics in common lambsquarters (Chenopodium album). Weed Science, 26, 255-258.

2. Cumming, B.G. (1963). The dependence of germination of photoperiod, light quality, and temperature in Chenopodium spp. Canadian Journal of Botany, 41, 1211-1233.

3. Everson, L. (1949). Preliminary studies to establish laboratory methods for the germination of weed seed. Proceedings of the International Seed Testing Association, 39, 84-89.

4. Henson, I.E. (1970). The effect of light, potassium nitrate and temperature on the germination of Chenopodium album L. Weed Research, 10, 27-39.

5. Herron, J.W. (1953). Study of seed production, seed identification, and seed germination of Chenopodium spp. Memoirs of Cornell University Agricultural Experiment Station, 320, 1-24.

6. Hoffman, G.R., Hogan, M.B. and Stanley, L.D. (1980). Germination of plant species common to reservoir shores in the northern Great Plains.

Bulletin of the Torrey Botanical Club, 107, 506-513.

7. Holm, R.E. and Miller, M.R. (1972). Weed seed germination responses to chemical and physical treatments. Weed Science, 20, 150-153.

8. Jordan, L.S. and Jolliffe, V.A. (1970). Germination and maturation of Chenopodium humile L. Weed Science, 18, 382-385.

9. Karssen, C.M. (1967). The light promoted germination of the seeds of Chenopodium album L. 1. The influence of the incubation time on quantity and rate of the response to red light. Acta Botanica Neerlandica, 16, 156-160.

10. Karssen, C.M. (1970). The light promoted germination of the seeds of Chenopodium album L. III. Effect of the photoperiod during growth and development of the plants on the dormancy of the produced seeds. Acta Botanica Neerlandica, 19, 81-84.

11. Karssen, C.M. (1970). The light promoted germination of the seeds of Chenopodium album L. V. Dark reactions regulating quantity and rate of the response to red light. Acta Botanica Neerlandica, 19, 187-196.

12. Karssen, C.M. (1970). The light promoted germination of the seeds of Chenopodium album L. VI. Pfr requirement during different stages of the germination process. Acta Botanica Neerlandica, 19, 297-312.

13. Karssen, C.M. (1976). Two sites of hormonal action during germination of Chenopodium

album seeds. Physiologia Plantarum, 36, 264-270.

14. Khan, A.A. and Karssen, C.M. (1980). Induction of secondary dormancy in Chenopodium bonus-henricus L. seeds by osmotic and high temperature treatments and its prevention by light and growth regulators. Plant Physiology, 66, 175-181.

15. Martin, J.N. (1943). Germination studies of the seeds of some common weeds. Proceedings of the Iowa Academy of Sciences, 50, 221-228.

16. Moursi, M.A., Rizk, T.Y. and El-Deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

17. Murdoch, A.J. (1982). Factors influencing the depletion of annual weed seeds in the soil. Ph.D. Thesis, University of Reading.

18. Roberts, E.H. and Benjamin, S.K. (1979). The interaction of light, nitrate and alternating temperature on the germination of Chenopodium album, Capsella bursa-pastoris and Poa annua before and after chilling. Seed Science and Technology, 7, 379-392.

19. Vincent, E.M. and Roberts, E.H. (1977). The interaction of light, nitrate and alternating temperature in promoting the germination of dormant seeds of common weed species. Seed Science and Technology, 5, 659-670.

20. Vincent, E.M. and Roberts, E.H. (1979). The influence of chilling, light and nitrate on the germination of dormant seeds of common weed species. Seed Science and Technology, 7, 3-14.

21. Watanabe, Y. (1978). [Physiological and ecological studies on upland weeds in Hokkaido.] Research Bulletin of the Hokkaido National Agricultural Experiment Station, 123, 17-77.

22. Williams, J.T. and Harper, J.L. (1965). Seed polymorphism and germination. I. The influence of nitrates and low temperatures on the germination of Chenopodium album. Weed Research, 5, 141-150.

SPINACIA

S. glabra

S. oleracea L. spinach, spinage

S. turkestanica

I. Evidence of dormancy

Seeds of S. oleracea tested for germination at about 20°C or above may exhibit dormancy (1, 12, 18, 20). After-ripening of such seeds at room temperature for 2 months is reported to increase germination from 3% to 29% (20). Seeds of S. turkestanica may show deeper dormancy, requiring 21 months after-ripening to remove dormancy (16).

II. Germination regimes for non-dormant seeds

S. oleracea

TP; BP: 15°C; 10°C: 21d (ISTA)

TP: 15°C; 10°C: 21d (AOSA)

AOSA rules state that the germination test substratum should be relatively dry.

Constant temperatures: 25°C, 10d (7, 19)

S. turkestanica

Constant temperatures: 20°C (16)

III. Unsuccessful dormancy-breaking treatments

S. glabra

Pre-dry: 35°C, 5-7d (5)

S. oleracea

Constant temperatures: 36°C (8); above 35°C (11); 20°C, plus excess moisture (12, 13)

Potassium nitrate: co-applied, 0.6% (12)

Potassium ferricyanide: pre-applied, 2-5h, 0.75-6% (12)

Calcium chloride: pre-applied, 3-6h, 1-10% (12)

Mercuric chloride: pre-applied, 1h, 0.06%, then pre-wash (12)

GA_{1-3}: co-applied, 50 ppm (12)

Hydrogen peroxide: (15)

Polyethylene glycol: pre-applied, 7, 14d, -10 bars, 15°C, germinate at 30°C (17)

Pre-wash: 20°C, 48h, germinate at 30°C (1); 30°C, 24,48h, germinate at 30°C (1)

Pre-soak: plus oxygen, 1, 6 bar (12)

IV. Partly-successful dormancy-breaking treatments

S. oleracea

Constant temperatures: 25°C, 30°C (1); 4°C, 29°C (9); 15°-30°C (11); 10°-20°C, plus excess moisture (12); 18°-20°C (18)

Pre-chill: 0°-2°C, 3-5d (20)

Pre-dry: 30°C, 40°C, 1-60d (20); 50°-60°C, 7d (21); 70°-75°C, 1h (21)

Pre-wash: 5°C, 10°C, 1-48h, germinate at 30°C (1); 20°C, 1-24h, germinate at 30°C (1); 30°C, 1-12h, germinate at 30°C (1)

Pre-soak: plus oxygen, 1.5, 4, 5 bar (12)

Removal of seed covering structures: pericarp, germinate at 30°C (1); cut (10)

Scarification: concentrated sulphuric acid, 20 min (15); sulphuric acid, 50%, 60°C, 5 min (12)

Hydrogen peroxide: pre-applied, 2-6% (12)

Sodium carbonate: pre-applied, 24h, 10% (12)

Calcium hypochlorite: pre-applied, 2h, 0.6% (12)

Polyethylene glycol: pre-applied, 7d, -12.5 bar, 10°C, germinate at 30°C (2); pre-applied, 14d, -12.5 bar, 5°-30°C, germinate at 30°C (2); pre-applied, 14d, -15 to -20 bar, 10°C, germinate at 30°C (2); co-applied, -5.5 bar, at 20°C (12)

V. Successful dormancy-breaking treatments

S. glabra

Constant temperatures: 10°C (5)

S. oleracea

Pre-chill (ISTA)

Constant temperatures: 0°-5°C, plus excess moisture (12); 0°-10°C (11); 0°-25°C (12); 1°-4°C (18); 3°-17°C (3); 5°-20°C (1); 8°-22°C (8,9); 10°C (4,6)

Pre-chill: 5°C, 5d, germinate at 10°C (4)

Pre-soak: plus oxygen, 2-3 bar (12)

Removal of seed covering structures: fruit coat (12, 13); pericarp (18); pericarp, then pre-wash, 24h, 10°C, germinate at 30°C (1); perforate husk in region of root (10)

Oxygen: 100% (18)

Hydrogen peroxide: (14); pre-applied, 3h, 6% (13); pre-applied, 8% (12)

Polyethylene glycol: pre-applied, 14,21d, -12.5 bar, 10°C, germinate at 30°C (2); pre-applied, 7,14d, -10 bar, 20°C, 25°C, germinate at 30°C (17)

S. turkestanica

Constant temperatures: 5°-27°C (16)

VI. Comment

Provided that low temperatures and long enough test periods are provided, problems from seed dormancy in germination tests of accessions of Spinacia spp. will be minimised. Although the rate of germination is highest at 20° or 25°C, the optimum temperature range for total germination is 5°-10°C (11). Consequently it is suggested that the lower of the two constant temperature regimes prescribed by ISTA/AOSA (10°C) be used in gene banks for testing seeds of Spinacia spp.

One possible source of difficulty may be the moisture of the filter papers used in germination tests; if the substratum is too wet percentage germination will be reduced (12,13). Testing for germination at a low temperature should minimise the likelihood of such problems arising (12,13), but nevertheless attempts should be made to maintain a relatively dry germination test substrate.

VII. References

1. Atherton, J.G. and Farooque, A.M. (1983). High temperature and germination in spinach. I. The role of the pericarp. Scientia Horticulturae, 19, 25-32.

2. Atherton, J.G. and Farooque, A.M. (1983). High temperature and germination in spinach. II.

Effects of osmotic priming. Scientia Horticulturae, 19, 221-227.

3. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. I. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

4. Fornerod, C. (1975). Remarques sur la germination des semences potagères en laboratoire. Revue Horticole Suisse, 48, 6-9.

5. Frank, W.J. and Wieringa, G. (1928). Artificial drying and low temperature as means employed in obtaining an increase in germination of some vegetable seeds. Proceedings of the Association of Official Seed Analysts, 19, 24-27.

6. Gadd, I. (1939). On methods for the elimination of seed dormancy in seed control work. Proceedings of the International Seed Testing Association, 11, 96-118.

7. Goyal, R.D., Singh, M.B. and Singh, P.V. (1978). Enhancement of germination of the seeds of spinach (Spinacia oleracea). Seed Research, 6, 145-150.

8. Guy, R. (1980). Quelques exemples des effets de la temperature sur la germination des plantes potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 12, 35-37.

9. Guy, R. (1981). Influence de la temperature sur la duree de germination des semences de dix espèces potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 13, 219-225.

10. Hagiya, K. (1949). [Studies on the delayed germination in spinach seed.] Journal of the Horticultural Association of Japan, 18, 198-201.

11. Harrington, J.F. (1963). The effect of temperature on the germination of several kinds of vegetable. Proceedings of the 16th International Horticulture Congress, 2, 435-441.

12. Heydecker, W. and Orphanos, P.I. (1968). The effect of excess moisture on the germination of Spinacia oleracea L. Planta, 83, 237-247.

13. Heydecker, W., Orphanos, P.I. and Chetram, R.S. (1969). The importance of air supply during seed germination. Proceedings of the International Seed Testing Association, 34, 297-304.

14. Jensen (1962). [Contribution to discussion.] Proceedings of the International Seed Testing Association, 27, 756.

15. Kerin, V. (1975). [The effect of the chemical treatment of spinach seed on germination.] Gradinarska i Lozarska Nauka, 12, 61-66. (From Horticultural Abstracts, 1975, 45, 8338.)

16. Khalilov, M. Kh. (1977). [Biology of germination of Spinacia turkestanica seeds.] Rastitel'nye Resursy, 13, 518-520. (From Horticultural Abstracts, 1978, 48, 1352.)

17. Nakamura, S., Teranishi, T. and Aoki, M. (1982). [Beneficial effect of polyethylene glycol on the germination of celery and spinach seeds.] Journal of the Japanese Society for Horticultural Science, 50, 461-467.

18. Sifton, H.B. (1927). On the germination of the seed of Spinacia oleracea L. at low temperatures. Annals of Botany, 41, 557 -569.

19. Singh, H. and Kumar, A. (1979). Germination studies on vegetable crops onion, pea and spinach. Journal of Research, India, 16, 164-168.

20. Tamura, T., Ito, K. and Takano, S. (1957). [Breaking of the dormancy of spinach seeds.] Kyushu Agricultural Research, 19, 54-56.

21. Watanabe, S. and Aki, S. (1959). [Effect of heat treatment on germination of spinach, Spinacia oleracea L.J Technical Bulletin of the Faculty of Agriculture, Kagawa University, 10, 20-26.

CHAPTER 30. COMPOSITAE

The Compositae comprise about 20000 species of herbaceous plants in more than 800 genera which provide oils (e.g. Guizotia abyssinica (L. f.) Cass., niger), leaf vegetables (e.g. Lactuca sativa L., lettuce), edible tubers (e.g. Helianthus tuberosus L., Jerusalem artichoke) and other products (e.g. Chrysanthemum cinerariaefolium (Trev.) Bocc., pyrethrum). The seeds are achenes (see Chapter 3, Volume I) and show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

In most genera the seeds normally exhibit dormancy, but the problem this poses when attempting to promote seed germination varies considerably between both species and accessions. Light, pre-chill, potassium nitrate and temperatures around 15°C tend to promote germination. The seeds are non-endospermic and B.R. Atwater classifies the Compositae as a unique morphological category, viz: axile foliar embryos with fibrous seed coat and spearate inner semi-permeable membranous layer (see Table 17.2, Chapter 17).

Detailed information on seed dormancy and germination is provided in this chapter for the genera Carthamus, Cichorium, Guizotia, Helianthus, Lactuca and Parthenium. In addition, Table 30.1 provides a summary of germination test procedures and dormancy-breaking treatments for very many other species and the algorithm below may be helpful in developing germination test procedures for species where no advice is provided here and for difficult accessions where the regimes summarised in Table 30.1 are unable to promote full germination.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test three samples of seeds at constant temperatures of 11°C, 16°C and 26°C with light applied for 12h/d.

If none of these regimes is successful in promoting full germination then the second step of this algorithm is to test a further sample of seeds at a constant temperature of 6°C with light applied for 12h/d if the greatest germination occurred at 11°C in step one, or to test a further sample of seeds at a constant temperature of 21°C with light applied for 12h/d if the greatest germination occurred at 16°C or 26°C in step one. If there was little difference in germination between tests at the three constant temperatures (step one) then test two further samples of seeds at 6°C and 21°C with light applied for 12h/d.

If any of the regimes applied in the second step does not promote full germination then the third step of the algorithm is to test a further sample of seeds at an alternating temperature of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature of each cycle if the second step was to test at 6°C or, where two regimes were used in step two, the greatest germination was observed at 6°C. Otherwise take two further samples of seeds and test in alternating temperatures of 23°/9°C (12h/12h) and 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature of each cycle.

If any of the regimes applied in the third step of the algorithm does not promote full germination then the fourth step of the algorithm is to pre-chill a further sample of seeds at 2° to 6°C for 8w: the subsequent germination test regime is that judged most suitable

from a comparison of the results of the previous steps of the algorithm.

If the additional treatment of pre-chilling does not result in full germination then the *fifth step* of the algorithm is to take a further three samples of seeds, *chip* the fibrous seed coats and test in the most promotory regime determined in the previous steps (this may include a pre-chill treatment if the fourth step resulted in an increase in germination over previous steps) with GA_3 co-applied in the germination test substrates at three concentrations, viz: 3×10^{-4} M, 7×10^{-4} M, and 2.6×10^{-3} M. Some experimentation with these conditions may be helpful. For example, if a trend in the results at different GA_3 concentrations is apparent it may be worthwhile investigating the response of germination to a more extreme concentration; or chipping plus pre-chill may be sufficient to promote germination without a GA_3 treatment.

If full germination has not been promoted, the *sixth step* of the algorithm is to estimate viability using a *tetrazolium test* (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environment can be obtained from the information provided for six genera in this chapter, from Table 17.2 (Chapter 17) and the long list of dormancy-breaking treatments in Table 30.1.

TABLE 30.1 Summary of germination test recommendations for species within the Compositae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Achillea clavennae L.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
Achillea filipendulina Lam.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
Achillea millefolium L.	TP	20°/30°C	14d		ISTA
	TP	20°/30°C			M&O
Achillea ptarmica L.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
	TP	20°/30°C	10d	light, check for empty seeds	AOSA
		20°/30°C	14d		Atwater
Ageratum houstonianum Mill.	TP	20°/30°C; 20°C	14d		ISTA
	TP	20°/30°C	7d		AOSA
		20°/30°C	10d		Atwater
Agoseris grandiflora	TP	15°C; 20°C			M&O
Amberboa moschata (L.) DC.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
	TP	15°C	21d		AOSA
Ambrosia artemsifolia	TP	20°/30°C		light	M&O
Ammobium alatum R. Br.	TP; BP	20°/30°C; 20°C	14d		ISTA

Anthemis tinctoria L. Kelwayi	TP	15°C	14d	light, avoid temperatures above 15°C	AOSA
Anthemis sancti-johannis Turrill	TP	15°C	14d	light, avoid temperatures above 15°C	AOSA
Arctium lappa L.	BP	20°/30°C	14d		AOSA
Arctium minus Schk.	TP	23°/30°C	28d		R&S
Arctotis stoechadifolia Bergius	TP; BP	20°/30°C; 15°C; 20°C	21d	light	ISTA
Var grandis (Thunb.) Less	TP	15°C	18d	check for empty seeds	AOSA
		15°C	21d		Atwater
Artemisia absinthium L.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	14d		Heit
Artemisia dracunculus L.	TP	20°/30°C	21d		ISTA
Artemisia maritima L.	TP	20°/30°C	21d		ISTA
Artemisia vulgaris L.	TP	20°/30°C	21d		ISTA
		20°C	14d		Atwater
Aster alpinus L.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Aster amellus L.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Aster canescens	TP	15°C		light	M&O
Aster dumosus L.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Aster glaucoides (Nutt.) Elliot		20°C	5d	excise embryos	Atwater
Aster spp.	TP	20°/30°C		light	M&O
Baccharis spp.		20°C	10d		Atwater
Baileya multiradiata Torr.	TP	20°/30°C	14d	light, if seeds infected then treat	AOSA
Balsamorhiza sagittata (Pursh.) Nutt.		20°C	5d	excise embryos	Atwater
Bellis perennis L.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP	20°/30°C	6d	light	AOSA
		20°C	14d		Atwater
Brachycome iberidifolia Benth.	TP	20°/30°C; 15°C	14d		ISTA
	TP	15°C	12d	avoid temperatures above 15°C	AOSA
Buphthalmum salicifolium L.	TP	20°/30°C	14d	light	AOSA
Calendula officinalis L.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP	20°C	10d	potassium nitrate, test at 15°C	AOSA
		15°C	14d	light, potassium nitrate, 0.2%	Atwater
Callistephus chinensis (L.) Nees	TP	20°/30°C; 20°C	14d	light	ISTA

	TP	20°C	8d	fungicide treatment may be necessary	AOSA
		20°C	14d		Atwater
Castalis tragus (Ait.) Norl.	TP; BP	20°/30°C; 15°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
Centaurea americana Nutt.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill, pre-soak, 24h	ISTA
	BP	20°/30°C	14d	clip radicle end of seed, extend test for 5d	AOSA
		20°/30°C	28d		Atwater
Centaurea cineraria L.	TP	15°C	21d		AOSA
		15°C	21d		Atwater
Centaurea cyanus L.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
	TP	15°C	8d	fungicide treatment may be necessary	AOSA
		15°C	14d		Atwater
Centaurea dealbata Willd.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Centaurea diffusa	TP	20°/30°C			M&O
Centaurea gymnocarpa Moris & DeNot.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
	TP	15°C	16d		AOSA
		15°C	21d		Atwater
Centaurea imperialis Bornm.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
	TP	15°C	16d		AOSA
		15°C	21d		Atwater
Centaurea macrocephala Puschk. ex Willd.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Centaurea montana L.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Centaurea ragusina L.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Centaurea solstitialis	TP	20°/30°C; 15°C; 20°C		light	M&O
Chrysanthemum carinatum Schousb.	TP; BP	20°/30°C; 15°C	21d	light, pre-chill	ISTA
	TP	15°C	10d	check for empty seeds	AOSA
Chrysanthemum coronarium L.	TP; BP	20°/30°C; 15°C	21d	light, pre-chill	ISTA
	TP	15°C	10d	check for empty seeds	AOSA
Chrysanthemum multicaule Desf.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Chrysanthemum nivellei Br.-Blanq. & Maire	TP; BP	20°/30°C; 20°C	21d	pre-chill	ISTA
Chrysanthemum ptarmiciflorum (Webb) Brenan	TP	15°C	12d	light, fungicide treatment may be necessary	AOSA

Chrysanthemum segetum L.	TP; BP	20°/30°C; 15°C	21d	pre-chill	ISTA
	TP	15°C	10d	check for empty seeds	AOSA
Chrysanthemum spp.		20°C	14d		Atwater
Chrysopsis spp.		20°C	5d	excise embryos	Atwater
Chrysothamnus nauseosus (Pall.) Britt.		20°C	14d		Atwater
Cirsium vulgare	TP	20°/30°C			M&O
Cnicus benedictus L.	TP; BP; S	20°/30°C	21d	pre-chill	ISTA
Coreopsis basalis (Otto & A. Dietr.) Blake	TP	20°C	8d		AOSA
Coreopsis cardaminifolia (DC.) Nutt.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
Coreopsis coronata L.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
Coreopsis drummondii Torr. & Gray	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
Coreopsis lanceolata L.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C; 15°C	21d	light, potassium nitrate	AOSA
		20°/30°C; 15°C; 20°C	40d	potassium nitrate, 0.2%	Atwater
Coreopsis maritima (Nutt.) Hook. f.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
Coreopsis tinctoria Nutt.	TP	20°/30°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°C	8d		AOSA
Cosmos bipinnatus Cav.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	8d	light, potassium nitrate, extend test period	AOSA
		20°/30°C	14d	test at 15°C	Atwater
Cosmos sulphureus Cav.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	8d	light, potassium nitrate	AOSA
		20°/30°C	14d	test at 15°C	Atwater
Crepis capillaris	TP	20°/30°C; 15°C		light	M&O
Cynara cardunculus L.	BP; S	20°/30°C	21d		ISTA
	BP	20°/30°C	21d		AOSA
Cynara scolymus L.	BP; S	20°/30°C	21d		ISTA
	BP	20°/30°C	21d		AOSA
	TP	20°/30°C	21d		Fornerod
Dahlia pinnata Cav.	TP; BP	20°/30°C; 15°C; 20°C	21d	pre-chill	ISTA
		15°C	14d		Atwater

Dahlia spp.	TP; BP	15°C	14d	seeds sensitive to drying out in test	AOSA
Dendrathema indicum (L.) Desm.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Dimorphotheca pluvialis (L.) Moench	TP; BP	20°/30°C; 15°C	14d	light, pre-chill, potassium nitrate	ISTA
Dimorphotheca sinuata DC.	TP	15°C	10d	light, potassium nitrate, check for empty seeds	AOSA
		15°C	14d		Atwater
Doronicum orientale Hoffm.	TP	20°/30°C; 20°C	21d	potassium nitrate, pre-chill	ISTA
	TP	20°C	21d	light	AOSA
Echinacea purpurea (L.) Moench	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°/30°C	12d	light	AOSA
Echinops ritro L.	TP; BP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light, good moisture supply	AOSA
Encelia californica Nutt.		20°C	5d	excise embryos	Atwater
Encelia farinosa Gray		20°C	5d	excise embryos	Atwater
Erigeron speciosus (Lindl.) DC.	TP	20°/30°C; 20°C	28d		ISTA
	TP	15°C	16d	light	AOSA
Eriophyllum confertiflorum (DC.) Gray		20°C	5d	excise embryos	Atwater
Eriophyllum lanatum Forbes	TP	20°/30°C			M&O
Gaillardia aristata Pursh.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°/30°C	10d	light, check for empty seeds	AOSA
	TP	20°/30°C		light	M&O
		20°/30°C	14d		Atwater
Gaillardia pulchella Foug.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°/30°C	10d	light, check for empty seeds	AOSA
		20°/30°C	14d		Atwater
Gazania rigens (L.) Gaertn.	TP; BP	20°/30°C; 15°C	21d	pre-chill	ISTA
	TP	15°C	12d	check for empty seeds	AOSA
		15°C	21d		Atwater
Gerbera jamesonii Hook. f.	TP	20°/30°C; 20°C	14d		ISTA
	TP; BP	20°/30°C; 20°C	10d	light	AOSA
		20°/30°C	14d		Atwater
Gnaphalium microcephalum	TP	15°C		light	M&O
Grindelia stricta DC.		20°C	14d	excise embryos	Atwater
Helenium autumnale L.	TP; BP	20°/30°C;	14d		ISTA

		20°C			
Helenium spp.	TP	20°/30°C	16d	light, check for empty seeds	AOSA
Helichrysum bracteatum (Vent.) Andr.	TP; BP	20°/30°C; 15°C	14d	light, potassium nitrate, pre-chill	ISTA
	TP	15°C	10d	light, potassium nitrate	AOSA
Heliopsis helianthoides (L.) Sweet	TP; BP	20°/30°C	21d	potassium nitrate, pre-soak, 24h	ISTA
Heliopsis spp.	TP	20°/30°C	18d		AOSA
Helipterum craspedioides				excise embryos	Atwater
Helipterum humboldtianum (Gaudich.) DC.	TP; BP	20°/30°C; 15°C	21d	pre-chill	ISTA
Helipterum manglesii (Lindl.) F. Muell.	TP; BP	20°/30°C; 15°C	21d	pre-chill	ISTA
Helipterum roseum (Hook.) Benth.	TP; BP	20°/30°C; 15°C	21d	pre-chill	ISTA
	TP	15°C	18d		AOSA
		20°C	14d		Atwater
Hymenoclea salsola T. & G.		20°C	5d	excise embryos	Atwater
Hypochaeris radicata	TP	20°/30°C			M&O
Inula grandiflora Willd.	TP	20°/30°C	14d	light	AOSA
Inula helenium L.	TP	20°/30°C; 20°C	28d		ISTA
Lapsana communis	TP	20°/30°C			M&O
Layia platyglossa (F. & M.) Gray	TP	15°C	8d	light, avoid temperatures above 15°C	AOSA
		20°C	14d		Atwater
Leontodon nudicaulis		20°/30°C			M&O
Leontopodium alpinum Cass.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Leucanthemum maximum Ram. DC.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Leucanthemum vulgare Lam.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Liatris pycnostachya Michx.	TP	20°/30°C	28d		ISTA
Liatris spicata (L.) Willd.	TP	20°/30°C	28d		ISTA
Lonas annua (L.) Vines & Druce	TP	20°/30°C	28d		ISTA
Machaeranthera tanacetifolia (HBK) Nees	TP	15°C	10d	avoid temperatures above 18°C	AOSA
Madia exigua	TP	15°C			M&O
Matricaria chamomilla L.	TP	20°/30°C	14d	pre-chill	ISTA
Matricaria maritima	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Matricaria perforata Merat	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Matricaria recutila L.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA

Matricaria spp.	TP	20°/30°C; 20°C	7d	light	AOSA
		20°C	14d		Atwater
Osteospermum ecklonis (DC.) Norl.	TP; BP	20°/30°C; 15°C	14d	light, pre-chill, potassium nitrate	ISTA
Pyrethrum spp.	TP	15°C	21d	potassium nitrate	AOSA
Rudbeckia fulgida Ait.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Rudbeckia hirta L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Rudbeckia spp.		20°/30°C	14d		Atwater
Sanvitalia procumbens Lam.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP; BP	20°/30°C; 20°C	7d	light, check for empty seeds	AOSA
Scorzonera hispanica L.	TP; BP	20°/30°C; 20°C	8d	pre-chill	ISTA
	BP	20°/30°C	8d	pre-chill, 10°C, 5d	Fornerod
Senecio bicolor (Willd.) Tod.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Senecio cruentus (L'Her.) DC.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
	TP	20°C	14d	light	AOSA
		20°C	14d		Atwater
Senecio elegans L.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Senecio jacobea	TP	15°C		light	M&O
Sonchus arvensis	TP	20°/30°C		light	M&O
Silybum marianum (L.) Gaertn.	TP; BP; S	20°/30°C; 20°C	21d	pre-chill	ISTA
Tagetes erecta L.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
Tagetes patula L.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
Tagetes tennifolia Cav.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
Tagetes spp.	TP	20°/30°C; 20°C	7d	light, check for broken seedlings	AOSA
		20°/30°C	10d		Atwater
Tanacetum achilleifolium (Bieb.) Sch. Bip.	TP; BP	20°/30°C; 15°C	21d	light, pre-chill	ISTA
Tanacetum cineraiifolium (Trev.) Sch. Bip.	TP; BP	20°/30°C; 20°C	21d	pre-chill	ISTA
Tanacetum coccineum (Willd.) Grierson	TP; BP	20°/30°C; 15°C	21d	light, pre-chill, potassium nitrate	ISTA
Tanacetum parthenium (L.) Sch. Bip.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Tanacetum vulgare L.	TP	20°/30°C			M&O
Taraxacum erythrospermum	TP	20°/30°C;		light, test at 15°C	M&O

		15°C; 20°C			
Taraxacum officinale Wigg.	TP	20°/30°C; 20°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
	TP	20°/30°C; 15°C		light	M&O
	TP	20°C	14d	light	Heit
Tithonia rotundifolia (Mill.) Blake	TP; BP	20°/30°C	8d	light	AOSA
Tragopogon porrifolius L.	TP; BP	20°C	10d	pre-chill	ISTA
	BP	15°C	10d	pre-chill, 10°C, 3d	AOSA
	TP	20°/30°C		light	M&O
Tragopogon spp.	BP	15°C	10d		Everson
Venidium fastuosum (Jacq.) Stapf	TP	20°/30°C	10d	light	AOSA
Viquiera laciniata Gray		20°C	5d	excise embryos	Atwater
Xeranthemum annuum L.	TP; BP	20°/30°C; 20°C	14d		ISTA
Zinnia acerosa (DC.) Gray	TP; BP	20°/30°C; 20°C	7d	light, check for empty seeds	AOSA
Zinnia angustifolia HBK	TP; BP	20°/30°C; 20°C	7d	light, check for empty seeds	AOSA
Zinnia elegans Jacq.	TP; BP	20°/30°C; 20°C	10d	light, pre-chill	ISTA
	TP; BP	20°/30°C; 20°C	7d	light, check for empty seeds	AOSA
Zinnia grandiflora Nutt.	TP; BP	20°/30°C; 20°C	7d	light, check for empty seeds	AOSA
Zinnia haageana Regel	TP; BP	20°/30°C; 20°C	10d	light, pre-chill	ISTA
Zinnia peruviana L.	TP; BP	20°/30°C; 20°C	7d	light, check for empty seeds	AOSA
Zinnia spp.		20°/30°C	7d		Atwater

CARTHAMUS

C. alexandrius
C. flavescens
C. glaucus
C. lanatus L. saffron thistle
C. oxyacantha Bieb. wild safflower
C. palaestinus Eig.
C. tinctorius L. safflower

I. Evidence of dormancy

Freshly harvested seeds of the cultivated safflower (C. tinctorius L.) are usually non-dormant (4,6,7,9), but seeds of the wild species, C. alexandrius, C. flavescens, C. glaucus, C. lanatus, C. oxyacantha and C. palaestinus may show considerabl e dormancy (1,3,4,6-9). For example, seeds of C. oxyacantha after-ripened for one year at 23°C gave only 33% germination despite

being 82% viable (3). Seeds of the inter-specific hybrids between C. tinctorius and the wild species can also be dormant (7,9).

II. Germination regimes for non-dormant seeds

C. tinctorius

TP; BP; S: 25°C; 20°/30°C (16h/8h): 14d (ISTA)

BP; TP; S: 15°C; 20°C: 14d (AOSA)

Constant temperatures: 15°-20°C (4)

Alternating temperatures: 16°/27°C (12h/12h) (9)

III. Unsuccessful dormancy-breaking treatments

C. lanatus

Pre-soak: in dark, germinate at 25°C in dark (8)

Pre-wash: 24h with far red irradiation, $7x10^{-6}$ mol m^{-2} s^{-1} (8)

C. oxyacantha

Pre-chill: 0°C, 28d, then scarify (4); 4°C, 70d (3); 4°C, 70d, then scarify (3)

IV. Partly-successful dormancy-breaking treatments

C. lanatus

Pre-soak: 2-24h, continuous light, 10^{-5} mol m^{-2} s^{-1} (8); 24h, in dark, germinate at 25°C in light, 10^{-5}, $25x10^{-5}$ mol m^{-2} s^{-1} (8); 24h, in light, 10^{-5} mol m^{-2} s^{-1}, germinate at 25°C in dark or light, 10^{-5}, $25x10^{-5}$ mol m^{-2} s^{-1} (8); 24h, in light, $25x10^{-5}$ mol m^{-2} s^{-1}, germinate at 25°C in dark or light, 10^{-5}, $25x10^{-5}$ mol m^{-2} s^{-1} (8)

Pre-wash: 24h, continuous light, 10^{-5} mol m^{-2} s^{-1} (8)

C. oxyacantha

Constant temperatures: 5°C, 10°C, 15°C, 20°C, 25°C, 30°C, optimum at 15°-20°C, in dark (4)

Pre-chill: 0°C, 1m (4); 3°-5°C, 2-8w (3); 3°-5°C, 2-8w, then cut off tip of seed coat (3)

Removal of seed covering structures: cut off tip of seed coat (1,3,4)

Polyethylene glycol: co-applied, -1, -2 bar (2)

Pre-wash: (6)

V. Successful dormancy-breaking treatments

C. lanatus

Pre-soak: 24h, continuous light, 650 nm, $7x10^{-6}$ mol m^{-2} s^{-1}, germinate at 25°C in dark (8)

C. oxyacantha

Pre-soak: 1-4d, germinate at 18°C in dark (6)

C. tinctorius

Light at 15°C (AOSA)

Constant temperatures: 15°C (5)

VI. Comment

Constant temperatures of 15°C and 20°C are suitable for the germination of seeds of C. oxyacantha and C. tinctorius (4,6). Pre-soaking the seeds in water for 24 hours promotes the germination of C. oxyacantha and C. lanatus (6,9), and does not damage seeds of C. tinctorius (6). The effect of light is very significant during both the pre-soak period and the germination test - high light intensity ($25x10^{-5}$ mol m^{-2} s^{-1}) being less suitable for germination than a low light intensity (10^{-5} mol m^{-2} s^{-1}) (8).

Consequently the following germination test regime is suggested for seeds of all Carthamus spp. - including the cultivated C. tinctorius and its hybrids: pre-soak the seeds in water for 24 hours under red light (650 nm, $7x10^{-6}$ mol m^{-2} s^{-1}) and test for germina tion at 15°C in the dark.

VII. References

1. Bassiri, A. and Kheradnam, M. (1976). Relationships between seed color and viability, germination and seedling growth of wild safflower ecotypes. Canadian Journal of Plant Science, 56, 911-917.

2. Bassiri, A., Khosh-Khui, M. and Rouhani, I. (1977). The influences of simulated moisture stress conditions and osmotic substances on germination and growth of cultivated and wild safflowers. Journal of Agricultural Science (Cambridge), 88, 95-100.

3. Bassiri, A. and Rouhani, I. (1976). Effect of seed treatment on germination of wild safflower. Weed Science, 24, 233-234.

4. Bassiri, A., Rouhani, I. and Ghorashy, S.R. (1975). Effect of temperature and scarification on germination and emergence of wild safflower, Carthamus oxyacantha Bieb. Journal of Agricultural Science (Cambridge), 84, 239-243.

5. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

6. Kheradnam, M. and Bassiri, A. (1980). Seed germination and seedling growth inhibition caused by safflower seed extracts. Agronomy Journal, 72, 31-35.

7. Kotecha, A. and Zimmerman, L.H. (1978). Genetics and seed dormancy and its association with other traits in safflower. Crop Science, 18, 1003-1007.

8. Wright, G.C., McWilliam, J.R. and Whalley, R.D.B. (1980). Effects of light and leaching on germination of saffron thistle (Carthamus lanatus L.). Australian Journal of Plant Physiology, 7, 587-594.

9. Zimmerman, L.H. (1972). Variation and selection for pre-harvest seed dormancy in safflower. Crop Science, 12, 33-34.

CICHORIUM

C. endivia L. endive
C. intybus L. chicory, succory
C. pumilum Jacq. wild chicory

I. Evidence of dormancy

Freshly harvested seeds of C. endivia can exhibit considerable dormancy (11). Secondary dormancy may be induced if seeds of Cichorium spp. are exposed to high temperatures in the absence of light (6).

II. Germination regimes for non-dorment seeds

C. endivia

TP: 20°C; 20°/30°C (16h/8h): 14d (ISTA)

TP; TS: 20°/30°C (16h/8h): 14d (AOSA)

Constant temperatures: 20°C (11)

Alternating temperatures: 20°/30°C (16h/8h) (11)

C. intybus

TP: 20°C; 20°/30°C (16h/8h): 14d (ISTA)

TP; TS: 20°/30°C (16h/8h): 14d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (3)

III. Unsuccessful dormancy-breaking treatments

C. endivia

Constant temperatures: 2°C (1,9); above 30°C, dark (6,9)

Potassium nitrate: co-applied, 0.1, 0.2% (11)

IV. Partly-successful dormancy-breaking treatments

C. endivia

Constant temperatures: 7°C, light, 8h/d (1)

Warm stratification: 18°C, 25°C, 4-24h, germinate at 30°C, with or without thiourea, co-applied, 0.5% (6)

C. intybus

Constant temperatures: 20°C, light (2); 15°-25°C, dark (8); 11°-25°C, light, 30 W m^{-2}, 8h/d (10)

Alternating temperatures: 20°/30°C (18h/6h) in light (2); 20°/30°/8°C (10h/8h/6h) in light (2)

C. pumilum

Thiourea: co-applied, 0.2%, at 27°C in light (5)

V. Successful dormancy-breaking treatments

C. endivia

Potassium nitrate (ISTA)

Light, Potassium nitrate, test in soil, excess moisture for first 24h (AOSA)

Constant temperatures: 17°C, light, 30 W m^{-2}, 8h/d (1); 13°-21°C, light, 30 W m^{-2}, 8h/d (9)

Thiourea: co-applied, 0.5% (11)

C. intybus

Potassium nitrate (ISTA)

Light, Potassium nitrate, test in soil (AOSA)

Constant temperatures: 10°-20°C, dark (7)

Alternating temperatures: 20°/30°C (16h/8h), light (4)

VI. Comment

Although thiourea, co-applied at 0.5%, promoted the germination of dormant seeds of C. endivia (11), abnormal germination occurred (11): treatment at a lower concentration might be worth investigating. Seeds of Cichorium spp. require light (1,2,4,5,9-11) and a relatively low temperature - 10° to 25°C - (1,7-11) for germination. The seed lots used in most of the cited papers showed little dormancy. For such seed lots the ISTA/AOSA germination test procedures are satisfactory. We suggest, however, that gene banks handling more dormant accessions of Cichorium spp. should test the seeds at 15°C in light.

The amount of moisture held by the germination test substratum can be critical: excess moisture, either from the use of many layers of wetted paper or thoroughly wetted absorbent cotton, can greatly promote the germination of dormant seeds of C. endivia (11). It has been suggested that light is only promotory when applied to tests carried out in the presence of excess moisture (11). Hence the AOSA recommendations. We suggest, therefore, that where possible germination tests are carried out on thoroughly wetted absorbent cotton.

VII. References

1. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

2. Cross, H. (1931). Laboratory germination of weed seeds. Proceedings of the Association of Official Seed Analysts, 24, 125-128.

3. Fornerod, C. (1975). Remarques sur la germination des semences potagères en laboratoires. Revue Horticole Suisse, 48, 6-9.

4. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

5. Moursi, M.A., Rizk, T.Y. and El-Deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

6. Thompson, R.C. (1946). Germination of endive seed (Cichorium endivia) at high temperature stimulated by thiourea and by water treatments. Proceedings of the American

Society for Horticultural Science, 47, 323-326.

7. Valette, R. (1978). Influence de la température sur la germination des semences de chicoreé de Bruxelles. Bulletin des Recherches Agronomiques de Gembloux, 13, 183-196.

8. Valette, R. (1981). Etude de la germination à differentes temperatures de semences de Chicoreé de Bruxelles. Revue de l'Agriculture, 34, 995-1007.

9. Wagenvoort, W.A. and Bierhuizen, J.F. (1977). Some aspects of seed germination in vegetables. II. The effect of temperature fluctuation, depth of sowing, seed size and cultivar, on heat sum and minimum temperature for germination. Scientia Horticulturae, 6, 259-270.

10. Wagenvoort, W.A., Boot, A. and Bierhuizen, J.F. (1981). Optimum temperature range for germination of vegetable seeds. Gartenbauwissenschaft, 46, 97-101.

11. Munn, M.T. (1949). Endive seed germination. Proceedings of the Association of Official Seed Analysts, 39, 122-125.

GUIZOTIA

G. abyssinica (L. f.) Cass. niger, noog

I. Evidence of dormancy

There is little literature on niger seed germination in the literature and little evidence of dormancy.

II. Germination regimes for non-dormant seeds

Constant temperatures: 15°C, 17°C, 20°C in light (1)

III. Unsuccessful dormancy-breaking treatments

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IV. Partly-successful dormancy-breaking treatments

Pre-chill: 10°C, 2-14h, then germinate at 27°-30°C, 52h (2) Warm stratification: 35°C, 2-12h, then germinate at 27°-30°C, 52h (2)

Diethyl sulphate: pre-applied, 12h, $3x10^{-2}$ M (3)

V. Successful dormancy-breaking treatments

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VI. Comment

Non-dormant seeds of G. abyssinica germinate readily at both 20°C and 20°/30°C (16h/8h) (A). It is suggested that the seeds be tested on top of filter paper in an alternating temperature regime of 20°/30°C (16h/8h) for 14 days. Dormant seeds may benefit from a warm stratification or pre-chill treatment prior to testing in this regime (2).

VII. References

1. Mesfin, A. (1977). Ecophysiology of noog (Guizotia abyssinica Cass.). Dissertation Abstracts International, B, 38, 990-991.

2. Pasha, M.K. and Salehuzzaman, M. (1978). Effect of low and high temperatures on the germination of rape seed and niger seed. Indian Journal of Agricultural Science, 48, 284-286.

3. Rao, P.K. and Raj, A.S. (1967). Studies on the effects of diethyl sulphate on niger (Guizotia abyssinica Cass.). Andhra Agriculture Journal, 14, 4-11. (From Field Crop Abstracts, 1968, 21, 1229.)

HELIANTHUS

H. annuus L.	sunflower
H. bolanderi Gray	
H. debilis Nutt.	
H. exilis Gray	serpentine sunflower
H. petiolaris Nutt.	sand-hill sunflower

I. Evidence of dormancy

Freshly harvested seeds of H. annuus can show considerable dormancy (1,2,5,7,9,11,14-18,20,21). This causes problems for breeding programmes (7). Dormant seeds require between 2 and 7 weeks after-ripening at room temperature to lose dormancy (2,5,11,14,16,17,21) and the dormancy of seeds buried in soil can prevent them from germinating for more than 50 years (18). The seeds of the wild species H. bolanderi, H. exilis and H.petiolaris are rather more dormant (8,12,22).

II. Germination regimes for non-dormant seeds

H. annuus

BP; S: 20°/30°C (16h/8h); 25°C; 20°C: 10d (ISTA)

BP: 20°/30°C (16h/8h): 7d (AOSA)

Constant temperatures: 20°C, 25°C, 30°C (6)

Alternating temperatures: 20°/30°C (16h/8h) (6)

H. debilis

BP; S; TP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

Helianthus spp.

TP: 20°/30°C (16h/8h): 7d (AOSA)

III. Unsuccessful dormancy-breaking treatments

H. annuus

Pre-chill: 3°C, 10°C, 3-7d (5); 5°C, 7-21d (3); 5°C, 28d, in light (18)

Pre-soak: 1-24h (3); 12-72h (21)

Oxygen: (9)

Ethephon: pre-applied, 3,6,23h, 120-480 g/1 (3)

Light: dark, at 20°C, 20°/30°C (16h/8h) (19)

Removal of seed covering structures: excise embryo (18)

Scarification: sulphuric acid (18)

GA_3: (18)

H. exilis

Light: far red, 8h/d, at 20°C, with or without pre-chill, 10°C, 12d (12)

IV. Partly-successful dormancy-breaking treatments

H. annuus

Constant temperatures: 15°C in light (19)

Alternating temperatures: 20°30°C (16h/8h) (19)

Pre-chill: 3°C, 10°C, 1-3d (5); 5°C, 28d, dark, germinate at 15°/25°C (16h/8h) in light, 8h/d (18); 3°C, 7-28d, germinate at 20°/30°C (16h/8h) in light (19); 2-4m (22)

Potassium nitrate: co-applied, 0.2% (5); co-applied, 0.2%, dehulled seeds (5)

GA_3: (21); pre-applied, 24h, up to 1000 ppm (9); pre-applied, 24,48h (10); co-applied, 3 ppm (14); co-applied, 3, 30 ppm, dehulled seeds (13); co-applied, 0.2% (1)

Ethephon: (21); pre-applied, 12-48h, 10-1000 ppm, intact or dehulled seeds (7); co-applied, 25 ppm (14); co-applied, 5, 100 ppm, dehulled seeds (13)

Indoleacetic acid: pre-applied, 24,48h (10)

Hydrogen peroxide: pre-applied, 24h (5)

Pre-soak: 24h (5)

Removal of seed covering structures: (5,7,13,14)

Pre-dry: 30°C, 9d (1); 40°C, 14d (5); 39°C, 16h (7); 39°C, 16h, then ethephon, pre-applied, 6-24h, 50-200 ppm (7); 30°C, 9d, then GA_3, co-applied, 0.2% (1)

Benzyladenine: co-applied, 2, 20 ppm, dehulled seeds (13); co-applied, 2 ppm (14)

H. bolanderi

Pre-chill: 10°C, 12d (8, 12)

Light: red, far red, 8h/d, with or without pre-chill, 10°C, 12d (8,12)

H. exilis

Pre-chill: 10°C, 12d (12)

Light: red, 8h/d, with or without pre-chill, 10°C, 12d (12)

V. Successful dormancy-breaking treatments

H. annuus

Pre-chill, Pre-dry (ISTA)

Pre-chill: 2°-5°C, 60d, germinate at 15°/25°C (16h/8h) (9)

Pre-dry: 35°C, 70d (15); 0°C, 4,9d (5)

GA_3: pre-applied, 24h, 300, 500 ppm (5); pre-applied, 24h, 300, 500 ppm, then pre-dry 0°C, 3d (5)

Removal of seed covering structures: husk, pericarp (3)

Ethrel: co-applied, 25, 50 ppm, dehulled seeds (13); co-applied, 250 ppm (21); pre-applied, 24h, 100 ppm (7)

H. debilis

Pre-chill (ISTA)

VI. Comment

The most dormant seeds of H. annuus require 60 days pre-chilling to promote germination (9). Consequently the treatment prescribed by ISTA (3°-5°C for up to 7 days) is unlikely to be a sufficiently adequate treatment for gene banks. Moreover, in less dormant seed lots a 2 to 3 day pre-chill treatment can reduce germination (3,5). Thus it appears that pre-chill treatments are ruled out for gene bank use. No completely satisfactory dormancy-breaking methods have been found for the wild Helianthus spp.

It is surprising that little work has been done on the effect of the germination test temperature (both constant and alternating) in promoting the germination of dormant seeds of Helianthus spp. It is suggested that gene banks dealing with these species might investigate this topic. In the meantime it is suggested that seeds of Helianthus accessions be tested in rolled paper towels or sand at an alternating temperature regime of 20°/30°C (16h/8h). For many accessions it will be necessary to increase the germination test duration considerably beyond the 7 or 10 days prescribed by AOSA and ISTA respectively and additional dormancy-breaking treatments will also be required. Ethephon is one of the more effective dormancy-breaking agents for H. annuus (7,13,14,20,21): it is suggested that it be co-applied at 100 ppm for all Helianthus spp. accessions with dormant seeds with the additional treatment of removal of seed covering structures from ungerminated seeds after 14 to 21 days in test.

VII. References

1. Blagodyr, A.P. (1979). [A method of determining germination of freshly-harvested sunflower seeds.] Selektsiya i Semenovodstvo, 3, 49-50. (From Seed Abstracts, 1981, 4, 3719.)

2. Clerc, P. (1972). Contribution à l'étude de la dormancy des akènes de tournesol (Helianthus annuus L.). Information Techniques, Centre Technique Interprofessionnel des Oléagineux Mètropolitains, 26, 10-19.

3. Côme, D., Simond-Côte, E. and Rollier, M. (1977). Etude de la germination des semences de tournesol. Information Techniques, Technique Interprofessionnel des Oléagineux Métropolitains, 54, 3-28.

4. Cseresnyes, Z. (1974). Application of the tetrazolium topographical test in the sunflower seed viability determination. In Proceedings of the Sixth International Sunflower Conference, 1974, Bucharest, Romania.

5. Cseresnyes, Z. (1979). Studies on the duration of dormancy and method of determining the germination of dormant seeds of Helianthus annuus. Seed Science and Technology, 7, 179-

188.

6. Cseresnyes, Z. (1979). The germination of Helianthus annuus seeds under optimum laboratory conditions. Seed Science and Technology 7, 319-328.

7. Harada, W.S. (1982). The effects of ethephon on dormant seeds of cultivated sunflower (Helianthus annuus L.). Proceedings of the 10th International Sunflower Conference, 1982, Toowoomba, Australia.

8. Jain, S.K., Olivieri, A.M. and Fernandez-Martinez, J. (1977). Serpentine sunflower, Helianthus exilis, as a genetic resource. Crop Science, 17, 477-479.

9. Lane, F.E. (1965). Dormancy and germination in fruits of sunflowers. Dissertation Abstracts, 26-N, 3603-3604.

10. Majid, F.Z., Begum, S. and Rahman, A. (1980). Sunflower as oil seed crop in Bangladesh. VIII. Effects of some hormones on sunflower variety Krasnodarets. Bangladesh Journal of Scientific and Industrial Research, 15, 174-176. (From Seed Abstracts, 1982, 5 2240.)

11. Mehrotra, O.N., Pal, M. and Singh, G.S. (1978). Studies on post harvest dormancy in sunflower seeds. Seed Research, 6, 91-93.

12. Olivieri, A.M. and Jain, S.K. (1978). Effects of temperature and light variations on seed germination in Sunflower (Helianthus) species. Weed Science, 26, 277-280.

13. Udaya Kumar, M. and Krishna Sastry, K.S. (1974). Effect of exogenous application of growth regulators on germinating ability of developing sunflower seed. Indian Journal of Experimental Biology, 12, 543-545.

14. Udaya Kumar, M. and Krishna Sastry, K.S. (1975). Effect of growth regulators on germination of dormant sunflower seeds. Seed Research, 3, 61-65.

15. Wallace, R.N. and Habermann, H.M. (1958). Absence of seed dormancy in a white mutant strain of Helianthus annuus L.. Plant Physiology, 33, 252-254.

16. Zimmerman, D.C. and Zimmer, D.E. (1978). Influence of harvest date and freezing on sunflower seed germination. Crop Science, 18, 479-481.

17. Dighe, R.S. and Patil, V.N. (1980). A note on dormancy in sunflower and the relationship of some seed characters with germination. Seed Research, 8, 91-93.

18. Leather, G.R., Frederick, M.D. and Sung, S.-J.S. (1983). Ecological significance of native wild sunflower seed germination patterns. Plant Physiology, 72, 98.

19. Maguire, J.D. and Overland, A. (1959). Laboratory germination of seeds of weedy and native plants. Washington Agricultural Experiment Station, Circular No. 349, 15 pp.

20. Ruud, R. (1976). The use of ethrel to break dormancy of sunflower seeds in a germination test. Newsletter of the Association of Official Seed Analysts, 50, 43-44.

21. Srivastava, A.K. and Dey, S.C. (1982). Physiology of seed dormancy in sunflower (Helianthus annuus L.). Acta Agronomica Academiae Scientiarum Hungaricae, 31, 70-81.

22. Tolstead, W.L. (1941). Germination habits of certain sand-hill plants in Nebraska. Ecology, 22, 393-397.

LACTUCA

L. biennis (Moench) Fern.	blue lettuce
L. sativa L.	lettuce
L. serriola L. [L. scariola L.]	wild or prickly lettuce

I. Evidence of dormancy

Much of the work which has led to a greater understanding of the way in which light quality and quantity affects seed germination - either promoting germination or inducing dormancy - has used lettuce as the experimental material. Also thermodormancy (failure to germinate at high temperatures) can be a considerable problem for commercial lettuce growers. Consequently the literature devoted to lettuce seed dormancy is considerable. This review is, however, limited to papers which are relevant to the problems facing gene bank staff: what laboratory method(s) will promote germination of all viable lettuce seeds.

II. Germination regimes for non-dormant seeds

L. sativa

TP; BP: 20°C: 7d (ISTA)

TP: 20°C: 7d (AOSA)

III. Unsuccessful dormancy breaking treatments

L. biennis

Constant temperatures: 20°C, dark (22,36); 15°C in light or dark, continuous (22)

Alternating temperatures: 20°/30°C (16h/8h), dark (22) Pre-chill: 5°-8°C, 5d, germinate at 20°C, dark (22)

L. sativa

Constant temperatures: 30°C in dark (3-6,27,29,31)

Pre-chill: 1°-4°C, up to 24h, then tested at 30°C (6)

Pre-dry: 35°C, 7d (27)

Light: far red (6,11,12,34,35); green (9); blue (9)

Carbon dioxide: 0-40% (2)

Cycloheximide: co-applied, 1-100 ppm (10)

p-Fluorophenylalanine: co-applied, 1-100 ppm (10)

Puromycin: co-applied, 1-100 ppm (10)

Hydroxylamine hydrochloride: co-applied, 3.2×10^{-4} M (15)

Ammonium chloride: co-applied, 10^{-2} M (15)

Potassium nitrate: co-applied, 10^{-3} M (15)

Sodium nitrite: co-applied, 10^{-3} M (15)

GA_3: co-applied, 100-10000 ppm (11)

Ethephon: co-applied, 1000 ppm (11)

Potassium thiocyanate: co-applied, 1% (33)

Urea: co-applied, 1% (33)

Acetamide: co-applied, 0.5, 1% (33)

Potassium cyanide: co-applied, 0.5% (33)

Allylurea: co-applied, 0.5, 1% (33)

Ammonium sulphate: co-applied, 1% (33)

Asparagin: co-applied, 0.5, 1% (33)

Calcium thiocyanate: co-applied, 0.5, 1% (33)

Potassium ferricyanide: co-applied, 0.5, 1% (33)

Potasium ferrocyanide: co-applied, 1% (33)

Semicarbazide hydrochloride: co-applied, 0.5, 1% (33)

Sodium nitrate: co-applied, 1% (33)

Sodium thiocyanate: co-applied, 0.5, 1% (33)

Sulphuric acid: co-applied, 0.5, 1% (33)

Ammonium nitrite; co-applied, 0.5, 1% (33)

Hydrazine: co-applied, 0.5, 1% (33)

Sulphanilic acid: co-applied, 0.5, 1% (33)

Abscisic acid: pre-applied, 1h, 10^{-5}, 10^{-4} M (35)

Ethanol: pre-applied, 20 min, 4, 8% (24)

Removal of seed covering structures: two outer seed coats (6)

IV. Partly-successful dormancy breaking treatments

L. biennis

Constant temperatures: 20°C in light, continuous (22)

Alternating temperatures: 15°/25°C (16h/8h), dark (22)

L. sativa

Constant temperatures: 20°C in dark or light (27); above 20°C in daylight (7)

Alternating temperatures: 15°/30°C (12h/12h) (20) Pre-chill: 1°C, 1-3d (6);16°-18°C, 1d (6); 6°C, 6d (27); 4°-12°C, 6h (34)

Oxygen: 20-90% (5)

Ethylene: 1-100 ppm, in dark or 15 min red light (1)

Carbon dioxide: 60, 80% (2); 10, 15%, plus ethylene, 1 ppm, in dark or 15 min red light (1)

Thiourea: pre-applied, 16h, 0.5, 1% (2); pre-applied, 8h, 100-1500 ppm (26); co-applied, 10^{-2} - 10^{-4} M (16); co-applied, 0.2% (18,20); co-applied, 0.5% (18,33)

Allyl thiourea: co-applied, 0.5% (32,33)

Ammonium thiocyanate: co-applied, 0.5% (32,33)

Potassium thiocyanate: co-applied, 0.5% (32)

Urea: co-applied, 0.5% (32)

Sodium nitrate: co-applied, 0.5% (32)

Ammonium sulphate: co-applied, 0.1% (32)

Potassium ferricyanide: co-applied, 0.2% (32)

Potassium ferrocyanide: co-applied, 0.5% (32)

Calcium sulphate: co-applied, 1% (32)

Thiosemicarbazide: co-applied, 0.5% (32)

Thioacetamide: co-applied, 0.4% (32)

GA_3: co-applied, $5x10^{-5}$, $5x10^{-4}$, 10^{-3} M (4); co-applied, $3x10^{-6}$ M (14); co-applied, 10^{-5} M (19); co-applied, 1-50 ppm (10); co-applied, 10-40 ppm (17); co-applied, 100, 200 ppm (18); co-applied, 1-200 ppm (20); pre-applied, 8h, 10-250 ppm (26); pre-applied, 1h, $5x10^{-6}$, 10^{-5} M (35); co-applied, $3x10^{-6}$ M, plus kinetin, $5x10^{-7}$ M (14); pre-applied, 8h, 50 ppm, plus thiourea, 1000 ppm (26); pre-applied, 1h, 10^{-6} M, then hydrogen cyanide, pre-applied, 1h, 10^{-6} M (35)

Kinetin: co-applied, $5x10^{-5}$ M (14,21); co-applied, $5x10^{-7}$ M (14) Hydrogen cyanide: pre-applied, 1h, 10^{-6} M, imbibed seeds (35); pre-applied, 1h, 10^{-6} M, then GA_3, pre-applied, 1h, 10^{-6} M (35)

Potassium cyanide: co-applied, 10^{-4} M (15)

Potassium azide: co-applied, 10^{-5} M (15)

Catechol: co-applied, 10^{-4} -$3.2x10^{-3}$ M (16)

Pyrogallol: co-applied, 10^{-2} M (16)

Calcium chloride: pre-applied, 20 min, $5x10^{-3}$ M (24)

Ethanol: pre-applied, 20 min, 0.5-4%, imbibed seeds (24); pre-applied, 20 min, 1%, then calcium chloride, pre-applied, 20 min, $5x10^{-3}$ M (24)

Light: red, yellow, orange, 6400 lux (9)

Pre-soak: 2h in light (27); 1-72h in light (31)

L. serriola

Constant temperatures: 15°C in light (36); 23°C in light (37)

Alternating temperatures: 20°/30°C (16h/8h) in light or dark (36); 23°/30°C (24h/24h) in light (37)

Thiourea: co-applied, 0.5%, at 25°C in light, 1560 lux (25)

V. Successful dormancy breaking treatments

L. biennis

Alternating temperatures: 15°/25°C (16h/8h) in light (22); 20°/30°C (16h/8h) in light (22,36)

Pre-chill: 5°-8°C, 5d germinate at 20°C in light (22) Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h), dark (22)

L. sativa

Pre-chill, (ISTA)

Pre-chill, test at 15°C (AOSA)

Constant temperatures: 3°C (23); 5°C in light (2); 3°-20°C in dark (3); 5°-20°C, low light, 14h/d (29,30); 8°-12°C (6); 10°C in red light or dark (28,31); 10°C, 14°C, in dark or daylight, 14h/d (7); 12.5°C in dark (4); 15°C in dark (1,20); 15°C in light (27); 10°-20°C in light or dark (5); 10°-20°C in dark (8); 15°-22°C in light (13); 20°C, plus 5 min red light, 8.1×10^{-5} W cm^{-2} (11,12,28)

Pre-chill: 4°C, 1d (34); 4°C, 2-3d (6); 3°C, 2d (23)

Pre-dry: 55°C, 21d (7)

Light: diffuse daylight, fluorescent (2,27);red (8); red, 660 nm, 8 min, applied 2-12h after dark imbibition at constant temperatures below 22°C (5); continuous red light, 4.8×10^{-2} W cm^{-2} (4); red, 1.5×10^{-4} W cm^{-2}, 10 min (10); 8.1×10^{-5} W cm^{-2}, 5-15 min (11,12); 7×10^{-5} W cm^{-2}, 1-4 min (19); 4.5×10^{-4} W cm^{-2}, 15s (34)

Removal of seed covering structures: inner seed coat (6)

GA_3: co-applied, 50-100 ppm (17); co-applied, 100-1000 ppm (10); co-applied, 3×10^{-4} M (14); co-applied, 10^{-3} M (19)

$GA_{4/7}$: co-applied, 10^{-4} M (12)

Thiourea: co-applied, 10^{-1} M (16); co-applied, 0.5% (25,32) Threo-chloramphenicol: co-applied, 0.1-0.3%, 10 min red light, 1.5×10^{-4} W cm^{-2} (10)

L. serriola

Constant temperatures: 20°C, dark (36); 23°C, dark (37)

VI. Comment

The considerable literature on lettuce seed dormancy might provide the impression that it is difficult to achieve full germination of lettuce seeds. This is not so. Full germination of dormant

seeds of L. sativa can be achieved by testing at 12° to 15°C in diffuse light or the light regime given in Chapter 6.

Prolonged exposure to higher temperatures may induce dormancy (thermodormancy) whereby the seeds will fail to germinate - even when subsequently removed to a lower temperature. As a precaution imbibing seeds should be placed in the germination test incubator as soon as possible: that is imbibing seeds should not be left at laboratory temperature.

This regime is, however, unlikely to be successful in promoting the germination of all dormant seeds of L. biennis (22) or L. serriola (36,37). It is suggested that seeds of L. biennis be tested for germination at an alternating temperature regime of 20°/30°C (16h/8h) in light, but that seeds of L. serriola be tested in the dark at a constant temperature of 20°C since light inhibits germination in this species (36,37).

VII. References

1. Abeles, F.B. and Lonski, J. (1969). Stimulation of lettuce seed germination by ethylene. Plant Physiology, 44, 277-280.

2. Barton, L.V. and Crocker, W. (1948). Twenty years of seed research at Boyce Thompson Institute for Plant Research. Faber and Faber Limited, London.

3. Berrie, A.M.M. (1966). The effect of temperature and light on the germination of lettuce seeds. Physiologia Plantarum, 19, 429-436.

4. Berrie, A.M.M. and Taylor, G.C.D. (1981). The use of population parameters in the analysis of germination of lettuce seed. Physiologia Plantarum, 51, 229-233.

5. Borthwick, H.A., Hendricks, S.B., Toole, E.H. and Toole, V.K. (1954). Action of light on lettuce seed germination. Botanical Gazette, 115, 205-225.

6. Borthwick, H.A. and Robbins, W.W. (1928). Lettuce seed and its germination. Hilgardia, 3, 275-305.

7. Eewink, A.H. (1977). Influence of temperature on seed dormancy in lettuce. Scientia Horticulturae, 6, 1-13.

8. Elliott, R.F. and French, C.S. (1959). Germination of light sensitive seed in crossed gradients of temperature and light. Plant Physiology, 34, 454-456.

9. Flint, L.H. (1934). Light in relation to dormancy and germination in lettuce seed. Science, 80, 38-40.

10. Frankland, B. and Smith, H. (1967). Temperature and other factors affecting chloramphenicol stimulation of the germination of light-sensitive lettuce seeds. Planta, 77, 354-366.

11. Globerson, D. (1981). Germination and dormancy in immature and fresh-mature lettuce seeds. Annals of Botany, 48, 639-643.

12. Globerson, D., Ginzburg, C. and Zahari, K.A. (1973). Comparative studies of seed germination of two newly isolated lines of Grand Rapids lettuce. Annals of Botany, 37, 699-704.

13. Gray, D. (1975). Effects of temperature on the germination and emergence of lettuce (Lactuca sativa L.) varieties. Journal of Horticultural Science, 50, 349-361.

14. Haber, A.H. and Tolbert, N.E. (1959). Effects of gibberellic acid, kinetin, and light on the germination of lettuce seed. In Photoperiodism and Related Phenomena in Plants and Animals, pp. 197-206. American Association for the Advancement of Science, Washington D.C.

15. Hendricks, S.B. and Taylorson, R.B. (1974). Promotion of seed germination by nitrate, nitrite, hydroxylamine and ammonium salt. Plant Physiology, 54, 304-309.

16. Hendricks, S.B. and Taylorson, R.B. (1975). Breaking of seed dormancy by catalase inhibition. Proceedings National Academy of Science, U.S.A., 72, 306-309.

17. Ikuma, H. and Thimann, K.V. (1960). Action of gibberellic acid on lettuce seed germination. Plant Physiology, 35, 557-566.

18. Kahn, A. (1960). Promotion of lettuce seed germination by gibberellin. Plant Physiology, 35, 333-339.

19. Kojima, H. and Oota, Y. (1980). Promotion by gibberellin of lettuce seed germination as a function of presoaking period. Plant and Cell Physiology, 21, 561-569.

20. Kretschmer, M. (1978). Temperature and lettuce seed germination. Acta Horticulturae, 83, 167-173.

21. Leff, J. (1964). Interaction between kinetin and light on germination of Grand Rapids lettuce seeds. Plant Physiology, 39, 299-30

22. Lincoln, W.C. Jr. (1981). Laboratory germination of Lactuca biennis - blue lettuce. Newsletter of the Association of Official Seed Analysts, 55, 30-31.

23. Margaris, N.S. and Fiakou, E. (1974). Low temperature effect on lettuce seed dormancy. Scientia Horticulturae, 2, 209-210.

24. Pecket, R.C. and Al-Charchafchi, F. (1978). Dormancy in light-sensitive lettuce seeds. Journal of Experimental Botany, 29, 167-173.

25. Raleigh, G.I. (1943). The germination of dormant lettuce seed. Science, 98, 538.

26. Sarma, C.M. and Chakraborty, P. (1977). Effect of gibberellic acid and thiourea, singly and in combination, on the germination of lettuce seeds. Indian Journal of Agricultural Sciences, 47, 18-21.

27. Shuck, A.L. (1934). Some factors influencing the germination of lettuce seed in seed laboratory practice. New York State Agricultural Experiment Station, Technical Bulletin No. 222.

28. Takeba, G.O. and Matsubara, S. (1976). Analysis of temperature effect on the germination of New York lettuce seeds. Plant and Cell Physiology, 17, 91-101.

29. Thompson, P.A. (1973). Geographical adaptation of seeds. In Seed Ecology (ed. W. Heydecker), pp. 31-58, Butterworths, London.

30. Thompson, P.A., Cox, S.A. and Sanderson, R.H. (1979). Characterization of the germination responses to temperature of lettuce (Lactuca sativa L.) achenes. Annals of Botany, 43, 319-334.

31. Thompson, R.C. (1938). Dormancy in lettuce seed and some factors influencing its germination. U.S.D.A., Technical Bulletin, No. 655, 20pp.

32. Thompson, R.C. and Kosar, W.F. (1938). Germination of lettuce seed stimulated by chemical treatment. Science, 87, 218-219.

33. Thompson, R.C. and Kosar, W.F. (1939). Stimulation of germination of dormant lettuce seed by sulfur compounds. Plant Physiology, 14, 567-573.

34. VanDerwoude, W.J. and Toole, V.K. (1980). Studies of the mechanism of enhancement of phytochrome-dependent lettuce seed germination by pre-chilling. Plant Physiology, 66, 220-224.

35. Zagorski, S. and Lewak, S. (1983). Interactions between hydrogen cyanide, gibberellin, abscisic acid and red light in germination of lettuce seeds. Physiologia Plantarum, 59, 95-98.

36. Maguire, J.D. and Overland, A, (1959). Laboratory germination of seeds of weedy and native plants. Washington Agricultural Experiment Station, Circular No. 349, 15 pp.

37. Rogers, B.J. and Stearns, F.W. (1955). Preliminary studies on the germination of weed seeds. Proceedings of the North Central Weed Control Conference, 12, 7.

PARTHENIUM

P. argentatum Gray guayule
P. hysterophorus L.

I. Evidence of dormancy

Freshly harvested seeds of P. argentatum can show considerable dormancy (1,2,5) and require 6-12 months after-ripening at room temperature before dormancy is lost.

II. Germination regimes for non-dormant seeds

P. argentatum

Constant temperatures: 25°C in light (1); 26°C in light (5,6)

Alternating temperatures: 20°/30°C (17h/17h) (1,3)

III. Unsuccessful dormancy-breaking treatments

P. argentatum

Pre-chill: 4°-5°C, up to 60d (1)

Vatsol OS: pre-applied, 20h, 0.01-0.5% (1)

Formaldehyde: pre-applied, 10 min, 2% (1)

Oxygen: pre-applied, 2h, 100% (1) pH: pre-applied, 2h, low (1)

IV. Partly-successful dormancy-breaking treatments

P. argentatum

Constant temperatures: 25°C (1,5)

Alternating temperatures: 20°/30°C (17h/7h) (1,2,3)

Light: continuous (1,3); 3-4d (2,3); light/dark (14h/10h) (5)

Potassium nitrate: pre-applied, 20h, 0.5% (1)

Sodium hypochlorite: pre-applied, 2h, 0.5-1% (2); pre-applied, 1.5% (1); pre-applied, 6h (3)

Removal of seed covering structures: pericarp (1); puncture (1); chaff (6); chaff, then pre-soak, 8h (6)

Pre-soak: 8h (6); 20h (1); 4-24h (5); 18h, then calcium chlorite, pre-applied, 2-4h, 1-7% (1); 18h, then sodium chlorite, pre-applied, 1,2h, 1-2% (1); 18h, then mercuric chloride dissolved in ethanol, pre-applied, 1 min, 0.2% (1); 18h, then hydrogen peroxide, pre-applied, 20h, 1.5-5% (1); 18h, then perchloric acid, pre-applied, 2h, 1.5% (1); 18h, then nitric acid, pre-applied, 2h, 1% (1); 18h, then sulphuric acid, pre-applied, 1 min, 95% (1); 18h, then potassium dichromate, pre-applied, 2h, 0.5% (1); 8h, then sodium hypochlorite, pre-applied, 2h, 0.25-2% (5); 8h, then GA_3, pre-applied, 2h, 200 ppm (5)

P. hysterophorus

Alternating temperatures: 4°/15°C, 10°/15°C, 7°/18°C, 13°/18°C, 13°/24°C, 19°/24°C, 25°/30°C, 28°/33°C, 31°/36°C (16h/8h) (7)

Light: dark (7)

V. Successful dormancy-breaking treatments

P. argentatum

Removal of seed covering structures: fruit and seed coat (1): puncture seed coat, scarify embryo (1)

Pre-wash: 12-18h, then sodium hypochlorite, pre-applied, 2h, 1.5%, germinate at 20°/30°C (17h/7h) in light (1,4); 8h, then 200 ppm GA_3 plus 1% sodium hypochlorite, pre-applied, 2h, germinate at 26°C in light, 14h/d (5)

GA_3: pre-applied, 6h, 1000 ppm (3)

P. hysterophorus

Alternating temperatures: 16°/21°C (16h/8h), dark (7); 19°/30°C (16h/8h), dark (7); 25°/36°C (16h/8h) in light, 16h/d (7)

VI. Comment

A single application of GA_3 is able to break dormancy in partially dormant seeds of P. argentatum but is unlikely to be successful for freshly harvested seeds. Sodium hypochlorite pre-applied singly at 1.5% or at 1% combined with GA_3 at 200 ppm is effective for promoting germination in freshly harvested seeds but is unfortunately detrimental to less dormant seeds (2,5). Whilst light treatments promote the germination of dormant seeds of P. argentatum (1-3), the effect on the germination of dormant seeds of P. hysterophorus appears to be mo re equivocal; promotion by light has been observed in a few temperature regimes, but inhibition of germination by light has been observed in the majority of temperature regimes investigated (7).

Consequently it is suggested that seeds of both species be tested in an alternating temperature regime of 20°/30°C (16h/8h), but that the light regimes should differ with seeds of P. argentatum being tested in the light and seeds of P. hysterophorus being tested in the dark Pre-washing of the seeds may be advantageous, and it is suggested that the seed covering

structures be removed from ungerminated seeds in test and that the seeds then be pricked and returned for further testing.

VII. References

1. Benedict, H.M. and Robinson, J. (1946). Studies on the germination of guayule seeds. U.S.D.A., Technical Bulletin No. 921, 48pp.

2. Emparan, P.R. and Tysdal, H.M. (1957). The effect of light and other factors on breaking the dormancy of guayule seeds. Agronomy Journal, 49, 15-19.

3. Hammond, B.L. (1959). Effect of gibberellin, sodium hypochlorite, light, and planting depth on germination of guayule seeds. Agronomy Journal, 51, 621-623.

4. McCallum, W.B. (1929). Method of treating and sowing guayule seed. U.S. Patent No. 1,735,835, U.S. Patent Office, Official Gazette, 388, 520.

5. Naqvi, H.H. and Hanson, G.P. (1980). Recent advances in guayule seed germination procedures. Crop Science, 20, 501-504.

6. Naqvi, H.H. and Hanson, G.P. (1982). Germination and growth inhibitors in guayule (Parthenium argentatum Gray) chaff and their possible influence in seed dormancy. American Journal of Botany, 69, 985-989.

7. Williams, J.D. and Groves, R.H. (1980). The influence of temperature and photoperiod on growth and development of Parthenium hysterophorus L. Weed Research, 20, 47-52.

CHAPTER 31. CONVOLVULACEAE

The Convolvulaceae comprise roughly 1000 species of shrubs and herbaceous plants in about 50 genera. The most important genus is Ipomoea which provides edible roots (Ipomoea batatas (L.) Lam., sweet potato), leaf vegetables (e.g. Ipomoea eriocarpa R. Br.) and fodder (e.g. Ipomoea pes-caprae (L.) Sweet). The seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

The major problem in seed germination tests of the Convolvulaceae is the presence of the seed coat which can delay or prevent imbibition: that is, hardseededness is a common problem. The seeds are non-endospermic, and B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos within hard seed coats (see Table 17.2, Chapter 17). Consequently scarification and chipping treatments are useful in promoting germination. Detailed information on seed dormancy and germination is provided in this chapter for the genus Ipomoea and Table 31.1 provides a summary of germination test procedures and dormancy-breaking treatments for species in other genera. In addition the algorithm below may be helpful in developing germination test procedures for other species.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test several samples of seeds at constant temperatures of 11° to 26°C with light applied for 12h/d. Four constant temperature regimes at 5°C intervals are suggested.

If none of these constant temperature regimes is successful in promoting full germination then the second step of the algorithm is to pre-chill a further sample of seeds at 2° to 6°C for 8w and then test for germination in the most successful germination test regime determined in step one.

If the second step of the algorithm does not result in full germination then the third step is to chip a further sample of seeds and then test in the most successful regime determined in steps one and two. This may include a pre-chill treatment if the second step of the algorithm results in an appreciable increase in germination compared to step one.

TABLE 31.1 Summary of germination test recommendations for species within the Convolvulaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Convolvulus arvensis L.	TP; BP; S	20°/30°C	7d	scarify, concentrated sulphuric acid, 1h, rinse	Everson
				scarify, absolute alcohol, 20h, or file	Atwater
Convolvulus lanatus Vahl.				scarify, sulphuric acid, 30 min, or percussion, shake, 4h	Atwater
Convolvulus tricolor L.	TP; BP	20°/30°C; 20°C	14d	pierce, chip or file cotyledon end of testa	ISTA
		20°/30°C	14d	clip hard seeds	Atwater
Dichondra repens Forst. & G. Forst.	TP	20°/30°C	21d		ISTA

	BP	20°/30°C	28d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Pharbitis purpurea (Roth) Bojer	TP; BP; S	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa	ISTA
Quamoclit vulgaris Choisy	TP; BP; S	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa	ISTA

IPOMOEA

I. alba L.	moon flower
I. aquatica Forsk. [I. reptans Poir.]	water convolvulus, water spinach, kangkong
I. arborescence Don	
I. batatas (L.) Lam. [Convolvulus batatas L.]	sweet potato
I. bederacea (L.) Jacq. var bederacea	ivyleaf morning glory
I. bederacea (L.) Jacq. var intergriuscula Gray	entireleaf morning glory
I. coccinea L.	scarlet morning glory
I. heptophylla (Rottb. & Willd.) Voigt	palmleaf morning glory
I. lacunosa L.	pitted or white morning glory
I. noctiflora L.	
I. obscura Hassk.	
I. purpurea Lam. [Convolvulus purpureus L.; Convolvulus major Hort.; Pharbitis purpurea Voigt]	common or tall morning glory
I. quamoclit L.	cypress vine
I. sinensis	
I. trichocarpa Ell.	
I. tricolor Cav. [I. rubro-caerulea Hook.; Pharbitis rubro-caerulea (Hook.) Choisy]	
I. wrightii Gray	willow leaf morning glory

I. Evidence of dormancy

Whilst the production of viable seeds from sweet potato (I. batatas) clones - particularly those subject to repeated vegetative propagation - is difficult, e.g. (17,18,24), seed viability can be maintained in the long-term with, for example, no appreciable loss in viability over a 20 year period (13-15). Moreover, no problems have been encountered when raising plants from seeds in long-term storage (19,29).

Embryos extracted from sweet potato seeds have been reported to be non-dormant (4). However, seed germination can be severely restricted by hardseededness (1,4,13,15,21,23,24,26,28,30). Reported proportions of hard seeds in seed populations vary from around 50% (20,21) to 90 or 95% (23,28). The germination of seeds of other Ipomoea spp. can also be restricted by hardseededness (3,5-9,22,25,27). As far as possible the information is presented below according to species, but this has not been possible in all cases.

II. Germination regimes for non-dormant seeds

I. alba

BP: 20°/30°C (16h/8h): 21d (AOSA)

I. aquatica

BP; S: 30°C: 10d (ISTA)

I. noctiflora

BP; TP; S: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

I. quamoclit

BP: 20°/30°C (16h/8h): 14d (AOSA)

I. tricolor

BP; TP; S: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

Ipomoea spp.

BP: 20°/30°C (16h/8h); 20°C: 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

I. batatas

Scarification: sulphuric acid, 50%, 2,7,10 min (26); concentrated sulphuric acid, 2,5 min (26); mechanical, crack outer seedcoat with pliers (26)

I. bederacea var bederacea

Constant temperatures: 40°C (6)

Alternating temperatures: 15°/10°C (day/night) (27)

Light: to intact seeds (27)

I. coccinea

Scarification: concentrated sulphuric acid, 60 min, germinate at 5°C, 45°C, 50°C (7,9)

I. lacunosa

Constant temperatures: 40°C (6)

I. obscura

Scarification: concentrated sulphuric acid, 60 min, germinate at 5°C, 45°C, 50°C (8)

I. purpurea

Abscisic acid: co-applied, 10^{-3} M (10)

Naphthaleneacetic acid: co-applied, 10^{-2} -10^{-7} M (10)

Mannitol: co-applied, $3x10^{-1}$ M (11)

Light: far red, 4h, 23°C (11)

IV. Partly-successful dormancy-breaking treatments

I. aquatica

Alternating temperatures: 30°/25°C, 25°/20°C (day/night) on top of filter papers (12); 20°/15°C, 15°/13°C (day/night) on top of filter papers or in soil (12)

I. arborescence

Scarification: concentrated sulphuric acid, 3-15 min (22)

I. batatas

Scarification: concentrated sulphuric acid, 20-60 min (1,30); concentrated sulphuric acid, 10 min (26,28); sulphuric acid, 50%, 20 min (26); concentrated sulphuric acid, 15-60 min (20); rub, 3-4 min, medium emery cloth (26); emery paper (23).

I. bederacea var bederacea

Constant temperatures: 20°C, 25°C, 30°C, 40°C, scarified seeds, concentrated sulphuric acid, 1h (6)

Alternating temperatues: 20°/30°C (16h/8h), intact seeds (6); 20°/30°C (12h/12h), scarified seeds, concentrated sulphuric acid, 1h (6); 32°/27°C (day/night), scarified seeds (27)

Light: at 32°/27°C (day/night), scarified seeds (27)

I. bederacea var intergriuscula

Alternating temperatures: 20°/30°C (16h/8h), intact seeds (6)

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°C (3); concentrated sulphuric acid, 60 min, germinate at 40°C (6)

I. coccinea

Scarification: concentrated sulphuric acid, 30-105 min (7); concentrated sulphuric acid, 30-120 min (9); concentrated sulphuric acid, 60 min, germinate at 10°-40°C (9)

I. heptophylla

Scarification: concentrated sulphuric acid, 30,45 min (7)

I. lacunosa

Alternating temperatures: 20°/30°C (16h/8h), intact seeds (6)

Scarification: concentrated sulphuric acid, 30 min (7)

I. obscura

Scarification: concentrated sulphuric acid, 30 min, germinate at 10°-40°C (8); concentrated sulphuric acid, 60 min, germinate at 10°C, 40°C (8)

I. purpurea

Constant temperatures: 15°C, 35°C (2)

Light: fluorescent, at 23°C (11); red, 1,2h (11); infra red, 5s (10)

CA_3: co-applied, 10^{-4} M (10, 11)

Thiourea: co-applied, 10^{-4} M (10)

Kinetin: co-applied, 10^{-4} M (10)

Mannitol: co-applied, $3x10^{-1}$ M, at 23°C in red or white light (11)

I. sinensis

Alternating temperatures: 14.5°/28°C (night/day) in light or dark (5)

I. trichocarpa, I. wrightii

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°C (3)

Ipomoea spp.

Scarification: mechanical (25)

V. Successful dormancy-breaking treatments

I. aquatica

Alternating temperatures: 25°/20°C, 30°/25°C (day/night) in soil (12); 30°/25°C, 25°/20°C (day/night) on top of filter papers (12)

I. batatas

Scarification: concentrated sulphuric acid (4, 14); concentrated sulphuric acid, 45 min (20,24); concentrated sulphuric acid, 20 min (26); concentrated sulphuric acid, 20 min, germinate at 30°C, then prick seedcoats of non-imbibed seeds (15); mechanical (4); emery wheel, 1750 rpm (20)

Removal of seed covering structures: part of seed cost (23); clip (24); file (26)

I. bederacea var bederacea

Alternating temperatures: 20°/30°C (16h/8h), then prick non-germinated seeds (6)

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3); concentrated sulphuric acid, 1h, germinate at 35°C (6)

I. bederacea var intergriuscula

Alternating temperatures: 20°/30°C (16h/8h), then prick non-germinated seeds (6)

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3); concentrated sulphuric acid, 1h, germinate at 20°/30°C (12h/12h), 20°C, 25°C, 30°C, 35°C (6)

I. coccinea

Scarification: concentrated sulphuric acid, 3h (9); concentrated sulphuric acid 4,6h (7)

Removal of seed covering structures: prick (7,9)

I. heptophylla

Scarification: concentrated sulphuric acid, 1-6h (7) Removal of seed covering structures: prick (7)

I. lacunosa

Alternating temperatures: 20°/30°C (16h/8h), then prick non-germinated seeds (6)

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3); concentrated sulphuric acid, 1h, germinate at 20°/30°C (12/12h), or 20°-40°C (6); concentrated sulphuric acid, 45 min-6h (7)

Removal of seed covering structures: prick (7)

I. noctiflora

Pierce, chip or file off fragment of testa (ISTA)

I. obscura

Scarification: concentrated sulphuric acid, 45-180 min (8); concentrated sulphuric acid, 60 min, germinate at 15°-35°C (8) Removal of seed covering structures: prick (8)

I. purpurea

Pierce, chip or file off fragment of testa (ISTA)

Constant temperatures: 20°-30°C (2)

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3)

Pre-soak: 70°C, 10 min (10)

Ultrasonics: 20 kc/s, 2 min (10)

I. quamoclit

Pierce, chip or file off fragment of testa (ISTA)

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3)

I. trichocarpa

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3)

I. tricolor

Pierce, chip or file off fragment of testa (ISTA)

I. wrightii

Scarification: concentrated sulphuric acid, 30 min, germinate at 16°-32°C (3)

VI. Comment

Imbibed seeds of Ipomoea spp. will germinate over a wide range of constant and alternating temperatures: those prescribed by ISTA/AOSA are suitable, and there may be some advantage in testing in the alternating temperature regime 20°/30°C (16h/8h) since this may help in removing hardseededness. Germination can be promoted by light (11,12,27), and thus it is recommended that light be applied to germination tests. Mechanical methods of removing hardseededness are preferred. For germination tests it is probably simplest to prick, with a needle, the seed coats of all impermeable seeds remaining after 4 or 5 days in test. If some form of acid scarification is deemed essential, e.g. for field sowings, then a 10 minute treatment with concentrated sulphuric acid is suggested. This is unlikely to render all seeds permeable (26,28), but longer treatments may be damaging to some seeds (20).

VII. References

1. Abramides, E., Pereira, A.S. and Monteiro, D.A. (1977). [Scarification of seeds of sweet potato (Ipomoea batatas (L.) Lam.) with sulphuric acid.] Ciencia e Cultura, 29, 7. (From Seed Abstracts, 1978, 1, 1983.)

2. Cole, A.W. and Coats, G.E. (1973). Tall morning glory germination response to herbicides and temperature. Weed Science, 21, 443-446.

3. Crowley, R.H. and Buchanan, G.A. (1980). Responses of Ipomoea spp. and smallflower morning glory (Jacquemontia tamnifolia) to temperature and osmotic stresses. Weed Science, 28, 76-82.

4. Edmond, J.B. and Ammerman, G.R. (1971). Sweet potatoes: production, processing, marketing, 26 pp. The AVI Publishing Company Inc., Westport, Connecticut.

5. Fenner, M. (1980). Germination tests on thirty-two East African weed species. Weed Research, 20, 135-138.

6. Gomes, L.F., Chandler, J.M. and Vaughan, C.E. (1978). Aspects of germination, emergence, and seed production of three Ipomoea taxa. Weed Science, 26, 245-248.

7. Hardcastle, W.S. (1978). Enhancement of Ipomoea seed germination. Proceedings of the 31st Annual Meeting of the Southern Weed Science Society, 280-281.

8. Hardcastle, W.S. (1978). The influence of temperature and acid scarification duration on Ipomoea obscura Hassk. seed germination. Weed Research, 18, 89-91.

9. Hardcastle, W.S. (1978). Influence of temperature and acid scarification duration on scarlet morning glory (Ipomoea coccinea) seed germination. Weed Science, 26, 261-263.

10. Holm, R.E. and Miller, M.R. (1972). Weed seed germination responses to chemical and physical treatments. Weed Science, 20, 150-153.

11. Holm, R.E. and Miller, M.R. (1972). Hormonal control of weed seed germination. Weed Science, 20, 209-211.

12. Huang, H. (1981). [Effects of temperature on germination, growth and dry matter contents of two tropical vegetable with high nutritive value - edible amaranth and water convolvulus.] Memoirs of the College of Agriculture, National Taiwan University, 21, 88-105.

13. Jones, A. (1980). Sweet potato. In Hybridization of Crop Plants (eds. W.R. Fehr and H.H.adley), pp. 645-655. American Society of Agronomy Inc., Madison, Wisconsin.

14. Jones, A. and Dukes, P.D. (1981). Viability of stored sweet potato seed. HortScience, 16, 287-288.

15. Jones, A. and Dukes, P.D. (1982). Longevity of stored seed of sweet potato. HortScience, 17, 756-757.

16. Jones, A., Dukes, P.D. and Cuthbert, F.D. Jr. (1977). Pesticides increase true seed production of sweet potato. HortScience, 12, 165-167.

17. Jones, A. and Jackson, C.R. (1968). Fungi from floral parts of sweet potato (Ipomoea batatas (L.) Lam.). HortScience, 3, 76-77.

18. Martin, F.W. and Cabanillas, E. (1966). Post-pollen-germination barriers to seed set in

sweet potato. Euphytica, 15, 404-411.

19. Martin, F.W. and Jones, A. (1971). Flowering and fertility changes in six generations of open pollinated sweet potatoes. Journal of the American Society for Horticultural Science, 96, 493-495.

20. Martin, J.A. Jr. (1946). Germination of sweet potato seed as affected by methods of scarification. Proceedings of the American Society for Horticultural Science, 47, 387-390.

21. Miller, J.C. (1937). Inducing the sweet potato to bloom and set seed. Journal of Heredity, 28, 347-349.

22. Nalawadi, U.G., Elengovan, R., Gowda, J.V.N. and Sulladmath, U.V. (1978). Acid scarification improves germination in Ipomoea arborescens Don. Current Research, 7, 104.

23. Nunes, W. De O. (1968). [Improvement of sweet potato. 2. Harvest of fruit and germination of seed.] Pesquisa Agropecuaria Brasileira, 3, 263-266.

24. Purseglove, J.W. (1968). Convulvulaceae. In Tropical Crops. Dicotyledons, pp. 78-88. Longmans, London.

25. Rose, D.H. (1915). A study of delayed germination in economic seeds. Botanical Gazette, 59, 425-444.

26. Steinbauer, C.E. (1937). Methods of scarifying sweet potato seed. Proceedings of the American Society for Horticultural Science, 35, 706-608.

27. Thullen, R.J. and Keeley, P.E. (1982). The effects of some environmental conditions on the germination of black nightshade and ivyleaf morning glory. Proceedings of the Western Society of Weed Science, 35, 76-82.

28. Venkataratnam, L. and Satyanarayanamurthy, K. (1953). A simple method of germinating sweet potato seeds. Current Science, 22, 29.

29. Yen, D.E. (1974). The sweet potato and Oceania, pp. 235-237. Bishop Museum Press, Honolulu, Hawaii, Bulletin 236.

30. Monteiro, D.A., Castro, J.L. and Abramides, E. (1977). [Scarification of sweet potato seeds in concentrated sulphuric acid.] Instituto Agronomico (Sáo Paulo), Boletim Técnico, No. 42, 6 pp.

CHAPTER 32. CRUCIFERAE

The Cruciferae comprise roughly 3000 species of herbaceous plants within more than 300 genera. They provide numerous leaf vegetables (e.g. Brassica chinensis L., Chinese cabbage), edible roots (e.g. Raphanus sativus L., radish), condiments (e.g. Armoracia rusticana Gaertn.) and oil crops (e.g. Brassica campestris L., field mustard). The fruits are usually dehiscent pod-like capsules: if they are longer than they are broad they are called a siliqua; if they are as broad as they are long they are called a silicula. The seeds show orthodox storage characteristics.

SEED DORMANCY AND GERMINATION

Dormancy is a potential problem for most accessions of the Cruciferae. The seeds have a curved embryo and no endosperm. B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos enclosed within thin, mucilaginous seed coats (see Table 17.2, Chapter 17). Promotory treatments include potassium nitrate, light, pre-chilling and alternating temperatures.

Detailed information is provided in this chapter for the genera Barbarea (including synonyms within Erysimum), Brassica (including synonyms within Eruca and Sinapis), Crambe, Lepidium, Nasturtium (including synonyms within Radicula, Rorippa and Sisymbrium) and Raphanus. Further information is provided for additional species (including some of the synonyms listed above) in Table 32.1. For difficult accessions and other species the algorithm below may enable a suitable germination test procedure to be developed.

RBG Kew Wakehurst Place algorithm

The first and second steps of the algorithm are dependent upon the accession's origin. Temperate accessions are tested at constant temperatures of 11°C, 16°C and 31°C with light applied for 12h/d. If the results suggest a trend in the response of germination to constant temperatures then further samples of seeds are tested at intermediate, or more extreme constant temperatures. For example, if germination is greatest at 11°C then a further sample of seeds is tested at 6°C with light applied for 12h/d. Tropical accessions are tested at constant temperature of 21°C and 26°C with light applied for 12h/d. Again, if a trend in the results is apparent then a further sample of seeds is tested at a more extreme constant temperature. If it is not possible to distinguish between temperate and tropical accessions then five samples of the seeds are tested at each constant temperature regime: that is at 11°C, 16°C, 21°C, 26°C and at 31°C.

If the first step of the algorithm does not result in full germination then the second step is to test a further sample of seeds in an alternating temperature regime: temperate accessions are tested at 23°/9°C (12h/12h); tropical accessions at 33°/19°C (12h/12h); in each regime light is applied for 12h/d during the period spent at the upper temperature. If it is not possible to distinguish between temperate and tropical accessions then test seeds in both alternating-temperature regimes.

Further steps in the algorithm do not distinguish between temperate and tropical accessions. If full germination has not been promoted by the second step of the algorithm then the third step of the algorithm is to pre-chill a further sample of seeds at 2° to 6°C for 8w, and then test for germination in the most successful regime determined in steps one and two.

If full germination has not been promoted then the fourth step of the algorithm is to remove the seed coats from a fresh sample of seeds and test in the most successful regime determined from the results of steps one to three. This may include a pre-chill treatment if this resulted in an increase in germination in step three.

If full germination has not been promoted by step four then the fifth step of the algorithm is to co-apply 7×10^{-4} M GA_3 in the germination test substrate and test at the most successful regime determined in steps one to four.

If full germination has not been promoted, the sixth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided for the six genera in this chapter, from Table 17.2 and from Table 32.1.

TABLE 32.1 Summary of germination test recommendations for species within the Cruciferae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Alyssum argenteum All.	TP	20°/30°C; 15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
Alyssum compactum De Not.	TP	15°C	8d	light, potassium nitrate	AOSA
Alyssum montanum L.	TP	20°/30°C; 15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
Alyssum saxatile L.	TP	20°/30°C; 15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
	TP	15°C	8d	light, potassium nitrate	AOSA
Arabis alpina L.	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
	TP	15°C	14d	light, potassium nitrate	AOSA
		15°C	21d	light, potassium nitrate, 0.2%	Atwater
Arabis x arendsii Wehrhahn	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Arabis blepharophylla Hook. & Arn.	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Arabis caucasica Willd.	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Arabis glabra	TP	20°/30°C	14d	light	SGCF
Arabis holboelli	TP	20°/30°C; 15°C; 20°C		pre-chill, 2, 3w	M&O
Arabis procurrens Waldst. & Kit.	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Arabis scopoliana Boiss.	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Aubrieta deltoidea DC.	TP	10°C; 15°C; 20°C	21d	pre-chill	ISTA
	TP	15°C	18d	sensitive to warm temperatures	AOSA

		15°C	21d	light	Atwater
Aurina saxatile (L.) Desv.		15°C	14d	potassium nitrate, 0.2%	Atwater
Berteroa incana	TP	20°C	10d	potassium nitrate	SGCF
Camelina microcarpa	TP	20°/30°C	14d	potassium nitrate, pre-chill, 2w	SGCF
	TP	15°C; 20°C			M&O
Camelina sativa (L.) Crantz	TP	20°/30°C	10d		ISTA
Capsella bursa-pastoris L.	TP	20°/30°C	21d	potassium nitrate, pre-chill, 2w	SGCF
Cardaria draba	TP	20°/30°C; 15°C		light	M&O
Cardaria draba var repens	TP	15°C		light	M&O
Cardaria pubescens	TP	20°/30°C		light	M&O
Cheiranthus cheiri L.	TP	20°/30°C; 15°C; 20°C	14d	light, potassium nitrate, pre-chill	ISTA
	TP	20°/30°C	10d	light, potassium nitrate	AOSA
		20°C	10d	light, potassium nitrate, 0.2%	Atwater
Descurainia pinnata	TP	20°/30°C; 20°C			M&O
Eruca sativa Mill.	TP; BP	20°C	7d		ISTA
	BP	20°C	7d		AOSA
	TP	20°C	7d		Heit
Erysimum x allionii Hort.	TP	20°/30°C; 15°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	10d		AOSA
Erysimum cheiranthoides	TP	20°/30°C	7d	potassium nitrate	SGCF
Hesperis matronalis L.	TP	20°/30°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	8d	light, potassium nitrate	AOSA
	TP	20°/30°C	7d	potassium nitrate	SGCF
Iberis amara L.	TP; BP	20°/30°C; 15°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	15°C	14d		AOSA
		20°C	14d	test at 15°C	Atwater
Iberis gibraltarica L.	TP; BP	20°/30°C; 15°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	15°C	21d	potassium nitrate	AOSA
Iberis sempervirens L.	TP; BP	20°/30°C; 15°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	15°C	21d	potassium nitrate	AOSA
Iberis umbellata L.	TP; BP	20°/30°C; 15°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	15°C	14d		AOSA
Lesquerella fendleri (Gray) Wats.		15°/25°C		light, potassium nitrate, 0.2%, GA, 100ppm	Atwater
Lesquerella gordonii (Gray) Wats.		15°/25°C		light, GA, 100ppm	Atwater
Lesquerella palmeri Wats.		10°/30°C		light, GA, 1000ppm	Atwater
Lobularia maritima (L.) Desv.	TP	20°/30°C; 15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA

	TP	15°C	8d	light, potassium nitrate	AOSA
		15°C	14d	potassium nitrate, 0.2%, or GA, 400ppm	Atwater
Lunaria annua L.	TP; BP	15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
	TP	15°C	14d	potassium nitrate	AOSA
		20°C	14d	GA, 400ppm	Atwater
Lunaria vulgaris Mill.	TP; BP	15°C; 20°C	21d		ISTA
Malcolmia maritima (L.) R. Br.	TP	20°/30°C; 15°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	8d	light	AOSA
		20°C	7d	test at 15°C	Atwater
Matthiola incana (L.) R. Br.	TP	20°/30°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C; 20°C	7d	light, sensitive to drying out in test	AOSA
		15°C; 20°C	10d	light, potassium nitrate, 0.2%	Atwater
Matthiola longipetala (Vent.) DC.	TP	20°/30°C; 15°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	15°C	8d	light, potassium nitrate	AOSA
		15°C	10d	potassium nitrate, 0.2%	Atwater
Sisymbrium altissimum	TP	20°/30°C; 20°C			M&O
	TP	20°/30°C	8d	potassium nitrate, pre-chill	SGCF
	TP; S	20°/30°C	7d	light	Everson
Sisymbrium officinale	TP	20°/30°C		light	M&O
	TP	20°/30°C	10d	potassium nitrate, pre-chill	SGCF
	TP; S	15°/30°C	10d	light	Everson
Thlaspe arvense	TP	20°/30°C	10d	potassium nitrate	SGCF
	S	15°/30°C	10d	light	Everson

BARBAREA

B. orthoceras	erectpod wintercress
B. verna (Mill.) Aschers. [B. praecox R. Br.; Erysimum vernum Mill.]	early cress, Belle Isle cress upland cress, wintercres
B. vulgaris R. Br. [Erysimum Barbarea L.]	yellow rocket, spring mustard

I. Evidence of dormancy

Freshly harvested seeds of Barbarea spp. can show considerable dormancy (1,2,5). Seeds of B. vulgaris require 4 months after-ripening at room temperature to lose dormancy (2).

II. Germination regimes for non-dormant seeds

B. verna

TP: 20°/30°C (16h/8h): 7d (AOSA)

III. Unsuccessful dormancy-breaking treatments

B. verna

Constant temperatures: 10°-35°C (6)

Alternating temperatures: 20°/30°C (17h/7h) in light or dark (6); 20°/35°C (17h/7h) in dark (6)

Warm stratification: 20°C, 3d, dark, then 40°C, 1-8 min (5)

Sodium nitrite: co-applied, 10^{-3} M (1)

Hydroxylamine hydrochloride: co-applied, $3.2x10^{-4}$ M (1)

Ethylene: co-applied, 1, 10, 100 ppm (4)

B. vulgaris

Constant temperatures: 20°C, 25°C, 30°C (2)

Warm stratification: 20°C, 3d, dark, then 40°C, 1-16 min (5)

Potassium nitrate: co-applied, 10^{-2} M (1)

Sodium nitrite: co-applied, 10^{-3} M (1)

Hydroxylamine hydrochloride: co-applied, $3.2x10^{-4}$ M (1)

Ethylene: co-applied, 1, 10, 100 ppm (4)Light: far red (7)

IV. Partly-successful dormancy-breaking treatments

B. orthoceras

Constant temperatures: 15°C, 20°C, dark (8)

Alternating temperatures: 20°/30°C, in light or dark (8)

Pre-chill: 3°C, 7-28d, germinate at 20°/30°C, dark (8)

B. verna

Warm stratification: 20°C, 3d, dark, then 40°C, 16 min-6h (5)

Potassium nitrate: co-applied, 10^{-2} M (1); co-applied, 0.2%, at 20°/30°C (17h/7h), dark (6)

Ammonium chloride: co-applied, $5x10^{-2}$ -10^{-3} M (1)

Ammonium nitrate: co-applied, 10^{-2} M (1)

Sodium nitrate: co-applied, 10^{-2} M (1)

Light: (4); $0.4\text{-}3.3x10^{-9}$ mol cm^{-2} s^{-1}, 20s, 5 min (5)

B. vulgaris

Warm stratification: 20°C, 3d, then 40°C, 32 min-6h (5)

Ammonium chloride: co-applied, 10^{-2} M (1)

Potassium nitrate: co-applied, 0.2% (2)

Light: (4); 50 fc (2); $0.4\text{-}3.3x10^{-9}$ mol cm^{-2} s^{-1}, 20s, 5 min (5); red, 16 min (7)

V. Successful dormancy-breaking treatments

B. verna

Potassium nitrate, Light (AOSA)

Warm stratification: 20°C, 3d, then 40°C, 64 min, in light, $4x10^{-7}$ mol cm^{-2} s^{-1} (5); 10°-35°C, 28d, germinate at 20°/30°C, 20°/35°C (17h/7h) in light, plus potassium nitrate, co-applied, 0.2% (6)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C, 20°/35°C (17h/7h) in light (6)

B. vulgaris

Alternating temperatures: 20°/30°C (16h/8h) in light (3)

VI. Comment

Successful germination of dormant seeds of B. verna and B. vulgaris requires alternating temperatures and light (2,3,6). Ammonium nitrate and ammonium chloride are reported to be more effective in promoting the germination of dormant seeds than potassium nitrate (1).

Consequently if the AOSA procedure for B. verna - potassium nitrate, co-applied, 0.2%, in an alternating temperature regime of 20°/30°C (16h/8h) in light (but see Chapter 6) does not prove satisfactory try replacing potassium nitrate with ammonium nitrate (10^{-2} M).

The AOSA procedure for B. verna appears to be satisfactory for seeds of B. vulgaris. Pre-chilling dormant seeds of B. orthoceras at 3°C for between 21 and 28 days with subsequent testing for germination in an alternating temperature regime of 20°/30°C is an effective procedure for breaking dormancy (8) and is suggested here. The germination tests should be carried out in the dark, however, since light can inhibit seed germination in this regime (8).

VII. References

1. Hendricks, S.B. and Taylorson, R.B. (1974). Promotion of seed germination by nitrate, nitrite, hydroxylamine, and ammonium salts. Plant Physiology, 54, 304-309.

2. Steinbauer, G.P. and Frank, P. (1954). Primary dormancy and germination requirements of seeds of certain Cruciferae. Proceedings of the Association of Official Seed Analysts, 44, 176-181.

3. Steinbauer, G.P., Grigsby, B., Correa, L. and Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-51.

4. Taylorson, R.B. (1979). Response of weed seeds to ethylene and related hydrocarbons. Weed Science, 27, 7-10.

5. Taylorson, R.B. and Hendricks, S.B. (1972). Interactions of light and a temperature shift on seed germination. Plant Physiology, 49, 127-130.

6. Toole, E.H. and Toole, V.K. (1940). Note on the germination of seeds of Barbarea verna and Lepidium virginicum. Proceedings of International Seed Testing Association, 12, 32-38.

7. Toole, E.H., Toole, V.K., Hendricks, S.B. and Borthwick, H.A. (1957). Effect of temperature on germination of light-sensitive seeds. Proceedings of the International Seed Testing Association, 22, 196-204.

8. Maguire, J.D. and Overland, A. (1959). Laboratory germination of seeds of weedy and native plants. Washington Agricultural Experiment Station, Circular No. 349, 15 pp.

BRASSICA

B. alba (L.) Rabenh. [B. hirta Moench; Sinapis alba L.]	white mustard
B. campestris L.	field mustard
B. chinensis L.	Chinese cabbage, pakchoi
B. chinensis L. var pekinensis (Rupr.) Sun [B. pekinensis Rupr.; B. Pe-Tsai Bailey;	pe-tsai Sinapis pekinensis Lour.]
B. juncea (L.) Czern.& Coss. [B. rugosa Hort.; Sinapis juncea L.;]	leaf mustard, Indian mustard
B. juncea (L.) Czern.& Coss. var crispifolia Bailey [B. japonica Hort.]	
B. kaber (DC.) Wheeler [B. arvensis Rabenh.; Sinapis kaber DC.; Sinapis arvensis L.]	charlock, wild mustard
B. napella Chaix	rape
B. napus L.	annual rape, winter rape, colza
B. napus L. var napobrassica (L.) Reichb. [B. Napobrassica Mill.; B. oleracea L. var Napobrassica L.]	rutabaga, swede
B. napus L. var oleifera	
B. nigra Koch [B. cernua Coss.; Sinapis nigra L.; Sinapis cernuaThunb.]	black mustard
B. oleracea L. var acephala DC.	borecole, collard, kale
B. oleracea L. var acephala DC.	borecole, collard, kale
B. oleracea L. var alboglabra (Bailey) Musil.	Chinese kale
B. oleracea L. var botrytis L. [B. cauliflora Gars.; B. botrytis Mill.]	broccoli, cauliflower
B. oleracea L. var capitata L.	cabbage
B. oleracea L. var gemnifera DC.	brussel sprouts
B. oleracea L. var gongylodes L. [B. caulorapa Pasq.; B. oleracea L. var caulo-rapa DC.]	kohlrabi
B. oleracea L. var sabauda	savoy cabbage
B. oleracea L. var tronchuda Bailey	tronchuda cabbage, Portuguese kale
B. perviridis (Bailey) Bailey	spinach mustard
B. rapa L. [B. campestris L. var rapifera Metz.]	turnip
B. spinescens Pomel	
B. tournefortii Gouan	
B. vesicaria [Eruca vesicaria (L.) Cav.]	

I. Evidence of dormancy

Seeds of the cultivated Brassica spp. can show considerable dormancy (7-9,14,25,26,30-33,35,37,41,44-50,52,54). This causes problems in both commercial seed testing stations and plant breeding programmes (5,38,54). A dormancy period of 2-3 months has been reported for seeds of B. napus and B. nigra, but dormancy can remain for as long as 2 years when the whole fruits are stored (47). Seeds of B. campestris, B. nigra and B. juncea require at least 7 months after-ripening at room temperature to remove dormancy (52). Not surprisingly the wild species of Brassica show much deeper dormancy, e.g. B. kaber (6,12,13,16,32,38,53,55), B. spinescens (40), B. tournefortii (40) and B. vesicaria (40). Secondary dormancy is reported to be induced by high carbon dioxide concentrations (19-21), by high temperatures (35), or by prolonged pre-chilling (35). Certain seed drying regimes can also induce dormancy (50).

II. Germination regimes for non-dormant seeds

B. chinensis, B. chinensis var pekinensis

TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

BP: 20°/30°C (16h/8h): 7d (AOSA)

B. juncea

TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

TP: 20°/30°C (16h/8h): 7d (AOSA)

B. napus

TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

BP: 20°/30°C (16h/8h): 7d (AOSA)

Alternating temperatures: 20°/30°C, 18°/25°C (16h/8h) (18)

B. napus var napobrassica

TP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

TP; BP: 20°/30°C (16h/8h): 14d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (18)

B. napus var oleifera

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) (23)

B. nigra

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP: 20°/30°C (16h/8h): 7d (AOSA)

B. oleracea var acephala

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

Constant temperatures: 5°-17°C (2)

B. oleracea var alboglabra

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

B. oleracea var botrytis

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

Constant temperatures: 5°-17°C (2); 20°C (15); 7.5°-32.5°C (43)

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) (23)

B. oleracea var capitata

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

Constant temperatures: 7.5°-32.5°C (43)

B. oleracea var gemnifera

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

Constant temperatures: 5°-17°C (2); 20°C (15); 7.5°-32.5°C (43)

B. oleracea var gongylodes

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

Constant temperatures: 30°C (36)

B. oleracea var sabauda

Constant temperatures: 5°-17°C in light, 8h/d (2)

B. oleracea var tronchuda

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 20°/30°C (16h/8h): 10d (AOSA)

B. perviridis

TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

BP: 20°/30°C (16h/8h): 7d (AOSA)

B. rapa

TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

BP: 20°/30°C (16h/8h): 7-10d (AOSA)

Constant temperatures: 5°-17°C (2); 15°-35°C (10)

III. Unsuccessful dormancy-breaking treatments

B. alba

Pre-chill: 1°-3°C, 3d (21)

Warm stratification: 50°C, 3h (21)

Pre-soak: (40)

Light: white, continuous, $150x10^{-6}$ mol m^{-2} s^{-1} (26); red, continuous, $2x10^{-5}$ mol m^{-2} s^{-1} (26); blue, continuous, $2x10^{-5}$ mol m^{-2} s^{-1} (26)

Carbon dioxide: 3-24% (19,20); 9-12%, plus oxygen, 5% (20); 5-90%, plus oxygen, 10% (21)

B. campestris

Light: continuous, 50 fc (38)

B. juncea

Constant temperatures: 35°C, red light (27); 30°C, 35°C, dark (27)

Ethylene: co-applied, 1, 10, 100 ppm (42)

B. kaber

Constant temperatures: 23°C and above (53)

Light: far red (1); far red, 4h (13)

GA_3: co-applied, 500 ppm (4)

Naphthaleneacetic acid: co-applied, 10^{-2} -10^{-7} M (12)

Ethylene: co-applied, 1-100 ppm (42)

Oxygen: 2.5% (11)

Ethanol: 1 ppm, plus acetone, 0.1 ppm plus acetaldehyde (11)

Mannitol: co-applied, 0.2 M (13)

Ultrasonics: 20 kc/s, 30s-5 min (12)

Liquid nitrogen: 10s (12)

B. napella

Removal of seed covering structures: (41)

Carbon dioxide: (41)

B. nigra

Constant temperatures: 25°C (48); 25°C, 30°C (35)

Pre-chill: 6°C, 20d (35)

Potassium nitrate: co-applied, 0.2% (52); co-applied, 0.2%, at 25°C, 30°C (35)

Indoleacetic acid: co-applied, 50, 100 ppm (34)

Kinetin: co-applied, 50, 100 ppm (34)

B. oleracea var capitata

Scarification: concentrated sulphuric acid, 15,30 min, 4°C (5)

Carbon dioxide: 25-44% (19)

B. rapa

Pre-chill: 10°C, 3d, germinate at 20°/30°C (16h/8h) in light (33)

B. tournefortii

Light: (40)

IV. Partly-successful dormancy-breaking treatments

B. alba

Pre-chill: -4°C, 3h (21); -7°C, 5h (21)

Hydrochloric acid: co-applied, 10^{-3}, 10^{-2} N (21)

Propionic acid: co-applied, 10^{-3}, 10^{-2} N (21)

Removal of seed covering structures: (21,22)

Light: dark (26); continuous light, 1.5×10^{-4} mol m^{-2} s^{-1}, 26°C (26)

B. campestris

Constant temperatures: 5°-30°C (52); 20°C (9)

Alternating temperatures: 15°/25°C, 20°/30°C, 20°/35°C, 20°/40°C (16h/8h), in daylight or dark (52); 20°/30°C, 15°/25°C (16h/8h) (9)

Potassium nitrate: co-applied, 0.2% (38,52)

Scarification: sulphuric acid (38)

Removal of seed covering structures: (38)

Light: daylight (52)

B. chinensis

Constant temperatures: 20°C (7)

Alternating temperatures: 20°/30°C (16h/8h) (7); 10°/32°C (16h/8h) (7)

Pre-dry: 35°C, 5-7d (7)

B. juncea

Constant temperatures: 20°C, 25°C, 30°C, red light (27); 15°C, 20°C, 25°C, dark (27); 20°-30°C (52)

Alternating temperatures: 20°/30°C in light (25,52); 20°/30°C (16h/8h) in red light or dark (27); 20°/35°C, 20°/40°C (16h/8h) (52)

Pre-chill: 3°-5°C, 2d (30); 5°C, 2d (45)

Light: (30,51,52); 1500 lux, 8h/d (42); red, 1.9x10 W cm , 5 min, after 24h dark imbibition (42)

Potassium nitrate: co-applied, 0.2%, at 20°C (30,52)

Thiourea: co-applied, 0.5%, at 20°C in dark (30)

GA_3: co-applied, 50 ppm (30); co-applied, 100 ppm, at 20°C in light (30)

Removal of seed covering structures: (45); slit seed coat (45); slit seed coat, then pre-soak (45)

Pre-soak: 17h (45)

B. juncea var crispifolia

Constant temperatures: 5°C, 25°C, 35°C (49)

Alternating temperatures: (48)

B. kaber

Constant temperatures: 25°C in light (3); 1°-10°C (6); 18°-27°C, scarified seeds (6); 20°C, light or dark (32); 10°C, 14°C, 20°C, 26°C (53)

Alternating temperatures: 1°-10°/18°-27°C (16h/8h) (6); 10°/30°C (16h/8h) (16); 20°/30°C (16h/8h) in light (32,38)

Pre-chill: 6°C, 1-7d (6); 1°-7°C, 6m (32)

Pre-soak: 35°C, 100 min (12)

Potassium nitrate: co-applied (17); co-applied, 0.2% (38)

Thiourea: co-applied (17); co-applied, 10^{-2} -10^{-7} M (12)

GA_3: co-applied (17); co-applied, 10^{-4} M (13); co-applied, 10-200 ppm (55); pre-applied, 24h, 100, 500 ppm (6); pre-applied, 2,6h, 2000 ppm (6); pre-applied, 24h, 50-1000 ppm, plus sucrose, 2% (6)

Kinetin: co-applied, 10^{-2} -10^{-7} M (12)

Sodium hypochlorite: pre-applied, 15-120 min, 6%, germinate at 10°/30°C (16h/8h) in dark (16); pre-applied, 90,120 min, 6%, germinate at 10°/30°C (16h/8h) in light (16)

Sucrose: pre-applied, 24h, 2% (6)

Scarification: concentrated sulphuric acid (38); concentrated sulphuric acid, 5-30 min (6); concentrated sulphuric acid, 1-4 min (32)

Light: incandescent, $2.3x10^{-3}$ W cm^{-2}, 12h/d, at 25°C (3); fluorescent, $1.3x10^{4}$ ergs cm^{-2} s^{-1}, 8h/d (16); diffuse daylight (32); 1500 lux, 8h/d (42); red, 5 min (1); red, 1, 2h (13); red, $1.9x10^{-4}$ W cm^{-2}, 5 min, after 24h dark imbibition (42); infra red, 1-30s (12)

B. napella

Constant temperatures: 20°-35°C (41)

Pre-chill: 4°C (41)

Scarification: sulphuric acid (41)

Pre-soak: (41)

Alcohol: (41)

Oxygen: (41)

Hydrogen peroxide: (41)

B. napus

Constant temperatures: 5°C, 25°C, 35°C (49)

Light: fluorescent, at 25°C (29)

B. napus var naprobrassica

Constant temperatures: 20°C in daylight (44)

Alternating temperatures: 20°/30°C (16h/8h) (44)

Light: daylight (8)

B. nigra

Constant temperatures: 20°C, dark (44); 5°-30°C (52); 20°C in daylight (35)

Alternating temperatures: (48); 20°/30°C (16h/8h) (38); 15°/25°C, 20°/30°C, 20°/35°C, 20°/40°C (16h/8h) (52); 15°/25° (16h/8h) (35)

Pre-chill: 10°C (8)

Urea: co-applied, 0.5% (28)

Potassium nitrate: co-applied, 0.3% (28); co-applied, 0.2% (37,38); co-applied, 0.2%, at 15°C, 20°C (35)

Thiourea: co-applied, 0.2% (28)

GA_3: co-applied, 50, 100 ppm (34)

Light: daylight (8,51); 50 fc (38)

B. oleracea

Light: daylight (8)

B. oleracea var acephala

Constant temperatures: 20°C in dark (44)

Alternating temperatures: 20°/30°C (16h/8h) in dark (44)

Light: daylight (44)

B. oleracea var botrytis

Constant temperatures: 11°C (24); 20°C in daylight (44)

Alternating temperatures: 20°/30°C in dark (44)

B. oleracea var capitata

Constant temperatures: 20°C (9,44); 8°C (24)

Alternating temperatures: 20°/30°C, 15°/25°C (16h/8h) (9); 20°/30°C (16h/8h) in dark (44)

Pre-chill: 3°-5°C, 2d (30)

Light: (30)

Thiourea: co-applied, 0.5%, at 20°C in dark (30)

Potassium nitrate: co-applied, 0.2% (30)

Scarification: concentrated sulphuric acid, 2-8 min, at 4°C (5)

Removal of seed covering structures: slit seed coat (5)

B. oleracea var gemnifera

Pre-dry: room temperature, 1w (54)

B. rapa

Constant temperatures: 20°C in light (33); 20°C in dark (44)

Alternating temperatures: 20°/30°C, 15°/20°C, 5°/20°C in light (33)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (33); co-applied, 0.2%, plus pre-chill, 10°C, 3d, germinate at 20°/30°C (16h/8h) in light (33)

Thiourea: pre-applied, 1,5h, 1, 5% (33)

Benzyladenine: co-applied, 100 ppm (33)

GA_3: co-applied, 1000 ppm (33)

GA_7: co-applied, 50, 200 ppm (33)

Light: daylight (8,33)

B. tournefortii

Light: dark (40)

V. Successful dormancy-breaking treatments

B. alba

Constant temperatures: 5°-25°C (52); 17°C in continuous light, $1.5x10^{-4}$ mol m^{-2} s^{-1} (26); 26°C in light, $1.5\text{-}6x10^{-5}$ mol m^{-2} s^{-1} (26); 26°C, dark (26)

Alternating temperatures: 18°/36°C, 10°/36°C in light (8)

GA_3: co-applied, 100 ppm (40)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C in light (52)

Removal of seed covering structures: testa (21,22)

B. campestris

Alternating temperatures: 20°/30°C (16h/8h) in dark (38,39)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (52)

B. chinensis var pekinensis

Pre-chill (ISTA)

B. juncea

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Constant temperatures: 15°C in red light (27); 5°-15°C (52)

Alternating temperatures: 15°/25°C (16h/8h) (52)

GA_3: co-applied, 100 ppm, at 20°C in dark (30); co-applied, 50, 100 ppm, plus thiourea, 0.5% (30); co-applied, 50, 100 ppm, plus thiourea, 0.5%, then pre-chill, 3°-5°C, 2d (30); co-applied, 50, 100 ppm, then pre-chill, 2°-5°C, 2d (30)

Thiourea: co-applied, 0.5%, at 20°C in light (30); co-applied, 0.5%, then pre-chill, 3°-5°C, 2d (30)

Removal of seed covering structures: then pre-wash, 17h (45)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (25,52)

B. juncea var crispifolia

Constant temperatures: 15°C (49)

B. kaber

Constant temperatures: 15°C in light (3); 17°C (53)

Alternating temperatures: 20°/30°C (16h/8h) (39)

Pre-chill: 7°C, 8d (53)

GA_3: co-applied, 10^{-3} M (12); co-applied, 100 ppm (40); co-applied, 500 ppm (27); co-applied, 500, 1000 ppm (55); co-applied, $5x10^{-4}$ M, at 10°/30°C (16h/8h) (16); pre-applied, 24h, 500 ppm (4); pre-applied, 24h, 1000-5000 ppm (6); pre-applied, 24h, 2000 ppm (55); pre-applied, 12-24h, 2000 ppm (6)

Sucrose: pre-applied, 24h, 2%, plus GA_3, 5, 10 ppm (6)

Removal of seed covering structures: excise embryo (6)

Sodium hypochlorite: pre-applied, 30,60 min, 6%, germinate at 10°/30°C (16h/8h) in dark (16); pre-applied, 15-60 min, 6%, germinate at 10°/30°C (16h/8h) in light (16); pre-applied, 15-120

min, 6%, plus GA_3, co-applied, $5x10^{-4}$ M, at 10°/30°C (16h/8h) in light or dark (16)

B. napella

Alternating temperatures: room temperature/32°C (41)

B. napus

Pre-chill (ISTA)

Constant temperatures: 15°C (49)

Thiourea: co-applied, 0.5-1% (14)

Urea: co-applied, 0.01-0.1% (14)

B. napus var napobrassica

Pre-chill (ISTA)

Alternating temperatures: 18°/36°C, 10°/36°C (16h/8h) in light (8)

B. nigra

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate, Pre-chill (AOSA)

Constant temperatures: 15°C (49); 6°-15°C (35)

Alternating temperatures: 18°/36°C, 10°/36°C (16h/8h) in light (8); 20°/30°C in light (16h/8h) (52); 20°/30°C (16h/8h) (39,44)

Pre-chill: 6°C, 3-5d (35)

Pre-dry: 30°C, 2-5d (35)

Pre-soak: 6h, 20°C (44)

GA_3: co-applied, 100 ppm (40)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (25,52)

B. oleracea

Pre-chill, Potassium nitrate (ISTA)

Alternating temperatures: 18°/36°C, 10°/36°C (16h/8h) in light (8); 20°/30°C (16h/8h) (18)

B. oleracea var acephala

Light, Pre-chill, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light (44)

B. oleracea var alboglabra, B. oleraceae var botrytis

Light, Pre-chill, Potassium nitrate (AOSA)

B. oleracea var capitata

Light, Pre-chill, Potassium nitrate (AOSA)

Thiourea: co-applied, 0.5%, at 20°C in light (30); co-applied, 0.5%, plus pre-chill, 3°-5°C, 2d (30)

GA_3: co-applied, 50, 100 ppm (30); co-applied, 50, 100 ppm, plus thiourea, 0.5% (30); co-applied, 50, 100 ppm, plus pre-chill, 3°-5°C, 2d (30); co-applied, 50, 100 ppm, plus thiourea, 0.5%, then pre-chill, 3°-5°C, 2d (30)

Scarification: concentrated sulphuric acid, 1 min, at 4°C, germinate at 30°C (5)

Removal of seed covering structures: (5)

B. oleracea var gemnifera

Light, Pre-chill, Potassium nitrate (AOSA)

Pre-dry: room temperature, 3w (54)

Removal of seed covering structures: excise embryo (54)

B. oleracea var gongylodes, B. oleracea var tronchuda

Light, Pre-chill, Potassium nitrate (AOSA)

B. perviridis

Pre-chill (ISTA)

B. rapa

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Constant temperatures: 20°C in light (44)

Alternating temperatures: 18°/36°C, 10°/36°C (16h/8h) in light (8); 20°/30°C (16h/8h) in light (44)

GA_3: co-applied, 400 ppm (33)

B. spinescens, B. tournefortii, B. vesicaria

GA_3: co-applied, 100 ppm (40)

VI. Comment

In general seeds of Brassica spp. require light and alternating temperature regimes for the promotion of germination. The following alternating temperature regimes are likely to be more effective in promoting germination than the standard regime of 20°/30°C: 10°/30°C (7,16); 10°/36°C (8); 15°/25°C (23). If constant germination test temperatures have to be used then the range 10°-15°C, in light, is preferable to higher temperatures. Pre-chill treatments appear to produce somewhat erratic results and are probably better avoided.

Although potassium nitrate is recommended by ISTA and AOSA for breaking dormancy in

many Brassica spp., gibberellins are more effective (A). Although ISTA/AOSA prescriptions and recommendations are reasonably effective, with particularly dormant accessions, however, standard treatments such as 20°/30°C (16h/8h) in light with potassium nitrate, co-applied, 0.2%, are not entirely effective. As an alternative test at 10°/30°C or 15°/25°C (16h/8h) in light, with GA_3, co-applied at 100, 200 ppm - or possibly higher.

VII. References

1. Bartley, M.R. and Frankland, B. (1982). Analysis of the dual role of phytochrome in the photoinhibition of seed germination. Nature, 300, 750-752.

2. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

3. Chakrabarti, A.G. (1977). Effects of temperature shift on weed seed germination. Castanea, 42, 279-285.

4. Corns, W.G. (1960). Effects of gibberellin treatment on germination of various species of weed seeds. Canadian Journal of Plant Science, 40, 47-51.

5. Cox, L.G., Munger, H.M. and Smith, E.A. (1945). A germination inhibitor in the seed coats of certain varieties of cabbage. Plant Physiology, 20, 289-294.

6. Edwards, M.M. (1968). Dormancy in seeds of charlock. II. The influence of the seed coat. Journal of Experimental Botany, 19, 583-600.

7. Frank, W.J. and Wieringa, G. (1928). Artificial drying and low temperature as means employed in obtaining an increase in germination of some vegetable seeds. Proceedings of the Association of Official Seed Analysts, 19, 24-27.

8. Gadd, I. (1939). On methods for the elimination of seed dormancy in seed control work. Proceedings of the International Seed Testing Association, 11, 96-118.

9. Gugnani, D., Banerjee, S.K. and Singh, D. (1975). Germination capacity in relation to seed coat colour in cabbage and mustard. Seed Science and Technology, 2, 575-579.

10. Harrington, J.F. (1963). The effect of temperature on the germination of several kinds of vegetable seeds. Proceedings of the 16th International Horticulture Congress, 2, 435-441.

11. Holm, R.E. (1972). Volatile metabolites controlling germination in buried weed seeds. Plant Physiology, 50, 293-297.

12. Holm, R.E. and Miller, M.R. (1972). Weed seed germination responses to chemical and physical treatments. Weed Science, 20, 150-153.

13. Holm, R.E. and Miller, M.R. (1972). Hormonal control of weed seed germination. Weed Science, 20, 209-212.

14. Hori, Y. and Sugiyama, T. (1954). [Dormancy of the seeds of leaf mustards. II.] Journal of the Horticultural Association of Japan, 22, 223-229. (Cited by Takahashi and Suzuki (1980).)

15. Horvath, G., Balla, I. and Nagy, L. (1981). Some environmental factors effecting the germination of Brassicas. Kertgazdasag, 5, 79-85.

16. Hsiao, A.I. (1980). The effect of sodium hypochlorite, gibberellic acid and light on seed dormancy and germination of stink weed and wild mustard. Canadian Journal of Plant

Science, 60, 643-649.

17. Jennings, R.W., Collins, H.A., Bettis, R.B. and Biswas, P.K. (1968). Effects of several chemical stimulants and inhibitors on seed germination and oxygen consumption of selected weed species. Abstracts of the 1968 Meeting of the Weed Science Society of America, 23-24.

18. Johnston, M.E.H. and Miller, J.G. (1963). Optimum germination conditions for some species of the genus Brassica. Proceedings of the International Seed Testing Association, 28, 39-44.

19. Kidd, F. (1914). The controlling influence of carbon dioxide in the maturation, dormancy and germination of seeds. - Part I. Proceedings of the Royal Society, Series B, 87, 408-421.

20. Kidd, F. (1914). The controlling influence of carbon dioxide in the maturation, dormancy and germination of seeds. - Part II. Proceedings of the Royal Society, Series B, 87, 609-625.

21. Kidd, F. and West, C. (1917). The controlling influence of carbon dioxide. IV. On the production of secondary dormancy in seeds of Brassica alba following treatment with carbon dioxide, and the relation of this phenomenon to the question of stimuli in growth processes. Annals of Botany, 31, 457-487.

22. Kidd, F. and West, C. (1920). The role of the seed-coat in relation to germination of immature seed. Annals of Botany, 34, 440-446.

23. Klitgard, K. (1972). Report of the working group on the germination of Beta. Brassica and Allium. Proceedings of the International Seed Testing Association, 37, 365-375.

24. Kotowski, F. (1926). Temperature relations to germination of vegetable seeds. Proceedings of the American Society for Horticultural Science, 23, 176-186.

25. Lewis, N.G. (1942). Dormancy in cultivated mustard and the use of potassium nitrate. Proceedings of the Association of Official Seed Analysts, 34, 17-18.

26. MacDonald, I.R. and Hart, J.W. (1981). An inhibitory effect of light on the germination of mustard seed. Annals of Botany, 47, 275-277.

27. Mayer, A.M. and Poljakoff-Mayber, A. (1963). The germination of seeds. Pergamon Press.

28. Moursi, M.A., Rizk, T.Y. and El-Deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

29. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

30. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effects of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

31. Nutile, G.E. (1952). Persistence of dormancy in seed of some cultivated Brassica. Newsletter of the Association of Official Seed Analysts, 26, 6-8.

32. Povilaitis, B. (1956). Dormancy studies with seeds of various weed species. Proceedings of the International Seed Testing Association, 21, 88-111.

33. Renard, H.A. and Clerc, P. (1978). Levée de dormance par les gibberellines chez quatre espèces Impatiens balsamina, Lavandula angustifolia, Brassica rapa et Viola odorata. Seed Science and Technology, 6, 661-677.

34. Rizk, T.Y., Fayed, M.T. and El-Deepah, H.R. (1978). Effect of some promoters on weed seed germination. Research Bulletin, Faculty of Agriculture, Ain Shams University, 818, 30 pp.

35. Shuck, A.L. (1936). A preliminary report on the germination of mustard seed. Proceedings of the Association of Official Seed Analysts, 28, 74-76.

36. Singh, R.D., Tiwari, S.N. and Lal, S.D. (1975). Studies on the temperature and media relations to germination of vegetable seeds. I. Knol Kohl (B. oleracea L. var. caulorapa) and Capsicum (C. annuum L.). Progressive Horticulture, 7, 47-50.

37. Steinbauer, G.P. (1942). Use of potassium nitrate in overcoming dormancy of seed of cultivated mustard. Newsletter of the Association of Official Seed Analysts, 16, 19.

38. Steinbauer, G.P. and Frank, P. (1954). Primary dormancy and germination requirements of seeds of certain Cruciferae. Proceedings of the Association of Official Seed Analysts, 44, 176-181.

39. Steinbauer, G.P., Grigsby, B., Correa, L. and Frank P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-51.

40. Takahashi, N. and Suzuki, Y. (1980). Dormancy and seed germination. In Brassica Crops and wild allies (eds. S. Tsunoda, K. Hinata and C. Gomez-Campo), pp. 323-337. Japan Scientific Societies Press, Tokyo.

41. Takiguti, Y. (1930). [On the germination of Brassica napella seed.] Scientific Bulletin, Faculty of Agriculture, Kyushu Imperial University, 4, 22-36.

42. Taylorson, R.B. (1979). Response of weed seeds to ethylene and related hydrocarbons. Weed Science, 27, 7-10.

43. Thompson, P.A. (1972). Geographical adaptation of seeds. In Seed Ecology (ed. W. Heydecker), pp. 31-58. Butterworths, London.

44. Thurlimann, L. (1928). Germination of Brassicas (vegetable). Proceedings of the Association of Official Seed Analysts, 19, 71-74.

45. Tokumasu, S. (1970). Prolongation of seed dormancy by dry storage in Brassica japonica Sieb. Journal of the Japanese Society of Horticultural Science, 39, 169-177.

46. Tokumasu, S. (1971). Effect of dry and wet storage upon seed dormancy in Cruciferous vegetables. Journal of the Japanese Society of Horticultural Science, 40, 23-28.

47. Tokumasu, S. (1975). Prolonged dormancy in the seeds preserved in harvested fruit of Brassica vegetables. Scientia Horticulturae, 3, 267-273.

48. Tokumasu, S. (1977). Seasonal periodicity of the loss of dormancy of imbibed seeds in Brassica vegetables. Scientia Horticulturae, 6, 101-106.

49. Tokumasu, S., Kamei, S. and Kato, M. (1981). [Effects of storage humidity and germination temperature on germination percentage of Brassica seed.] Japanese Journal of Breeding, 31, 109-120. (From Seed Abstracts, 1982, 5, 1595.)

50. Tokumasu, S., Kato, M. and Yano, F. (1975). [The dormancy of seed as affected by different humidities during storage in Brassica.] Japanese Journal of Breeding, 25, 197-202.

51. Toole, E.H. (1961). The effect of light and other variables on the control of seed

germination. Proceedings of the International Seed Testing Association, 26, 659-673.

52. Toole, E.H. and Toole, V.K. (1939). Germination of some Brassica types at different temperatures. Proceedings of the International Seed Testing Association, 11, 51-56.

53. Went, F.W. (1961). Problems in seed viability and germination. Proceedings of the International Seed Testing Association, 26, 674-685.

54. Wilmar, J.C. and Hellendoorn, M. (1968). Embryo culture of brussels sprout for breeding. Euphytica, 17, 28-37.

55. Witcombe, J.R. and Whittington, W.J. (1972). The effects of selection for reduced dormancy in charlock (Sinapis arvensis). Heredity, 29, 37-49.

CRAMBE

C. abyssinica Hochst. ex R.E. Fries crambe
C. cordifolia Steven

I. Evidence of dormancy

Crambe seeds (C. abyssinica) can show slight dormancy (1), but seeds of C. cordifolia can show considerable dormancy, requiring, for example, more than 2 years after-ripening for dormancy to be lost (7).

II. Germination regimes for non-dormant seeds

C. abyssinica

Constant temperatures: 25°C in dark (6)

III. Unsuccessful dormancy-breaking treatments

C. abyssinica

Alternating temperatures: 20°/30°C (16h/8h) (2)

Pre-chill: 5°C, 5d (1,3)

Potassium nitrate: co-applied, 0.2% (5,6)

Light: 9h/d (1); 100 fc, 8h/d or continuous, either above 28°C or below 25°C (2,6)

IV. Partly-successful dormancy-breaking treatments

C. abyssinica

Constant temperatures: 15°C in light, with or without potassium nitrate, co-applied, 0.2% (1)

Alternating temperatures: 15°/35°C, 20°/35°C (16h/8h), light, 9h/d, with or without potassium nitrate, co-applied, 0.2% (1); 15°/20°C, 15°/25°C, 15°/30°C, 20°/25°C (16h/8h) in light, 9h/d (1)

Light: 8h/d, at 26°-28°C (2); dark, continuous (2,4,6)

V. Successful dormancy-breaking treatments

C. abyssinica

Constant temperatures: 20°C, 25°C in light, 9h/d (1)

Alternating temperatures: 20°/30°C (16h/8h) in light, 9h/d (1,3)

Potassium nitrate: co-applied, 0.2%, at 15°/20°C, 15°/25°C, 15°/30°C, 20°/30°C (16h/8h) in light, 9h/d (1)

Removal of seed covering structures: dehull, germinate at 20°C, dark (3,4)

C. cordifolia

Pre-chill: 0°-2°C, 30-90d (7)

Removal of seed covering structures: testa, germinate at 20°C, 25°C (7)

VI. Comment

Dormancy, though present, is not a major problem for seeds of C. abyssinica; crambe seeds are able to germinate over a wide range of temperatures (1,2). However, attempts to germinate the seeds under unfavourable conditions can induce abnormal germination. For example, seeds germinated on top of filter papers in light produced abnormal seedlings at an alternating temperature regime of 20°/30°C, and at constant temperatures above 28°C, whereas normal seedlings were produced at a constant temperature of 20°C (6). In contrast seeds germinated between papers at 20°C, 25°C and 20°/30°C gave high, normal germination (6).

Two alternative test procedures are suggested. In both cases test the seeds between papers - for example, as in the rolled paper towel test. One alternative is to test at 20°C in light, 9h/d, with potassium nitrate, co-applied, 0.2% (1). The second alternative is to test at 25°C, dark (6). In addition potassium nitrate, co-applied, 0.2%, could be provided as a further stimulus to promote germination in this regime. These treatments are also suggested for seeds of C. cordifolia with the additional treatment of removal of the seed covering structures.

VII. References

1. Bass, L.N., Clark, D.C. and Sayers, R.L. (1965). Germination experiments with crambe seed. Proceedings of the Association of Official Seed Analysts, 55, 47-51.

2. Larsen, A.L. and Skaggs, D.P. (1969). Crambe seed germination response on a thermogradient plate. Proceedings of the Association of Official Seed Analysts, 59, 44-50.

3. Maguire, J.D. and Youngman, V. (1963). Germination of crambe. Newsletter of the Association of Official Seed Analysts, 37, 6-7.

4. Maguire, J.D. and Youngman, V. (1965). Laboratory testing of crambe. Proceedings of the Association of Official Seed Analysts, 55, 169-176.

5. Schroeder, E.M. (1963). Preliminary report on germination tests of Crambe abyssinica. Newsletter of the Association of Official Seed Analysts, 37, 10-11.

6. Skaggs, D.P. and Larsen, A.L. (1969). Recommendation for germination of crambe seed. Proceedings of the Association of Official Seed Analysts, 59, 51-57.

7. Kolomiets, I.A., Parfenova, T.M. and Teplitskaya, E.V. (1968). [The physiology of dormancy and germination of Crambe cordifolia seeds.] Fiziologia Rast, 15, 979-987. (From Horticultural Abstracts, 1969, 39, 1482.)

LEPIDIUM

L. campestre (L.) R. Br.	field cress, field pepperweed
L. densiflorum Schrad. [L. apetalum L.]	
L. draba L.	
L. lasiocarpum Nutt.	
L. muelleri-ferdinandi Thell.	
L. perfoliatum L.	yellowflower pepperweed
L. sativum L.	garden-cress
L. virginicum L.	Virginia peppergrass

I. Evidence of dormancy

Seeds of all Lepidium spp. can show very deep dormancy (1,2,4,9,12,15,17,20,22). After-ripening periods of 3 months for L. campestre and L. sativum (8,9), 4 months for L. perfoliatum (20), 1-2 years for L. lasiocarpum (1) and between 8 months to 3 years for L. virginicum (9) have been reported to be required for dormancy to be lost.

II. Germination regimes for non-dormant seeds

L. muelleri-ferdinandi

Constant temperatures: 16°C (24)

L. sativum

TP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

TP; BP: 15°C: 10d (AOSA)

III. Unsuccessful dormancy-breaking treatments

L. campestre

Constant temperatures: 20°C, 30°C, light or dark (9)

Alternating temperatures: 20°/30°C (16h/8h), light or dark (9)

Light: dark, continuous, at 25°C, 30°C (9); dark, continuous, at 30°C, 35°C (16); red, 0.3×10^{-3} W cm^{-2}, 16 min, at 35°C (16)

L. densiflorum

Light: far red (15)

L. lasiocarpum

Constant temperatures: 20°-35°C, diffuse daylight (1,2)

Alternating temperatures: 20°/30°C (16h/8h), diffuse daylight (1,2)

L. perfoliatum

Constant temperatures: 0.5°C, 10°C, 20°C (20)

Alternating temperatures: 0.5°-20°/-20°C (20)

Pre-chill: -20°C, 30,60, 120d (20)

L. sativum

Urea: co-applied, 0.5% (7)

Potassium nitrate: co-applied, 0.3% (7)

Indoleacetic acid: co-applied, 50, 100 ppm (8)

Kinetin: co-applied, 50, 100 ppm (8)

L. virginicum

Pre-chill: 3°-5°C, 7-14d, germinate at 20°/30°C (17h/7h), dark (14)

Warm stratification: 25°C, 2d, dark, germinate at 15°C, dark (12); 15°C, 2d, dark, germinate at 25°C, dark (12); 20°C, 3d, dark, 40°C, 1-4min, red light, germinate at 20°C, dark (11)

Light: dark, continuous, at 15°-35°C (6,12,14,16); dark, at 15°/25°C (2d/2d) (22); dark, continuous, at 20°/30°C (16h/8h) (6,14,16); red, at 30°C, 35°C (6,15,16); red, at 30°C, with potassium nitrate, co-applied, 0.2% (15); far red (12, 15); far red, 180×10^{-6} W cm^{-2}, 1 min (22)

GA_3: co-applied, 10^{-6}-10^{-4} M (22)

Kinetin: co-applied, 100 ppm (22)

IV. Partly-successful dormancy-breaking treatments

L. campestre

Constant temperatures: 15°-20°C, red light, 0.3×10^{-3} W cm^{-2}, 16 min (16); 20°C (9)

Alternating temperatures: 20°/30°C (16h/8h) (9); 20°/30°C (16h/8h), red light, 0.3×10^{-3} W cm^{-2}, 16 min (16)

Potassium nitrate: co-applied, 0.2% (9)

Scarification: concentrated sulphuric acid (9)

Removal of seed covering structures: (9)

L. draba

Constant temperatures: 0.5°-35°C (21)

Alternating temperatures: 20°/30°C, 20°/35°C (16h/8h) (21)

L. lasiocarpum

Constant temperatures: 10°C, 15°C (1,2)

Alternating temperatures: 10°/20°C, 10°/30°C, 15°/30°C (16h/8h) (1,2)

L. perfoliatum

Alternating temperatures: 15°/20°C (16h/8h) (20); 20°/30°C (16h/8h), light or dark (23)

L. sativum

Thiourea: co-applied, 0.2% (7)

GA_3: co-applied, 50, 100 ppm (8)

L. virginicum

Alternating temperatures: 20°/30°C (16h/8h), light, 50 fc (9)

Light: red, continuous, at 15°C, 20°C, 25°C, 20°/30°C (16h/8h) (6); red, $0.3x10^{-3}$ W cm^{-2}, 16 min, at 15°C, 25°C (12); red, $0.3x10^{-3}$ W cm^{-2}, 16 min, at 15°-25°C, 20°/30°C (15, 16); dark, 2d, at 25°C, germinate at 15°C, red, $0.3x10^{-3}$ W cm^{-2}, 16 min (12); dark, 1d, at 20°C, then red, 10-20s before or after 35°C, 2h (12); dark, 3d, at 20°C, 25°C, 30°C, 50°C, 64 min, red (11); dark, 2d, at 25°C, then red, 1h, 1 J cm^{-2}, germinate at 15°C, dark (15)

Potassium nitrate: co-applied, 0.2% (9,13)

Thiourea: co-applied (13)

Coumarin: co-applied, $2x10^{-5}$ M (15)

Scarification: concentrated sulphuric acid (9)

Removal of seed covering structures: (9)

V. Successful dormancy-breaking treatments

L. campestre

Constant temperatures: 15°C, light, 50 fc (10)

Alternating temperatures: 15°/30°C, light, 50 fc (10)

L. perfoliatum

Constant temperatures: 5°C (20); 15°C, 20°C, dark (23)

L. sativum

Pre-chill (ISTA)

Light (AOSA)

Constant temperatures: 3°-17°C, light, 8h (3,19)

Alternating temperatures: 10°/36°C (16h/8h) (4)

Pre-soak: (18)

L. virginicum

Alternating temperatures: 20°/30°C (16h/8h), light (10)

Potassium nitrate: co-applied, 0.2%, at 15°/25°C (16h/8h), light (5,15,16); co-applied, 0.2%, at 20°/30°C (17h/7h), light (14)

GA_3: co-applied, $2.5x10^{-3}$ M (13,17); co-applied, 10^{-3} M, at 15°/25°C (2d/2d) (22)

Light: dark, 3d, at 20°C, then 40°C, 32-64 min, then red, $0.4x10^{-7}$ mol cm^{-2}, 16 min (11); dark, 2d, at 15°C, red, 1 J cm^{-2}, 1h, germinate at 25°C (15); dark, 1,2d, at 15°C, then red, $0.3x10^{-3}$

W cm , 16 min, germinate at 25°C (12); dark, 1d, at 20°C, then red, 0.3x10 W cm , 16 min, then 35°C, dark, 2h, then germinate at 20°C, dark (13); dark, 2d, at 15°C, then red, $18x10^{-5}$ W cm^{-2}, 1s, germinate at 25°C, dark (22)

VI. Comment

Successful germination of seeds of Lepidium spp. requires light (5,6,11-16,22), low constant temperatures - viz. 5°C for L. perfoliatum (20), 10°-15°C for the other species (1,2,3,10,19) - or alternating temperatures - viz. 10°/30°C (1,2), 10°/36°C (4), 15°/25°C (5,15,16), or 15°/30°C (10). The alternating temperature regime prescribed by ISTA (20°/30°C) is probably less effective than these four alternating temperature regimes in promoting the germination of dormant seeds (1,2,16).

When combined with a suitable alternating temperature regime, potassium nitrate is quite effective in promoting germination (5,13-16). It is therefore suggested that the seeds be tested for germination at alternating temperature regimes of 10°/30°C, 15°/25°C, or 15°/30°C (16h/8h) in diffuse light (see Chapter 6) with 0.2% potassium nitrate co-applied.

VII. References

1. Barton, L.V. (1936). Germination of some desert seeds. Contributions from the Boyce Thompson Institute, 8, 7-11.

2. Barton, L.V. and Crocker, W. (1948). Twenty years of seed research at Boyce Thompson Institute for plant research. Faber and Faber, London.

3. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

4. Gadd, I. (1939). On methods for the elimination of seed dormancy in seed control work. Proceedings of the International Seed Testing Association, 11, 96-118.

5. Hendricks, S.B., Borthwick, H.A. and Downs, R.J. (1956). Pigment conversion in the formative responses of plants to radiation. Proceedings of the National Academy of Sciences of the USA, 42, 19-26.

6. Mayer, A.M. and Poljakoff-Mayber (1963). The germination of seeds. Pergamon Press.

7. Moursi, M.A., Rizk, T.Y. and El-Deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

8. Rizk, T.Y., Fayed, M.T. and El-Deepah, H.R. (1978). Effect of some promoters on weed seed germination. Research Bulletin, Faculty of Agriculture, Ain Shams University, 818, 30 pp.

9. Steinbauer, G.P. and Frank, P. (1954). Primary dormancy and germination requirements of seeds of certain Cruciferae. Proceedings of th e Association of Official Seed Analysts, 44, 176-181.

10. Steinbauer, G.P., Grigsby, B., Correa, L. and Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-52.

11. Taylorson, R.B. and Hendricks, S.B. (1972). Interactions of light and a temperature shift on seed germination. Plant Physiology, 49, 127-130.

12. Toole, E.H. (1959). Effect of light on the germination of seeds. In Photoperiodism and

Related Phenomena in Plants and Animals (ed. R.B. Withrow), pp. 89-99. American Association for the Advancement of Science, Washington, Publication No. 55.

13. Toole, E.H. (1961). The effect of light and other variables on the control of seed germination. Proceedings of the International Seed Testing Association, 26, 659-673.

14. Toole, E.H. and Toole, V.K. (1940). Note on the germination of seeds of Barbarea verna and Lepidium virginicum. Proceedings of the International Seed Testing Association, 12, 32-38.

15. Toole, E.H., Toole, V.K., Borthwick, H.A. and Hendricks, S.B. (1955). Photocontrol of Lepidium seed germination. Plant Physiology, 30, 15-21.

16. Toole, E.H., Toole, V.K., Borthwick, H.A. and Hendricks, S.B. (1955). Interaction of temperature and light in germination of seeds. Plant Physiology, 30, 473-478.

17. Toole, V.K. and Cathey, H.M. (1961). Responses to gibberellin of light-requiring seeds of lettuce and Lepidium virginicum. Plant Physiology, 36, 663-671.

18. Trotter, W.R. (1949). Effect of thiouracil and uracil on the germination of cress seeds. Nature, 164, 63.

19. Wagenvoort, W.A. and Bierhuizen, J.F. (1977). Some aspects of seed germination in vegetables: II. The effect of temperature fluctuation, depth of sowing, seed size and cultivar, on heat sum and minimum temperature for germination. Scientia Horticulturae, 6, 259-270.

20. Young, J.A., Evans, R.A., Gifford, R.O. and Eckert, R.E. Jr. (1970). Germination of three species of Cruciferae. Weed Science, 18, 41-48.

21. Brown, E.O. and Porter, R.H. (1942). The viability and germination of seeds of Convolvulus arvensis L. and other perennial weeds. Iowa Agricultural Experiment Station, Research Bulletin No. 294, 475-504.

22. Evans, R.O. and Fratianne, D.G. (1977). Interactions of applied hormones in the germination of Lepidium virginicum seeds. Ohio l of Science, 77, 236-239.

23. Maguire, J.D. and Overland, A. (1959). Laboratory germination of seeds of weedy and native plants. Washington Agricultural Experiment Station, Circular No. 349.

24. Ross, M.A. (1976). The effects of temperature on germination and early growth of three plant species indigenous to Central Australia. Australian Journal of Ecology, 1, 259-263.

NASTURTIUM

N. microphyllum (Boenn.) Reichb. [N. uniseriatum Howard & Manton; Rorippa microphylla (Boenn.) Hyl.]	brown watercress
N. officinale R. Br. [Rorippa Nasturtium-aquaticum (L.) Hayek; Sisymbrium Nasturtium-aquaticum L.; Radicula Nasturtium-aquaticum Britt. & Rendle]	green watercress
N. palustre DC. [N. islandica; Rorippa islandica (Oeder) Borb.]	marsh cress

I. Evidence of dormancy

The above Nasturtium [Rorippa] spp. show considerable seed dormancy (1-5,7-9,11,12). After-ripening periods are reported to vary from 2 (1) to 8 months (11) at room temperature and 8 months in soil (9). Seeds of N. microphyllum are reported to be more dormant than seeds of N. officinale (8).

II. Germination regimes for non-dormant seeds

N. officinale

BP; TP: 20°/30°C (16h/8h): 14d (ISTA)

TP: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

N. microphyllum

Light: dark (8,9)

Removal of seed covering structures: prick, test in dark (8)

N. officinale

Constant temperatures: 20°C (5)

Light: continuous, at 25°C (2); at 15°C (3); far red, 10 min (2); dark (3)

$GA_{4/7}$: co-applied, 10^{-6}, 10^{-5} M, at 20°C in dark (2)

Cytokinin: co-applied, 10^{-4} -10^{-7} M, at 20°C in dark (2)

N. palustre

Constant temperatures: 23°C in light or dark (7); 20°C, 25°C, 35°C, daylight, 50 fc (11); 20°C, 25°C, dark, 233d (13)

IV. Partly-successful dormancy-breaking treatments

N. microphyllum

Light: dark, 1-4d, then 5 min light (8); continuous daylight (8,9) Removal of seed covering structures: prick, test in light (8)

N. officinale

Constant temperatures: 5°-30°C, daylight (10)

Alternating temperatures: 10°/22°C, 10°/27°C, 10°/32°C, 10°/38°C, 15°/27°C, 15°/32°C, 15°/38°C, 22°/32°C, 22°/38°C (18h/6h) in daylight (10)

Light: continuous, at 20°C (2); red, 10 min, at 15°C (2)

$GA_{4/7}$: co-applied, 10^{-3}, 10^{-4} M, at 20°C, dark (2); co-applied, 10^{-4} M, plus cytokinin, co-applied, 10^{-4} -10^{-7} M, at 20°C, dark (2); co-applied, 10^{-5} M, plus cytokinin, co-applied, 10^{-6}, 10^{-7} M, at 20°C, dark (2)

Hydrogen peroxide: co-applied, 0.25, 0.6% (6)

N. palustre

Alternating temperatures: 20°/30°C (16h/8h), light, 50 fc (11)

Light: dark, at 23°C, 5d, plus GA_3, pre-applied, 24,48h, 5-100 ppm, then light, 1500 lux (7);

dark, at 23°C, 1-7d, then light, 24h, 1500 lux, then dark, at 5°C, 24h, germinate at 23°C in light, 1500 lux (7); dark, at 23°C, 5d, then light, 48,72h, 1500 lux, then dark, at 5°C, 6,12h, germinate at 23°C in light, 1500 lux (7); dark, at 23°C, 5d, then light, 6,12h, 1500 lux, then dark, at 5°C, 6-24h, germinate at 23°C in light, 1500 lux (7)

Potassium nitrate: co-applied, 0.2% (11)

V. Successful dormancy-breaking treatments

N. microphyllum

Light: continuous, 28d (8); dark, 3d, then daylight, 5 min, then dark, 11d, then daylight, 5 min, then dark, 14d (8)

N. officinale

Light (AOSA)

Constant temperatures: 10°C, 15°C, continuous light (2)

Warm stratification: 35°C, light or dark, 28d, germinate at 20°C in light (4)

$GA_{4/7}$: co-applied, 10^{-5} M, plus cytokinin, co-applied, 10^{-4}, 10^{-5} M (2,3)

Pre-dry: 40°C, 2-3d (2,3)

N. palustre

Light: dark, at 23°C, 5d, then light, 24h, 1500 lux, then dark, 6-24h, at 5°C, germinate at 23°C in light, 1500 lux (7)

VI. Comment

Light is an essential requirement for the promotion of germination in dormant seeds of Nasturtium spp. (2-4,7-9). Alternating temperatures are more likely to promote germination than constant temperatures (10,14); a regime of 10°/27°±5°C (18h/6h) has been reported to be better than either 15°/32°C or 22°/32°C (10), suggesting that the former regime or that of 10°/30°C (16h/8h) previously, but no longer, prescribed by ISTA should be used in preference to the 20°/30°C (16h/8h) regime currently prescribed by AOSA and ISTA. Treatment with gibberellin or gibberellin plus cytokinin co-applied (2) in addition to light and the above alternating temperature environment are likely to be satisfactory in promoting the germination of most dormant seeds.

VII. References

1. Austin, R.B. (1966). The growth of watercress (Rorippa nasturtium - aquaticum (L.) Hayek) from seed as affected by the phosphorus nutrition of the parent plant. Plant and Soil, 24, 113-120.

2. Biddington, N.L. and Ling, B. (1983). The germination of watercress (Rorippa nasturtium - aquaticum) seeds. I. The effect of age, storage, temperature, light and hormones on germination. Journal of Horticultural Science, 58, 417-426.

3. Biddington, N.L., Ling, B. and Dearman, A.S. (1982). Dormancy and viability of watercress seeds. National Vegetable Research Station, Wellesbourne, Annual Report, 1981, 32, 97.

4. Biddington, N.L., Ling, B. and Dearman, A.S. (1983). The germination of watercress

(Rorippa nasturtium - aquaticum) seeds. II. The relationship between seed colour and germination. Journal of Horticultural Science, 58, 27-433.

5. Bleasdale, J.K.A. (1958). The propagation of watercress from seed. National Vegetable Research Station, Wellesbourne, Annual Report, 1957, 8, 35.

6. Demoussy, E. (1916). Influence de l'eau oxygénée sur la germination. Comptes Rendus de l'Académie des Sciences (Paris), 162, 435-438.

7. Fujii, T. and Isikawa, S. (1961). Successive processes involved in the germination response of Nasturtium seed. Plant and Cell Physiology, 1, 77-86.

8. Howard, H.W. and Lyon, A.G. (1951). Effect of light on the germination of watercress seeds. Nature, 168, 253-254.

9. Howard, H.W. and Lyon, A.G. (1952). Biological flora of the British Isles, Nasturtium R.Br., Nasturtium officinale R.Br. (Rorippa nasturtium-aquaticum (L.) Hayek). Journal of Ecology, 40, 228-245.

10. Morinaga, T. (1926). Germination of seeds under water. American Journal of Botany, 13, 126-140.

11. Steinbauer, G.P. and Frank, P. (1954). Primary dormancy and germination requirements of seeds of certain Cruciferae. Proceedings of the Association of Official Seed Analysts, 44, 176-181.

12. Watanabe, Y. (1978). [Physiological and ecological studies on upland weeds in Hokkaido.] Research Bulletin of the Hokkaido National Agricultural Experiment Station, 123, 17-77.

13. Mitchell, E. (1926). Germination of seeds of plants native to Dutchess County, New York. Botanical Gazette, 81, 108-112.

14. Thompson, K. and Grime, J.P. (1983). A comparative study of germination responses to diurnally-fluctuating temperatures. Journal of Applied Ecology, 20, 141-156.

RAPHANUS

R. sativus L. [R. Raphanistrum L.] radish

I. Evidence of dormancy

Freshly harvested seeds of cultivated varieties of radish can show dormancy (21). Dry storage for 6 weeks, at room temperature, is required to completely remove dormancy (21). Wild types' seeds can show deep dormancy (10, 12) and require 6 months storage, at 20°C, for dormancy to be lost (10,16).

II. Germination regimes for non-dormant seeds

TP; BP: 20°/30°C (16h/8h); 20°C: 10d (ISTA)

BP: 20°C: 6d (AOSA)

Constant temperatures: 3°-17°C (2); 21°C, dark (1); 23°C, dark (5); 11°-30°C (6); 20°C, light, 16h (23)

III. Unsuccessful dormancy-breaking treatments

Pre-chill: 4°C, 3-18w (10)

Warm stratification: 20°C, 6d, with potassium nitrate, co-applied, 2%, then pre-dry, 20°C, 2d (22)

Wet/dry: 1d/2d, 3 cycles, at 20°C (22)

Abscisic acid: pre-applied, 1h, $4x10^{-5}$ M (7)

Mannitol: co-applied, 0.4, 0.5 M (9)

Ethanol: co-applied, 0.5% (1); co-applied, 0.1-3% (20)

Coumarin: co-applied, 10^{-3} M (1)

Sorbic acid: pre-applied, 24h, 0.04-0. 16% (13)

Light: 3h/d - continuous, 200 lux (5); continuous, at 22°C, 32°C (9); 8h/d, 150 fc (10); continuous fluorescent light at low temperatures (11); 20 fc, at 25°C (14); red (19); far red (19); blue (19)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 5°-35°C (12)

Alternating temperatures: 5°/15°C, 5°/25°C, 5°/35°C, 15°/25°C, 15°/35°C, 25°/35°C (18h/6h), light, 12h/d (12); 5°/15°C, 10°/20°C, 15°/25°C, 20°/30°C (10); 20°/30°C (16h/8h) (16)

Pre-chill: 5°C, 1-4w, in light (12)

Light: dark (9,14,19); daylight, 12h/d (12); incandescent light (19)

GA_3: pre-applied, 1h, $3x10^{-4}$ M (7)

N-6-Benzyladenine: pre-applied, 1h, 10^{-4} M (7)

Indoleacetic acid: co-applied, 10^{-7} -10^{-9} M (8)

Sorbic acid: pre-applied, 24h, 0.0025-0.01% (13)

Naphthaleneacetic acid: pre-applied, 10, 20 ppm (15)

Potassium nitrate: pre-applied, $5x10^{-3}$-$2x10^{-2}$ M (18); co-applied, 0.2% (16)

Removal of seed covering structures: (12,16)

Pre-wash: 21°C, 8-24h, germinate at 5°/15°C, 15°/25°C, 20°/30°C (10)

V. Successful dormancy-breaking treatments

Pre-chill (ISTA)

Constant temperatures: 15°-17°C (3)

Alternating temperatures: 10°/30°C (3); 18°/36°C in light (4); 20°/30°C (16h/8h) in light (17)

Fusicoccin: pre-applied, 1h, $1.5x10^{-5}$ M, germinate at 25°C, dark (7)

Pre-wash: 21°C, 8,24h, germinate at 10°/20°C (10)

VI. Comment

Alternating temperature regimes are required to break radish seed dormancy (3,10,12); alternations of 5°/15°C or 10°/20°C (10) or 5°/25°C (18h/6h) (12) are more effective than the regime 20°/30°C prescribed by the ISTA. Testing in the dark (9,14,19) is promotory. Pre-chill treatments are unsuccessful for very dormant seeds (10,12), whereas gibberellin and fusicoccin are successful in promoting germination for the very dormant seeds (7). It is suggested that the seeds be tested for germination in an alternating temperature regime of 10°/30°C or 10°/20°C (16h/8h) either in dark or in the light regime given in Chapter 6 with 100 ppm GA_3 either co-applied or pre-applied for 1 hour.

VII. References

1. Bernhard, R.A. (1959). Some studies of coumarin and coumarin analogues as germination inhibitors of radish seeds. Botanical Gazette, 121, 17-21.

2. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

3. Eifrig, H. (1957). [New observations on germination tests with various agricultural and vegetable seeds.] Sonderh. Landw. Forsch., 9, 134-139. (From Horticultural Abstracts, 1957, 27, 2466.)

4. Gadd, I. (1939). On methods for the elimination of seed dormancy in seed control work. Proceedings of the International Seed Testing Association, 11, 96-118.

5. Isikawa, S. (1962). Light sensitivity against the germination. III. Studies on various partial process in light sensitive seeds. Japanese Journal of Botany, 18, 105-132.

6. Kotowski, F. (1926). Temperature relations to germination of vegetable seeds. Proceedings of the American Society for Horticultural Science, 23, 176-186.

7. Lado, P., Rasi-Caldogno, F. and Colombo, R. (1974). Promoting effect of fusicoccin on seed germination. Physiologia Plantarum, 31, 149-152.

8. Landau, N. (1940). The effect of hetero-auxin on the germination of some seeds. Palestine Journal of Botany, 1, 409-412.

9. McDonough, W.T. (1967). Dormant and non-dormant seeds: similar germination responses when osmotically inhibited. Nature, 214, 1147-1148.

10. Mekenian, M.R. and Millemsen, R.W. (1975). Germination characteristics of Raphanus raphanistrum. I. Laboratory studies. Bulletin of the Torrey Botanical Club, 102, 243-252.

11. Nakamura, S., Okasako, Y. and Yamada, T. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

12. Piggin, C.M., Reeves, T.G., Brooke, H.D. and Code, G.R. (1978). Germination of wild radish (Raphanus raphanistrum L.). Proceedings of the 1st Conference of the Council of Australian Weed Science Societies, 233-240.

13. Rubtsova, I.D. (1972). [The effect of sorbic acid on seed germination.] Biologicheskii Sbornik, Tambov, 65-68. (From Horticultural Abstracts, 1974, 44, 2490.)

14. Siegel, S.M. (1950). Effects of exposures of seeds to various physical agents. I. Effects of brief exposures to heat and cold on germination and light-sensitivity. Botanical Gazette, 112,

57-70.

15. Singh, K. and Dohare, S.R. (1964). Pre-sowing treatments with naphthaleneacetic acid in relation to growth and development of radish (Raphanus sativus L.). Punjab Horticulture Journal, 4, 160-164. (From Horticultural Abstracts, 1966, 36, 3063.)

16. Steinbauer, G.P. and Frank, P. (1954). Primary dormancy and germination requirements of seeds of certain Cruciferae. Proceedings of the Association of Official Seed Analysts, 44, 176-181.

17. Steinbauer, G.P., Grigsby, B., Correa, L. and Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-51.

18. Sugawara, T. (1955). [Influence of nitrate on the germination of seeds under oxygen supply of various concentrations.] Proceedings of the Crop Science Society of Japan, 23, 295-296. (From Horticultural Abstracts, 1956, 26, 3298.)

19. Swarnkar, P.L. and Kumar, A. (1977). Observations on the influence of red, far red and blue light on the germination of seeds of the radish, Raphanus sativus. Comparative Physiology and Ecology, 2, 109-110.

20. Thiess, D.E. and Lichtenthaler, H.K. (1973). [The inhibition of seed germination by lower primary alcohols.] Naturwissenschaften, 60, 302.

21. Tokumasu, S. (1971). Effect of dry and wet storage upon dormancy in Cruciferous vegetables. Journal of the Japanese Society of Horticultural Science, 40, 23-28.

22. Wickham, B.D. and Nichols, M.A. (1976). Germination studies with "hardened" vegetable seed. New Zealand Journal of Experimental Agriculture, 4, 457-461.

23. Williams, J.T. and Hanson, J. (1974). The potential of vigour testing for long-term seed storage. Journal of Horticultural Science, 49, 395-401.

CHAPTER 33. CUCURBITACEAE

The Cucurbitaceae comprise more than 700 species of herbaceous plants within about 90 genera. They provide vegetables (e.g. Cucumis sativus L., cucumber), fruits (e.g. Cucumis melo L., melon), oils (e.g. Luffa cylindrica (L.) M.J. Roem., smooth loofah, and Telfairia pedata (Sims) Hook., oyster nut), and several other useful products. The fruits are usually pepos (fleshy berry-like structures with a rind and spongy seed interiors), but sometimes a papery bladdery pod. The seeds are usually flat and plate-like. Some care may be required when producing or collecting the seeds: seeds extracted from commercially ripe fruits may be immature. Consequently some storage in the fruit (very roughly until the fruit rinds go yellow) may be beneficial, although too long a period of storage in the fruit results in viviparous germination.

In general seed storage behaviour is orthodox. However, in two species we must correct our previous classification of seed storage behaviour. Telfairia occidentalis (Hook. f.) and Sechium edule Sw. must be classified as having uncertain seed storage behaviour at present. For the time being this will mean treating the seeds as if they are recalcitrant: certainly conventional drying treatments result in seed death. However, we suspect that the species are in fact orthodox and, whilst this has not yet been proved, investigations at Reading are continuing. Any progress in these investigations will be reported in Plant Genetic Resources Newsletter.

SEED DORMANCY AND GERMINATION

The seeds are non-endospermic and germination is epigeal. Dormancy can be a severe problem in some species: it is comparatively easy to induce dormancy by testing the seeds for germination in unfavourable environments. In particular the germination test substrate should not be too moist and only very low intensity light treatments should be applied; in most cases it is probably best to test the seeds for germination in darkness.

Detailed information is provided in this chapter for the genera Citrullus (including synonyms within Colocynthis), Cucumis, Cucurbita, Lagenaria (including synonyms within Cucurbita), Luffa and Momordica. Some advice is provided below for Benincasa and Trichosanthes spp., and for other species it may be possible to develop suitable germination test procedures using the algorithm provided below.

Benincasa hispida (Thunb.) Cogn. wax gourd, white gourd

Light inhibits seed germination (3). Cracking the seed coat (1) and testing at a constant temperature of 30°C in the dark (3) or at 30° to 35°C in moist sand (1) (i.e. a very low light intensity at the seed surface) have been suggested as suitable germination test regimes.

Trichosanthes spp. snake gourd, pointed gourd

Seed germination is promoted if the seeds have been extracted from ripe fruits with 3% hydrochloric acid added to aid extraction (2). Presumably the acid treatment affects the seed coats and in some way reduces their ability to act as a barrier to germination. Neither thiourea, pre-applied, 24h, 0.5% nor GA_3, pre-applied, 24h, 50 ppm, promote the germination of seeds extracted in this way (2). It has been suggested that the seeds be tested for germination in moist sand at 30° to 35°C with removal of the seed coats if full germination does not occur (1). Alternatively try testing at 30°C in the dark.

References

1. Fursa, T.B. and Gvozdeva, Z.V. (1971). [Increasing of seed germination rate in some species of the family Cucurbitaceae Juss.] Trudy Po Prikladnoi Botanike Genetike I Selektsii, 44, 211-214.

2. Mukhopadhyay, G.K. and Chattopadhyay, T.K. (1976). Studies in propagation of pointed gourd (T. dioica, Rox.) - II. Progressive Horticulture, 7, 65-68.

3. Nakamura, S., Okasako, Y. and Yamada, E. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

RBG Kew Wakehurst Place algorithm

The first step of the algorithm is to test the seeds at a constant temperature of 31°C. If this does not result in full germination then test additional samples of seeds at constant temperatures of 26°C and 36°C.

If none of the above constant temperature regimes results in full germination then the second step of the algorithm is to test in an alternating temperature regime of 33°/19°C (12h/12h).

If this alternating temperature regime does not result in full germination then the third step of the algorithm is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test at the most successful regime determined from the results in steps one and two.

No recommendation is made for the provision of light in the algorithm presented here in view of the problems mentioned already.

CITRULLUS

C. colocynthis (L.) Schrad.

C. lanatus (Thunb.) Mansfield [C. vulgaris Schrad.; Colocynthis citrullus (L.) Kuntze] water melon, citron

C. naudinianis

I. Evidence of dormancy

Although seeds of C. lanatus germinate readily when tested under favourable conditions (1,4,5,15), seed dormancy has been reported (12). Seeds of C. colocynthis may show strong dormancy (6,9).

II. Germination regimes for non-dormant seeds

C. lanatus

BP; S: 20°/30°C (16h/8h); 25°C: 14d (ISTA)

C. lanatus var caffer

BP; S: 20°/30°C (16h/8h); 25°C: 14d (AOSA)

AOSA rules emphasise that the germination test substrate should not be too moist. The following method is given by AOSA: the moistened substratum should be pressed against a dry absorbent surface such as a dry paper towel or blotter to remove excess moisture.

C. lanatus var citroides

BP: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

C. colocynthis

Constant temperatures: 15°-40°C in light or dark (6); 20°C in light, 12h/d (9)

Alternating temperatures: 20°/30°C (16h/8h), continuous light or dark, or 2d dark, 15 min light, then dark (6)

Pre-chill: 5°C, 2d (6)

Light: white, 4-24h/d, at 25°C (6); far red (2)

Oxygen: 100%, at 26°C in dark (6); plus nitrogen, 1:4, 2:3, 3:2, 4:1, at 26°C in dark (6)

Nitrogen: 100%, at 26°C in dark (6)

Scarification: concentrated sulphuric acid, 4h (6); hydrochloric acid, 10%, 10 min (6); sodium hydroxide, 10%, 10 min (6)

Acetone: pre-applied, 30 min (6)

Pre-soak: 100°C, 10 min (6)

Pre-dry: 60°C, 2h (6); 90°C, 10 min (6)

Removal of seed covering structures: testa filed off (6); dehull, continuous white light, at 20°C (6); dehull, white light, 12h/d (9); dehull, continuous white light, 21-1400 lux, at 24°C (6); dehull, continuous green light, 670 nm (6); dehull, continuous blue light, 630 nm (6)

C. lanatus

Scarification: file (7); sulphuric acid, 50, 100%, 30,60 min (14); hydrochloric acid, 50, 100%, 30,60 min (14); nitric acid, 50, 100%, 30,60 min (14)

Acetone: pre-applied, 30,60 min (14)

Ethyl alcohol: pre-applied, 30,60 min (14)

GA_3: pre-applied, 52h, 50, 100 ppm (7)

Pre-soak: 2h, then pre-dry, 25°C (11)

Light: continuous, white, 200-300 lux (10); continuous, far re 6.9×10^{-6} mol m^{-2} s^{-1} (8); continuous, far red, after 16h at 30°C in dark (8)

IV. Partly-successful dormancy-breaking treatments

C. colocynthis

Constant temperatures: 20°C, light, 8h/d (9)

Removal of seed covering structures: seed coat, germinate at 20°C in dark (6); seed coat, germinate at 25°-35°C in light (6); seed coat, germinate at 20°C, continuous red light, 530 nm (6); seed coat, germinate at 20°C, continuous yellow light, 450 nm (6); seed coat, germinate at

20°C, continuous violet light, 575 nm (6); seed coat, germinate at 20°C, continuous red blue light, 550 nm (6)

C. lanatus

Constant temperatures: 24°-35°C (3)

Scarification: mechanical at cotyledon end (8); mechanical, germinate at 30°C in dark for 20-32h, then continuous far red light, $6.9x10^{-6}$ mol m^{-2} s^{-1} (8); mechanical, continuous far red light, 3d, then 30°C in dark (8)

Ethephon: pre-applied, 16h, $3.5x10^{-3}$ M (11); $3.5x10^{-3}$ M, plus $GA_{4/7}$, 10^{-3} M, pre-applied, 16h (11)

GA_3: pre-applied, 24h, 25 ppm (13)

Indolebutyric acid: pre-applied, 24h, 25-100 ppm (13)

Boron: pre-applied, 24h, 25-100 ppm (13)

Napthaleneacetic acid: pre-applied, 24h, 25-100 ppm (13)

V. Successful dormancy-breaking treatments

C. colocynthis

Constant temperatures: 20°C in dark (9)

Removal of seed covering structures: seed coat, germinate at 25°C or 30°C in dark (6); seed coat, germinate at 35°C in light or dark (6); seed coat, germinate at 33°C, dark (2); seed coat, germinate at 22°C in red light, 5 min (2)

Scarification: crack seed coat, test in moist sand at 30°-35°C (16)

C. lanatus

Constant temperatures: 30°C, dark (10)

Scarification: mechanical, germinate at 30°C in dark (8); mechanical, germinate at 30°C in red light, $2.7x10^{-7}$ mol m^{-2} s^{-1} (8); crack seed coat, test in moist sand at 30°-35°C (16)

Pre-soak: 12,24h (14).

C. lanatus var caffer

Test at 30°C (AOSA)

C. lanatus var citroides

Pre-soak, test at 30°C (AOSA)

C. naudinianis

Scarification: crack seed coat, test in moist sand at 30°-35°C (16)

VI. Comment

Light is a strong inhibitor of seed germination in Citrullus spp. (2,6,8-10). Consequently it is

recommended that the seeds be tested in the dark. Suitable temperatures are 20°/30°C (16h/8h) (1,4,5) or 30°C (8,10). Scarification or seed coat removal (the latter being preferable) may also be required (2,6,8,16).

VII. References

1. Andersen, A.M. and Justice, O.L. (1948). Germination of seeds of five kinds of Cucurbits at two temperatures. Proceedings of the Association of Official Seed Analysts, 38, 45-47.

2. Bhandari, M.C. and Sen, D.N. (1973). Phytochrome and seed germination in Citrullus colocynthis (Linn.) Schrad. Science and Culture, 39, 458-459.

3. Earhart, D.R., Fuqua, M.C., Tereskovich, G, and Downes, J. (1979). The effect of temperature and moisture levels on germination of the triploid watermelon, Citrullus vulgaris var caffer. HortScience, 14, 123.

4. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

5. Harty, R.L. (1981). Report of the germination committee working group on Cucurbitaceae, 1977-1980. Seed Science and Technology, 9, 141-146.

6. Koller, D., Poljakoff-Mayber, A., Berg, A. and Diskin, T. (1963). Germination-regulating mechanisms in Citrullus colocynthis. American Journal of Botany, 50, 597-603.

7. Lopez, A.P. (1961). Effects of scarification and gibberellic acid on germination of Congo watermelon seed. Journal Agr. Univ. Puerto Rico, 45, 182-187.

8. Loy, J.B. and Evensen, K.B. (1979). Phytochrome regulation of seed germination in a dwarf strain of watermelon. Journal of the American Society of Horticultural Science, 104, 496-499.

9. Mayer, A.M. and Poljakoff-Mayber, A. (1963). The germination of seeds. Pergamon Press, Oxford.

10. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). Effect of light on the germination of vegetable seeds. Journal of the Horticultural Association of Japan, 24, 17-28.

11. Nelson, J.M. and Sharples, G.C. (1980). Effect of growth regulators on germination of cucumber and other cucurbit seeds at suboptimal temperatures. HortScience, 15, 253-254.

12. Odland, M.J. (1937). Observations on dormancy in vegetable seed. Proceedings of the American Society for Horticultural Science, 35, 562-566.

13. Singh, B., Vashistha, R.N. and Singh, K. (1973). Note on the effect of certain chemicals on seed germination of bottle gourd, bitter gourd, watermelon and bhindi. Haryana Journal of Horticultural Sciences, 2, 70-71.

14. Singh, K. and Singh, A. (1969). Effect of various chemicals on the germination of some hard-coated vegetable seeds. Journal of Research, Ludhiana, 6, 801-807.

15. Smith, D.T. and Cooley, A.W. (1973). Wild watermelon emergence and control. Weed Science, 21, 570-573.

16. Fursa, T.B. and Gvozdeva, Z.V. (1971). [Increasing of seed germination rate in some species of the family Cucurbitaceae Juss.] Trudy Po Prikladnoi Botanike Genetike I Selektsii, 44, 211-214.

CUCUMIS

C. anguria L. [C. grossulariaeformis Hort.]	West Indian gherkin
C. melo L.	melon, muskmelon, cantaloupe
C. myriocarpusNaud.	
C. sativus L.	cucumber

I. Evidence of dormancy

In a recent survey seeds of 12 Cucumis spp. - including the cultivated C. anguria, C. melo and C. sativus - were not dormant whereas seeds of four other Cucumis spp. which originated from Africa - C. africanus, C. ficifolius, C. leptodermis and C. myriocarpus - were strongly dormant - particularly C. myriocarpus (11). Despite the results of this survey, however, dormancy can be considerable in freshly harvested seeds of the cultivated species C. anguria (5,6,21), C. melo (10,22) and C. sativus (3,4,23,26). Reports from India indicate that dormancy is present in seeds of cultivated, wild and hybrid cucumbers (23).

Seeds of C. sativus have been reported to lose dormancy when after-ripened for 1 month (22), 1-2 months (26), 6 months (3) and 6-12 months (23), but seeds of C. myriocarpus retain strong dormancy after 1 year (11). It is particularly important to note that in C. sativus at least (and quite possibly other Cucumis spp.) unfavourable germination test conditions - continuous white, far red or blue light - result in the induction of secondary dormancy (15).

II. Germination regimes for non-dormant seeds

C. melo

BP; S: 20°/30°C (16h/8h); 25°C: 8d (ISTA)

BP; S: 20°/30°C (16h/8h): 10d (AOSA)

C. sativus

TP; BP; S: 20°/30°C (16h/8h); 25°C: 8d (ISTA)

BP; S: 20°/30°C (16h/8h): 7d (AOSA)

AOSA rules for the above two species emphasise that the germination test substrate should not be too moist. The following method is given by AOSA: the moistened substratum should be pressed against a dry absorbent surface such as a dry paper towel or blotter to remove excess moisture.

III. Unsuccessful dormancy-breaking treatments

C. anguria

Light: continuous, white, 1.2×10^{-6} W cm^{-2}, germinate at 25°C (5,21); white, at 25°C, 1-3d, then 45°C, 45 min or 165 min, germinate at 25°C, continuous, white (5); 1d dark, 8d white, at 20°C (21); continuous, blue, 1.2×10^{-6} W cm^{-2}, at 25°C (21); continuous, far red, 1.2×10^{-6} W cm^{-2} (5,21); far red/dark, at 25°/5°C (both 12h/12h) (5); far red/white, at 25°/5°C (both 12h/12h) (5)

6-Benzyladenine: co-applied, 10 ppm, at 25°C, continuous white light (6)

GA_3: co-applied, 100, 500, 1000 ppm, at 25°C, continuous far red light (6)

C. melo

Light: continuous (16); infra red (18); blue (18); white, continuous, 200-300 lux (18)

Removal of seed covering structures: plus white light, continuous, at 20°C (16)

C. myriocarpus

Constant temperatures: 15°C, light or dark (11); 20°C, light (11); 20°C, light, continuous (11)

Alternating temperatures: 20°/30°C, 15°/30°C (12h/12h) in light, 20°C, light, continuous (11)

Pre-chill: 3°-5°C, 150d, germinate at 15°C, light (11)

Removal of seed covering structures: (11); nick (11)

Scarification: concentrated sulphuric acid, 30 min (11)

Hydrogen peroxide: pre-applied, 8-24h, 5% (11)

Potassium nitrate: co-applied (11)

GA_3: co-applied, 2-500 ppm (11)

C. sativus

Light: (17); red, at 30°C (23); far red, continuous, $7x10^{-4}$ W cm^{-2} (4,14,15,24,27); far red, continuous, at 30°C (23); far red, 30 min, 1h, $8x10^{-4}$ W cm^{-2} (25); incandescent filament lamp, continuous (15); white, 200-300 lux (18); 720, 730, 740 nm, continuous (4); 400-500 nm, $37x10^{-5}$ W cm^{-2}, continuous (15)

GA_3: (23)

Oxidising agents: (23)

Removal of seed covering structures: (23)

Chloroform: 4h fumigation (26)

Ether: 4h fumigation (26)

Mannitol: co-applied, 0.35, 0.45M (17)

Moisture: excess, in test substrate (10)

IV. Partly-successful dormancy-breaking treatments

C. anguria

Alternating temperatures: 0°/25°C, 15°/25°C, 20°/25°C, 20°/35°C, 25°/35°C (12h/12h), continuous white light (5); 5°/25°C, far red/dark (both 12h/12h) (5)

Light: continuous, white, at 25°C, 1-3d, then 0°C, 55 min or 3h, then 25°C (5); 1-7d white/2-8d dark, at 20°C (21); 3-7d dark/2-6d light, at 20°C (21); 6-18h dark/3d far red, at 25°C (21); 3d far red, then germinate at 25°C in dark (21)

6-Benzyladenine: co-applied, 25, 50, 75, 100 ppm, at 25°C, continuous light (6)

Ethrel: co-applied, 25, 50 ppm, at 25°C, continuous light (6); co-applied, 25, 50, 100 ppm, blue light (6); co-applied, 100 ppm, far red light (6)

GA : co-applied, 50, 100, 250, 500, 2000 ppm, at 25°C, continuous light (6); co-applied, 100,

3
500, 1000 ppm, continuous blue light (6)

C. melo

Pre-soak: 24h, aerate (20)

Potassium nitrate: pre-applied, 24h, 3% (20)

Kinetin: pre-applied, 24h, 10^{-4} M (20)

Removal of seed covering structures: then germinate in light (18)

GA_3: pre-applied, 24h, 10^{-4} M (20)

C. myriocarpus

Constant temperatures: 20°C, 25°C, dark (11)

Alternating temperatures: 10°/30°C, 15°/30°C (12h/12h), light (11); 20°/30°C (12h/12h) (11)

Pre-chill: 3°-5°C, 45d, germinate at 20°C, dark (11); 3°-5°C, 150d, germinate at 15°C, 20°C, 10°/30°C, 20°/30°C (12h/12h), light (11)

C. sativus

Constant temperatures: 30°C (26)

Removal of seed covering structures: (26); then germinate in light (18)

V. Successful dormancy-breaking treatments

C. anguria

Constant temperatures: 25°C, dark (5,21,23)

Alternating temperatures: 5°/25°C, 10°/25°C, 15°/35°C, (12h/12h), light or dark (5)

Light: red, at 25°C (21)

Ethrel: co-applied, 100, 250 ppm (6)

GA_3: co-applied, 1000 ppm (6)

C. melo

Constant temperatures: 25°C (9,20); 30°C (1); 32°C (9)

Alternating temperatures: 20°/33°C (9h/15h) (7); 20°/30°C (16h/8h) (1,9,10)

Removal of seed covering structures: then germinate at 17.5°-20°C in dark (16)

Light: dark (18); dark, at 17.5°-20°C (16); dark, at 25°C (20)

C. myriocarpus

Alternating temperatures: 10°/30°C (12h/12h) (11)

Pre-chill: 3°-5°C, 20,30,45d, germinate at 25°C, dark, or 10°/30°C, 20°/30°C (12h/12h) (11);

15°C, 28d, germinate at 25°C in dark (11)

C. sativus

Constant temperatures: 18°C, dark (15); 20°C, 25°C, dark (4,14,24,25,27); 27°C (13); 30°C (1)

Alternating temperatures: 20°/30°C (16h/8h) (1,2,12); 20°/33°C (9h/15h) (7)

Light: dark (4,14,15,18,24,25,27); red, continuous or 1 min, 6.35×10^{-4} W cm^{-2} (4,15); red, 30 min, 8×10^{-4} W cm^{-2} (25)

Removal of seed covering structures: inner seed coat (3); cut end of cotyledon (26)

Pre-dry: 50°C, 6d (23)

$GA_{4/7}$: pre-applied, 16h, 10^{-3} M, in acetone (19); pre-applied, 16h, 10^{-3} M combined with kinetin, 0.5×10^{-3} M (19); pre-applied, 16h, 10^{-3} M combined with ethephon, 3.5×10^{-3} M (19); pre-applied, 16h, 10^{-3} M combined with kinetin, 0.5×10^{-3} M, and ethephon, 3.5×10^{-3} M (19)

Fusicoccin: pre-applied, 16h, 0.5×10^{-3} M, in acetone (19)

Cucumis spp.

Removal of seed covering structures: then test at 20°C in dark (11)

VI. Comment

Light strongly inhibits the germination of seeds of all Cucumis spp. (4,5,11,14-16,18,21,23-25,27) - even at optimum temperatures for germination (5,21). In C. sativus continuous light at 20°C induces secondary dormancy: if subsequently tested in darkness no germination occurs unless the seeds are exposed to red light for a short period or the germination test temperature is increased (15). Thus, in contrast to previous ISTA recommendations, darkness is essential for testing the germination of seeds of Cucumis spp. Germination, particularly of dormant seeds, is reduced if the germination test substratum is excessively moist (10). Gene bank staff should take care to avoid this problem: see the AOSA advice in the section on germination regimes for non-dormant seeds.

Suggested germination test conditions for seeds of C. melo and C. sativus are 25°C, 30°C or 20°/30°C (16h/8h or possibly 8h/16h) in the dark with a relatively dry germination test substratum. However, this procedure may be inadequate for the most dormant accessions (11,23). It is suggested that brief light treatments (20 minutes irradiance of white light, 0.16 W m^{-2} per day or 30 minutes irradiance of red light, 8×10^{-4} W cm^{-2}) may be a suitable further stimulus to promote the germination of the more dormant seeds (e.g. 25), and it is further suggested that the seed coats be removed from the ungerminated seeds after 10 to 14 days in test and that these seeds be tested for at least one further week. For the more dormant Cucumis spp. pre-chilling treatments at 3° to 5°C for between 20 and 45 days are suggested. Subsequent alternating temperature regimes of 25°/5°C, 25°/10°C, or 15°/35°C (12h/12h) for seeds of C. anguria, and 10°/30°C (12h/12h) for seeds of C. myriocarpus can be particularly effective in promoting germination (5, 12).

VII. References

1. Andersen, A.M. and Justice, O.L. (1948). Germination of seeds of five kinds of cucurbits at two temperatures. Proceedings of the Association of Official Seed Analysts, 38, 45-47.

2. Davis, G.N. (1938). Germination of cucurbit seed in sand. Proceedings of the Association of

Official Seed Analysts, 30, 133-135.

3. Dzhein, B.P. and Kaloshina, Z.M. (1971). [On seed dormancy in Indian varieties of Cucumber.] Izvestiya Timiryazevskoi sel'skokhozyaistvennoi akademii, 3, 15-19. (From Horticultural Abstracts, 1972, 42, 1130.)

4. Eisenstadt, F.A. and Mancinelli, A.L. (1974). Phytochrome and seed germination. VI. Phytochrome and temperature interaction in the control of cucumber seed germination. Plant Physiology, 53, 114-117.

5. Felippe, G.M. (1980). Germination of the light-sensitive seeds of Cucumis anguria and Rumex obtusifolius: effects of temperature. New Phytologist, 84, 439-448.

6. Felippe, G.M. and Litjens, M.H.M. (1979). Effect of growth regulators on overcoming the light inhibition on germination of Cucumis anguria L. Biologia Plantarum, 21, 407-411.

7. Harrington, G.R. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

8. Harty, R.L. (1978). Report of the germination committee working group on Cucurbitaceae, 1974-1977. Seed Science and Technology, 6 187-192.

9. Harty, R.L. (1981). Report of the germination committee working group on Cucurbitaceae, 1977-1980. Seed Science and Technology, 9, 141-146.

10. Heit, C.E. (1948). Report of subcommittee on dormancy in seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

11. Heit, C., Robinson, R.W. and Mishanec, W. (1978). Dormancy of Cucumis species. Cucurbit Genetics Co-operative, 1, 36-37.

12. Kamra, S.K. (1964). Determination of germinability of cucumber seed with X-ray contrast method. Proceedings of the International Seed Testing Association, 29, 519-534.

13. MacNeil, M.M. and Hall, B. (1982). Factors affecting the germination of cucumber seed (Cucumis sativus L.). The Plantsman, 3, 251-253.

14. Mancinelli, A.L. and Tolkowsky, A. (1968). Phytochrome and seed germination. V. Changes in phytochrome content during the germination of cucumber seeds. Plant Physiology, 43, 489-494.

15. Mancinelli, A.L., Lindquist, P., Anderson, O.R. and Eisenstadt, F.A. (1975). Photocontrol of seed germination. VII. Preliminary observation on the development of the photosynthetic apparatus in light-inhibited seeds of Cucumber (Cucumis sativus). Bulletin of the Torrey Botanical Club, 102, 93-99.

16. Mayer, A.M. and Poljakoff-Mayber, A. (1963). The germination of seeds. Pergamon, Oxford.

17. McDonough, W.T. (1967). Dormant and non-dormant seeds: similar germination reponses when osmotically inhibited. Nature, 214, 1147-1148.

18. Nakamura, S., Okasado, Y. and Yamada, Y. (1955). Effect of light on the germination of vegetable seeds. Journal of the Horticultural Association of Japan, 24, 17-28.

19. Nelson, J.M. and Sharples, G.C. (1980). Effect of growth regulators on germination of cucumber and other cucurbit seeds at sub-optimal temperatures. HortScience, 15, 253-254.

20. Nerson, H., Cantliffe, D.L., Paris, H.S. and Karchi, Z. (1982). Low-temperature germination of birdsnest-type muskmelon. HortScience, 17, 639-640.

21. Noronha, A., Vicente, M. and Felippe, G.M. (1978). Photocontrol of germination of Cucumis anguria. Biologia Plantarum, 20, 281-286.

22. Odland, M.J. (1937). Observations on dormancy in vegetable seed. Proceedings of the American Society for Horticultural Science, 35, 562-566.

23. Shifriss, O. and George, W.L. (1965). Delayed germination and flowering in cucumber. Nature, 206, 424-425.

24. Spruit, C.J.P. and Mancinelli, A.L. (1969). Phytochrome in cucumber seed. Planta, 88, 303-310.

25. Suzuki, Y. and Takahashi, N. (1969). Red and far red reversible photoreactions on seed germination of Cucumis sativa. Plant and Cell Physiology, 10, 475-479.

26. Watts, V.M. (1938). Rest period in cucumber seeds. Proceedings of the American Society for Horticultural Science, 36, 652-654.

27. Yaniv, Z., Mancinelli, A.L. and Smith, P. (1967). Phytochrome and seed germination. III. Action of prolonged far red irradiation on the germination of tomato and cucumber seeds. Plant Physiology, 42, 1479-1482.

CUCURBITA

C. foetidissima HBK	buffalo gourd
C. maxima Duchesne squashes	pumpkin, autumn and winter
C. moschata Duchesne ex Poir. squashes	pumpkin, cushaw, winter crookneck
C. pepo L. [C. verrucosa L.; C. polymorpha Duchesne] squash	field pumpkin, marrow, butternut
C. Texana Gray	Texas gourd

I. Evidence of dormancy

Seeds extracted from mature fruits of Cucurbita spp. can show dormancy (6,10,13-16). After-ripening periods of 1 to 2 months (6) and 5 months (10) are reported to be required to remove dormancy from seeds of C. pepo and C. maxima respectively. The storage of ripe fruits of C. foetidissima, C. pepo and C. Texana for 3 weeks or so at room temperature prior to seed extraction can also result in loss in dormancy (10,14-16), but immature fruits may require 2 to 3 months storage before dormancy is lost (13).

II. Germination regimes for non-dormant seeds

C. foetidissima

Constant temperatures: 30°C, dark (14-16)

C. maxima

BP; S: 20°/30°C (16h/8h); 25°C: 8d (ISTA)

BP; S: 20°/30°C (16h/8h); 7d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (5)

C. moschata

BP; S: 20°/30°C (16h/8h); 25°C: 8d (ISTA)

BP; S: 20°/30°C (16h/8h); 7d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (5)

C. pepo

BP; S: 20°/30°C (16h/8h); 25°C: 8d (ISTA)

BP; S: 20°/30°C (16h/8h): 7d (AOSA)

Constant temperatures: 30°C (12)

Alternating temperatures: 20°/30°C (16h/8h) (5)

C. Texana

Constant temperatures: 30°C, dark (14-16)

Cucurbita spp.

TP;BP: 20°/30°C (16h/8h): 7-10d (AOSA)

AOSA rules for Cucurbita spp. emphasise that the germination test substrate should not be too moist. The following method is given by AOSA: the moistened substratum should be pressed against a dry absorbent surface such as a dry paper towel of blotter to remove excess moisture.

III. Unsuccessful dormancy-breaking treatments

C. maxima

Light: (11)

C. moschata

Constant temperatures: 20°C, 24°C, light (7)

Light: (8)

C. pepo

Constant temperatures: 18°C (2); 20°C (6)

Oxygen: low partial pressure (6)

Light: (2,8); infra red, blue, green (8); far red, 4.2×10^{-4} W cm^{-2}, 15 min, 1,2d, at 20°C, 25°C (2)

Removal of seed covering structures: puncture (6)

C. Texana

Constant temperatures: 10°C, 40°C (16)

Light: 8,16,24h/d (16)

IV. Partly-successful dormancy-breaking treatments

C. foetidissima

Constant temperatures: 30°C (14); 29°C (15)

C. moschata

Sodium thiosulphate: pre-applied, 2-6h, 10^{-3} M (9)

C. pepo

Constant temperatures: 30°C (6); 25°C in light (2)

Alternating temperatures: 12°/30°C (15h/9h) (6)

Oxygen: high partial pressure (6)

Pre-dry: 37°C, 7d (6)

C. Texana

Constant temperatures: 30°C in light, 16h/d (16)

V. Successful dormancy-breaking treatments

C. moschata

Constant temperatures: 20°C, 24°C, dark (7); 30°C, dark (8)

Alternating temperatures: 20°/33°C (9h/15h) (4)

C. pepo

Constant temperatures: 25°C in dark (2); 30°C, 100d (6)

Removal of seed covering structures: naked caryopses, germinate at 30°C in dark (6)

Pre-dry: 37°C, 14-30d (6)

Hydrogen peroxide: pre-applied, 16h, 5%, germinate at 30°C in dark, 30d (6)

Cucurbita spp.

Clip radicle end of seeds (AOSA)

VI. Comment

The storage of fruits at room temperature for several weeks prior to seed extraction is not recommended as a dormancy-breaking treatment. However, where immature fruits have been collected, a short period of fruit storage can enable seed development to continue in the fruit (13-16) and may, therefore, be worthwhile in such circumstances, but prolonged fruit storage, e.g. 6 months (3), results in viviparous germination.

Light can inhibit the germination of seeds of all Cucurbita spp. (2,7,8,11,16). Moreover, not only can light severely reduce the percentage of seeds germinating, but it can also result in a high proportion of abnormal seedlings (7). It is suggested that germination in the dark at an alternating temperature of 20°/30°C (16h/8h) (1,4,5) or (if this alternating temperature regime cannot be provided) at a constant temperature of 30°C (1,6,12) will be satisfactory for seeds of C. maxima and C. moschata. For very dormant seeds of C. pepo - and possibly C. foetidissima and C. Texana - however, the removal of the seed covering structures may also be necessary (6).

VII. References

1. Andersen, A.M. and Justice, O.L. (1948). Germination of seeds of five kinds of Cucurbits at two temperatures. Proceedings of the Association of Official Seed Analysts, 38, 45-47.

2. Boisard, J. and Malcoste, R. (1970). Le photocontrôle de la germination des graines de Cucurbita pepo L. (Courge) et le site de photosensibilité. Comptes Rendus de l'Académie de Science, Paris, 271, 304-307.

3. De, R.N. (1955). Peculiar germination of Cucurbita pepo DC. Science and Culture (Calcutta), 20, 342.

4. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

5. Harty, R.L. (1981). Report of the germination committee working group on Cucurbitaceae, 1977-1980. Seed Science and Technology, 9, 141-146.

6. Ingold, M. (1960). Contribution à l'étude de la germination des semences d'Allium cepa L. et Cucurbita pepo L. Proceedings of the International Seed Testing Association, 25, 787-799.

7. Kasahara, Y. and Akita, S. (1951). The abnormality in the germination of squash, Cucurbita moschata Duch., caused by light. Ohara Inst. Landwirtsch. Forsch. Ber., 9, 451-453.

8. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

9. Nandi, A. and Mallik, S.C. (1982). Effect of pre-soaking seeds of pumpkin (Cucurbita moschata Poir) in different chemicals on seedling emergence and growth. Indian Agriculturist, 26, 65-68.

10. Odland, M.J. (1937). Observations on dormancy in vegetable seed. Proceedings of the American Society for Horticultural Science, 35, 562-566.

11. Ogawara, K. and Watanabe, I. (1953). [Studies on the germination of squash seeds. 1. On the relation of light to the germination of Cucurbita maxima Duch. seeds.] Bull. Hort. Jap. Soc., 22, 45-49. (From Horticultural Abstracts, 1954, 24, 444.)

12. Solanki, S.S., Singh, R.D. and Yadav, J.P. (1980). Studies on the temperature and media relations and coefficient velocity of germination of vegetable seeds. II. Summer squash (Cucurbita pepo L.) and okra (Abelmoschus esculentus (L.) Moench.). Progressive Horticulture, 12, 59-65.

13. Young, R.E. (1949). The effect of maturity and storage on germination of butternut squash seed. Proceedings of the American Society for Horticultural Science, 53, 345-346.

14. Ba-Amer, M.A. and Bemis, W.P. (1968). Fruit and seed development in Cucurbita foetidissima. Economic Botany, 22, 297-299.

15. Costa, J.T.A. and Bemis, W.P. (1972). After-ripening effect on seed germination and viability of Cucurbita foetidissima seed. Turrialba, 22, 207-209.

16. Oliver, L.R., Harrison, S.A. and McClelland, M. (1983). Germination of Texas gourd (Cucurbita Texana) and its control in soybeans (Glycine max). Weed Science, 31, 700-706.

LAGENARIA

L. siceraria (Molina) Standl. [L. vulgaris Ser.; L. leucantha (Duchesne) Rusby; bottle gourd Cucurbita siceraria Molina; Cucurbita leucantha Duchesne]

I. Evidence of dormancy

Seeds of L. siceraria can show dormancy and require 2.5 months after-ripening for dormancy to be lost (2).

II. Germination regimes for non-dormant seeds

L. siceraria

BP; S: 20°/30°C (16h/8h): 14d (ISTA)

Constant temperatures: 20°C (5); 25°C (2); 30°C, moist sand (5,7)

Alternating temperatures: 20°/30°C (16h/8h) (5)

Lagenaria spp.

TP; BP: 20°/30°C (16h/8h): 7-10d (AOSA)

III. Unsuccessful dormancy-breaking treatments

L. siceraria

Scarification: sulphuric acid, 50, 100%, 30,60 min (4); concentrated nitric acid, 30,60 min (4); hydrochloric acid, 50%, 30,60 min (4)

Alcohol: pre-applied, 30,60 min (4)

Urea: pre-applied, 6-24h, 150-250 ppm (3)

IV. Partly-successful dormancy-breaking treatments

L. siceraria

Pre-soak: 6-24h (3)

Acetone: pre-applied, 30,60 min (4)

Succinic acid: pre-applied, 12h, 600 ppm (3)

GA_3: pre-applied, 24h, 25-100 ppm (6)

Indolebutyric acid: pre-applied, 24h, 25-100ppm (6)

Boron: pre-applied, 24h, 25-100 ppm (6)

Napthaleneacetic acid: pre-applied, 24h, 25-100 ppm (6)

V. Successful dormancy-breaking treatments

L. siceraria

Constant temperatures: 30°-35°C, scarified seeds in moist sand (1)

Pre-dry: 40°C, 75°C, 3-9d (2)

Lagenaria spp.

Clip radicle end of seeds (AOSA)

VI. Comment

On the basis of the evidence available at present it is suggested that the seeds be tested at a constant temperature of 30°C or an alternating temperature of 20°/30°C (16h/8h or possibly 8h/16h) in the dark. In addition it may be necessary for the seed covering structures to be removed or clipped.

VII. References

1. Fursa, T.B. and Gvozdeva, Z.V. (1971). [Increasing of seed germination rate in some species of the family Cucurbitaceae Juss.] Trudy Po Prikladnoi Botanike, Genetike i selektsii, 44, 211-214.

2. Nakamura, H., Yamada, H. and Shimizu, T. (1978). Several factors affecting the heat resistance of the seeds of bottle gourd, Lagenaria siceraria. Bulletin of the Vegetable and Ornamental Crops Research Station, Japan, Series A, 4, 119-147.

3. Singh, A. and Singh, H.N. (1976). A note on effect of pre-soaking of seeds in nitrogen and succinic acid solution on germination and seedling growth in bottle gourd. Progressive Horticulture, 7, 35-38.

4. Singh, K. and Singh, A. (1969). Effect of various chemicals on the germination of some hard-coated vegetable seed. Journal of Research, Ludhiana, 6, 801-807.

5. Singh, P.V., Singh, M.B. and Khanna, A.N. (1973). Germination studies on bottle gourd (Lagenaria siceraria). Seed Research, 1, 63-66.

6. Singh, B., Vashistha, R.N. and Singh, K. (1973). Note on the effect of certain chemicals on seed germination of bottle gourd, bitter gourd, watermelon and bhindi. Haryana Journal of Horticultural Sciences, 2, 70-71.

7. Solanki, S.S. and Seth, J.N. (1981). A note on the physical factors affecting coefficient of germination of bottle gourd (Lagenaria siceraria (Mol.) Standl.) and methi (Trigonella foenum-graecum) seeds. Progressive Horticulture, 13, 57-60.

LUFFA

L. acutangula (L.) Roxb.	angled loofah
L. cylindrica (L.) Roem. [L. aegyptiaca Mill.; L. aegyptica (L.) Roem.]	smooth loofah, rag gourd

I. Evidence of dormancy

Alternating temperatures and light can promote seed germination in L. cylindrica (2). Consequently it is assumed that seed dormancy can prevent germination.

II. Germination regimes for non-dormant seeds

L. acutangula

BP; S: 30°C: 14d (ISTA)

L. cylindrica

BP; S: 20°/30°C (16h/8h); 30°C: 14d (ISTA)

Constant temperatures: 21°C, 31°C (2)

III. Unsuccessful dormancy-breaking treatments

L. acutangula

Acetone: pre-applied, 30,60 min (3)

Ethyl alcohol: pre-applied, 30,60 min (3)

Scarification: sulphuric acid, 50, 100%, 30,60 min (3);

hydrochloric acid, 50, 100%, 30,60 min (3); nitric acid, 50, 100%, 30,60 min (3)

L. cylindrica

Constant temperatures: 15°C, 31°C, 41°C (2)

Alternating temperatures: 21°/41°C, 31°/41°C (12h/12h) (2)

IV. Partly-successful dormancy-breaking treatments

L. cylindrica

Alternating temperatures: 21°/31°C (12h/12h) (2)

Light: white, 12h, 2500-5000 lux (2)

V. Successful dormancy-breaking treatments

L. acutangula

Constant temperatures: 30°-35°C, scarified seeds, crack seed coat, moist sand (1)

Pre-soak: 12,24h (3)

L. cylindrica

Constant temperatures: 30°-35°C, scarified seeds, crack seed coat, moist sand (1)

VI. Comment

In contrast to other members of the Cucurbitaceae the germination of seeds of L. cylindrica is reported to be promoted by light (2). On the basis of the limited evidence available it is suggested that the seeds be tested in an alternating temperature environment of 20°/30°C (12h/12h) with light for 12 hours per day (2). Nevertheless, the apparent requirement for light is not proven: the germination of seeds when tested buried in sand is promoted (1); and seeds buried in soil germinate equally as well as those in a laboratory test in the presence of light (2). Finally, the response of germination to constant temperatures appears to differ between seed lots (1,2); hence the suggestion to test the seeds in an alternating temperature regime.

VII. References

1. Fursa, T.B. and Gvozdeva, Z.V. (1971). [Increasing of seed germination rate in some species of the family Cucurbitaceae Juss.] Trudy Po Prikladnoi Botanike, Genetike i selektsii, 44, 211-214.

2. Okusanya, O.T. (1978). The effects of light and temperature on germination and growth of Luffa aegyptica. Physiologia Plantarum, 44, 429-433.

3. Singh, K. and Singh, A. (1969). Effect of various chemicals on the germination of some hard-coated vegetable seeds. Journal of Research, Ludhiana, 6, 801-807.

MOMORDICA

M. balsamina L. balsam-apple
M. charantia L. balsam-pear, bitter gourd

I. Evidence of dormancy

Considerable dormancy is shown by the seeds of M. charantia (A). Light inhibits germination (1) and the problem of seed dormancy appears to be similar to most other members of the Cucurbitaceae.

II. Germination regimes for non-dormant seeds

M. balsamina

Constant temperatures: 30°C, dark (1)

M. charantia

BP; S: 20°/30°C (16h/8h); 30°C: 14d (ISTA)

III. Unsuccessful dormancy-breaking treatments

M. balsamina

Light: (1)

M. charantia

Scarification: concentrated sulphuric acid, 30,60 min (3); concentrated nitric acid, 30,60 min (3); concentrated hydrochloric acid, 30,60 min (3)

Alcohol: pre-applied, 30,60 min (3)

Acetone: pre-applied, 30,60 min (3)

IV. Partly-successful dormancy-breaking treatments

M. charantia

Pre-wash: 12,24h (3)

GA_3: pre-applied, 24h, 75, 100 ppm (2)

Indolebutyric acid: pre-applied, 24h, 25-100 ppm (2)

Napthaleneacetic acid: pre-applied, 24h, 25-100 ppm (2)

Boron: pre-applied, 24h, 25-100 ppm (2) 2,4-Dichlorophenoxyacetic acid: pre-applied, 24h, 25-100 ppm (2)

V. Successful dormancy-breaking treatments

M. balsamina

Constant temperatures: 30°C, dark (1)

M. charantia

GA_3: pre-applied, 24h, 25, 50 ppm (2)

VI. Comment

It is suggested that the seeds be tested in the dark at either 30°C or, preferably, 20°/30°C (16h/8h). In addition we have found it necessary to remove the seed covering structures (endocarp and testa) and to test for more than 56 days (A). Pre-treatment with gibberellins may also be promotory (2).

VII. References

1. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

2. Singh, B., Vashistha, R.N. and Singh, K. (1973). Note on the effect of certain chemicals on seed germination of bottle gourd, bitter gourd, watermelon and bhindi. Haryana Journal of Horticultural Sciences, 2, 70-71.

3. Singh, K. and Singh, A. (1969). Effect of various chemicals on the germination of some hard-coated vegetable seeds. Journal of Research, Ludhiana, 6, 801-807.

CHAPTER 34. DIOSCOREACEAE

The Dioscoreaceae are usually considered to comprise about 650 species of herbaceous plants within ten genera. They possess rhizomes and tubers which are edible (e.g. Dioscorea alata L., greater yam). Do not confuse the term yam with other species, e.g. sweet potato (see Chapter 31) and the aroids (see Chapter 24). The seeds are winged, show orthodox seed storage characteristics and can exhibit considerable dormancy. Detailed information is provided in this chapter for the genus Dioscorea only.

DIOSCOREA

D. bulbifera L.	potato yam, aerial yam, air potato
D. cayenensis Lam.	yellow yam, yellow Guinea yam, attoto yam
D. composita	
D. deltoidea	
D. floribunda	
D. hirtifloria Benth.	
D. japonica Thunb.	
D. nipponica Makino	
D. odoratissima Pax.	
D. opposita Thunb. [D. batatas Decne.]	Chinese yam, cinnamon yam
D. praehensilis Benth.	
D. preussii Pax.	wild yam
D. quinqueloba Thunb.	
D. rotundata Poir.	white yam, white Guinea yam, Guinea yam, 8-months yam
D. septemloba Thunb.	
D. tenuipes Franch. & Sav.	
D. tokoro Makino	
D. villosa L.	

I. Evidence of dormancy

Seed dormancy is a major problem in Dioscorea spp., sufficient in the past to have prevented improvement by breeding (7,8). Between 3 and 5 months after-ripening removes dormancy from most seeds, at least in West African collections (7,8,13,14). However, in Japanese collections 6 months after-ripening was only partly effective in removing dormancy (6). Within the species D. japonica, D. nipponica, D. quinqueloba, D. septemloba, D. tenuipes and D. tokoro, seeds of D. septemloba are the most dormant and seeds of D. nipponica the least dormant (5), although of course there is considerable variation in the degree of dormancy between lots within each species (5). A further problem is the absence of embryos in some seeds due to poor pollination and/or fertilization (7).

II. Germination regimes for non-dormant seeds

D. bulbifera

Constant temperatures: 30°C, 21d (3)

D. cayenensis

Calcium hypochlorite: pre-applied, 20 min, 10% (2)

D. composita

Constant temperatures: 30°C, diffuse light, 20d (9)

D. deltoidea

Constant temperatures: 25°C, diffuse light, 20d (9)

D. floribunda

Constant temperatures: 30°C, diffuse light, 20d (9)

D. hirtifloria

Constant temperatures: 30°C, 21d (3)

D. nipponica

Constant temperatures: 20°-29°C, 70d (5)

D. odoratissima

Constant temperatures: 30°C, 21d (3)

D. opposita

Constant temperatures: 25°C, light, 4000 lux, 16h/d, 30d (10)

D. praehensilis, D. preussii

Constant temperatures: 30°C, 21d (3)

D. rotundata

Constant temperatures: 25°-30°C (8, 13, 14)

Calcium hypochlorite: pre-applied, 20 min, 10% (2)

D. tenuipes

Constant temperatures: 20°C (4)

D. tokoro

Constant temperatures: 20°C, dark, 30d (6); 25°C (4)

III. Unsuccessful dormancy-breaking treatments

D. japonica

Constant temperatures: 11°C, 17°C, 23°C, 26°C, 29°C, 70d (5)

Pre-chill: 0°C, 65d, germinate at 26°C, 29°C, 85d (5)

D. preussii

Pre-chill: 5°C, 1,3w (1)

Pre-wash: 2d (1)

GA_3: co-applied, 500 ppm (1)

D. quinqueloba

Constant temperatures: 17°-29°C, 70d (5)

Pre-chill: 5°C, 65d, germinate at 29°C, 85d (5); 5°C, 20,35d, germinate at 20°C, 65-80d (5)

D. septemloba

Constant temperatures: 11°-29°C, 70d (5)

Pre-chill: 0°C, 65d, germinate at 29°C, 85d (5)

D. tenuipes

Constant temperatures: 23°-29°C (5)

Pre-chill: 5°C, 50d, germinate at 29°C (5)

Light: fluorescent, 1500 lux (4); green, 1500 lux (4); far red, 1500 lux (4); blue, 1500 lux (4)

D. tokoro

Constant temperatures: 26°-29°C, 70d (5)

Pre-chill: 5°C, 50d, germinate at 29°C, 50d (5); 5°C, 30,50d, germinate at 25°C in light (4)

Light: fluorescent, 1500 lux (4); green, 1500 lux (4); far red, 1500 lux (4); blue, 1500 lux (4)

GA_3: co-applied, $3x10^{-7}$ -$3x10^{-4}$ M, at 25°C (4)

D. villosa

Constant temperatures: 20°-25°C, light or dark, 30d (12)

IV. Partly-successful dormancy-breaking treatments

D. japonica

Constant temperatures: 14°C, 20°C, 70d (5)

Pre-chill: -2° to 2°C, 100d, germinate at 20°C, dark, 40d (5); 0°C, 65d, germinate at 11°-23°C, dark, 85d (5); 5°C, 30,80d, germinate at 20°C, dark, 20-70d (5)

D. opposita

Constant temperatures: 25°C, light, 4000 lux, 16h/d, 30d (10)

Pre-chill: 0°C, 4,8w, germinate at 25°C in light, 4000 lux, 16h/d, 30d (10)

GA_3: co-applied, 1, 30 ppm, at 25°C in light, 4000 lux, 16h/d, 30d (10)

D. preussi

Pre-soak: 45°C, 2d (1)

Potassium nitrate: co-applied, 10^{-2} M (1)

D. quinqueloba

Constant temperatures: 11°-14°C, 70d (5).

Pre-chill: 2°-11°C, 75d, germinate at 20°C, dark, 15d, (5); 5°C, 65d, germinate at 11°C, 17°C, 20°C, 23°C, dark, 85d (5); 5°C, 50,80d, germinate at 20°C, dark, 20-50d (5)

D. septemloba

Pre-chill: 0°-2°C, 65d, germinate at 20°C, dark, 60d (5); 0°C, 65d, germinate at 11°-20°C, dark, 85d (5); 0°C, 30,60d, germinate at 20°C, dark, 40-70d (5)

D. tenuipes

Constant temperatures: 11°-20°C, 70d (5)

Pre-chill: 5°C, 20d, germinate at 20°C, in dark or light (4); -2° to 17°C, 30d, germinate at 20°C, dark, 30d (5); 5°C, 35d, germinate at 11°C, 14°C, 17°C, 20°C, 26°C, dark, 50d (5); 5°C, 20,35d, germinate at 20°C, dark, 65-80d (5)

Light: red, 1500 lux (4)

GA_3: co-applied, $3x10^{-7}$ -$3x10^{-4}$ M, at 20°C in dark (4)

D. tokoro

Constant temperatures: 11°-23°C, 70d (5)

Pre-chill: 2°-17°C, 20d, germinate at 20°C, dark, 15d (5); 5°C, 35d, germinate at 26°C, dark, 50d (5); 5°C, 20-50d, germinate at 20°C, dark, 50-80d (5); 5°C, 30,50d, germinate at 25°C, dark (4); 5°C, 80d, germinate at 25°C, light (4)

Light: red, 1500 lux (4)

D. villosa

Removal of seed covering structures: cut through to endosperm, germinate at 20°-25°C, dark, 30d (12)

V. Successful dormancy-breaking treatments

D. opposita

Removal of seed covering structures: excise embryo, culture on Murashige and Skoog's medium with sucrose, 20 g/l, and agar, 7 g/l, at 25°C in light, 4000 lux, 16h/d (10)

D. quinqueloba

Pre-chill: 5°C, 65d, germinate at 14°C, dark, 85d (5)

D. rotundata

Removal of seed covering structures: clip wings (11)

D. tenuipes

Pre-chill: 5°C, 35d, germinate at 23°C, dark, 50d (5); 5°C, 50,80d, germinate at 20°C, dark, 20-50d (5); 5°C, 50,80d, germinate at 20°C in dark or light (4)

D. tokoro

Pre-chill: 5°C, 30d, germinate at 20°C, dark, 11d (6); 5°C, 35d, germinate at 11°-23°C, dark, 50d (5); 5°C, 80d, germinate at 20°C, dark, 20d (5); 5°C, 80d, germinate at 25°C, dark (4)

VI. Comment

Seed germination in Dioscorea spp. is inhibited - or at best not promoted - by white light (4,5) and/or high germination test temperatures, 23°-40°C (5,6). The response of germination to gibberellins appears complicated; germination is both promoted and inhibited by treatment with gibberellins (4,10). It appears that gibberellins may mitigate against the inhibition of germination by inhibitory light sources (and thus in these circumstances appear to be promotory), but that in the dark or in red light their action is generally inhibitory (4). Consequently it is suggested that treatment with gibberellins is not worthwhile.

Pre-chill treatments are particularly effective in removing dormancy (4,5,10). Optimum pre-chill treatment temperatures and subsequent germination test temperatures, however, vary between species and possibly between seed lots within a species (5). Nevertheless the following treatment is suggested for breaking dormancy and promoting germination in dormant seeds of Dioscorea spp.: pre-chill at 5°C for 30 days, then transfer to a germination test regime of 14°-17°C for 21-28 days; repeat this cycle (as many times as necessary) for those dormant (fresh) seeds which fail to germinate; apply red light throughout both the pre-chill and germination test treatments; if this is not possible, test the seeds in the dark. In addition it may be worthwhile to clip or prick the fresh seeds which fall to germinate after the first pre-chill germination cycle, since such treatments can be promotory over a wide range of species (11,12). Non-dormant seed lots can be tested for germination at 20°C, again either in red light or dark. Micro-organism contamination may be a problem in germination tests (2), particularly if these extend over considerable periods. Pre-treatment in a 10% calcium hypochlorite solution for 20 minutes has been reported to minimise such problems (2).

In ecological terms the suggested treatment of dormant accessions from tropical regions at low temperatures (pre-chill) may appear surprising. Certainly the evidence that such treatments are effective is limited to Japanese collections (4,5), and thus more work is needed. Nevertheless, within the Japanese collections accessions from the warmer climates had the lower optimum pre-chilling temperatures and benefitted most from longer pre-chill treatments (5,6). Moreover, evidence in other species (rice, for example) demonstrates that pre-chill treatments can be effective in breaking dormancy in accessions collected from regions where such low temperatures would never be experienced in the soil.

VII. References

1. Anonymous (1972). Yam seed germination. In IITA 1971 Annual Report, p. 106.

2. Anonymous (1976). Root and tuber improvement program. In IITA 1975 Annual Report, pp. 127-151.

3. Lawton, J.R.S. and Lawton, J.R. (1967). The morphology of the dormant embryo and young seedlings of five species of Dioscorea from Nigeria. Proceedings of the Linnean Society London, 178, 153-159.

4. Okagami, N. and Kawai, M. (1977). Dormancy in Dioscorea: gibberellin-induced inhibition or promotion in seed germination of D. tokoro and D. tenuipes in relation to light quality. Plant

Physiology, 60, 360-362.

5. Okagami, N. and Kawai, M. (1982). Dormancy in Dioscorea: differences of temperature responses in seed germination among six Japanese species. Botanical Magazine Tokyo, 95, 155-166.

6. Okagami, N. and Kawai, M. (1983). Dormancy in Dioscorea: range, duration and timing of high-temperature treatment in germination inhibition of D. tokoro seeds. Plant and Cell Physiology, 24, 509-515.

7. Sadik, S. (1975). Root and tuber physiology with emphasis on yam improvement. In Proceedings of Physiology Program Formulation Workshop, pp. 35-40. IITA, Ibadan, Nigeria.

8. Sadik, S. (1976). Methods for seed germination and seedling establishment of yam, Dioscorea rotunda Poir. Technical Report No. 1, pp. 1-7, IITA, Ibadan, Nigeria.

9. Tyagi, M.C., Singh, M.P. and Bammi, R.K. (1973). The effect of temperature on seed germination in Dioscorea species. Planta Medica, 24, 294-296.

10. Yakuwa, T., Harada, T., Kasai, N. and Araki, H. (1981). Studies on the botanical characteristics of the genus Dioscorea. II. On the formation and germination of the seed in Chinese yam (c.v. Nagaimo). Journal of the Faculty of Agriculture, Hokkaido University, 60, 220-228.

11. Doko, E.V. (1973). Sexuality and reproductive biology in Ghanaian yam (Dioscorea species) cultivars. 1. Preliminary studies. Proceedings of the 3rd International Symposium of Tropical Root Crops, pp. 2-9, Ibadan, Nigeria.

12. Mitchell, E. (1926). Germination of seeds of plants native to Dutchess County, New York. Botanical Gazette, 81, 108-112.

13. Sadik, S. and Okereke, O.U. (1975). Flowering, pollen grain germination, fruiting, seed germination and seedling development of white yam, Dioscorea rotundata Poir. Annals of Botany, 39, 597-604.

14. Sadik, S. and Okereke, O. (1975). A new approach to improvement of yam Dioscorea rotundata. Nature, 254, 134-135.

CHAPTER 35. EBENACEAE

The Ebenaceae comprise 300 species of trees and shrubs with very hard wood within about six genera, one of which provides edible fruits (Diospyros virginiana L., common persimmon). The fruit is generally a leathery or fleshy indehiscent berry with between one and ten seeds.

Seed storage behaviour was originally thought to be recalcitrant, but there is now considerable doubt about this classification in at least some species. Seed dormancy can be considerable, much of the problem being due to the seed covering structures. Detailed information is provided in this chapter for the genus Diospyros only. This information includes details of storage behaviour as well as dormancy and germination.

DIOSPYROS

D. digyna	
D. discolor Willd.	
D. kaki L. f. [D. chinensis Blume]	kaki, Japanese persimmon
D. lotus L.	date-plum
D. marmorata R.N. Parker	marblewood
D. melaxoxylon	tendu
D. texana Scheele	Texas persimmon
D. virginiana L.	American persimmon, common persimmon

I. Evidence of dormancy

Seeds of D. lotus and D. texana are reported to germinate readily (5,11). However, elsewhere seeds of D. melaxoxylon, D. kaki, D. virginiana, D. digyna, D. discolor, D. melaxoxylon and D. lotus are reported to show considerable dormancy (1-3,6,8,10,14,15). The seed covering structures are reported to be the main cause of dormancy, by hindering the absorption of water by the seeds (2,8). Prolonged pre-chilling is reported to induce dormancy in seeds of D. texana (13).

II. Germination regimes for non-dormant seeds

D. kaki

Constant temperatures: 30°C, 30d (10)

D. texana

Constant temperatures: 20°-30°C (5)

Alternating temperatures: 20°/30°C (16h/8h) (5)

D. virginiana

Alternating temperatures: 20°/30°C (night/day), 125d (2); 20°/30°C (16h/8h), light, fluorescent, 160 fc, 8h/d (9)

III. Unsuccessful dormancy-breaking treatments

D. marmorata

Pre-soak: 24,48,96h (15); hot water, 24,48,96h (15)

D. texana

Constant temperatures: 15°C, 40°C (5)

Alternating temperatures: 10°/20°C, 15°/25°C (16h/8h) (5)

Pre-chill: 5°C, 30-120d (13)

Scarification: concentrated sulphuric acid, 30-120 min (13); concentrated sulphuric acid, 30 min, then pre-chill, 5°C, 30-120d (13)

Light: $2x10^{-4}$ E m^{-2} s^{-1}, 8h/d (5); dark (5)

D. virginiana

Scarification: acetone, 1h (3); concentrated sulphuric acid, 2h (3); concentrated sulphuric acid, 2h, then pre-chill, 3°-10°C, 2m (3)

IV. Partly-successful dormancy-breaking treatments

D. marmorata

Warm stratification: in fruit, room temperature, 10-15d, then extract seeds (15)

D. melaxoxylon

Pre-soak: 24h (1)

D. texana

Constant temperatures: 17.5°C, 32.5°C, 35°C (5)

Alternating temperatures: 25°/35°C (16h/8h) (5)

D. virginiana

Pre-chill: 3°-10°C, 6-18w (3)

Scarification: acetone, 1h, then pre-chill, 3°-10°C, 2m (3)

Pre-soak: 24h (9)

GA_3: pre-applied, 24h, 100-400 ppm (9)

V. Successful dormancy-breaking treatments

D. digyna, D. discolor

Warm stratification: (14)

Hydrogen peroxide: pre-applied, 20 min, 3%, then pre-soak, 24h (14)

D. kaki

Pre-chill: 3°-5°C, 60d (6); 10°C, 120d (8); 0°-7°C, 1-6m (14)

Pre-soak: 2d, then pre-chill, 10°C, 120d (8); 30°C, 24h, then remove part of seed coat around radicle (10)

Scarification: file or abrade seed coat (14)

D. lotus

Pre-chill: 3°-5°C, 90d (6); 10°C, 120d (8)

Pre-soak: 2d, then pre-chill, 10°C, 120d (8)

Succinic acid: pre-applied, 48h, 0.1% (12)

D. texana

Constant temperatures: 20°-30°C (5)

Alternating temperatures: 20°/30°C (16h/8h) (5)

Pre-chill: 0°-7°C, 1-6m (14)

Scarification: file or abrade seed coat (14)

D. virginiana

Pre-chill: 90d (4); 3°-5°C, 60,90d (6); 10°C, 60-90d (8); 10°C, 60-90d, germinate at 20°/30°C, 60d (2); 0°-7°C, 1-6m (14)

Removal of seed covering structures: part of seed coat over radicle (2); file or abrade seed coat (14)

VI. Comment

Seeds of Diospyros spp. can be tested for germination on top of moist paper (5,9,10). Light has no apparent effect on germination, whereas germination is very sensitive to temperature (5). The seeds will germinate at constant temperatures between 20° and 30°C, but beyond this range germination is reduced considerably (5). An alternating temperature regime of 20°/30°C (16h/8h) is reported to be satisfactory for germination (2,5,9). In general pre-chilling the seeds breaks dormancy (2-4,6,8,14), except in one report where pre-chilling for between 30 and 120 days induced dormancy in seeds of D. texana (13).

It is suggested that intact seeds of Diospyros spp. be tested for germination on or between moist papers at 20°/30°C (16h/8h) for at least 4 months (2). However, filing the seed coat or removing the seed covering structures should enable this germination test duration to be reduced.

In the past D. dignya, D. discolor, some varieties of D. kaki, and D. virginiana have been reported to show recalcitrant seed storage behaviour (4,7,10,14). However, there is now strong evidence that seeds of D. texana and D. virginiana show orthodox seed storage behaviour (2,5,14). For example, seeds of D. virginiana can be dried to between 3 and 8% moisture content and stored safely at -20°C (14). Similarly seeds of some varieties of D. kaki can be dried to 15% moisture content and stored safely at 0°C, -5°C, -20°C, and -196°C (10).

VII. References

1. Ahmad, A. (1962). A preliminary report on germination of tendu seed. Pakistan Journal of Forestry, 12, 138-144.

2. Anonymous (1948). Diospyros virginiana L. Common persimmon. In Woody-plant Seed Manual, U.S.D.A. Forest Service, Miscellaneous Publication No. 654.

3. Aroreira, J.S. (1962). [On dormancy and seed storage of some fruit trees.] Experientiae, 2, 541-609.

4. Darrow, G.M. (1975). Minor temperate fruits. In Advances in fruit breeding (eds. J. Janick and J.N. Moore), pp. 269-284. Purdue University Press, Indiana.

5. Everitt, J.H. (1984). Germination of Texas persimmon seed. Journal of Range Management, 37, 189-192.

6. Gasanov, Z.M. (1968). [Investigations on new rootstocks for oriental persimmons.] Subtropicheskie Kul'tury, 5, 104-110. (From Horticultural Abstracts, 1969, 39, 5674.)

7. Harrington, J.F. (1972). Seed storage and longevity. In Seed Biology, Vol. III (ed. T.T. Kozlowski), pp. 145-245, Academic Press, New York.

8. Hartmann, H.T. and Kester, D.E. (1975). Plant Propagation: principles and practices, 567 pp. Prentice Hall Inc., New Jersey.

9. Hogg, N.J. and Orr, H.P. (1969). Effect of gibberellic acid on germination of seeds from selected native trees and shrubs. Plant Propagator, 15, 8-9.

10. Kotobuki, K. (1978). Seed storage of Japanese persimmon, Diospyros kaki. In Long term preservation of favourable germplasm in arboreal crops, pp. 36-42, Ibaraki-ken, Japan.

11. Massover, B.L. and Kirillova, G.L. (1973). [Rational methods for propagating persimmon in the Gissarskaya valley of Tadzhikistan.] Subtropicheskie Kul'tury, 6, 61-65. (From Horticultural Abstracts, 1975, 45, 1308.)

12. Mkervali, V.G. (1977). [Studies on the problem of artificial immunization of laurel and persimmon.] Subtropicheskie Kul'tury, 4, 93-95. (From Horticultural Abstracts, 1978, 48, 9430.)

13. Plowman, R.D. and Munson, R.H. (1983). Seed dormancy in Texas persimon (Diospyros texana Scheele). Plant Propagator, 29, 14-15.

14. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

15. Sharma, S.K. (1977). A further contribution to the study of nursery behaviour of Diospyros marmorata R.N. Parker (marblewood). Indian Forester, 103, 542-549.

CHAPTER 36. ERICACEAE

The Ericaceae comprise roughly 1500 species of trees and shrubs within about 70 genera, several of which provide edible fruits (e.g. Vaccinium oxycoccus L., European cranberry). Some authorities classify Vaccinium and related genera as Vacciniaceae. The fruits are either capsules, berries or drupes. Seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

B.R. Atwater classifies seed morphology as endospermic seeds with axillary linear embryos (see Table 17.1, Chapter 17). Dormancy can be a severe problem: sometimes very long pre-chill treatments may be given, but light and GA_3 are alternative treatments. Detailed information is provided for the genus Vaccinium in this chapter (including synonyms within Cyanococcus and Oxycoccus). A limited number of additional recommendations for germination test conditions and dormancy-breaking treatments are summarised in Table 36.1. The algorithm below may be helpful in developing suitable seed germination test regimes for other species.

RBG Kew Wakehurst Place algorithm

The first step of the algorithm is to test the seeds at constant temperatures of 16°C and 26°C with light applied for 12h/d in each case.

If this is not successful in promoting full germination then the second step of the algorithm is to pre-chill the seeds at 2° to 6°C for 8w and then test for germination at the constant temperature which resulted in the greater proportion of seeds germinating in step one.

TABLE 36.1 Summary of germination test recommendations for species within the Ericaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Arbutus unedo L.			30d	pre-chill, 1°-5°C, 30-60d	Riley
Calluna vulgaris (L.) Hull		20°C	28d	potassium nitrate, 0.2%	Atwater
Gaultheria shallon			30d	pre-chill, 1°-5°C, 30-60d	Riley
Gaylussacia spp.			30d	pre-soak, 24h, then pre-chill/warm stratification, cycle	Riley
Rhododendron ferrugineum L.		20°C	28d	GA, 800ppm	Atwater
Rhododendron spp.	TP; BP	20°/30°C; 25°C	21d	light	AOSA

VACCINIUM

V. angustifolium Ait. [V. pensylvanicum var angustifolium Gray]	lowbush blueberry
V. ashei Reade	rabbiteye blueberry
V. canadense Kalm	
V. corymbosum L. [Cyanococcus corymbosus Rydb.]	highbush or swamp blueberry
V. macrocarpon Ait. [Oxycoccus macrocarpus Pers.]	large or American cranberry

V. oxycoccus L. [Oxycoccus palustris Pers.; Oxycoccus oxycoccus MacM.] small or European cranberry
V. uliginosum
V. vitis-idaea L. var minus Lodd. foxberry, mountain cranberry

I. Evidence of dormancy

Seed dormancy in Vaccinium spp. is often manifested by low, slow and erratic germination, as observed in V. angustifolium (1), V. ashei (5,16), V. canadense (3), V. corymbosum (7,16,19), V. macrocarpon (9,10,18) and V. oxycoccus (18). In particular, seed dormancy in V. macrocarpon has been the subject of much attention (9-12). Although seeds of Vaccinium spp. have often been stored moist (at freezing or sub-freezing temperatures) for short-term storage (1,5,8,13,17,20), the seeds are orthodox and can thus be stored satisfactorily at a low moisture content at low temperatures for long-term storage (7).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

V. ashei

Constant temperatures: 16°C in fluorescent and incandescent light, 73 x 10^{-6} mol m^{-2} s^{-1}, 12h/d (4)

Pre-chill: 4°C, dark, 1-4w (4)

GA_3: pre-applied, 24,48h, 100-1000 ppm, to seeds pre-chilled in fruits, 4°C, 75d (5)

$GA_{4/7}$: pre-applied, 48h, 100 ppm (4); pre-applied, 24,48h, 100-1000 ppm, to seeds pre-chilled in fruits, 4°C, 75d (5); pre-applied, 48h, 100 ppm plus 100 ppm benzyladenine (4)

V. canadense

Pre-chill: over winter (3)

V. corymbosum

Alternating temperatures: 0°/21°C (4d/4d), 16,32,64d, then 17°C (21)

Pre-chill: 0°C, 8-64d (21); 2°C, 3m (20); 2°C, 3m, then pre-soak, 48h (20); 2°C, 3m, then sodium hypochlorite, pre-applied, 4-48h, 1% (20)

Light: dark, at 18°/21°-27°C (night/day) (19); dark, at 17°C, 24°C (21); white, continuous, at 17°C, 24°C (21); white, 24h, then dark, at 24°C (21); red, continuous, at 17°C, 24°C (21); red, 24h, then dark, at 24°C (21)

Potassium nitrate: co-applied, 0.2% (21)

Coumarin: co-applied, 10^{-5} M (21)

V. macrocarpon

Pre-chill: 3°-4°C, 8w (18); 3°-4°C, 8w, in fruit (18)

Light: dark, at 25°C (9,10,11)

GA_3: pre-applied, 20h, 300 ppm, germinate at 25°C in dark (10)

Scarification: concentrated sulphuric acid, 5-20 min, germinate at 25°C in dark (10)

Removal of seed covering structures: prick (12); seed coat (18); seedcoat, then pre-chill, 3°-4°C, 8w (18)

V. oxycoccus

Pre-chill: 3°-4°C, 8w (18); 3°-4°C, 8w, in fruit (18)

Removal of seed covering structures: seed coat (18); seed coat, then pre-chill, 3°-4°C, 8w (18)

V. uliginosum pH: 3-9 (6)

V. vitis-idaea var minus

Pre-chill: -2°C, 37d (14)

Scarification: sulphuric acid, 0.1 N, 5 min (14)

IV. Partly-successful dormancy-breaking treatments

V. angustifolium

Constant temperatures: 19°-21°C (1); 21°C, in soil (15)

Alternating temperatures: 16°/18°C, dark/light (16h/8h) (2)

V. ashei

Alternating temperatures: 18°/21°-27°C, dark/light (night/day) (16)

Pre-chill: 100d (7)

Light: $18x10^{-6}$ mol m^{-2} s^{-1}, 30-60 min/d, at 16°C (4)

Pre-soak: 48h, germinate at 16°C in light, 1h/d, $18x10^{-6}$ mol m^{-2} s^{-1}

V. canadense

Light: test in soil (3)

V. corymbosum

Alternating temperatures: 10°/25°-32°C (night/day) in light or dark (21); 18°/21°-27°C, dark/light (night/day) (16,19); 0°/21°C (4d/4d), 16-64d, then 10°/25°-32°C in light (21)

Pre-chill: 100d (7)

Light: white, continuous, at 10°/25°-32°C (21); white, 24h, then dark, at 17°C or 10°/25°-32°C (21); red, continuous, at 10°/25°-32°C (21); red, 24h, then dark, at 17°C or 10°/25°-32°C (21)

V. macrocarpon

Pre-chill: 3°-5°C, 3m, in fruit, germinate at 15.5°C (8)

Light: white, 1000 fc, 1,3d, then dark, at 25°C (9); white, continuous, 4.3, 43 lux, at 25°C (11);

white, 4300 lux, 1,3d, then dark, at 25°C (10)

GA_3: pre-applied, 20h, 300 ppm, germinate at 25°C in light, 1,3d, 4300 lux, then dark (10); pre-applied, 20h, 10-100 ppm, germinate at 25°C in dark (11)

Scarification: concentrated sulphuric acid, 25-35 min, germinate at 25°C in dark (10); concentrated sulphuric acid, 5-35 min, then GA_3, pre-applied, 20h, 300 ppm, germinate at 25°C in dark (10) Removal of seed covering structures: prick, germinate at 25°C in dark (11); prick, then GA_3, pre-applied, 20h, 10-1000 ppm, germinate at 25°C in dark (11); prick, then kinetin, pre-applied, 20h, 10 ppm, germinate at 25°C in dark (11) Ether: pre-applied, 20 min, 100% atmosphere (18)

V. oxycoccus

Ether: pre-applied, 20 min, 100% atmosphere (18)

V. uliginosum

Pre-chill: 3m, germinate at 25°C in light (6)

Light: (6)

V. vitis-idaea var minus

Constant temperatures: 21°C in light, in soil (14)

V. Successful dormancy-breaking treatments

V. macrocarpon

Pre-chill: 3°-5°C, 3m, in fruit, germinate at 21°C, 26.5°C (8); 2°C, 3m, in fruit, germinate at 18°/24°C, dark/light (night/day) (13); 1°C, 5°C, 30-60d, germinate at room temperature in diffuse light (17)

Light: 1000 fc, 5-20d, then dark, at 25°C (9); 4300 lux, 5-20d, then dark, at 25°C (10); continuous, 430, 4300 lux, at 25°C (11); 4300 lux, 10d, then dark, at 25°C (12); diffuse, at room temperature (17)

GA_3: pre-applied, 20h, 300, 500 ppm, germinate at 25°C in light (10, 11); pre-applied, 20h, 1000 ppm, germinate at 25°C in dark (11)

Removal of seed covering structures: seed coat, germinate on agar (18); prick, germinate at 25°C in light, continuous, 4300 lux (11)

V. oxycoccus

Removal of seed covering structures: seed coat, germinate on agar (18)

VI. Comment

Light is an essential component of any successful dormancy-breaking regime for seeds of Vaccinium spp. (2,4,6,9-12,17,19,21), but high light intensities may reduce germination - for example, $73x10^{-6}$ mol m^{-2} s^{-1} applied for 12 hours per day (4). The second essential component is an alternating temperature regime (16,19,21). These two factors account for the observations that seeds of Vaccinium spp. germinate readily in glasshouse sowings (2,15,17) - despite the reports of low, slow and erratic germination already noted.

Although 3 month pre-chill treatments had been thought to be effective in promoting loss in dormancy and had consequently been advocated as suitable short-term storage environments (5,7,8,13,20), they have subsequently been shown to be either comparatively ineffective in breaking dormancy (3,18,21) - for example, only increasing germination by 0-8% (17) - or damaging to germination (4,14,20). Chemical treatments - such as potassium nitrate (21), $GA_{4/7}$ (4,5) or coumarin (21) - are generally ineffective in breaking dormancy, but GA_3 can, apparently, substitute for the effect of light when pre-applied for 20 hours at 1000 ppm (11).

From limited investigations it would appear that 18°/27°C is a suitable alternating temperature germination test regime (16,19). This is sufficiently close to the widely used laboratory germination test regime of 20°/30°C (16h/8h) to suggest that seeds of Vaccinium spp. be tested for germination on top of filter paper in this regime with light applied in the manner described in Chapter 6. For the most dormant seeds, a 20 hour pre-treatment with 500 ppm GA_3 is satisfactory (10,11) and is suggested as an additional treatment.

VII. References

1. Aalders, L.E. and Hall, I.V. (1975). Germination of lowbush blueberry seeds stored dry and in fruit at different temperatures. HortScience, 10, 525-526.

2. Aalders, L.E. and Hall, I.V. (1979). Germination of lowbush blueberry seeds as affected by sizing, planting cover, storage, and pelleting. Canadian Journal of Plant Science, 59, 527-530.

3. Adams, J. (1927). The germination of the seeds of some plants with fleshy fruits. American Journal of Botany, 14, 415-428.

4. Austin, M.E. and Cundiff, J.S. (1978). Factors affecting rabbiteye blueberry seed germination. Journal of the American Society for Horticultural Science, 103, 530-533.

5. Ballington, J.R., Galletta, G.J. and Pharr, D.M. (1976). Gibberellin effects on rabbiteye blueberry seed germination. HortScience, 11, 410-411.

6. Butkene, Z.P. and Butkus, V.F. (1980). [Biological and biochemical characteristics of blueberry. 2. Effect of the duration and method of stratification, time of seed harvest, temperature, light, substrate and medium pH on seed germination.] Trudy Akad. Nauk. Lit. SSR, C, 3, 45-55. (From Seed Abstracts, 1981, 4, 1197.)

7. Darrow, G.M. and Scott, D.H. (1954). Longevity of blueberry seed in cool storage. Proceedings of the American Society for Horticultural Science, 63, 271.

8. Demoranville, I.E. (1974). The effect of temperature on germination of cranberry seeds. Cranberries, 38, 7.

9. Devlin, R.M. and Karczmarczyk, S.J. (1974). The effect of light on cranberry seed germination. Cranberries, 38, 3, 16.

10. Devlin, R.M. and Karczmarczyk, S.J. (1975). Effect of light and gibberellic acid on the germination of 'Early Black' cranberry seeds. Horticultural Research, 15, 19-22.

11. Devlin, R.M. and Karczmarczyk, S.J. (1977). Influence of light and growth regulators on cranberry seed dormancy. Journal of Horticultural Science, 52, 283-288.

12. Devlin, R.M., Karczmarczyk, S.J. and Deubert, K.H. (1976). The influence of abscisic acid in cranberry seed dormancy. HortScience, 11, 412-413.

13. Greidanus, T., Rigby, J.B.F. and Dana, M.N. (1971). Seed germination in cranberry. Cranberries, 36, 13.

14. Hall, I.V. and Beil, C.E. (1970). Seed germination, pollination, and growth of Vaccinium vitis-idaea var. minus Lodd. Canadian Journal of Plant Science, 50, 731-732.

15. Hall, I.V., Forsyth, F.R., Aalders, L.E. and Jackson, L.P. (1972). Physiology of the lowbush blueberry. Economic Botany, 26, 68-73.

16. Hellman, E.W. and Moore, J.N. (1983). Effect of genetic relationship to pollinizer on fruit, seed, and seedling parameters in highbush and rabbiteye blueberries. Journal of the American Society for Horticultural Science, 108, 401-405.

17. Paglietta, R. (1977). Cranberry seed storage trials. Acta Horticulturae, 61, 211-215.

18. Rayner, M.C. (1929). The biology of fungus infection in the genus Vaccinium. Annals of Botany, 43, 56-70.

19. Scott, D.H. and Draper, A.D. (1967). Light in relation to seed germination of blueberries, strawberries and Rubus. HortScience, 2, 107-108.

20. Scott, D.H. and Ink, D.P. (1955). Treatments to hasten the emergence of seedlings of blueberry and strawberry. Proceedings of the American Society for Horticultural Science, 66, 237-242.

21. Stushnoff, C. and Hough, L.F. (1968). Response of blueberry seed germination to temperature, light, potassium nitrate and coumarin. Proceedings of the American Society for Horticultural Science, 93, 260-266.

CHAPTER 37. EUPHORBIACEAE

The Euphorbiaceae comprise over 8000 species of herbaceous plants, shrubs and trees within about 280 genera which provide edible roots (e.g. Manihot esculenta Crantz, cassava), oils (e.g. Ricinus communis L., castor), edible fruits (e.g. Antidesma bunius (L.) Spreng., bignay), medicinal products (e.g. Croton tiglium L.) and other products (e.g. Hevea brasiliensis Muell.-Arg., para rubber). The fruits are usually dehiscent capsules, but sometimes dehiscent and berry- or drupe-like.

Seed storage behaviour in Euphorbiaceae is generally orthodox. For example, Euphorbia spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank. There are, however, important exceptions. For example, seeds of Hevea brasiliensis are recalcitrant.

SEED DORMANCY AND GERMINATION

Seeds can be either endospermic or non-endospermic; germination can be either epigeal or hypogeal. Dormancy can be a severe problem; many, but certainly not all the problems in germinating the seeds can be overcome by removing part of the seed coat and the surrounding structures. B.R. Atwater classifies seed morphology in some species as non-endospermic seeds with axile foliar embryos within woody seed coats and an inner semi-permeable layer (see Table 17.2, Chapter 17). Detailed information on seed dormancy and germination is provided in this chapter for the genera Aleurites, Hevea, Manihot and Ricinus. Table 37.1 provides a limited number of recommended germination test procedures and dormancy-breaking treatments for several other species. In addition the algorithm below may be helpful in developing suitable germination test procedures for species where no advice is provided in this chapter.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 16°C and 26°C with light applied for 12h/d in each case.

If this is not successful in promoting full germination then the second step in the algorithm is to chip the seeds and test at whichever temperature gave the greater germination in the first step.

If this is not successful in promoting full germination then the third step of the algorithm is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test in the most promotory regime determined in steps one and two. (This may include a requirement to chip the seeds.)

TABLE 37.1 Summary of germination test recommendations for species within the Euphorbiaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Baccaurea motleyana Muell. Arg.	S	25°-30°C	35d	light, continuous	CHML
Euphorbia heterophylla L.	TP	20°/30°C	16d	light	AOSA
Euphorbia marginata Pursh	TP	20°C	14d	excise embryos or pre-chill, 5°C, 2m	AOSA

ALEURITES

A. Fordii Hemsl.	China wood-oil-tree, tung-oil-tree
A. moluccana Willd. [A. triloba Forst.]	candlenut, candle-berry-tree, varnish-tree
A. montana (Lour.) Wils.	tung, mu-tree

I. Evidence of dormancy

Seeds of Aleurites spp. tolerate desiccation to at least 3% moisture content (5,9), and can be stored dry (7) at low temperatures (3). Thus despite reports that they are short-lived (3) and the preference of many growers to store the seeds moist in cool conditions, seeds of Aleurites spp. show orthodox, not recalcitrant, seed storage characteristics. Seed germination is slow, erratic and low and thus problematic for growers (1,4,6,7,8). The seed coat is reported to be the cause of delayed germination (1,8,9).

II. Germination regimes for non-dormant seeds

A. Fordii

Constant temperatures: 24°-32°C (7)

III. Unsuccessful dormancy-breaking treatments

A. Fordii

Pre-soak: fruit, 48h (5)

Removal of seed covering structures: crack seed coat (5); crack seed coat, then store in oxygen, 100%, 18d (5)

Scarification: emery wheel (5)

Tergetol: pre-applied, 12,24,48h, 0.2, 0.4% (8); pre-applied, 48h, 0.1% (8)

Morpholine: pre-applied, 48h, 1% (5)

A. moluccana

Removal of seed covering structures: crack exocarp (1); crack exocarp, then pre-soak, 10 min (1)

Scarification: sulphuric acid, 5, 10, 15, 20%, 10-30 min (1); hydrochloric acid, 5, 10, 15, 20%, 10-30 min (1); nitric acid, 5, 10, 15, 20%, 10-30 min (1)

Pre-soak: 100°C, 10,50 min (1)

A. montana

Removal of seed covering structures: crack seed coat by exposure to sunlight, 1-10h (9)

Pre-soak: cold or 60°-80°C, 6,24,48h (9)

IV. Partly-successful dormancy-breaking treatments

A. Fordii

Pre-chill: 0°C, 3°C, 4°-15°C, 4m (4); seed or fruit, 40-140d (7)

Warm stratification: 25°C, 41d (5); 9°-24°C, 41d (5); 9°-24°C, 30d, then 25°C, 42d (5)

Pre-soak: 12-48h (8)

Tergetol: pre-applied, 12,24h, 0.1% (8)

Morpholine: pre-applied, 12-48h, 0.25, 0.5, 1% (8)

Removal of seed covering structures: crack seed coat (9); seed coat, then pre-chill, 40-140d (7)

A. montana

Warm stratification: 100-150d (9)

Removal of seed covering structures: crack seed coat (9)

V. Successful dormancy-breaking treatments

A. Fordii

Warm stratification: 9°-24°C, 75-100d (5)

A. montana

Scarification: by hand, near hilum (9)

VI. Comment

No reports on laboratory germination test procedures for seeds of Aleurites spp. have been found; those summarised above concern treatments prior to field sowings. For nursery sowings sphagnum moss, sand or soil are suitable (8,9); seeds should be sown 2.5 cm deep (8), with the hilum at the side or top - since germination is greatly reduced when seeds are sown with the hilum at the bottom (9). The period required for germination can be considerable. For example, there may be a 60 day delay before the first seeds to germinate begin to emerge through the soil surface for A. Fordii (6), and a 75 day delay for A. moluccana (1).

Although substantial pre-chill - 3°-5°C, 4 months (4,7) - or warm stratification - 9°-24°C, 3 months (5) - treatments result in substantial increases in subsequent germination, their major effect appears to be in enabling seed moisture content to rise (5,7), suggesting that much of the delay to germination may be caused by the seed coat delaying imbibition. Certainly cracking the seeds coats of freshly harvested seeds is promotory and reduces the time taken to germinate, but for stored seeds the treatment may be damaging (9). Rather than crack the seed coat, it is better to scarify it by hand near the hilum (9). It is suggested that this be done and the seeds then tested for germination in moist (sterile) sand at 25°C. However, investigations into the response of germination to a range of constant and alternating temperature regimes might be tried since an alternating temperature regime could possibly be more suitable than a constant 25°C.

VII. References

1. Eakle, T.W. and Garcia, A.S. (1977). Hastening the germination of lumbang (Aleurites moluccana (L.) Willd.) seeds. Sylvatrop, 2, 291-295.

2. François, M.T. (1936). Sur l'analyse de graines de tung (Aleurites Fordii) cultiveés au Maroc (Récolte 1933). Agronomie Coloniale 25, 89-91.

3. Large, J.R., Fernholz, D.L., Merrill, S. Jr. and Potter, G.F. (1947). Longevity of tung seed as affected by storage temperatures. Proceedings of the American Society for Horticultural Science, 49, 147-150.

4. Li, L.Y. (1943). The influence of stratification of tung seeds upon emergence and establishment of seedlings in the nursery. New Zealand Journal of Science and Technology, Section A, 25, 43-48.

5. Merrill, S. Jr. (1947). Germination of early-planted and late-planted tung seeds as affected by stratification and various seed treatments. Proceedings of the American Society for Horticultural Science, 49, 151-157.

6. Merrill, S. Jr., Slick, W.A., Painter, J.H. and Brown, R.T. (1941). Effect of planting date on germination of tung nuts in the nursery. Proceedings of the American Society for Horticultural Science, 39, 153-156.

7. Sharpe, R.H. and Merrill, S. Jr. (1942). Effect of stratification and time of planting on germination of tung seed. Proceedings of the American Society for Horticultural Science 40, 286-291.

8. Shear, C.B. and Crane, H.L. (1943). Germination of the nuts of the tung tree as affected by penetrants, substrata, depth of planting, and storage conditions. Botanical Gazette, 105, 251-256.

9. Webster, C.C. (1948). The effect of seed treatments, nursery technique and storage methods on the germination of tung seed. East African Agricultural Journal, 14, 38-48.

HEVEA

H. brasiliensis (Willd. ex Adr. de Juss.) Muell.-Arg. para rubber

I. Evidence of dormancy

H. brasiliensis shows recalcitrant seed storage characteristics: that is the seeds are killed by desiccation (4,8,9,12). Consequently, since the seeds cannot be safely dried, the seeds are killed by exposure to sub-zero temperatures (4). Seed longevity in moist storage conditions is short (2,3,6,8,11,14).

Although freshly harvested rubber seeds are reported to show no dormancy (2), seeds from certain clones show the slow, erratic and low germination typical of dormant seed populations (5,6,7). Moreover, after-ripening of rubber seeds in moist storage has been shown to reduce this problem (12). A high partial pressure of carbon dioxide can induce dormancy in the seed (8).

II. Germination regimes for non-dorment seeds

Constant temperatures: 25°C (13); 27°C (8); 28°C in diffuse light, 12-13 h/d (4,10,11)

Alternating temperatures: 25°/30°C, light, 24h/d, 21d (15)

III. Unsuccessful dormancy-breaking treatments

Pre-soak: 12h (7); c. 100°C, 5-10 min (7)

Scarification: concentrated sulphuric acid, 2-5 min (7); file seed coat (7)

Light: direct sunlight through clear plastic, 0.5-2h (7)

IV. Partly-successful dormancy-breaking treatments

-

V. Successful dormancy-breaking treatments

Pre-soak: 16h (5)

Scarification: file seed coat near hylum (5)

Removal of seed covering structures: seed coat (5); micropylar cap (6)

VI. Comment

Moist sand is generally reported to be the best germination medium for both laboratory tests and nursery sowings (1,4,6,10,11,13). The seeds should be sown deep enough just to bury the micropyle under the surface with the grooved side of the seed underneath (6). 25°C is a suitable germination test temperature, but direct sunlight should be avoided (7). Although the majority of seeds germinate 3 to 25 days after sowing (6,10), where dormancy is present 56 days, or more, may be required before germination is complete (7). After 14 days in test seeds which have not begun to germinate can be scarified by hand and returned to the germination test. There is one report that testing the seeds between wet hessian bags rather than moist sand is preferable (7). It would be worthwhile testing whether a rolled paper towel test is more suitable for laboratory germination tests; an investigation of the response of seed germination to alternating temperatures would also be worthwhile. Finally a tetrazolium test can be used as an alternative test of viability (10) if this is required.

VII. References

1. Amma, C.K.S. and Nair, V.K.B. (1977). Relationship of seed weight and seedling vigour in Hevea. Rubber Board Bulletin, 13, 28-29.

2. Ang, B.B. (1977). Problems of rubber seed storage. In Seed Technology in the Tropics (eds. H.F. Chin, I.C. Enoch, and R.M. Raja Harun), pp. 117-122, Universiti Pertanian Malaysia, Malaysia.

3. Cardoso, M., Zink, E. and Bacchi, O. (1966). [A study on the storage of Hevea seeds.] Bragantia, 25, 35-40. (From Horticultural Abstracts, 1968, 38, 4488.)

4. Chin, H.F., Ariz, M., Ang, B.B. and Hamzah, S. (1981). The effect of moisture and temperature on the ultrastructure and viability of seeds of Hevea Brasiliensis. Seed Science and Technology, 9, 411-422.

5. Dahle, H.E. (1938). [Germination experiments with Hevea seed.] Bergcultures, 12, 1270. (From Horticultural Abstracts, 1939, 9, 264.)

6. Dijkman, M.J. (1951). Hevea. Thirty years of research in the Far East, 43pp. University of Miami Press, Coral Gables, Florida.

7. Keleny, G.P. and Van Haaren, A.J.H. (1967). Progress report on rubber seed investigation. Papua New Guinea Agriculture Journal, 19 19, 72-87.

8. Kidd, F. (1914). The controlling influence of carbon dioxide in the maturation, dormancy, and germination of seeds. Part II. Proceedings of the Royal Society, Series B, 87, 609-625.

9. Koopman, M.J.F. (1963). Result of a number of storage experiments conducted under controlled conditions. b. Other than agricultural seeds. Proceedings of the International Seed

Testing Association, 28, 853-860.

10. Mohamad Husin, S., Chin, H.F. and Hor, Y.L. (1981). Viability test on Hevea seeds by the tetrazolium method. Journal of the Rubber Research Institute of Malaysia, 29, 44-51.

11. Pa, O.T. and Koen, L.I. (1963). Results on storage test with seeds of Hevea Brasiliensis. Menara Perkebunan, 32, 183-192.

12. Pereira, J.D.P. (1977). [Conservation of viability of Hevea seeds.] Pesquisas Agropecuaries Brasileira Serie Agronomicas.

13. Van der Hoop, D.J.N. (1930). [Germination experiment with Hevea seed.] Archives Rubber Cultivation Nederl. Indie, 14, 81-84.

14. Wycherley, P.R. (1971). Hevea seed. Part 3. Planter, 47, 405-410.

15. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

MANIHOT

M. anomala
M. esculenta Crantz cassava, tapioca, manioc, mandioca, yuca
M. gracilis
M. longepetiolata
M. oligantha
M. pentaphylla
M. salicifolia

I. Evidence of dormancy

Cassava (M. esculenta) seeds are generally dormant for several months after harvest (1). However, estimating the proportion of dormant seeds in populations is quite difficult unless the range of environments over which non-dormant seeds will germinate is taken into account (3). Wild Manihot spp. can exhibit extreme seed dormancy (9).

II. Germination regimes for non-dormant seeds

M. esculenta

Constant temperatures: 34°-40°C (3)

III. Unsuccessful dormancy-breaking treatments

M. anomala

Constant temperatures: 18°-22°C (9)

M. esculenta

Constant temperatures: 4°-25°C, dark (7); 19°-31°C (3); 20°C, 25°C, 40°C (4)

Alternating temperatures: 19°-25°/28°C, 19°/22°C, 19°/25°C, 22°/25°C (4-20h/4-20h) (3); 19°-28°/31°C, 19°/34°-40°C (20h/4h) (3); 20°/25°C (16h/8h) (4)

Pre-chill: (8); 24h (5)

Pre-soak: 24h (5); 60°C, 0.5, 1h (5)

Scarification: acid (8); sulphuric acid, 0.25, 0.5, 1h (5)

Removal of seed covering structures: (5); file (5)

M. gracilis, M. longepetiolata, M. oligantha, M. pentaphylla, M. salicifolia

Constant temperatures: 18°-22°C (9)

IV. Partly-successful dormancy-breaking treatments

M. anomala

Alternating temperatures: 26°/38°C (16h/8h), 35d (9)

M. esculenta

Constant temperatures: 30°C, 21d (8); 30°C, 35°C, (4); 30°C, 37°C, dark, 35d (7)

Alternating temperatures: 25°/35°C (16h/8h), 42d (2); 19°-28°/34°-40°C, 34°-40°/34°-40°C (16h/8h or 8h/16h), 19°-37°/34°-40°C (4h/20h), 28°-34°/37°-40°C (20h/4h) (3); 25°/30°C, 30°/35°C, 35°/40°C, 20°/30°C, 25°/35°C, 30°/40°C, 20°/35°C, 25°/40°C (16h/8h) (4)

GA_3: pre-applied, in red light, germinate at 30°-35°C (6)

Pre-dry: 60°C, 14d (1)

Scarification: by hand, near micropyle (8)

M. gracilis, M. longepetiolata, M. oligantha, M. pentaphylla, M. salicifolia

Alternating temperatures: 26°/38°C (16h/8h), 35d (9)

V. Successful dormancy-breaking treatments

M. esculenta

Light: red, 24h, germinate at 28°C in dark (8)

VI. Comment

The following laboratory procedure has been reported for germinating cassava seeds (8): remove the cork-like caruncles and scarify in the region of the micropyle until the radicle is slightly visible; then sterilize the seeds in either 10% hydrogen peroxide or 0.15 N sodium hypochlorite for 30 minutes; rinse three times; pre-soak for 16-24 hours in aerated distilled water; sterilize again in 10% hydrogen peroxide for 1 minute; irradiate with red light for one day; and finally test for germination at 28°C in the dark. Unfortunately no evidence is provided of the success or otherwise of this lengthy procedure (8). Moreover, it is clear from other results that higher constant temperatures are required for germination (3,4), that the optimum constant germination test temperature may be altered by storage (4), and that often alternating temperature germination test regimes provide a further stimulus, promoting germination to higher levels than at constant temperatures (3).

From results of germination tests under a wide range of constant and alternating temperature regimes it is clear that certain minimum conditions must be provided before cassava seeds will germinate; the maximum temperature during part of the day must exceed 30°C and the mean temperature must be 24°C or more (3). However, the conditions required for full germination

are rather more stringent; the maximum temperature during part of the day must be between 36° to 40°C, the amplitude of the alternation must be between 3°-18°C, and the mean temperature must be 33°C or more (3). Alternating temperature regimes have also been shown to promote the germination of some, but not all, dormant seeds of wild Manihot spp. (9).

In view of these requirements an alternating temperature regime of 38°/30°C (16h/8h) has been recommended with a minimum test duration of 21 days for M. esculenta (3); for dormant seeds of other Manihot spp. a minimum test duration of 42 days is suggested here. In addition it is suggested that red light be applied intermittently - see Chapter 6.

VII. References

1. Anonymous (1981). Germplasm development. Seed germination studies. In Cassava Program, Annual Report 1980, p.32, CIAT, Cali, Colombia. (From Field Crop Abstracts, 1983, 36, 878.)

2. Ellis, R.H., Hong, T.D. and Roberts, E.H. (1981). The influence of desiccation on cassava seed germination and longevity. Annals of Botany, 47, 173-175.

3. Ellis, R.H., Hong, T.D. and Roberts, E.H. (1982). An investigation of the influence of constant and alternating temperature on the germination of cassava seed using a two-dimensional temperature gradient plate. Annals of Botany, 49, 241-246.

4. Ellis, R.H. and Roberts, E.H. (1979). Germination of stored cassava seed at constant and alternating temperatures. Annals of Botany, 44, 677-684.

5. Martin, F.W. and Ruberté, R. (1976). Germination and longevity of cassava seeds. Tropical Root and Tuber Crops Newsletter, 9, 54-56.

6. Mendes, R.A. (1981). [Improvement of seed germination of cassava (Manihot esculenta Crantz).] In Anais i Congresso Brasileira de Mandioca, 1, Pesquisas agronômicas, pp. 523-533. (From Seed Abstracts, 1982, 5, 2748.)

7. Mumford, P.M. and Grout, B.W.W. (1978). Germination and liquid nitrogen storage of cassava seed. Annals of Botany, 42, 255-257.

8. Nartey, F. (1978). Manihot esculenta (Cassava, Tapioca, Manioc, Mandioca, Yuca): Cyanogenesis, Ultrastructure and Seed Germination, 262 pp., Munksgaard, Copenhagen.

9. Nassar, N.M.A. and Teixeira, R.P. (1983). [Seed germination of wild cassava species (Manihot spp.).] Ciencia e Cultura, 35, 630-632.

RICINUS

R. communis L. castor bean, castor oil plant, palma christi

I. Evidence of dormancy

Freshly harvested seeds of R. communis show slow, erratic, low germination (1-4,6,8,9,12). After-ripening at room temperature for four (2), nine (6) or several (3) months is reported to avoid this problem in subsequent germination tests. The seed covering structures (testa and caruncle) are reported to be the major cause of poor germination (1,3,4,8,9). The seeds show orthodox storage behaviour.

II. Germination regimes for non-dormant seeds

BP; S: 20°/30°C (16h/8h): 14d (AOSA, ISTA)

In addition if the growth of moulds interfere with a germination test AOSA rules recommend that the caruncles be removed.

Constant temperatures: 25°C (13); 27°C (10,11,12); 30°C (13)

Alternating temperatures: 20°/30°C (16h/8h) (4,10,11,13); 20°/35°C (16h/8h) (13)

III. Unsuccessful dormancy-breaking treatments

Urea: pre-applied, 24h, 24% (5)

Scarification: sulphuric acid, 10%, 1,2d (7); concentrated nitric acid, 1 min (9); emery paper (7)

IV. Partly-successful dormancy-breaking treatments

Pre-soak: 24h (5); 2-3d (7)

V. Successful dormancy-breaking treatments

Pre-soak: pour on boiling water, then leave to cool, 24h (8)

Removal of seed covering structures: caruncle (9,12); caruncle, then scarify testa at caruncle end with emery paper (3,4,8); seed coat, germinate in moist sand (9)

VI. Comment

In addition to poor germination, difficulties in seed germination tests of R. communis may also be caused by the growth of fungi and bacteria. Removal of the caruncles from seeds reduces the delay to germination and can increase the proportion of seeds germinating (3,4,8,9); it can also reduce fungal and bacterial growth during germination tests (4,12). The latter problem can be further reduced by testing for germination in moist sand rather than paper towels (10,11). Consequently it is suggested that the seeds be tested for germination as follows: remove caruncle and hand scarify testa at the caruncle end (but do not damage the endosperm), and then test in moist (sterile) sand at 20°/30°C (16h/8h).

VII. References

1. Atsmon, D. (1958). Germination inhibition in castor-beans. Bulletin of the Research Council of Israel, 6D, 260.

2. Brighan, R.D. (1965). Delayed germination and seedling emergence of castorbean (Ricinus communis L.). Crop Science, 5, 79 -83.

3. Engelhardt, M. and Vincente, M. (1963). [How to make recently harvested castorbean (Ricinus communis L.) seeds germinate.] Biológico Brasil, 29, 191. (From Horticultural Abstracts, 1964, 34, 1391.)

4. Heit, C.E. (1949). Germinating castor-bean seed in the laboratory. Proceedings of the Association of Official Seed Analysts, 39, 114-117.

5. Kurdikeri, C.B. (1974). Soaking of castor in water promotes germination. Current Research, 3, 102.

6. Lago, A.A., Zink, E., Razera, L.F., Banzatto, N.V. and Savy-Filho, A. (1978). [Seed dormancy of three castorbean cultivars.] Bragantia, 38, 41-44.

7. Patel, G.J. and Jaisani, B.G. (1962). Studies on castor germination. Indian Oilseeds Journal, 6, 106-111.

8. Purseglove, J.W. (1968). Ricinus communis L. In Tropical Crops. Dicotyledons. pp. 180-186, Longmans, London.

9. Reilhes, R. (1942). Influence du tégument sur la germination des graines de ricin (Ricinus communis). Comptes Rendus de la Société de Biologie, 136, 70-73.

10. Stafford, R.E. and Metzer, R.B. (1970). Germination of four castor seed lots in paper towels, kimpak, and sterile sand. 14 pp., Texas Agricultural Experiment Station, Progress Report 2773.

11. Stafford, R.E. and Metzer, R.B. (1971). Relationships among laboratory germination, greenhouse, and field emergence of four castor seed lots. Agronomy Journal, 63, 805-808.

12. Williams, J.H. and Kittock, D.L. (1969). Management factors influencing viability of castor bean (Ricinus communis) seed. Agronomy Journal, 61, 954-958.

13. Carneiro, J.W.P. and Pires, J.C. (1983). [Influence of temperature and substrata in the germination of castorbean seeds.] Revista Brasileira de Sementes, 5, 127-131.

CHAPTER 38. FAGACEAE

The Fagaceae comprise over 600 species of trees and shrubs within six genera which provide timber. The fruits are one-seeded nuts which may be enclosed in a cupule or a bur. Quercus and Castanea spp. show recalcitrant seed storage behaviour, whereas Fagus and Nothofagus spp. show orthodox seed storage behaviour (although careful handling, drying, and long germination test periods may be required to demonstrate this in some Fagus spp.).

SEED DORMANCY AND GERMINATION

Dormancy can be a severe problem in some species (e.g. Fagus spp.) requiring long pre-chill treatments and overall germination test periods of more than 6 months. No detailed information is provided here for any one genus, but Table 38.1 provides a summary of recommended germination test procedures and dormancy-breaking treatments, and the algorithm below may be helpful in developing suitable germination test regimes for other species.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test the seeds at a constant temperature of 21°C with light applied for 12h/d.

If this is not successful in promoting full germination then the second step of the algorithm is to pre-chill a further sample of seeds at 2° to 6°C for 8w and then test at a constant temperature of 21°C with light applied for 12h/d.

In some species it is known that an 8w pre-chill treatment will be an inadequate dormancy-breaking treatment (e.g. see Table 38.1). Consequently where the seeds are known to be dormant and the algorithm does not promote full germination gene banks should consider extending the pre-chill treatment.

TABLE 38.1 Summary of germination test recommendations for species within the Fagaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Castanea sativa Mill.	TS; S	20°/30°C	21d	pre-soak, 48h, cut off 1/3 of seed at scar end and remove testa	ISTA
				if dry, pre-soak, 48h, cold water	G&R
Castanea spp.			28d	pre-chill, 1°-5°C, 30-60d	Riley
Fagus sylvatica L.	TP	3°-5°C		test for up to 24w	ISTA
				pre-chill, 1°-5°C, 4-20w	G&R
Nothofagus obliqua (Mirbel) Oersted	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 28d	ISTA
Nothofagus procera (Poeppig & Endl.) Oersted	TP	20°/30°C	28d		ISTA
Nothofagus spp.				pre-chill, 1°-5°C, 0-9w, GA	G&R
Quercus alba L.	TP	20°/30°C	28d		AOSA
Quercus muehlenbergii	TP	20°/30°C	28d		AOSA

Engelm.					
Quercus virginiana Mill.	TP	20°/30°C	28d		AOSA
Quercus spp.	TS; S	20°C	28d	pre-soak, 48h, cut off 1/3 of seed at scar end and remove testa	ISTA
Quercus spp. (red and black oaks)	TP	20°/30°C	14d	cut 1/3 off cup at scar end, then remove pericarp	AOSA

CHAPTER 39. GRAMINEAE

The Gramineae comprise roughly 10000 species of herbaceous and sometimes woody plants within more than 600 genera. It is the most important of the plant families for man providing cereals, forage and fodders, sugar, construction materials, oils, and many other useful products. Consequently this chapter is substantially longer than other chapters.

In Gramineae the term seed is applied to a wide range of fruiting bodies. The basic component is the caryopsis, the single-seeded fruit: this may be naked (e.g. Triticum aestivum L.) or, more commonly, enclosed within other flower structures. The number and type of other structures which may enclose the caryopses are dependent upon how they become detached from the parent plant and the point of abscission. In many grasses abscission occurs in the spikelet-axis beneath the glumes: thus the caryopses are enclosed within the glumes. The following types of dispersal units may be observed in different species.

1. The caryopsis only.

2. The caryopsis loosely or tightly enclosed within the lemma and palea (a floret).

3. One or more florets enclosed within several glumes and bracts (a spikelet).

4. A cluster of spikelets.

See Chapter 3 (Volume I) for more information on seed development and morphology. In gene banks, the most important morphological feature is to confirm that dispersal units tested for germination do in fact contain a seed (see Chapter 8, Volume I).

Almost all Gramineae are known to exhibit orthodox seed storage characteristics. Two possible exceptions have been reported, viz: Glyceria striata Hitche (manna grass) and Zizania aquatica L. (wild rice). Whilst these species must be treated as recalcitrant seeds for the present, both species are known to exhibit considerable seed dormancy and it is possible that the species may, in fact, possess orthodox seeds and that dormancy and viability have been confused in the past. Some support for this assertion is provided in this chapter for the genus Zizania.

SEED DORMANCY AND GERMINATION

The seeds are endospermic and can show considerable dormancy. Part, but not all, of the problem of germinating the seeds may be associated with the seed covering structures. Typical treatments to overcome dormancy include pre-chilling, alternating temperatures, potassium nitrate and removal of the seed covering structures. Detailed information on seed germination and dormancy-breaking treatments is provided in this chapter for the 42 genera listed in Table 39.1. The table of genera is divided into their respective tribes since there may be some advantage to consult the information provided for closely related genera as well as for the genus of immediate concern. In addition Table 39.1 indicates whether the information on each genus includes information for species with synonyms in other genera. Table 39.2 provides a summary of recommendations for germination test procedures and dormancy-breaking treatments for other species. In addition the algorithm below may be useful in developing suitable germination test procedures for other species for which no information is provided here and for difficult accessions of all graminaceous species.

RBG Kew Wakehurst Place algorithm

Comment on, and an explanation of, the Gramineae algorithm have been provided in Chapter 17. Since that comment includes several alternative suggestions the reader is urged to read the appropriate section of Chapter 17 before attempting to follow this algorithm.

The first and second steps of the algorithm are dependent upon each accession's origin. In the first step of the algorithm accessions of temperate origin are tested at constant temperatures of 16°C and 21°C, whilst those of tropical origin are tested at constant temperatures of 21°C and 26°C. If an accession's origin is unknown or doubtful, test at all three constant temperatures, viz: 16°C, 21°C and 26°C. In all cases light is applied for 12h/d. If the results of these initial tests show a trend in the response of germination to constant temperatures (but full germination has not been achieved) then carry out further tests at more extreme constant temperatures. For example, if the germination of a temperate accession is greater at 16°C than at 21°C, then test further samples of seeds at constant temperatures of 6°C and 11°C with light applied for 12h/d.

If the first step of the algorithm has not resulted in full germination then the second step is to test a further sample of seeds in an alternating temperature regime: 23°/9° (12h/12h) for accessions of temperate origin; 33°/19°C (12h/12h) for accessions of tropical origin; in each case light is applied for 12h/d during the period spent at the upper temperature of each cycle. If an accessions' origin is unknown or doubtful then test a sample of seeds in each alternating temperature regime.

If the second step of the algorithm has not resulted in full germination then the third step is to co-apply 10^{-3} M potassium nitrate to the germination test substrate and test in the most successful temperature regime determined from the results of steps one and two.

If the third step of the algorithm has not resulted in full germination then the fourth step is to remove - in part or all - the seed covering structures from a fresh sample of seeds and then test in the most successful regime determined from the results of steps one to three. The actual treatment to the seed covering structures will be dependent upon the morphology of the dispersal units. Where possible extract each caryopsis from the floret (where this is the dispersal unit) and the lemma and palea (if present). This may not be easy for very small seeds, in which case the end of the dispersal unit opposite to the embryo can be chipped or cut away to expose the endosperm. In some cases the lemma and palea adhere very tightly to the caryopsis and their removal can be difficult - and possibly damaging. If this is the case then puncture the seed covering structures and the endosperm in the vicinity of the embryo. The removal of the lemma and palea, in particular, may be easier once the seeds have imbibed.

If the fourth step of the algorithm has not resulted in full germination then the fifth step of the algorithm is to pre-chill the seeds at 2° to 6°C for 8w and then test for germination in the most successful regime determined from the results of steps one to four. If this includes a requirement to remove the seed covering structures this may be easier to accomplish after the pre-chill treatment, but may be more effective in promoting germination if carried out before the pre-chill treatment.

If full germination has still not been promoted, the sixth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume 1).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been

broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided for 42 genera in this chapter. A glance at Table 39.2, however, will provide an initial indication of likely suitable treatments.

TABLE 39.1 List of genera by tribe within the Gramineae for which detailed information on seed germination procedures and dormancy-breaking treatments is provided in this chapter.

TRIBE and Genus	Synonyms
ANDROPOGONEAE	
- Andropogon	
- Bothriochloa	
- Cymbopogon	
- Saccharum	
- Sorghastrum	
- Sorghum	Andropogon, Holcus
- Themeda	
- Zea	Euchlaena
ARISTIDEAE	
- Aristida	
ARUNDINARIEAE	
- Sasa	Bambusa
AVENEAE	
- Agrostis	
- Avena	
- Phleum	
BROMEAE	
- Bromus	
CHLORIDEAE	
- Bouteloua	
- Chloris	
- Cynodon	Panicum
ERAGROSTIDEAE	
- Eleusine	Cynosurus
- Eragrostis	Poa
ORYZEAE	
- Oryza	
- Zizania	

PANICEAE	
- Brachiaria	Panicum
- Digitaria	
- Echinochloa	Panicum
- Panicum	
- Paspalum	
- Pennisetum	Panicum
- Setaria	Chaetochloa, Panicum
PHALARIDEAE	
- Phalaris	
POEAE	
- Dactylis	
- Festuca	Vulpia
- Lolium	
- Poa	
STIPEAE	
- Oryzopsis	
- Stipa	
TRITICEAE	
- Aegilops	Triticum
- Agropyron	
- Hordeum	
- Secale	
- Triticale	
- Triticum	
ZOYSIEAE	
- Zoysia	Agrostis

TABLE 39.2 Summary of germination test recommendations for species within the Gramineae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Alopecurus pratensis L.	TP	20°/30°C; 15°/25°C; 10°/30°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	14d	light	AOSA
Alysicarpus vaginalis (L.) DC.	BP	35°C	21d	pierce the seed coats and continue test for a further 5d if (reversible) hard seeds have begun to imbibe, or test swollen seeds at	AOSA

				20°C, 48h, then 35°C, 3d	
Anthoxanthum odoratum L.	TP	20°/30°C	14d		ISTA
	TP	20°/30°C	14d	light	AOSA
Arrhenatherum elatius (L.) Beauv.	TP	20°/30°C	14d	pre-chill	ISTA
	TP	20°/30°C	14d	light	AOSA
Axonopus affinis Chase	TP	20°/35°C	21d	potassium nitrate, light	ISTA/AOSA
Axonopus compressus (Sw.) Beauv.	TP	20°/35°C	21d	potassium nitrate, light	ISTA
Beckmannia eruciformis (L.) Host	TP	20°/30°C	21d		ISTA
Briza maxima L.	TP	20°/30°C	21d	pre-chill	ISTA
Buchloe dactyloides (Nutt.) Engelm. (burs)	TP; S	20°/35°C	28d	light, potassium nitrate, pre-chill, 5°C, 6w, then test for 14d	AOSA
(caryopses)	TP	20°/35°C	14d	light, potassium nitrate	AOSA
Calamagrostis canadensis (Michx.) Nutt.	TP	15°/25°C	21d	light, potassium nitrate, pre-chill, 5°C, 5d	AOSA
Cenchrus ciliaris L.	TP; S	20°/35°C; 20°/30°C; 30°C	28d	pre-dry, pre-chill, potassium nitrate	ISTA
	S	30°C	28d	light, press fascicles into well packed soil, then pre-chill, 5°C, 7d	AOSA
(caryopses)	TP	30°C	21d	pre-chill, 5°C, 7d, after test scratch firm seeds and continue test, 7d	AOSA
Cenchrus setigerus Vahl	TP	20°/35°C	14d	pre-dry (40°C), potassium nitrate	ISTA
Cynosurus cristatus L.	TP	20°/30°C	21d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	21d	light, pre-chill, 5°C or 10°C, 3d	AOSA
Coix lacrima-jobi L.	BP	20°/30°C	21d		ISTA
	BP	20°/30°C	16d	very sensitive to low temperatures	AOSA
Deschampsia caespitosa (L.) Beauv.	TP	20°/30°C; 20°C	16d	pre-chill, potassium nitrate	ISTA
Deschampsia flexuosa (L.) Trin.	TP	20°/30°C; 20°C	16d	pre-chill, potassium nitrate	ISTA
Dichanthium aristatum (Poir.) C.E. Hubbard	TP	20°/35°C	21d	potassium nitrate	ISTA
Ehrharta calycina Smith	TP	20°C	21d	pre-chill	ISTA
	TP	10°/30°C	28d	light	AOSA
Elymus canadensis L.	TP	15°/30°C	21d	light, pre-chill, 5°C, 2w	AOSA

Elymus junceus Fisch.	TP	20°/30°C	14d	pre-chill	ISTA
	TP	20°/30°C	14d	light, pre-chill, 5°C or 10°C, 5d	AOSA
Holcus lanatus L.	TP	20°/30°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	14d	light	AOSA
Melinis minutiflora Beauv.	TP	20°/30°C	21d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	21d	light	AOSA
Schizachyrium scoparium (Michx.) Nash	TP; S	20°/30°C	28d	light, potassium nitrate, pre-chill, 5°C, 2w	AOSA
Sporobolus cryptandrus (Torr.) Gray	TP	5°/35°C; 15°/35°C	28d	light, potassium nitrate, pre-chill, 5°C, 4w	AOSA
Trisetum flavescens (L.) Beauv.	TP	20°/30°C	21d	pre-chill, potassium nitrate	ISTA
Urochloa mosambicensis (Hack.) Dandy	TP	20°/35°C	21d		ISTA

AEGILOPS

A. cylindrica Host [Triticum cylindricum Ces., Pass. & Gib.]

A. Kotschyi Boiss.

A. ovata L.

A. triuncialis barb goatgrass

I. Evidence of dormancy

Freshly harvested seeds of Aegilops spp. show considerable dormancy (1-10, 12). Seeds of A. triuncialis require 3 to 4 months after-ripening for full germination (3), whereas after-ripening seeds of A. ovata for 1 year did not entirely remove dormancy (2).

II. Germination regimes for non-dormant seeds

A. cylindrica

Constant temperatures: 20°C, dark (4)

A. Kotschyi

Constant temperatures: 20°C, dark (6,7,8,12)

A. ovata

Constant temperatures: 20°C in light, 150-250 fc (1)

III. Unsuccessful dormancy-breaking treatments

A. cylindrica

Constant temperatures: 30°C, 35°C (4)

Potassium nitrate: co-applied, 0.1, 1 g/1, at 10°C, 15°C, 20°C (4)

GA_3: co-applied, 1000 ppm, at 10°C, 15°C (4)

A. kotschyi

Constant temperatures: 30°C (5)

Pre-dry: (6)

Auxin: co-applied, 50 ppm, at 20°C (8)

Cytokinin: co-applied, 50 ppm, at 20°C (8)

A. ovata

Constant temperatures: 35°C, 40°C, in light or dark (1)

IV. Partly-successful dormancy-breaking treatments

A. cylindrica

Constant temperatures: 10°C, 28d (4)

A. kotschyi

Constant temperatures: 5°C (5)

GA_3: co-applied, 50 ppm, at 20°C (8); co-applied, 10-100 ppm (11)

Removal of seed covering structures: dehull (5,6,8,11)

A. ovata

Constant temperatures: 5°C in light or dark (1); 10°C, dark (1); 15°C, 20°C, 25°C, light, 16d (1,2)

V. Successful dormancy-breaking treatments

A. cylindrica

Constant temperatures: 15°C, 20°C, 28d (4)

GA_3: co-applied, 1000 ppm, at 20°C (4)

A. kotschyi

Removal of seed covering structures: dehull, germinate at 5°C (5); dehull, plus GA_3, co-applied, 10-100 ppm (11)

GA_3: co-applied, 50 ppm (10); co-applied, 50 ppm, plus RNAase, 10g/ml, co-applied (10)

A. ovata

Constant temperatures: 10°C in light, 150-250 fc (1)

Removal of seed covering structures: dehull (1)

VI. Comment

We suggest that a constant temperature of between 5° and 10°C combined, where necessary, with removal of the seed covering structures should be satisfactory for testing accessions of Aegilops spp. for germination.

VII. References

1. Datta, S.C., Evenari, M. and Gutterman, Y. (1970). The heteroblasty of Aegilops ovata L. Israel Journal of Botany, 19, 463-483.

2. Datta, S.C., Gutterman, Y. and Evenari, M. (1972). The influence of the origin of the mother plants on yield and germination of their caryopses in Aegilops ovata. Planta, 105, 155-164.

3. Laude, H.M. (1956). Germination of freshly harvested seeds of some western range species. Journal of Range Management, 9, 126-129.

4. Morrow, L.A., Young, F.L. and Flom, D.G. (1982). Seed germination and seedling emergence of jointed goatgrass (Aegilops cylindrica). Weed Science, 30, 395-398.

5. Waisel, Y. and Adler, Y. (1959). Germination behavior of Aegilops Kotschyi Boiss. Canadian Journal of Botany, 37, 741-742.

6. Wurzburger, J. and Koller, D. (1973). Onset of seed dormancy in Aegilops Kotschyi Boiss. and its experimental modification. New Phytologist, 72, 1057-1061.

7. Wurzburger, J. and Koller, D. (1976). Differential effects of the parental photothermal environment on development of dormancy in caryopses of Aegilops Kotschyi. Journal of Experimental Botany, 27, 43-48.

8. Wurzburger, J. and Leshem, Y. (1967). Gibberellin and hull controlled inhibition of germination in Aegilops Kotschyi Boiss. Israel Journal of Botany, 16, 181-186.

9. Wurzburger, J. and Leshem, Y. (1969). Physiological action of the germination inhibitor in the husk of Aegilops Kotschyi Boiss. New Phytologist, 68, 337-341.

10. Wurzburger, J. and Leshem, Y. (1971). Ribonucleic acid as an inducer of germination inhibition in Aegilops Kotschyi. Plant and Cell Physiology, 12, 211-215.

11. Wurzburger, J. and Leshem, Y. (1974). The role of gibberellin and the hulls in the control of germination in Aegilops Kotschyi caryopses. Canadian Journal of Botany, 52, 1597-1601.

12. Wurzburger, J., Leshem, Y. and Koller, D. (1976). Correlative aspects of imposition of dormancy in caryopses of Aegilops Kotschyi. Plant Physiology, 57, 670-671.

AGROPYRON

A. cristatum (L.) Gaertn.	fairway crested
A. dasystachyum (Host) Scribn.	thickspike wheatgrass wheatgrass
A. desertorum Fisch. ex Link	standard crested wheatgrass
A. elongatum (Host) Beauv.	tall wheatgrass
A. intermedium (Host) Baumg.	intermediate wheatgrass
A. repens (L.) Beauv.	quackgrass
A. riparium Scribn. & Smith	streambank wheatgrass
A. semicostatum	
A. siberian Willd.	Siberian wheatgrass
A. smithii Rydb.	Western wheatgrass
A. spicatum (Pursh) Scribn. & Smith	bluebunch or beardless wheatgrass

A. trachycaulum (Link) H.F. Lewis	slender wheatgrass
A. trichophorum Link	pubescent wheatgrass

I. Evidence of dormancy

Severe dormancy has been reported in seed lots of A. repens (6, 7, 16), A. semicostatum (13), A. trachycaulum (13), A. interm edium (20), A. cristatum (1,8,9,20), A. siberian (20), A. trichophorum (20), A. smithii (2-4,10,12,15,18,20) and A. spicatum (2 0). Secondary dormancy has been induced: in A. elongatum where moist seeds experienced sub-zero temperatures before harvest (17); in A. smithii where seeds wer e pre-chilled at 10°C for 5 days (3); and in A. smithii where imbibed seeds were exposed to high constant temperatures (18).

II. Germination regimes for non-dormant seeds

A. cristatum, A. desertorum

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (AOSA, ISTA)

A. elongatum

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 15°/25°C (16h/8h): 21d (AOSA)

A. intermedium

TP: 15°/25°C; 20°/30°C (16h/8h): 28d (AOSA, ISTA)

A. repens

TP: 10°/30°C; 20°/30°C (16h/8h): 21d (ISTA)

A. smithii

TP; BP: 15°/25°C; 20°/30°C (16h/8h): 28d (ISTA)

TP; BP: 15°/30°C (16h/8h): 28d (AOSA)

A. spicatum

TP; BP: 15°/25°C (16h/8h): 14d (AOSA)

A. trachycaulum

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (ISTA)

TP: 20°/30°C (16h/8h): 14d (AOSA)

A. trichophorum

TP: 15°/25°C; 20°/30°C (16h/8h): 28d (AOSA,ISTA)

III. Unsuccessful dormancy-breaking treatments

A. desertorum

Potassium nitrate: co-applied, 0.2% (13)

A. smithii

Potassium nitrate: co-applied, 0.2% (13)

Thiourea: co-applied, 0.2% (13)

GA_3: co-applied, 100 ppm (13)

Light: white (10); white, 9h/d (3,4,15); incandescent, 22 lux, continuous (18); red, 15 min (15); far red, 1300 lux, intermittent (18)

A. trachycaulum

Potassium nitrate: co-applied, 0.2% (13)

Thiourea: co-applied, 0.2% (13)

GA_3: co-applied, 100 ppm (13,14)

IV. Partly-successful dormancy-breaking treatments

A. cristatum

Alternating temperatures: 15°/25°C, 10°/20°C, 10°/25°C, 10°/30°C, 15°/20°C, 15°/30°C, 20°/25°C, 20°/30°C (16h/8h) (20); 20°/30°C (16h/8h) (8); 20°/30°C (18h/6h) (9)

Pre-chill: 6°-8°C, 4d, germinate at 20°C (8); 10°C, 7d, germinate at 20°/30°C (16h/8h) in light (1)

A. desertorum

Constant temperatures: 20°C (14)

Light: (13,14)

GA_3: co-applied, 100 ppm (14)

A. elongatum

Pre-chill: 5°C, 5d, plus potassium nitrate, co-applied, germinate at 20°/30°C (16h/8h) in light (17)

A. intermedium

Alternating temperatures: 10°/25°C, 15°/25°C, 20°/25°C, 15°/20°C (16h/8h) (20)

A. repens

Alternating temperatures: (16); 15°/30°C (15h/9h) (6); 25°/30°C (16h/8h) in light (20)

Removal of seed covering structures: dehull (19)

A. semicostatum

Pre-chill: (13)

A. siberian

Alternating temperatures: 15°/25°C, 5°/20°C, 5°/25°C, 10°/20°C, 10°/25°C, 15°/20°C (16h/8h) (20)

A. smithii

Alternating temperatures: 15°/25°C, 15°/30°C (20h/4h) (18); 15°/40°C, 20°/40°C, 25°/40°C (16h/8h) (20); 15°/30°C (16h/8h) (12, 15); 20°/30°C, 20°/35°C (18h/6h) (10)

Pre-chill: (13); 8°-10°C, 14°-17°C, 6d, germinate at 20°/30°C (16h/8h) (10)

Light: dark, continuous (3); red, 4,8 min (15); red, 13000 lux, 3,5 min (18)

Potassium nitrate: co-applied, 0.2%, at 15°/30°C (16h/8h) (2,4,12); pre-applied, 24h, 0.2% (15)

Ethylene chlorohydrin: pre-applied, 24h, 750, 1250 ppm (3,4)

GA_3: co-applied, 10^{-3} M, plus kinetin, co-applied, 0.5 M (18); pre-applied, 24h, 100 ppm (15)

Kinetin: pre-applied, 24h, 100 ppm (15)

A. spicatum

Alternating temperatures: 15°/20°C, 20°/25°C (16h/8h) (20)

A. trachycaulum

Constant temperatures: 0°-40°C (20)

Alternating temperatures: 15°/25°C, 15°/30°C, 20°/30°C, 20°/35°C (16h/8h) (20)

Pre-chill: (13)

Light: (13)

A. trichophorum

Alternating temperatures: 15°/25°C, 15°/30°C (16h/8h) (20)

V. Successful dormancy-breaking treatments

A. cristatum

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Pre-chill: 8°-10°C, 4-6d (9); 10°C, 7d, plus potassium nitrate, co-applied, 0.2% (1)

A. dasystachyum

Alternating temperatures: 15°/25°C, 15°/30°C, 20°/30°C (16h/8h) (20)

A. desertorum

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Alternating temperatures: 15°/30°C (13); 15°/25°C, 10°/25°C (16h/8h) (20)

Pre-chill: (13)

Potassium nitrate: co-applied, 0.2% (13)

Thiourea: co-applied, 0.2% (13)

GA_3: co-applied, 100 ppm (13,14)

A. elongatum

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Constant temperatures: 8°C, 14°C (11)

Alternating temperatures: 15°/25°C, 15°/30°C (16h/8h) (20)

Pre-chill: 5°C, 5d, plus potassium nitrate, co-applied, 0.2%, germinate at 20°/30°C (16h/8h) in light, then pierce ungerminated seeds which remain (17)

Potassium nitrate: co-applied, 0.2%, germinate at 15°/30°C (16h/8h) and pierce ungerminated seeds which remain (17)

A. intermedium

Pre-chill, Potassium nitrate (ISTA)

Light (AOSA)

A. repens

Pre-chill, Potassium nitrate (ISTA)

Alternating temperatures: 20°/30°C in light, 25°/20°C (16h/8h) (19)

A. semicostatum

Alternating temperatures: 15°/30°C (16h/8h) (13)

Pre-chill: (13)

A. smithii

Pre-chill, Potassium nitrate (ISTA)

Potassium nitrate, test in soil (AOSA)

Alternating temperatures: 15°/30°C (13)

Removal of seed covering structures: expose embryo, germinate at 15°/30°C (16h/8h) in dark (2,3,4)

GA_3: co-applied, 10^{-3} M, plus kinetin, 0.5 M, germinate at 15°/25°C (20h/4h) in light, 13000 lux, 4h/d (18)

A. spicatum

Light, Pre-chill, Potassium nitrate (AOSA)

Constant temperatures: 20°C (5)

A. trachycaulum

Pre-chill, Potassium nitrate (ISTA)

Pre-chill, repeat Pre-chill, then test at 20°/30°C, 4d (AOSA)

Alternating temperatures: 15°/30°C (16h/8h) (13); 15°/25°C, 15°/30°C, 20°/30°C, 20°/35°C (16h/8h) (20)

A. trichophorum

Pre-chill, Potassium nitrate (ISTA)

Light (AOSA)

VI. Comment

It is essential that seeds of Agropyron spp. be provided with alternating temperature regimes for germination (13,15,16,18-20). In general alternating temperature regimes of 15°/25°C or 20°/25°C (16h/8h) appear to be suitable for accessions of Agropyron spp. with the possible exception of A. smithii where the temperature during the 8h cycle may have to be as high as 40°C (20), but the use of alternating temperature regimes alone is unlikely to be sufficient to promote full germination in all Agropyron accessions. For most Agropyron spp. the ISTA and AOSA recommendations for breaking dormancy suggest that potassium nitrate and pre-chilling treatments also be applied. For A. smithii treatment with potassium nitrate, only, is recommended in an alternating temperature regime of 15°/30°C (16h/8h). This regime, however, is not completely successful in promoting germination (2,4,12,15), but full germination can be promoted by careful removal of the seed covering structures, pricking and testing in alternating temperature regimes (2-4,12,17,19). Some labour can be avoided by removing the seed covering structures and/or pricking only those seeds which have failed to germinate after between 10 and 28 days in an alternating temperature germination test regime. Attention is drawn to the multifactor procedure outlined above for A. elongatum (17) - combining pre-chilling (5°C, 5 days), potassium nitrate (co-applied, 0.2%), pricking and testing at 20°/30°C (16h/8h) - which may be more widely applicable. Care is required with the light environment since light can inhibit the germination of some seed lots of A. repens, A. semicostatum, and A. smithii (2-4,10,13-16,18).

VII. References

1. Andersen, A.L. and Drake, V.C. (1944). Preliminary study of seed of crested wheatgrass exhibiting delayed germination. Proceedings of the Association of Official Seed Analysts, 35, 146-152.

2. Bass, L.N. (1955). Determining the viability of Western wheatgrass seed lots. Proceedings of the Association of Official Seed Analysts, 45, 102-104.

3. Delouche, J.C. (1956). Dormancy in seeds of Agropyron smithii, Digitaria sanguinalis and Poa pratensis. Iowa State Colle Journal of Science, 30, 348-349.

4. Delouche, J.C. and Bass, L.N. (1954). Effect of light and darkness upon the germination of seeds of western wheatgrass Agropyron smithii L. Proceedings of the Association of Official Seed Analysts, 44, 104-113.

5. Evans, G.R. and Tisdale, E.W. (1972). Ecological characteristics of Aristida longiseta and Agropyron spicatum in West-Central Ida Ecology, 53, 137-142.

6. Everson, L.E. (1954). The germination of mature and immature seeds of quackgrass

(Agropyron repens). Proceedings of the Association of Official Seed Analysts, 44, 127-128.

7. Grime, J.P., Mason, G., Curtis, A.V., Redman, J., Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. Journal of Ecology, 69, 1017-1059.

8. Hay, W.D. (1936). Germination of crested wheatgrass (Agropyron cristatum): preliminary studies. Proceedings of the Association of Official Seed Analysts, 28, 66-70.

9. Hay, W.D. (1936). Further studies with the germination of crested wheatgrass. Proceedings of the Association of Official Seed Analysts, 28, 86-88.

10. Hay, W.D. (1939). Laboratory germination studies with Agropyron smithii. Preliminary results. Proceedings of the Association of Official Seed Analysts, 30, 244-245.

11. Hunt, O.J. (1961). Low-temperature germination, a possible strain response of tall wheatgrass, Agropyron elongatum (Host.) Beauv. Agronomy Journal, 53, 277.

12. Kinch, R.C. (1963). A method of inducing rapid germination of Western wheatgrass. Proceedings of the Association of Official Seed Analysts, 53, 55-57.

13. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

14. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

15. Schultz, Q.E. and Kinch, R.C. (1976). The effect of temperature and growth promoters on seed dormancy in Western wheatgrass seed. Journal of Seed Technology, 1, 79-85.

16. Thompson, K., Grime, J.P. and Mason, G. (1977). Seed germination in response to diurnal fluctuations of temperature. Nature, 267, 147-149.

17. Thornton, M.L. (1966). Seed dormancy in tall wheatgrass (Agropyron elongatum). Proceedings of the Association of Official Seed Analysts, 56, 116-119.

18. Toole, V.K. (1976). Light and temperature control of germination in Agropyron smithii seeds. Plant and Cell Physiology, 17 1263-1272.

19. Williams, E.D. (1968). Preliminary studies of germination and seedling behaviour in Agropyron repens (L.) Beavu. and Agrostis gigantea Roth. Proceedings of the 9th British Weed Control Conference, Vol.1, 119-124.

20. Young, J.A. and Evans, R.A. (1982). Temperature profiles for germination of cool season range grasses. USDA, Agriculture Research Service, Agriculture Research Results, Western Series, No. 27.

AGROSTIS

A. canina L.	velvet bentgrass
A. capillaris	
A. gigantea Roth.	redtop
A. stolonifera L. [A. alba Auth.; A. maritima Lam.; A. palustris Huds.]	creeping bentgrass
A. tenuis Sibth. [A. capillaris Huds.; A. vulgaris With.]	colonial bentgrass

I. Evidence of dormancy

Freshly harvested seeds of Agrostis spp. can be very dormant (1-3,5,6,8,9,11,13-17). Between 6 and 8 months after-ripening may be required to remove dormancy (8,16), whilst seeds of A. capillaris stored for 41-44 weeks at 10°C remained dormant (17). Secondary dormancy was induced in imbibed seeds of A. capillaris exposed to an alternating temperature regime of 10°/20°C (12h/12h) in the dark (17).

II. Germination regimes for non-dormant seeds

A. canina

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 21d (ISTA)

TP: 20°/30°C (16h/8h): 21d (AOSA)

A. gigantea

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 10d (ISTA)

TP: 20°/30°C (16h/8h): 10d (AOSA)

A. stolonifera

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 28d (ISTA)

TP: 15°/30°C; 10°/30°C; 15°/25°C (16h/8h): 28d (AOSA)

A. tenuis

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 28d (ISTA)

TP: 15°/25°C; 15°/30°C; 10°/30°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

A. capillaris

Constant temperatures: 19°-22°C in dark or light, far red, 1.7×10^{-6} mol m^{-2} s^{-1}, 10 min (17)

A. gigantea

Constant temperatures: 20°C, dark (16)

Potassium nitrate: co-applied, 0.2% (9)

GA_3: co-applied, 100 ppm (9,10)

A. stolonifera

Constant temperatures: 20°C, dark (8)

A. tenuis

Constant temperatures: 20°C, dark (8); 5°-30°C (13)

Alternating temperatures: 10°/30°C (16h/8h), dark (2); 20°/30°C (16h/8h), dark (8)

IV. Partly-successful dormancy-breaking treatments

A. canina

Alternating temperatures: 15°/20°C (9h/15h) in light, 15h/d (6); 20°/30°C (16h/8h) in light, 5 lux (8)

A. capillaris

Alternating temperatures: 5°-16°/20°C, 23°-30°/20°C (12h/12h) in dark (17)

A. gigantea

Alternating temperatures: 15°/20°C (9h/15h) (6); 20°/30°C (16h/8h) (15); 20°/30°C (16h/8h) in light (9,10); 25°/30°C (16h/8h) in light (16)

Light: at 15°/20°C (9h/15h) (6)

Thiourea: co-applied, 0.2% (9)

A. stolonifera

Alternating temperatures: 15°/20°C (9h/15h) in light (6); 20°/30°C (16h/8h) in light, 50, 200 fc (8): 30°/40°C, 28°/34°C (12h/12h) (4) Light: red (14)

A. tenuis

Alternating temperatures: 10°/30°C, 15°/30°C, 20°/30°C (16h/8h) in light (2,5,8,9,11,14); 10°/30°C, 15°/30°C, 20°/30°C (18h/6h) in light (1,3); 15°/25°C (18h/6h), dark (1,11); 20°/30°C, 10°/26°C, 10°/30°C (18h/6h) (5); 20°/30°C, 5°/15°C (16h/8h) (12)

Pre-chill: 4°C, 2,7d (1); 5°C, 10°C, 33d, germinate at 10°/25°C (12h/12h) (13); 4°C, 10°C, 7d, plus potassium nitrate, co-applied, 0.2%, germinate at 20°/30°C (16h/8h) in light (2)

Warm stratification: 15°C, 20°C, 25°C, 30°C, 33d, germinate at 10°/25°C (12h/12h) (13)

Potassium nitrate: co-applied, 0.2%, at 15°/25°C (18h/6h) in dark (1); co-applied, 0.2%, at 10°/30°C, 20°/30°C (16h/8h) in light (2); co-applied, 0.2%, at 15°/25°C, 15°/30°C (15h/9h) in light (3)

V. Successful dormancy-breaking treatments

A. canina

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light, 50, 200 fc (8)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (8)

A. capillaris

Alternating temperatures: 5°-16°/20°C (12h/12h) in light, red, 1.4×10^{-6} mol m^{-2} s^{-1}, 10 min (17)

Potassium nitrate: co-applied, 2×10^{-2}, 2×10^{-3} M, at 5°-16°/20°C (12h/12h) dark (17)

GA_3: co-applied, 0.144 M, at 5°-16°/20°C in light, red, 1.4×10^{-6} mol m^{-2} s^{-1}, 10 min (17)

A. gigantea

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light (15, 16)

Pre-chill: 5°C, 10d (9)

A. stolonifera

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C, 25°/35°C (16h/8h) (7); 25°/18°C (12h/12h) (4); 15°/25°C (16h/8h) in light (14)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (8)

A. tenuis

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Alternating temperatures: 15°/30°C, 15°/35°C, 15°/40°C (16h/8h) (14); 10°/20°C (16h/8h) in light (12); 5°/19°-26°C, 9°-16°/25°C (12h/12h) (13)

Pre-chill: 5°C, 10°C, 33d, plus GA_3, co-applied, 500 ppm, germinate at 10°/25°C (12h/12h) (13); 4°C, 2-7d, plus potassium nitrate, co-applied, 0.2% (1)

Warm stratification: 15°-30°C, 33d, plus GA_3, co-applied, 500 ppm, germinate at 10°/25°C (12h/12h) (13)

Potassium nitrate:co-applied, 0.2%, germinate at 15°/25°C, 15°/30°C, 10°/30°C (16-18h/6-8h) in light (1,2,3,5,8,11)

VI. Comment

Dormant seed accessions of Agrostis spp. require light and alternating temperatures for germination (1-3,6,8,9,11,14-17): additionally potassium nitrate in the germination test medium may be of further benefit (1,8) or avoid the requirement for light (17). A brief, low intensity exposure of the seeds to light can promote germination considerably (2,8,11,17), but higher intensities can reduce the proportion of seeds germinating, e.g. 200 fc, 7.5 hours per day (8). The above tends to suggest that AOSA/ISTA prescriptions and recommendations are satisfactory, but in A. capillaris 10°/20°C (12h/12h) with a brief light treatment has been suggested (17).

VII. References

1. Andersen, A.M. (1944). Germination of freshly harvested seed of Western grown Astoria bentgrass. Proceedings of the Association of Official Seed Analysts, 35, 138-146.

2. Andersen, A.M. (1946). The effect of light, temperature and potassium nitrate on the germination of Agrostis tenuis Sibth. and A. tenu is var. Highland seed. Procedures of the Association of Official Seed Analysts, 36, 112-125.

3. Bass, L.N. (1959). Comparison of germination percentages obtained for highland bentgrass

seed tested at different temperature alternations. Proceedings of the Association of Official Seed Analysts, 49, 73-76.

4. Eggens, J.L. and Ormrod, D.P. (1982). Creeping bentgrass, Kentucky bluegrass and annual bluegrass seed germination response to elevated temperature. HortScience, 17, 624-625.

5. Gadd, I. (1955). Germination of seed of New Zealand browntop, Agrostis tenuis Sibth. Proceedings of the International Seed Testing Association, 20, 29-45.

6. Grime, J.P., Mason, G., Curtis, A.V., Rodman, J, Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. Journal of Ecology, 69, 1017-1059.

7. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-33 2.

8. Leggatt, C.W. (1946). Germination of seeds of three species of Agrostis. Canadian Journal of Research, C, 24, 7-21.

9. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

10. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

11. Pierpoint, M. and Jensen, L. (1958). Activation of germination of Highland bentgrass by infra-red lamp. Proceedings of the Association of Official Seed Analysts, 48, 75-80.

12. Schmidt, B. (1969). [On the influence of temperature at the course of germination of some important lawn grasses.] Saatgut Wirtschaft, 21, 584-589.

13. Schonfeld, M.A. and Chancellor, R.J. (1983). Factors influencing seed movement and dormancy in grass seeds. Grass and Forage Science, 38, 243-250.

14. Toole, V.K. and Koch, E.J. (1977). Light and temperature control of dormancy and germination in bentgrass seeds. Crop Science, 17, 806-811.

15. Williams, E.D. (1968). Preliminary studies of germination and seedling behaviour in Agropyron repens (L.) Beauv. and Agrostis gigante ea Roth. Proceedings of the 9th British Weed Control Conference, Vol. 1, 119-124.

16. Williams, E.D. (1973). Seed germination of Agrostis gigantea Roth. Weed Research, 13, 310-324.

17. Williams, E.D. (1983). Effects of temperature fluctuation, red and far-red light and nitrate on seed germination of five grasses. Journal of Applied Ecology, 20, 923-935.

ANDROPOGON

A. gayanus Kunth	gamba grass
A. furcatus Muhl.	big bluestem
A. gerardii Vitm.	big bluestem
A. gerardii Vitm. x A. hallii Hack.	champ bluestem
A. hallii Hack.	sand bluestem
A. ischaemum L.	bluestem

A. scoparius Michx. little bluestem

I. Evidence of dormancy

A. furcatus (2), A. gerardii (1,4,8), A. hallii (7) and A. scoparius (2,8) show considerable seed dormancy. For example, seeds of A. hallii and A. gerardii after-ripened for 1 (7) and 4 years (4) respectively remained dormant. Reports of dormancy in A. gayanus conflict: seeds have been reported to show both considerable dormancy (10) and no dormancy (12).

II. Germination regimes for non-dormant seeds

A. gayanus

Alternating temperatures: 25°/35°C (12h/12h) in light, $3.2x10^{-6}$ W cm^{-2} (12)

A. gerardii, A. hallii

TP; S: 20°/30°C (16h/8h): 28d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light, fluorescent, 16h/d (5)

III. Unsuccessful dormancy-breaking treatments

A. gayanus

Hydrogen peroxide: co-applied, 1, 1.5 M (10)

A. gerardii

Phosphine: fumigation, 120h, 3920-4720 ppm (9)

A. hallii

Light: 15000 lux, 8,12,16h/d (7) pH: 2.5 (6)

A. ischaemum, A. scoparius

Phosphine: fumigation, 120h, 3920-4720 ppm (9)

IV. Partly-successful dormancy-breaking treatments

A. gayanus

Pre-chill: 5°C, 2w (10)

Potassium nitrate: co-applied, 0.1-0.3% (10)

Hydrogen peroxide: co-applied, 0.5 M (10)

GA_3: co-applied, 250-1000 ppm (10)

Removal of seed covering structures: (10)

A. gerardii

Alternating temperatures: 15°/30°C, 20°/30°C (16h/8h) (1); 10°/20°C (6h/18h) in dark or light, 400-500 fc, 6h/d in 20°C cycle (4);20°/30°C (16h/8h) in light (11)

Pre-chill: 5°-8°C, 2w (1); 5°C, 10°C, 14d (11); then germinate at 20°/30°C (16h/8h) in light,

14d (14); 5°C, 10°C, 14d, plus potassium nitrate, co-applied, 0.2% (11)

GA_3: pre-applied, 24h, 100 ppm (4); pre-applied, 10-500 ppm (8)

Potassium nitrate: co-applied, 0.2% (11)

A. hallii

Constant temperatures: 25°C, 30°C, 35°C (7)

Alternating temperatures: 15°/25°C, 20°/30°C, 25°/35°C (16h/8h) in light or dark (7)

Pre-chill: then germinate at 20°/30°C (16h/8h) in light, 14d (14)

pH: 4-11.5 (6)

Phosphine: fumigation, 120h, 3920-4720 ppm (9)

A. scoparius

GA_3: pre-applied, 10-500 ppm (8)

V. Successful dormancy-breaking treatments

A. gerardii, A. hallii

Light, Pre-chill, Potassium nitrate (AOSA)

VI. Comment

Seeds of A. gayanus are likely to cause the greatest problems of dormancy, but it is important to ensure that the problem of lack of germination is not caused by empty seeds. The following germination test procedures have been recommended as at least partly effective in promoting the germination of dormant seeds of this species: germinate on top of filter papers - moistened optionally with potassium nitrate (probably 0.2%) - at 20°/35°C (presumably 16h/8h) with light for 21 days (3); germinate on top of filter papers moistened with potassium nitrate at 20°/30°C (16h/8h) with light applied for 8 hours per day for 28 days (3).

In a comparison of germination test results from different laboratories with seeds of A. gerardii x A. hallii at 15°/30°C or 20°/30°C (16h/8h) with no pre-chill or a 2 week pre-chill treatment at 5°C, 7°C or 8°C, the regime 20°/30°C after pre-chill at 7°C gave significantly greater germination (1), but the difference was only marginal. The pre-chill treatments were, however, beneficial (1).

Although most of the results for A. hallii were from tests where light was applied for 8 hours per day during the high temperature phase of the alternating temperature cycle (e.g. 6), there is one report of light being applied for 16 hours per day during the low temperature phase of the alternating temperature cycle (5). This is unlikely to be of any particular benefit (7). For this species a constant germination test temperature of 35°C or an alternating temperature regime of 25°/35°C (16h/8h) have been recommended (7).

It is suggested that seeds of Andropogon spp. be tested for germination at 20°/35°C (16h/8h) for at least 28 days with potassium nitrate co-applied at 0.2% and the light regime described in Chapter 6 after a 2-week pre-chill treatment at 5°-7°C. Alternatively removal of the seed covering structures - with subsequent testing at 20°/35°C (16h/8h) in light, 8h/d - can avoid the need to pre-chill and co-apply potassium nitrate (13).

References

1. Atkins, B.A. (1977). Variations on purities, germination and PLS (pure live seed) on champ bluestem. Journal of Seed Technology, 2 40-47.

2. Coukos, C.J. (1944). Seed dormancy and germination in some native grasses. Journal of American Society of Agronomy, 36, 337-345.

3. Ferguson, J.E. (1982). C.I.A.T. (Personal communication).

4. Kucera, C.L. (1966). Some effects of gibberellic acid on grass seed germination. Iowa State Journal of Science, 41, 137-143.

5. Shaidaee, G., Dahl, B.E. and Hansen, R.M. (1969). Germination and emergence of different age seed of six grasses. Journal of Range Management, 22, 240-243.

6. Stubbendieck, J. (1974). Effect of pH on germination of three grass species. Journal of Range Management, 27, 78-79.

7. Stubbendieck, J. and McCully, W.G. (1976). Effect of temperature and photoperiod on germination and survival of sand bluestem. Journal of Range Management, 29, 206-208.

8. Svedarsky, D. and Kucera, C.L. (1970). Effects of gibberellic acid and post-harvest age on germination of prafrie grasses. Iowa State Journal of Science, 44, 513-518.

9. White, G.D. and Jacobson, E.T. (1972). Phosphine fumigation: effects on the germination of grass seed. Journal of Economic Entomology, 65, 1523-1524.

10. Eira, M.T.S. (1983). [Comparison of methods for overcoming seed dormancy in Andropogon grass.] Revista Brasileira de Sementes, 5, 37-49.

11. Faroua, H., Ahring, R.M., Powell, J. and Rommann, L.M. (1976). Increasing seed germination of rangeland species. Oklahoma Agricultural Experiment Station, Research Report No. P.735, pp. 27-30.

12. Felippe, G.M., Silva, J.C.S. and Cardoso, V.J.M. (1983). Germination studies in Andropogon gayanus Kunth. Revista Brasileira de Botanica, 6, 41-48.

13. Goedert, C. (1984). Seed dormancy of tropical forage grasses and implications for the conservation of genetic resources. Ph.D. Thesis, University of Reading.

14. Prentice, L.J. (1981). Observations on the germination time on rangegrasses. Newsletter of the Association of Official Seed Analysts, 55, 59.

ARISTIDA

A. armata

A. contorta F. Muell.

A. longespica Poir.

A. longiseta

A. murina Cay.

A. purpurea

A. ramosa R. Br.

I. Evidence of dormancy

Seed lots of A. armata, A. ramosa, A. contorta and A. longespica have shown considerable dormancy requiring after-ripening periods of between 4 and 18 months for dormancy to be removed (1,2,6-8).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

A. contorta

Pre-chill: 5°C, 8w (7)

A. longespica

Constant temperatures: 10°C, 20°C, 30°C in light, 12h/d, or dark (1)

Potassium nitrate: co-applied, 200 ppm (1)

GA_3: co-applied, 200 ppm (1)

Thiourea: co-applied, 200 ppm (1)

A. longiseta

Constant temperatures: 20°C, 25°C, 35°C (3,5)

Pre-chill: 0°C (3)

A. murina

Light: fluorescent, 2.2 W m^{-2}, 12h/d, at 20°C, (4); red, 0.37 W m^{-2}, 5,25 min, at 20°C (4)

IV. Partly-successful dormancy-breaking treatments

A. armata

Alternating temperatures: 25°/30°C (12h/12h) in light (2)

Pre-chill: 4°C, 6w (2)

Pre-dry: 70°C (2)

A. contorta

Constant temperatures: 30°C in light (8)

Alternating temperatures: 25°/30°C (12h/12h) (7)

Scarification: sand paper (7)

Pre-soak: 48h (7)

GA_3: co-applied, 10^{-5}g/ml, with or without seed covering structures (8)

Thiourea: co-applied, 10^{-2} M, with or without seed covering structures (8)

Removal of seed covering structures: seed coat (8)

Hydrogen peroxide: pre-applied, 48h, 1 M (8)

Potassium cyanide: pre-applied, 24h, 10^{-2} M (8)

Sodium azide: pre-applied, 24h, 10^{-3} M (8)

A. ramosa

Constant temperatures: 20°-30°C (6)

Light: (6)

Removal of seed covering structures: seed coat (6)

V. Successful dormancy-breaking treatments

A. armata

Alternating temperatures: 25°/30°C (12h/12h), in light, dehulled seed (2)

A. contorta

Alternating temperatures: 25°/30°C (night/day), dehulled seed (7)

A. longespica

Pre-chill: 5°C, 12-24w, germinate at 30°C in light, 12h/d (1)

Removal of seed covering structures: excise embryo, germinate at 30°C in light, 12h/d (1)

A. longiseta

Alternating temperatures: 20°-24°/41°C (night/day) (3)

VI. Comment

Successful germination test regimes for accessions of Aristida spp. are likely to include alternating temperatures, seed coat removal, and probably light (low intensity). The amplitude of temperature alternation required to promote full germination does not appear to be particularly great - 5°C (2,7) - although greater amplitudes may also be satisfactory - 17°C (3). For the present it is suggested that the regime 25°/30°C (12h/12h) be used after the seed coats have first been removed.

VII. References

1. Baskin, J.M. and Caudle, C. (1967). Germination and dormancy in cedar glade plants. I. Aristida longespica and Sporobolus vaginiflorus. Journal of the Tennessee Academy of Science, 42, 132-133.

2. Brown, R.F. (1982). Seed dormancy in Aristida armata. Australian Journal of Botany, 30, 67-73.

3. Evans, G.R. and Tisdale, E.W. (1972). Ecological characteristics of Aristida longiseta and Agropyron spicatum in West-Central Idah o. Ecology, 53, 137-142.

4. Ginzo, H.D. (1978). Red and far red inhibition of germination in Aristida murina Cav. Zeitschrift fur Pflanzenphysiologie, 90, 303-307.

5. Jackson, C.V. (1928). Seed germination in certain New Mexico range grasses. Botanical Gazette, 86, 270-294.

6. Lodge, G.M. and Whalley, R.D.B. (1982). Establishment of warm- and cool-season native perennial grasses on the north-west slopes of New South Wales. I. Dormancy and germination. Australian Journal of Botany, 29, 111-119.

7. Mott, J.J. (1972). Germination studies on some annual species from an arid region of Western Australia. Journal of Ecology, 60, 293-304.

8. Mott, J.J. (1974). Mechanisms controlling dormancy in the arid zone grass Aristida contorta. I. Physiology and mechanisms of dormancy. Australian Journal of Botany, 22, 635-645.

AVENA

A. barbata Brot.	slender wild oat
A. byzantina K. Koch	red oat
A. fatua L.	spring or common wild oat
A. ludoviciana Durieu	winter wild oat
A. nuda L.	naked oat
A. sativa L.	common oat
A. sativa L. x A. fatua L.	dormoat
A. sterilis L.	animated oat
A. strigosa Schreber	bristle or small oat

I. Evidence of dormancy

Dormancy is common in the cultivated oat A. sativa (2,10,16,50,53), and pronounced in the wild oat species A. barbata (35,37), A. byzantina (13,48), A. fatua (1,5,6,9,21,30,31,42,51,52), A. ludoviciana (44,45,54), A. nuda (10), A. sterilis (13), and the hybrid dormoat A. sativa x A. fatua (3,18).

II. Germination regimes for non-dormant seeds

A. byzantina, A. sativa

BP; S: 20°C; 15°C: 10d (AOSA)

BP; S: 20°C: 10d (ISTA)

III. Unsuccessful dormancy-breaking treatments

A. byzantina

Pre-soak: 20h (48)

A. fatua

Constant temperatures: 5°-30°C (8); 5°-15°C (17); above 25°C (17,39,41,43,49)

Alternating temperatures: 10°-40°/40°-10°C (39)

Light: (5,23,28,31,39); $6x10^3$ erg cm^{-2} s^{-1} (21); white, blue, infra-red, red (14)

Oxygen: below 20% (5,21)

Carbon dioxide: 0-20% (21)

Pre-soak: 10°C, 48h (22); 25°C, 16-112h (23); 15 min-8h (26)

Aluminium phosphide: 48,72h fumigation (11)

Sodium azide: co-applied, $2x10^{-3}$ M (15); co-applied, $1\text{-}2x10^{-4}$ M (52); co-applied, 2, $4x10^{-3}$ M (52); co-applied, 10^{-3} M, plus 2-chloroethyl trimethylammonium chloride, co-applied, $5x10^{-2}$ M (52); co-applied, 10^{-3} M, plus salicylhydroxamic acid, co-applied, $3x10^{-3}$ M (52)

GA_3: co-applied, 1, 1000 ppm, in light (28); co-applied, 10^{-8}-10^{-5} M, intact or dehulled seeds (26)

Thiourea: co-applied, 10^{-2}-10^{-4} M (25)

Kinetin: co-applied, 10^{-4}-10^{-5} M (25)

Ethrel: co-applied, 10-500 ppm (25)

Naphthylacetic acid: co-applied, 10^{-6} M (25)

Abscisic acid: co-applied, 10^{-3}, 10^{-4} M (25)

Ethylene chlorohydrin: pre-applied, 1 min, 1, 3, 6% (31)

Dichloroethylene: pre-applied, 1 min, 0.1-1% (31)

Sodium thiocyanate: pre-applied, 1h, 2, 3% (31)

Potassium nitrite; co-applied, 1 M (39)

Methylene blue:pre-applied, 24h, 10^{-3} M (47)

Reduced nitrogenous compounds: pre-applied, 24h (47)

Sodium fluoride: pre-applied, 24h, 10^{-2}, 10^{-3} M (47)

2-4 Dinitrophenol: pre-applied, 24h, 10^{-3}-10^{-6} M (47)

Sodium arsenate: pre-applied, 24h, 10^{-2}, 10^{-3} M (47)

Sodium hypochlorite: pre-applied, 1 min-6h, 6% (26); pre-applied, 0.25-2h, $8x10^{-1}$ M (29); co-applied, dehulled seed, $1.3\text{-}135x10^{-3}$ M (29)

Sucrose: (22)

Hydrogen peroxide: co-applied, $0.375\text{-}3x10^{-1}$ M (29); co-applied, $1.5x10^{-1}$ M, dehulled seeds (29)

Removal of seed covering structures: (26,29,31); pierce, germinate in excess water (29)

Pre-dry: (25)

A. ludoviciana

Light: (54)

A. sativa

Vacuum: partial, 10,30 min (16)

Carbon dioxide: 30-38.7%, plus 12.8-14.7% oxygen (16)

Pre-soak: 1-5h (20); 12,24h (23,34)

Potassium cyanide: pre-applied, 24h, 10^{-4} M (36)

Sodium azide: pre-applied, 24h, 10^{-2} M (36)

Sodium sulphide: pre-applied, 24h, 10^{-3}, 10^{-4} M (36)

Hydroxylamine: pre-applied, 24h, 10^{-1}, 10^{-3}, 10^{-4} M (36)

Dimercaptol: pre-applied, 24h, 10^{-3}, 10^{-4} M (36)

Diethyldithiocarbamate: pre-applied, 24h, 10^{-3}M (36)

Iodoacetate: pre-applied, 24h, 10^{-3}, 10^{-4} M (36)

Sodium monofluoroacetate: pre-applied, 24h, 10^{-3} M (36)

2,4 Dinitrophenol: pre-applied, 24h, 10^{-2}-10^{-6} M (36)

A. sativa x A. fatua

Removal of seed covering structures: (3)

Warm stratification: 20°C, 1-4d, germinate at 3°C, 7°C (3)

GA_3: co-applied, 0.1, 1 ppm, dehulled seeds (3)

IV. Partly-successful dormancy-breaking treatments

A. barbata

Removal of seed covering structures: pricking (37)

A. byzantina

Pre-chill: 7°C, 5d (48)

Pre-dry: (48)

Scarification: sulphuric acid, 10%, 5 min, then pre-dry, 2h, then

GA_3, pre-applied, 20h, 100, 250, 500 ppm (48); sulphuric acid, 10%, 5 min, then pre-dry, 2h, then potassium nitrate, pre-applied, 20h, 0.1, 0.2, 0.5% (48)

A. fatua

Constant temperatures: 10°C (39,54); 10°-25°C (17,43); 15°C (1,44); 3°C, 10°C (40); 8°-16°C (42)

Alternating temperatures: 11°/14°-23°C (12h/12h) (43); 17°/20°-30°C (12h/12h) (43)

Light: dark (14,21,23,28,31,39)

Removal of seed covering structures: (5,6,9,21); cut, pierce or prick (6,27,28,29,37,54,58)

Ethrel: co-applied, 100-5000 ppm (1)

Potassium nitrate: pre-applied, 24, 48h, 0.2-2% (31); pre-applied, 1-6h, 1% (31); co-applied, 10^{-2}M (39,40); co-applied, 0.2% (23); co-applied, 0.2%, plus pre-chill, 5°-7°C, 10-14d (6)

Potassium nitrite: co-applied, 10^{-4} -10^{-1} M (39)

Potassium cyanide: pre-applied, 24h, 10^{-2} -10^{-4} M (47)

Sodium nitrate: co-applied, 0.2% (23)

Sodium nitrite: pre-applied, 24h, 10^{-2} M (47)

Sodium azide: pre-applied, 3,6h, 0.5-2x10^{-3}, M (15); pre-applied, 24h, 10^{-3}, 10^{-4} M (47); co-applied, 0.5x10^{-3}, 10^{-3} M (15); co-applied, 0.2-2x10^{-3} M (52)

Sodium hypochlorite: pre-applied, 1.5h, 0.8 M (29); pre-applied, 0.5-2h, 0.8 M, then GA_3, co-applied, 10^{-8} -10^{-3} M (26); pre-applied, 15,30 min, 0.8 M, dehulled seeds or naked caryopses (29); pre-applied, 1-30s, 0.8 M, dehulled seeds, then GA_3, co-applied, 5x10^{-4} M (29); pre-applied, 3h, 0.8 M, dehulled seeds (29); pre-applied, 6h, 0.54-0.8 M, dehulled seeds (29); pre-applied, 1h, 0.8 M, then hydrogen peroxide, co-applied, 0.15 M (29); co-applied, 5.4x10^{-3} M - 0.1 M, dehulled seeds (29)

Sodium thiocyanate: pre-applied, 1h, 1% (31)

GA_3: pre-applied, 30 min, 1,10,100 ppm (6); pre-applied, 24h, 400 ppm (55); co-applied, 10 ppm (6); co-applied, 25,50 ppm (19); co-applied, 10^{-2} M (25,39); co-applied, 50-500 ppm, light (28); co-applied, 1-500 ppm, dark (28); co-applied, 10^{-4} -10^{-3} M, intact or dehulled seeds (26,29); co-applied, 500, 1000, 2500 ppm (46); co-applied, 1500 ppm (51); co-applied, 1.44x10^{-3} M (58)

Hydrogen peroxide: co-applied, 0.1 M (22); co-applied, 0.15 M, intact, pierced, or dehulled seeds (29); co-applied, 37.5x10^{-3} -1.5x10^{-1} M, dehulled seeds (29); co-applied, 10^{-2} M, dehulled seeds (23)

Oxygen: above 20% (5); 20-80% (6,21); 60, 100% (31)

Pre-chill: 0°C, 90d (31)

Pre-soak: 48h (22,31)

Ether: (31)

Aluminium phosphide: 6-18h fumigation (11)

Removal of seed covering structures: pierce, plus GA_3, co-applied, 10^{-8} -10^{-3} M (27); dehull, pierce, plus GA_3, co-applied, 10^{-8} M (26); dehull, scarify (6,31)

A. ludoviciana

Removal of seed covering structures: (54)

A. sativa

Pre-chill: 5°C, 3d (2)

Potassium cyanide: pre-applied, 24h, 10^{-2}, 10^{-3} M (36)

Sodium azide: pre-applied, 24h, 10^{-3}, 10^{-4} M (36)

Hydrogen sulphide: pre-applied, 24h, 10^{-1}, 10^{-2} M (36)

Hydroxylamine: pre-applied, 24h, 10^{-2}, M (36)

Diethyldithiocarbamate: pre-applied, 24h, 10^{-4}, M (36)

Malonate: pre-applied, 24h, 10^{-1}, 10^{-2} M (36)

Sodium monofluoroacetate: pre-applied, 24h, 10^{-2} M (36)

Sodium sulphide: pre-applied, 24h, 10^{-1}, 10^{-2} M (36)

GA_3: co-applied, 20 ppm (32,33); co-applied, 400-800 ppm (34); pre-applied, 15-18h, 150 ppm (2)

Pre-dry: 2d (2); 50°C, 2d plus 70°C, 5h (2); 40°C, 12h (16); 40°C, 5d (20); 50°C, 2d, then pre-chill, 5°C, 3d (2)

Removal of seed covering structures: (16,32,50)

Vacuum: partial, 1h (16)

A. sativa x A. fatua

Pre-chill: 3°-7°C, 1-4d (3)

GA_3: co-applied, 10, 100 ppm, dehulled seeds (3); co-applied, 0.1-10 ppm, peeled caryopses (3)

A. sterilis

Removal of seed covering structures: dehull (59)

V. Successful dormancy-breaking treatments

A. barbata

Constant temperatures: 10°C (56)

Alternating temperatures: 5°/20°C, 5°/15°C (16h/8h) (56)

A. byzantina

Pre-dry, Pre-chill, GA_3 (ISTA)

Pre-chill, Pre-dry (AOSA)

A. fatua

Constant temperatures: 4°C (41,49)

Warm stratification: 20°C, 21d, plus GA_3, co-applied, $1.4x10^{-4}$ M (52)

GA_3: co-applied, 1000 ppm (6,28); co-applied, 100 ppm (19); co-applied, 100 ppm, dehulled seeds (23)

Sodium azide: pre-applied, 6h, 10^{-3} M (15); pre-applied, 21d, dark, $0.8x10^{-3}$, 10^{-3} M, then GA_3, co-applied, $1.4x10^{-4}$ M (52); co-applied, $0.8x10^{-3}$, 10^{-3} M, plus GA_3, $1.4x10^{-4}$, $2.8x10^{-4}$ M (52)

Potassium nitrate: pre-applied, 12,24h, 1% (31); pre-applied, 1-24h, 2% (31); co-applied, $2x10^{-4}$ -$2x10^{-2}$ M, in light (57)

Removal of seed covering structures: (22,28); plus oxygen, 100% (9); dehull and prick (5,14,23,29); dehull, prick and re-prick (39); dehull, prick, plus GA_3, co-applied, 10 ppm (42); dehull, prick, plus GA_3, co-applied, 10^{-7} -10^{-3} M (27); prick, plus GA_3, co-applied, $1.44x10^{-3}$ M, at 15°C in light, $10.7x10^{-6}$ mol m^{-2} s^{-1}, 8h/d (58); dehull, prick, plus hydrogen peroxide, co-applied, 0.15 M (26); dehull, plus sodium hypochlorite, pre-applied, 1h, 0.8 M (26,29); dehull, plus sodium hypochlorite, pre-applied, 1h, 0.8 M, then GA_3, co-applied, 10^{-8} -10^{-3} M (26,29); dehull, plus sodium hypochlorite, pre-applied, 1h, 0.8 M, then hydrogen peroxide, co-applied, 0.15 M (29); dehull, plus sodium hypochlorite, pre-applied, 1h, 0.8 M, then GA_3, co-applied, $5x10^{-4}$ M (29)

Sodium hypochlorite: pre-applied, 2h, 0.8 M, then GA_3, co-applied, 10^{-4} M (26); pre-applied, 2h, 0.8 M, then dehull (29)

Hydrogen peroxide: co-applied, 0.3 M, dehulled seeds (29); co-applied, 0.15 M, dehulled seeds in excess moisture (29)

Aluminium phosphide: 18-24h fumigation (11)

A. sativa

Pre-dry, Pre-chill, GA_3 (ISTA)

Pre-chill, Pre-dry (AOSA)

Constant temperatures: 12°-15°C (2); 7°-17°C (4); 4°-24°C (41); 5°-12°C (20); 6°-14°C (38); 4°-12°C (50); 2°C, 10°C (10); 7.5°C (12); 12°C, 7d, then 20°C, 3d (33,34); 15°C (13,24)

Pre-chill: 4°C, 4d (50); 10°C, 5d (16); 5°C, 6d (53); 5°C, 7d (32)

GA_3: co-applied, 200 ppm (32,33); co-applied, 400 ppm (32,34); co-applied, 500 ppm (7)

Potassium nitrate: co-applied, 0.2% (24,50); pre-applied 1h, 2% (50); co-applied, 0.2%, plus pre-chill, 10°C, 5d (32); co-applied, 0.2%, dehull (24)

Calcium nitrate: co-applied, 0.2% (50); pre-applied, 1h, 2% (50)

Ammonium nitrate: co-applied, 0.2% (50); pre-applied, 1h, 2% (50)

Removal of seed covering structures: (53); dehull, pre-chill, 10°C, 5d (16); dehull, prick (16,20)

Oxygen: 51, 59, 100% (16)

A. sativa x A. fatua

Constant temperatures: 7°C (3)

GA_3: co-applied, 100 ppm, naked caryopses (3)

Removal of seed covering structures: excise embryo (3)

VI. Comment

A low constant temperature is an essential component of suitable germination test regimes for accessions of Avena spp. The range 7° to 10°C is suggested as being the most suitable.

A. byzantina The ISTA and AOSA recommendations for breaking dormancy (pre-chill, pre-dry, potassium nitrate) are not completely effective in promoting the germination of dormant seeds of A. byzantina (48).

A. fatua Procedures which combine the action of several dormancy-breaking agents are more likely to be successful (e.g. 29). The following procedure has been found to be satisfactory. Test at 7.5° to 10°C for 28 days with removal of the seed covering structures once the seed has imbibed, pricking in the area of the embryo, and subsequent repricking of ungerminated seeds after 28 days and continue test for a further period (39,A). An alternative procedure (which is equally effective but delays the time at which the onerous task of removing seed coats and pricking is performed and reduces the number of seeds pricked) is to test intact seeds at 7.5° to 10°C for 21 days, then remove seed covering structures and prick ungerminated seeds in the area of the embryo and test for a further 21 days at 7.5° to 10°C (A). Another alternative is to prick the seeds and test in light with gibberellic acid co-applied at 1.44×10^{-3} M (58). Note that light tends to promote the germination of partly-dormant seed lots but is ineffective with strongly dormant seed lots (58) - unless combined with several other dormancy-breaking agents.

A. sativa Testing at low temperatures is the most satisfactory method of promoting germination in the cultivated oat (2,4,10,12,13,16,20,24,32,34,37,38,42). Testing at between 7.5° and 10°C for 28 days is recommended (A). Not only does this promote full germination of the dormant seeds but it is also safe for non-dormant and aged seeds (A).

VII. References

1. Adkins, S.W. and Ross, J.D. (1981). Studies in wild oat seed dormancy. I. The role of ethylene in dormancy breakage and germination of wild oat seeds (Avena fatua L.). Plant Physiology, 67, 358-362.

2. Andersen, S. (1965). The germination of freshly harvested seed of ripe and unripe barley and oats. Euphytica, 14, 91-96.

3. Andrews, C.J. and Burrows, V.D. (1972). Germination response of dormoat seeds to low temperature and gibberellin. Canadian Journal of Plant Science, 52, 295-303.

4. Atterberg, A. (1907). Die Nachreife des Getreides. Landwirtsch Versuch Stat, 67, 129-143.

5. Atwood, W.M. (1914). A physiological study of the germination of Avena fatua. Botanical Gazette, 57, 386-414.

6. Baker, L.O. and Leighty, D.H. (1958). Germination studies with wild oat seeds. Proceedings 16th West Weed Control Conference, 69-74.

7. Bekendam, J. (1975). Report of the working group on the application of gibberellic acid in routine germination testing to break dormancy of cereal seed. Seed Science and Technology, 3, 92-93.

8. Bewley, J.D. and Black, M. (1982). Physiology and biochemistry of seeds in relation to germination. Volume 2. Viability, dormancy and environmental control. Springer-Verlag, Berlin.

9. Black, M. (1959). Dormancy studies in seed of Avena fatua. I. The possible role of germination inhibitors. Canadian Journal of Botany, 37, 393-402.

10. Brown, E., Stanton, T.R., Wiebe, G.A. and Martin, J.H. (1948). Dormancy and the effect of storage on oats, barley, and sorghum. USDA Technical Bulletin, No. 953.

11. Cairns, A.L.P. and Villiers, O.T. de (1980). Effect of aluminium phosphide fumigation on the dormancy and viability of Avena fatua seed. South African Journal of Science, 76, 323.

12. Chippindale, H.G. (1934). The effect of soaking in water on the "seeds" of some gramineae. Annals of Applied Biology, 21, 225-232

13. Coffman, F.A. and Stanton, T.R. (1938). Variability in germination of freshly harvested Avena. Journal of Agricultural Research, 57-72.

14. Cumming, B.G. and Hay, J.R. (1958). Light and dormancy in wild oats (Avena fatua L.). Nature, 182, 609-610.

15. Fay, P.K. and Gorecki, R.S. (1978). Stimulating germination of dormant wild oat (Avena fatua) seed with sodium azide. Weed Science, 26, 323-326.

16. Forward, B.F. (1958). Studies of germination in oats. Proceedings of the International Seed Testing Association, 23, 5-37.

17. Friesen, G. and Shebeski, L.H. (1961). The influence of temperature on the germination of wild oat seeds. Weeds, 9, 634-638.

18. Garber, R.J. and Quisenberry, K.S. (1923). Delayed germination and the origin of false wild oats. The Journal of Heredity, 14, 267-274.

19. Green, J.G. and Helgeson, E.A. (1957). The effect of gibberellic acid on dormant seeds of wild oats. Proceedings 14th North Central Weed Control Conference, USA, 39.

20. Harrington, G.T. (1923). Forcing the germination of freshly harvested wheat and other cereals. Journal of Agricultural Research, 23, 79-100.

21. Hart, J.W. and Berrie, A.M.M. (1966). The germination of Avena fatua under different gaseous environments. Physiologia Plantarum, 19, 1020-1025.

22. Hay, J.R. (1962). Experiments on the mechanism of induced dormancy in wild oats, Avena fatua L. Canadian Journal of Botany, 40, 191-202.

23. Hay, J.R. and Cumming, B.G. (1959). A method for inducing dormancy in wild oats (Avena fatua L.). Weeds, 7, 34-40.

24. Heit, C.E. (1948). Thirty-eighth annual meeting. Report of subcommittee on dormancy of seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

25. Holm, R.E. and Miller, M.R. (1972). Weed seed germination responses to chemical and physical treatments. Weed Science, 20, 150-15

26. Hsiao, A.I. (1979). The effect of sodium hypochlorite and gibberellic acid on seed dormancy and germination of wild oats (Avena fatua). Canadian Journal of Botany, 57, 1729-1734.

27. Hsiao, A.I., McIntyre, G.I. and Hanes, J.A. (1983). Seed dormancy in Avena fatua. 1. Induction of germination by mechanical injury. Botanical Gazette, 144, 217-222.

28. Hsiao, A.I. and Simpson, G.M. (1971). Dormancy studies in seed of Avena fatua. 7. The effects of light and variation in water regime on germination. Canadian Journal of Botany, 49, 1347-1357.

29. Hsiao, A.I. and Quick, W.A. (1984). Actions of sodium hypochlorite and hydrogen peroxide on seed dormancy and germination of wild oats (Avena fatua). Weed Research, 24, 411-419.

30. Jana, S., Acharya, S.N. and Naylor, J.M. (1979). Dormancy studies in seed of Avena fatua. 10. On the inheritance of germination behaviour. Canadian Journal of Botany, 57, 1663-1667.

31. Johnson, L.P.V. (1935). General preliminary studies on the physiology of delayed germination in Avena fatua. Canadian Journal of Research, Section C, 13, 283-300.

32. Kahre, L. (1969). Comparisons of methods for germination. Report from the working group on cereal seed. Proceedings of the International Seed Testing Association, 34, 585-598.

33. Kahre, L., Kolk, N. and Fridz, T. (1965). Gibberellic acid for breaking of dormancy in cereal seed. Proceedings of the International Seed Testing Association, 30, 887-891.

34. Kahre, L., Kolk, H. and Wiberg, H. (1962). Note on dormancy-breaking in seeds. (Cereals and Timothy). Proceedings of the International Seed Testing Association, 27, 679-683.

35. Laude, H.M. (1956). Germination of freshly harvested seed of some western range species. Journal of Range Management, 9, 126-129.

36. Major, W. and Roberts, E.H. (1968). Dormancy in cereal seeds. I. The effects of oxygen and respiratory inhibitors. Journal of Experimental Botany, 58, 77-89.

37. Marshall, D.R. and Jain, S.K. (1970). Seed predation and dormancy in the population dynamics of Avena fatua and A. barbata. Ecology, 51, 886-891.

38. Munerati, M.O. (1926). Possibilité de déterminer l'âge des graines de blé par la temperature de leur germination. Comptes Rendus de l'Académie des Sciences, Paris, 182, 535-537.

39. Murdoch, A.J. (1982). Factors influencing the depletion of annual weed seeds in the soil. Ph.D. Thesis, University of Reading, UK.

40. Murdoch, A.J. and Roberts, E.H. (1982). Biological and financial criteria of long-term control strategies for annual weeds. Proceedings 1982 British Crop Protection Conference Weeds. 741-748.

41. Naylor, J.M. and Fedec, P. (1978). Dormancy studies in seed of Avena fatua. 8. Genetic diversity affecting reponse to temperature. Canadian Journal of Botany, 56, 2224-2229.

42. Naylor, J.M. and Jana, S. (1976). Genetic adaptation for seed dormancy in Avena fatua.

Canadian Journal of Botany, 54, 306-312.

43. Paterson, J.G., Boyd, W.J.R. and Goodchild, N.A. (1976). Effect of temperature and depth of burial on the persistence of seed of Avena fatua L. in western Australia. Journal of Applied Ecology, 13, 841-847.

44. Quail, P.H. and Carter, O.G. (1968). Survival and seasonal germination of seeds of Avena fatua and A. ludoviciana. Australian Journal of Agricultural Research, 19, 721-729.

45. Quail, P.H. and Carter, O.G. (1969). Dormancy in seeds of Avena ludoviciana and A. fatua. Australian Journal of Agricultural Research, 20, 1-11.

46. Richardson, S.G. (1979). Factors influencing the development of primary dormancy in wild oat seeds. Canadian Journal of Plant Science, 59, 777-784.

47. Roberts, E.H. and Madden, D. Cited by Roberts, E.H. (1972). Oxidative processes and the control of seed germination. In Seed Ecology (ed. W. Heydecker), pp. 189-218, Butterworths, London.

48. Santacruz, R.F. (1981). [Response of oats to seed dormancy breaking treatment.] ICA. Information Colombia, 15, 6-9. (From Seed Abstracts, 1983, 6, 2205.)

49. Sawhney, R. and Naylor. J.M. (1980). Dormancy studies in seed of Avena fatua. 12. Influence of temperature on germination behavior of non-dormant families. Canadian Journal of Botany, 58, 578-581.

50. Schwendiman, A. and Shands, H.L. (1943). Delayed germination on seed dormancy in vicland oats. Journal of American Society of Agronomy, 35, 681-688.

51. Somody, C.N., Nalewaja, J.D. and Miller, S.D. (1981). Morphology characteristics and dormancy of 1200 wild oat selections. Proceedings of North Central Weed Control Conference, 36, 34.

52. Upadhyaya, M.K., Naylor, J.M. and Simpson, G.M. (1982). The physiological basis of seed dormancy in Avena fatua L. I. Action of the respiratory inhibitors sodium azide and salicylhydroxamic acid. Physiologia Plantarum, 54, 419-424.

53. Whitcomb, W.O. (1923). Germination of newly threshed grains. Proceedings of the Association of Official Seed Analysts, 14, 84-88.

54. Whittington, W.J., Hillman, J., Gatenby, S.M., Hooper, B.E. and White, J.C. (1970). Light and temperature effects of the germination of wild oats. Heredity, 25, 641-650.

55. Wiberg, H. and Kolk, H. (1960). Effect of gibberellin on germination of seeds. Proceedings of the International Seed Testing Association, 25, 440-445.

56. Young, J.A., Evans, R.A. and Kay, B.L. (1973). Temperature requirements for seed germination in an annual-type rangeland community. Agronomy Journal, 65, 656-659.

57. Hilton, J.R. (1984). The influence of light and potassium nitrate on the dormancy and germination of Avena fatua L. (wild oat) seed and its ecological significance. New Phytologist, 96, 31-34.

58. Hilton, J.R. and Bitterli, C.J. (1983). The influence of light on the germination of Avena fatua L. (wild oat) seed and its ecological significance. New Phytologist, 95, 325-333.

59. Tal, M. (1977). Abscisic acid and germination in Avena sterilis L. Israel Journal of Botany,

26, 100-103.

BOTHRIOCHLOA

B. intermedia (R. Br.) A. Camus	
B. ischaemum (L.) Keng	yellow bluestem
B. macra (Steud.) Blake	red grass

I. Evidence of dormancy

Dormancy is often present in seeds of Bothriochloa spp. (2-4). After-ripening for 8 months or so is reported to result in loss in dormancy (4).

II. Germination regimes for non-dormant seeds

B. ischaemum

TP; S: 20°/30°C (16h/8h): 21d (AOSA)

B. macra

Constant temperatures: 25°C (4)

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) in light (3); 20°/30°C (16h/8h) in light (2)

III. Unsuccessful dormancy-breaking treatments

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IV. Partly-successful dormancy-breaking treatments

B. intermedia

Removal of seed covering structures: (1)

B. ischaemum

Alternating temperatures: 20°/30°C (16h/8h) in light (2)

Pre-chill: 5°-10°C, 5d (2); 5°-10°C, 5d, plus potassium nitrate, co-applied, 0.2% (2)

Potassium nitrate: co-applied, 0.2% (2)

Removal of seed covering structures: (1)

B. macra

Removal of seed covering structures: (3,4)

GA_3: co-applied, 100 ppm (3)

Light: 6.5-7.5 W m^{-2} (3)

V. Successful dormancy-breaking treatments

B. ischaemum

Light, Potassium nitrate, Pre-chill (AOSA)

B. macra

Removal of seed covering structures: lemma and palea, germinate at 20°/30°C (16h/8h) in light, plus GA_3, co-applied, 100 ppm (3); lemma and palea, germinate at 30°C (5)

VI. Comment

The literature cited (1-5) suggests light (8h/d), alternating temperatures and the removal of the lemma and palea to be the most stimulatory factors in promoting the germination of dormant seeds of Bothriochloa spp. It is suggested that the AOSA germination test procedure be followed but with the additional treatment of lemma and palea removal. AOSA recommend that seeds be pre-chilled at 5°C for 14 days. A 5-day pre-chill at 5°C is only partly-promotory (2), but treatment with gibberellic acid - co-applied, 100 ppm - can be effective when combined with seed coat removal (3). Consequently this treatment may be a worthwhile alternative to pre-chilling - particularly if a more rapid test procedure is required.

VII. References

1. Ahring, R.M., Eastin, J.D. and Garrison, C.S. (1975). Seed appendages and germination of two Asiatic bluestems. Agronomy Journal, 67,

2. Ahring, R.M. and Harlan, J.R. (1961). Germination characteristics of some accessions of Bothriochloa ischaemum (L.) Keng. Oklahoma Agricultural Experiment Station, Technical Bulletin T-89, 19pp.

3. Hagon, M.W. (1976). Germination and dormancy of Themeda australis, Danthonia spp., Stipa bigeniculata, and Bothriochloa macra. Australian Journal of Botany, 24, 319-327.

4. Lodge, G.M. and Whalley, R.D.B. (1981). Establishment of warm- and cool-season native perennial grasses on the North-west slopes of New South Wales. I. Dormancy and Germination. Australian Journal of Botany, 29, 111-119.

5. Watt, L.A. and Whalley, R.D.B. (1982). Establishment of small-seeded perennial grasses on black clay soils in North-western New South Wales. Australian Journal of Botany, 30, 611-623.

BOUTELOUA

B. chrondrosioides (HBK) Benth.	
B. curtipendula (Michx.) Torr.	coronada side-oats grama
B. eriopoda Torr.	black grama
B. filiformis (Fowen) Griff.	slender grama
B. gracilis (HBK) Lag.	blue grama
B. parryi (Fowen) Griff.	parry grama
B. rothrockii Vasey	Roth rock grama

I. Evidence of dormancy

Dormancy may be exhibited by seeds of Bouteloua spp. (1,2,4,8-11) and may persist after 5 years dry storage at room temperature (3). Seeds of B. parryi and B. rothrockii are particularly dormant and very difficult to germinate (7).

II. Germination regimes for non-dormant seeds

B. curtipendula

TP: 15°/30°C (16h/8h): 28d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light (4)

B. filiformis

Constant temperatures: 20°C, 30°C, 35°C (7)

Alternating temperatures: 35°/10°C, 10°/35°C, 20°/40°C, 20°/35°C, 20°/30°C, 10°/30°C, 15°/25°C, 25°/40°C (18h/6h) (7); 25°/40°C, 20°/40°C (21h/3h) (7)

B. gracilis

TP: 20°/30°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

B. curtipendula

Alternating temperatures: 10°-20°/20°-10°C (12h/12h) (8)

Potassium nitrate: co-applied, 0.2% (7)

B. eriopoda

Light: red, far red, 30 min (11); fluorescent, 8h/d (11)

Calcium nitrate: co-applied, 0.1, 0.2% (11)

Potassium nitrate: co-applied, 0.1-0.5% (11)

B. gracilis

Potassium nitrate: co-applied, 0.2% (7)

B. parryi, B. rothrockii

Constant temperatures: 20°-35°C (7)

Alternating temperatures: 20°/40°C, 25°/40°C, 35°/10°C, 10°/35°C, 20°/35°C, 20°/30°C in light (18h/6h) (7); 15°/25°C (18h/6h) (7)

Pre-chill: 3°-5°C, 7,14d (7)

Potassium nitrate: co-applied, 0.2%, alone or at the above alternating temperatures in the presence or absence of light (7)

Light: (7)

IV. Partly-successful dormancy-breaking treatments

B. chrondrosioides

Alternating temperatures: 20°/35°C, 25°/40°C (18h/6h) (7)

Potassium nitrate: co-applied, 0.2% (7)

B. curtipendula

Constant temperatures: 20°-35°C (7); 10°-40°C in light (8)

Alternating temperatures: 20°/30°C (16h/8h) in light (4,6,9); 10°/30°C, 15°/25°C, 20°/35°C, 25°/40°C, 20°/40°C, 35°/10°C (18h/6h) (7); 20°-40°/40°-20°C (12h/12h, 16h/8h, 20h/4h) (8)

Pre-chill: (3); 3°-5°C, 7, 14d (7); 3°-5°C, 7, 14d, plus potassium nitrate, co-applied, 0.2% (7)

Light: (3,5,6,7); 100 fc, 12h/d (8)

Sodium hypochlorite: pre-applied, 0.5h, 5.2% (3,4,5,6,9)

Removal of seed covering structures: (4); clip (9)

Alternating moisture: wet/dry/rewet (3)

Oxygen: 100% (3,9)

Pre-wash: (3); 0.5-3h (4)

Sodium carbonate: (3)

Hydrogen peroxide: (3)

B. eriopoda

Alternating temperatures: 20°-25°/35°C (18h/6h) (7); 20°/35°C, 15°/30°C, 20°/30°C (16h/8h) (11)

Potassium nitrate: co-applied, 0.2% (7)

GA_3: co-applied, 50 ppm (11)

Removal of seed covering structures: (11)

B. gracilis

Alternating temperatures: 20°/30°C, 15°/25°C (18h/6h) (7)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light (10)

V. Successful dormancy-breaking treatments

B. chrondrosioides

Potassium nitrate: co-applied, 0.2%, germinate at 20°/35°C or 25°/40°C (18h/6h) (7)

B. curtipendula

Light, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C in light (18h/6h) (7); 10°/30°C, 15°/25°C, 10°/35°C (18h/6h) (7)

Removal of seed covering structures: lemma and palea (3,9)

Sodium hypochlorite: pre-applied, 0.5h, 5.2%, germinate in 100% oxygen atmosphere (9)

B. eriopoda

Potassium nitrate: co-applied, 0.2%, germinate at 20°-25°/35°C (18h/6h) (7)

B. gracilis

Light, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C, 15°/25°C (18h/6h) (7)

VI. Comment

With the exception of those of B. parryi and B. rothrockii, the seed lots tested for germination in reference (7) were not particularly dormant. Consequently the dormancy-breaking treatments listed as successful by reference (7) may not promote full germination in more dormant accessions of B. chrondrosioides, B. curtipendula, B. eriopoda and B. gracilis. According to the AOSA dormant seed s of B. curtipendula require light or potassium nitrate for germination. In contrast to this recommendation light has been reported as inessential for germination (4-6,8,11) and potassium nitrate (co-applied, 0.2%) has been reported to reduce germination (7,11). Treatment with gibberellic acid, however, has been reported to be a very effective dormancy-breaking treatment (11).

Alternating temperature regimes are essential to promote the germination of dormant seeds of Bouteloua accessions (3,7,8,11). However, the AOSA prescription for B. curtipendula, 15°/30°C (16h/8h), appears to be less promotory than either 20°/30°C (16h/8h) or 15°/30°C (12h/12h) (8), whilst 35°/30°C (4h/20h) or 35°/15°C (8h/16h) are even more beneficial (8). Consequently it is suggested that the alternating temperature regime 20°/30°C (16h/8h) be adopted as a general germination test procedure for accessions of Bouteloua spp. with additional treatments of dehulling and GA_3 co-applied at 50 ppm where necessary, with a further suggestion that tests also be carried out at 35°/15°C (4-8h/20-16h) to determine whether this might provide a more suitable environment for germination.

References

1. Coukos, C.J. (1944). Seed dormancy and germination in some native grasses. Journal of American Society of Agronomy, 36, 337-345.

2. Jackson, C.V. (1928). Seed germination in certain New Mexico range grasses. Botanical Gazette, 86, 270-294.

3. Major, R.L. (1972). Seed dormancy of side-oats gramagrass Bouteloua curtipendula (Michx.). Dissertation Abstracts, 33B, 531

4. Sumner, D.C. and Cobb, R.D. (1962). Post harvest dormancy of coronado side-oats grama Bouteloua curtipendula (Michx.) Torr. as affected by storage temperature and germination inhibitors. Crop Science, 2, 321-325.

5. Sumner, D.C., Cobb, R.D. and Jones, L.G. (1959). Modification of standard germination procedure for coronado side-oats grama (Bouteloua curtipendula). Newsletter of the Association of Official Seed Analysts, 33, 7-9 and 27.

6. Sumner, D.C., Cobb, R.D. and Jones, L.G. (1960). The effect of temperature and light on the germination of coronado side-oats grama. Newsletter of the Association of Official Seed Analysts, 34, 12.

7. Toole, V.K. (1939). Germination requirements of the seed of some introduced and native range grasses. Proceedings of the Association of Official Seed Analysts, 30, 227-243.

8. Cole, D.F., Major, R.L. and Wright, L.N. (1974). Effects of light and temperature on germination of sideoats grama. Journal of Range Management, 27, 41-44.

9. Major, R.L. and Wright, L.N. (1974). Seed dormancy characteristics of sideoats gramagrass, Bouteloua curtipendula (Michx.) Torr. Crop Science, 14, 37-40.

10. Thornton, M.L. and Thornton, B.J. (1962). Firm seed and longevity of blue grama (Bouteloua gracilis). Proceedings of the Association of Official Seed Analysts, 52, 112-115.

11. Wright, L.N. and Baltensperger, A.A. (1964). Influence of temperature, light radiation, and chemical treatment on laboratory germination of black gramagrass, Bouteloua eriopoda Torr. Crop Science, 4, 168-171.

BRACHIARIA

B. brizantha (Hochst.) Stapf	palisade grass, signal grass
B. decumbens Stapf	signal grass, Surinam grass
B. dictyoneura (Fig. & De Not.) Stapf	
B. dura Stapf	
B. humidicola (Rendle) Schweickt	creeping signal grass, coronivia grass
B. miliiformis (Presl) Chase	
B. mutica (Forsk.) Stapf [Panicum muticum Forsk.; P. purppurascens Raddi; P. barbinode Trin.]	para grass, Mauritius grass, malohillo, Angola grass, capim angola, egipto, penhalonga grass, mirable
B. plantaginea (Link) Hitchc. [Panicum plantagineum Link]	marmalade grass
B. radicans Napper [B. arrecta (Hack. ex Th. Dur. & Schinz) Stent.]	tanner grass
B. ramosa	brown top millet
B. ruziziensis Germain & Evrard	ruzi grass, Congo grass, Congo signal grass, kennedy ruzi

I. Evidence of dormancy

Dormancy in Brachiaria species can be particularly persistent and pronounced resulting in considerable problems for seed testing (7,10) and germplasm evaluation (1).

II. Germination regimes for non-dormant seeds

B. decumbens

TP: 20°/35°C (16h/8h): 21d (ISTA)

Alternating temperatures: 20°/35°C (16h/8h) in light, 21d (7)

B. humidicola, B. mutica

TP: 20°/35°C (16h/8h): 21d (ISTA)

B. ramosa

BP; TP: 20°/30°C (16h/8h); 30°C: 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

B. decumbens

Potassium nitrate: co-applied, 0.2% (11)

Pre-dry: 40°-80°C, 14h (11); 40°C, 12d (11)

Pre-soak: 70°C, 10 min (11)

Scarification: concentrated sulphuric acid, 5-20 min (11)

Light: (3)

B. dictyoneura

Pre-dry: (1)

Scarification: concentrated sulphuric acid, 15 min, plus thiourea, co-applied (1)

B. mutica

Pre-dry: 55°C, 4d (8)

Scarification: concentrated sulphuric acid, 15 min (8); sandpaper (8)

B. ruziziensis

Constant temperatures: 20°C, 25°C (9)

Light: (9)

Pre-dry: 50°C, 3d (8)

Removal of seed covering structures: excision of spikelet top (9)

IV. Partly-successful dormancy-breaking treatments

B. decumbens

Pre-chill: 5°C, 7d (11)

Potassium nitrate: co-applied, 0.2% (2,3)

Scarification: concentrated sulphuric acid (2); concentrated sulphuric acid, 5-20 min (11); concentrated sulphuric acid, 15 min (5,6); concentrated sulphuric acid, 13 min (3); concentrated sulphuric acid, 13 min, plus potassium nitrate, co-applied, 0.2%, germinate at 20°/35°C (16h/8h) in light (3); mechanical (11)

Pre-dry: 40°-80°C, 14h (11)

Pre-soak: 24h (11)

Hydrogen peroxide: pre-applied, 24,48h, 1 M (11)

Removal of seed covering structures: lemma and palea (5,11)

Light: 15000 lux (3)

B. dictyoneura

Removal of seed covering structures: lemma and palea (1)

Scarification: concentrated sulphuric acid, 20-25 min (1); concentrated sulphuric acid, 20-25 min, plus thiourea, co-applied (1)

B. humidicola

Potassium nitrate: co-applied, 0.2% (2)

Scarification: concentrated sulphuric acid, with or without potassium nitrate, co-applied, 0.2% (2)

B. ruziziensis

Alternating temperatures: 25°/15°C (12h/12h) (9)

Scarification: concentrated sulphuric acid, 15 min (4,8); mechanical (8)

V. Successful dormancy-breaking treatments

B. decumbens

Scarification, Light, Potassium nitrate (ISTA)

Potassium nitrate: co-applied, 0.2% (7)

Scarification: concentrated sulphuric acid, 13 min (7); concentrated sulphuric acid, 13 min, wash, then potassium nitrate, co-applied, 0.2% (10)

B. humidicola

Potassium nitrate (ISTA)

B. mutica

Scarification, Potassium nitrate (ISTA)

B. ramosa

Light, Potassium nitrate, Pre-dry, test at 30°C (AOSA)

B. ruziziensis

Scarification, Potassium nitrate (ISTA)

Removal of seed covering structures: dehull (9)

Hydrogen peroxide: pre-applied, 24h, 1 M (9)

Brachiaria spp.

Scarification: concentrated sulphuric acid, 13 min, wash, then potassium nitrate, co-applied, 0.2%, at 20°/35°C (16h/8h) in light (10)

VI. Comment

The apparently satisfactory procedure for Brachiaria (10) - described above - has been found elsewhere to fail to promote the germination of all viable seeds (3), at least over a 21 day germination test period. An alternating temperature regime of 15°/30°C or 10°/30°C (16h/8h) can be extremely promotory for B. humidicola but not promotory for B. decumbens (A). More recent work with B. humidicola has shown that alternating temperature regimes of 35°/13°C (4h/20h) or 35°/16°C (4h/20h) with the addition of potassium nitrate, co-applied, 10^{-2} M, in the latter regime can be very successful dormancy-breaking treatments (12). Note the short period of exposure to the higher temperature during each daily cycle: this is the most effective thermoperiod for this species (12). It is suggested that either of these regimes be applied to B. humidicola, whilst no suggestion can be made at present for dormant accessions of B.

decumbens.

VII. References

1. Anonymous (1981). Agronomy in the isohyperthermic savannas (carimagua). C.I.A.T. Tropical Pasture Program Report 1981, pp. 21-23.

2. Atalla, L.M.P. and Tosello, J. (1979). [Observations on dormancy in two species of Brachiaria: B. decumbens and B. humidicola under laboratory conditions.] Cientifica, 7, 353-355.

3. Beavis, C. (1984). Seed dormancy and germination of Brachiaria decumbens Stapf. (In press).

4. Davidson, D.E. (1966). Five pasture plants for Queensland. Queensland Agricultural Journal, 92, 460-466.

5. Filho, J.W. (1980). [Dormancy breaking studies on seeds of Brachiaria decumbens Stapf.] Boletim de Divulgacao, Escola Superior de Agricultura "Luiz de Queiroz", 24, 92-94.

6. Grof, B. (1968). Viability of seed of Brachiaria decumbens. Queensland Journal of Agricultural and Animal Science, 25, 149-152.

7. Johnston, M.E.H. (1981). Report of the germination committee working group on tropical and subtropical seeds 1977-1980. Seed Science and Technology, 9, 137-140.

8. MacLean, D. and Grof, B. (1968). Effect of seed treatments on Brachiaria mutica and B. ruziziensis. Queensland Journal of Agricultural and Animal Science, 25, 81-83.

9. Renard, C. and Capelle, P. (1976). Seed germination in ruzizi grass [Brachiaria ruziziensis (Germain & Evrard)]. Australian Journal of Botany, 24, 437-446.

10. Tonkin, J.H.B. (1981). Report of the germination committee working group on temperate grasses 1977-1980. Seed Science and Technology, 9, 147-156.

11. Whiteman, P.C. and Mendra, K. (1982). Effects of storage and seed treatments on germination of Brachiaria decumbens. Seed Science and Technology, 10, 233-242.

12. Goedert, C. (1984). Seed dormancy of tropical forage grasses and implications for the conservation of genetic resources. Ph.D. Thesis, University of Reading.

BROMUS

B. arvensis L.	field brome
B. brizaeformis Fisch. & Mey	quake grass
B. catharticus Vahl [B. willdenowii, B. unioloides HBK; B. Schraderi Kunth.]	rescue grass, Schraders brome
B. commutatus Schrad.	meadow brome
B. erectus Huds.	upright brome
B. inermis Leyss.	awnless brome, Hungarian brome, smooth brome
B. japonicus Thunb.	
B. marginatus Steud.	mountain brome
B. mollis L.	soft chess
B. ramosus Huds.	hairy brome, wood brome
B. rigidus Roth	ripgut
B. secalinus L.	rye brome

B. sitchensis	
B. sterilis L.	barren brome
B. tectorum L.	cheatgrass, downy chess, bronco grass, Mormon oats, junegrass

I. Evidence of dormancy

Seed lots of B. catharticus (7), B. marginatus (7), B. rigidus (6), B. secalinus (18) and B. sterilis (12) show onl y slight dormancy: after-ripening for 3 to 5 weeks is sufficient to remove this slight dormancy (12,18). Seed lots of B. inermis (1), B. mollis (6), B. ramosa (3) and B. tectorum (6) may be more dormant and may require after-ripening for between 4 (6) and 8 months (1) before dormancy is lost. Dormancy causes problems when testing seed lots of B. catharticus (5) and B. inermis (13,14) for germination.

II. Germination regimes for non-dormant seeds

B. arvensis

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (AOSA)

B. catharticus

TP; S; 20°/30°C (16h/8h): 28d (ISTA)

TP; S: 10°/30°C (16h/8h): 28d (AOSA)

B. inermis

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (ISTA)

TP; BP: 20°/30°C (16h/8h): 14d (AOSA)

B. marginatus

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (ISTA)

TP: 20°/30°C (16h/8h): 14d (AOSA)

B. mollis

TP: 20°/30°C (16h/8h): 14d (AOSA,ISTA)

B. sitchensis

TP: 20°/30°C; 15°/25°C (16h/8h): 21d (ISTA)

III. Unsuccessful dormancy-breaking treatments

B. brizaeformis

Light: at 10°C (16)

B. catharticus

Constant temperatures: 5°-35°C (5)

Potassium nitrate: co-applied, 0.2% (7)

Thiourea: co-applied, 0.2% (7)

B. commutatus

Light: at 10°C (16)

B. erectus

Light: red, 5 min, at 8.4°-11.8°C (12)

B. inermis

Constant temperatures: 22°-24°C (19)

Light: (7,13)

B. japonicus

Constant temperatures: 20°-30°C, in light or dark (16)

Light: at 10°C (16)

B. mollis

Light: red, 5 min, at 6.7°C, 8.4°C (12)

B. ramosus

Alternating temperatures: 20°/15°C (15h/9h), in light, 40 W m^{-2}, 15h/d (3)

B. rigidus

Light: at 10°C (16)

B. secalinus

Alternating temperatures: 20°/30°C (16h/8h) in light or dark (18)

Potassium nitrate: co-applied, 0.2% (18)

Light: 100-150 fc (18)

B. sterilis

Light: red, 5 min, at 10°-25.4°C (12); red, 1.4×10^{-6} mol m^{-2} s^{-1}, 8h/d, at 15°C (15); white, 10.7×10^{-6} mol m^{-2} s^{-1}, 8h/d, at 15°C (15)

B. tectorum

Alternating temperatures: 20°/30°C (16h/8h) in light or dark (18)

Potassium nitrate: co-applied, 0.2% (18)

Light: 100-200 fc, at 10°-30°C (16); 100-150 fc (18); dark, at 20°-30°C (16)

IV. Partly-successful dormancy-breaking treatments

B. brizaeformis

Constant temperatures: 15°C in light, 100-200 fc (16)

B. catharticus

Alternating temperatures: 10°/25°C (8h/16h), light, 8h/d (5); 5°-10°/15°-30°C (12h/12h) (5); 26°/5°C (24h/24h) (17)

Pre-chill: 3°-5°C, 7d (7)

Potassium nitrate: co-applied, 0.2% (5)

Light: (5,8)

Removal of seed covering structures: distal end cut (5)

GA_3: co-applied, 100 ppm (7)

B. commutatus

Constant temperatures: 15°C in light, 100-200 fc (16)

B. inermis

Alternating temperatures: 20°/30°C (16h/8h) in light, 8h/d (14)

Pre-chill: 3°-5°C, 7d (7)

Light: (8)

GA_3: co-applied, 100 ppm (7,8)

B. japonicus

Constant temperatures: 15°C, dark (16)

B. marginatus

Pre-chill: 3°-5°C, 7d (7)

Potassium nitrate: co-applied, 0.2% (7)

GA_3: co-applied, 100 ppm (7)

B. ramosus

Pre-chill: 5°C, 2m (3)

B. rigidus

Constant temperatures: 15°C (10); 15°C in light (16)

B. tectorum

Constant temperatures: 10°C, 15°C, dark (16)

Alternating temperatures: 7°/25°C, 7°/14°C (16h/8h) (16)

Potassium nitrate: co-applied, 10^{-5}, 10^{-4}, 10^{-3} M (11); co-applied, 10^{-4} M, plus GA_3, co-applied, $1.4x10^{-4}$ M (11)

V. Successful dormancy-breaking treatments

B. arvensis

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill (AOSA)

B. brizaeformis

Constant temperatures: 10°C, 15°C, dark (16)

B. catharticus

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-wash, 48h, test in soil at 15°C (AOSA)

Alternating temperatures: 15°/30°C (16h/8h) (7)

Pre-soak: 2h, deglume, germinate at 15°-18°C, plus potassium nitrate, co-applied, 0.2% (4)

GA_3: co-applied, 100 ppm, germinate at 20°C in light (8)

Removal of seed covering structures: deglume, pierce (2,4,17); clip off distal end, germinate at 10°/25°C (8h/16h), in light, 8h/d, plus potassium nitrate, co-applied, 0.2% (5)

B. commutatus

Constant temperatures: 10°C, 15°C, dark (16)

B. erectus

Constant temperatures: 8.4°-27°C, dark (12)

Alternating temperatures: 8°/23°C, 10°/20°C, 15°/23°C (16h/8h), dark (12); 20°/15°C (15h/9h) in light, 40 W m^{-2} (3)

Pre-chill: 2°C, 20d, germinate at 10°/20°C (16h/8h), dark (12)

B. inermis

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, test at 30°C for 9 additional days (AOSA)

Constant temperatures: 10°-30°C, dark (13)

Alternating temperatures: 15°/30°C (16h/8h) in dark (7); 20°/30°C (16h/8h) (19); 20°/30°C, 20°/35°C, 15°/25°C, 15°/30°C, 10°/20°C, 10°/30°C (15h/9h), dark (13)

Pre-chill: 10°C, 5d (13,14)

GA_3: co-applied, 100 ppm, at 20°C in light (8)

B. japonicus

Constant temperatures: 10°C, dark (16)

B. marginatus

Pre-chill, Potassium nitrate (ISTA)

Light (AOSA)

Alternating temperatures: 15°/30°C (16h/8h) (7)

GA_3: co-applied, 100 ppm, at 15°C in light (8)

B. mollis

Pre-chill (ISTA)

Light, Pre-chill (AOSA)

Constant temperatures: 15°C (10); 5°-28.8°C, dark (12)

Alternating temperatures: 5°/15°C, 15°/25°C, 10°/30°C, 15°/30°C, 15°/20°C, 20°/25°C, 25°/30°C (16h/8h) (10); 8°-23°C, 10°/20°C, 15°/23°C (16h/8h), dark (12)

B. rigidus

Constant temperatures: 10°C (10); 10°C, 15°C, dark (16)

Alternating temperatures: 5°/15°C, 2°/20°C (16h/8h) (10)

B. secalinus

Constant temperatures: 15°C, dark (18)

Pre-chill: 5°C, 7d, germinate at 20°/30°C (16h/8h) (18)

B. sitchensis

Pre-chill (ISTA)

B. sterilis

Constant temperatures: 15°C, dark (15)

Alternating temperatures: 8°/23°C, 10°/20°C, 15°/23°C (16h/8h), dark (12); 20°/15°C (15h/9h) in light, 40 W m^{-2} (3)

Pre-chill: 2°C, 20d, germinate at 10°/20°C (16h/8h), dark (12)

B. tectorum

Constant temperatures: 15°C (20); 15°C, dark (18)

Alternating temperatures: 10°/30°C, 15°/30°C, 10°/25°C, 15°/25°C, 10°/20°C (16h/8h) (9); 14°/25°C (16h/8h), dark (16)

Pre-chill: 5°C, 7d, germinate at 20°/30°C (16h/8h) (18)

VI. Comment

The germination of dormant seed lots of most Bromus spp. is inhibited by light (12, 15, 16): with less dormant seed lots no inhibitory effects of light are observed (13, 18), but neither is

germination promoted. Consequently despite AOSA prescriptions to the contrary it is suggested here that Bromus accessions be tested for germination in the dark. Slightly dormant or non-dormant seeds of Bromus spp. germin ate fully at constant temperatures between 10° and 15°C in the dark (10, 12, 13, 15, 16, 18, 20), but alternating temperatures are required for the more dormant lots (5, 7, 10, 12, 16). The AOSA/ISTA prescribed alternating temperature regime of 20°/30°C (16h/8h) is not entirely satisfactory however (5,13,14,18): 14°-15°/23°-25°C or 10°/20°C (15-16h/9-8h) are successful germination test regimes for B. erectus (12), B. inermis (13), B. mollis (13), B. sterilis (12) and B. tectorum (9). It is therefore suggested that seeds of Bromus accessions be tested for germination in the dark at 10°/20°C or 15°/25°C (16h/8h). Where this is not sufficient to promote full germination it is suggested that the seeds be pre-chilled and/or deglumed prior to testing in either regime.

VII. References

1. Coukos, C.J. (1944). Seed dormancy and germination in some native grasses. Journal of the American Society of Agronomy, 36, 337-34 5.

2. Drake, V.C. (1949). Germination of rescue grass seed as affected by temperature, substrata, light and removal of glumes. Newsletter of the Association of Official Seed Analysts, 23, 42-49.

3. Grime, J.P., Mason, G., Curtis, A.V., Rodman, J., Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. Journal of Ecology, 69, 1017-1059.

4. Heit, C.E. (1948). Report of subcommittee on dormancy in seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

5. Larsen, A.L., Montgillion, D.P. and Schroeder, E.M. (1973). Germination of dormant and non-dormant rescue grass seed on the thermogradient plate. Agronomy Journal, 65, 56-59.

6. Laude, H.M. (1956). Germination of freshly harvested seeds of some western range species. Journal of Range Management, 9, 126-129.

7. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

8. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

9. Young, J.A. and Evans, R.A. (1982). Temperature profiles for germination of cool season range grasses. USDA Agricultural Research Service, Agricultural Research Results, Western Series No. 27.

10. Young, J.A., Evans, R.A. and Kay, B.L. (1973). Temperature requirements for seed germination in an annual-type rangeland community. Agronomy Journal, 65, 656-659.

11. Evans, R.A. and Young, J.A. (1975). Enhancing germination of dormant seeds of downy brome. Weed Science, 23, 354-357.

12. Froud-Williams, R.J. (1981). Germination behaviour of Bromus species and Alopecurus myosuroides. In Grass Weeds in Cereals in the United Kingdom, Conference, 1981, pp.31-40, Association of Applied Biology.

13. Grabe, D.F. (1955). Germination responses of smooth bromegrass seed. Proceedings of the Association of Official Seed Analysts, 45, 68-71.

14. Grabe, D.F. and Bass, L.N. (1954). Comparative methods of germinating smooth bromegrass. Proceedings of the Association of Official Seed Analysts, 44, 121-126.

15. Hilton, J.R. (1982). An unusual effect of the far-red absorbing form of phytochrome: photoinhibition of seed germination in Bromus sterilis L. Planta, 155, 524-528.

16. Hulbert, L.C. (1955). Ecological studies of Bromus tectorum and other annual bromegrasses. Ecological Monographs, 25, 181-213.

17. Koduru, T. (1967). [Studies on the germination of rescue grass, Bromus unioloides.] Bulletin of the Kyoto University of Education, B, 30, 21-30. (From Herbage Abstracts, 1968, 38, 1987.)

18. Steinbauer, G.P. and Grigsby, B.H. (1957). Field and laboratory studies of the dormancy and germination of the seeds of chess (Bromus secalinus L.) and downy bromegrass (Bromus tectorum L.). Weeds, 5, 1-4.

19. Stevens, O.A. (1923). The testing of bromegrass and wheatgrass seeds. Proceedings of the Association of Official Seed Analysts, 15, 120-123.

20. Thill, D.C., Schirman, R.D. and Appleby, A.P. (1980). Influence of afterripening temperature and endogenous rhythms on downy brome (Bromus tectorum) germination. Weed Science, 28, 321-323.

CHLORIS

C. ciliata
C. distichophylla
C. gayana Kunth Rhodes-grass
C. orthonothon Doell
C. pycnothrix
C. truncata R. Br. windmill grass
C. verticillata Nutt.

I. Evidence of dormancy

Dormancy has been reported in seeds of Chloris spp. (1,6-10). After-ripening seeds of C. pycnothrix and C. truncata for 5 months (10) and 48 weeks (6) respectively are reported to result in loss of dormancy.

II. Germination regimes for non-dormant seeds

C. gayana

TP: 20°/30°C; 20°/35°C (16h/8h): 14d (ISTA)

TP: 20°/30°C (16h/8h): 14d (AOSA)

Constant temperatures: 25°C in light (11)

III. Unsuccessful dormancy-breaking treatments

C. ciliata

Light: continuous dark (3,4,5)

C. orthonothon

Light: continuous dark (9); imbibition in dark at 25°C, 24h, then red light, 15 min (9)

C. pycnothrix

Light: continuous dark (10)

IV. Partly-successful dormancy-breaking treatments

C. ciliata

Light: imbibition in dark, 12°C, 24h, then light, 10 min to 7h at 33°C, germinate in dark (3,4,5)

Oxygen: (3,4,5)

C. distichophylla

Constant temperatures: 18°C, 23°C, 28°C, in continuous light or dark (8)

Warm stratification: 28°C, in dark, germinate at 18°C in light (8)

Potassium permanganate: pre-applied, 18°C or 28°C in dark, germinate at 18°C in light (8)

Sodium thiosulphate: pre-applied, 18°C or 28°C in dark, germinate at 18°C in light (8)

Sodium perborate: pre-applied, 18°C or 28°C in dark, germinate at 18°C in light (8)

Potassium iodate: pre-applied, 18°C or 28°C in dark, germinate at 18°C in light (8)

C. gayana

Alternating temperatures: 35°/15°C (18h/6h) (1); 20°/30°C, 20°/35°C (16h/8h) in light (7)

Potassium nitrate: co-applied, 0.2% (1,7)

Light: (7)

Removal of seed covering structures: (1)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C, 20°/35°C (16h/8h) in light (7)

C. orthonothon

Scarification: concentrated sulphuric acid, 30-120s (9)

Light: dark, 24h, red light, 15 min, pre-dry, scarify (9)

Removal of seed covering structures: (9); dehull partly, imbibe in dark, 24h, red light, 15 min, then dark or far red light (9); dehull partly, imbibe in dark, 24h, then pre-soak, 40°C, 15-60 min, germinate at 25°C in dark (9)

C. truncata

Constant temperatures: 20°C, 25°C, 30°C (6)

Light: (6)

Removal of seed covering structures: (6)

C. verticillata

Alternating temperatures: 20°-25°/15°-20°C (day/night) (2)

Light: white or red, 30 min (2)

V. Successful dormancy-breaking treatments

C. ciliata

Removal of seed covering structures: (3,4,5)

Light: imbibe in dark at 12°C, 24h, then light at 33°C, 7.5h, germinate in dark (3,4,5)

C. gayana

Light, Potassium nitrate (AOSA, ISTA)

Removal of seed covering structures: deglume, plus potassium nitrate, co-applied, 0.2%, germinate at 35°/15°C (18h/6h) in light (1)

C. orthonothon

Removal of seed covering structures: dehull, imbide in dark, 25°C, 24h, then red light, 15 min, far red light, 15 min, red light, 15 min, germinate at 25°C in dark (9)

C. pycnothrix

Light: at 28°/14.5°C (day/night) (10)

VI. Comment

Light, particularly red light, promotes the germination of dormant seeds of Chloris spp. For dormant seeds of C. pycnothrix it appears that a high light intensity (direct sunlight) is required for germination since in a diffuse light regime (shaded from direct sunlight) percentage germination was reduced (10) - with no seeds germinating in the dark (10). However, the shading treatment - in a glasshouse - may have reduced the amplitude of the alternating temperature regime and it may have been this aspect of the germination test environment which caused the reduction in the proportion of seeds germinating. Unfortunately the ISTA and AOSA prescriptions for C. gayana are unlikely to be successful for the more dormant seed lots (7). It is suggested that it may be possible to improve these prescriptions by first degluming the seeds and then testing either as prescribed by AOSA/ISTA or at 35°/15°C (18h/6h) in light - see Chapter 6 - with 0.2% potassium nitrate co-applied. This regime may prove satisfactory for accessions of other Chloris spp.

VII. References

1. Cullinan, B. (1941). Germinating seeds of southern grasses. Proceedings of the Association of Official Seed Analysts, 33, 74-76.

2. Feltner, K.C. and Vesecky, J.F. (1968). Light quality and temperature effects on weed seed germination in two Kansas soils. Transaction of Kansas Academy of Sciences, 71, 7-12.

3. Gassner, G. (1910). Uber Keimungbedingugen einiger Südamerikanischer Gramineensamen, I, II. Berichte der Deutschen Botanischen Gesellschaft, 28, 350-364, 504-512.

4. Gassner, G. (1911). Keimuntersuchungen mit Chloris ciliata. Berichte der Deutschen Botanischen Gesellschaft, 29, 708-722.

5. Gassner, G. (1912). Untersuchungen über die Wirkung des Lichtes und des Temperaturewechsels auf die Keimung von Chloris ciliata. Jahrb. Hamberg, Wiss., 29, 1-121.

6. Lodge, G.M. and Whalley, R.D.B. (1981). Establishment of warm- and cool-season native perennial grasses on the north-west slopes of New South Wales. I. Dormancy and germination. Australian Journal of Botany, 29, 111-119.

7. Sharir, A. (1971). Germination temperatures of dormant and non-dormant Rhodes grass seed. Proceedings of the International Seed Testing Association, 36, 109-113.

8. Shimizu, N., Tajima, K. and Ogata, R. (1970). [Studies on promotion of germination at low temperature in tropical grass seed. I. Promotion of germination at low temperature in seeds of Chloris spp. and Eragrostis spp.] Bulletin of the National Grassland Research Institute, 11, 47-56.

9. Solange, M., Cruz, D. and Takaki, M. (1983). Dormancy and germination of seeds of Chloris orthonothon. Seed Science and Technology, 11, 323-329.

10. Fenner, M. (1980). Germination tests on thirty-two East African weed species. Weed Research, 20, 135-138.

11. Watt, L.A. and Whalley, R.D.B. (1982). Establishment of small-seeded perennial grasses on black clay soils in North-western New South Wales. Australian Journal of Botany, 30, 611-623.

CYMBOPOGON

C. caesius (Nees) Stapf	
C. jwarancusa (Jones) Schult.	
C. martinii (Roxb.) Wats.	rosha grass
C. martinii Stapf var Motia	palmarosa
C. olivieri (Boiss.) Bor	
C. parkeri Stapf	

I. Evidence of dormancy

In one investigation seed lots of C. caesius, C. jwarancusa, C. martinii, C. olivieri and C. parkeri were germinate d without special treatment within a comparatively short time (1) indicating little or no dormancy, but a separate investigation with seeds of C. martinii var Motia did show evidence of dormancy (2).

II. Germination regimes for non-dormant seeds

C. jwarancusa

Constant temperatures: room temperature, 14d (1)

C. olivieri

Constant temperatures: room temperature, 25d (1)

C. parkeri

Constant temperatures: room temperature, 14d (1)

III. Unsuccessful dormancy-breaking treatments

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IV. Partly-successful dormancy-breaking treatments

C. martinii var Motia

Removal of seed covering structures: glumes (2)

V. Successful dormancy-breaking treatments

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VI. Comment

It is suggested that seeds of Cymbopogon spp. be tested for germination on top of filter papers at 25°C for 14 days. Then remove the glumes from seeds which have not germinated within this period and test those seeds containing embryos for a further 14 days at 25°C and record the proportion of empty seeds. The empty seed proportion can be substantial for Cymbopogon spp. accessions.

VII. References

1. Ahmed, M., Hussain, A. and Hussain, T. (1978). Studies on some range grasses of Pakistan. Pakistan Journal of Forestry, 28, 7-12.

2. Nair, N.R. and Nair, N.G. (1981). Seed germination in palmarosa (Cymbopogon martini Stapf var Motia). Agricultural Research Jou rnal of Kerala, 19, 115-116.

CYNODON

C. dactylon (L.) Pers. [Panicum dactylon L.]	star grass, Bahama grass, Bermuda grass, doob
C. plectostachyum (Schum.) Pilger [C. dactylon var aridis Harlan & de Wet]	giant star grass

I. Evidence of dormancy

In 1918 C. dactylon seeds were described as some of the most difficult of agricultural seeds to germinate (3), and this species is still causing problems in seed testing laboratories (1). It appears that seed dormancy is not such a major problem in C. plectostachyum and that - when present - germination can be promoted more easily than is the case for C. dactylon (10).

II. Germination regimes for non-dormant seeds

C. dactylon

TP: 20°/35°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 20°/35°C (16h/8h): 21d (AOSA)

Constant temperatures: 25°C (7,13)

Alternating temperatures: 10°/40°C (16h/8h) (7); 10°-15°/40°C, 15°-20°/30°C, 20°/30°-40°C (16h/8h) (13)

C. plectostachyum

TP: 20°/35°C (16h/8h): L: 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

C. dactylon

Constant temperatures: 2°-10°C (13); 10°-38°C, dark (8); 20°C (1); 20°-35°C (5)

Pre-chill: 5°-10°C, 0-4w, dehulled seeds, germinate at 20°/30°C (16h/8h) in light with potassium nitrate, co-applied, 0.2% (1); 5°-10°C, 10d (10)

Scarification: concentrated sulphuric acid, 1-7 min (2); concentrated sulphuric acid, 5 min (4); sandpaper (4)

Pre-dry: 70°C, 17h (4)

Potassium nitrate: co-applied, 0.04, 1 N, at 32°C (8); co-applied, 0.2, 1-5% (10)

Sodium nitrate: co-applied, 0.04, 1 N, at 32°C (8); co-applied, 2.5, 5% (10)

Sodium nitrite: co-applied, 0.1, 1 N, at 32°C (8)

Nitric acid: co-applied, 0.01 N, at 32°C (8)

Ammonium nitrate: co-applied, 0.01 N, at 32°C (8)

GA_3: pre-applied, 24h, $7x10^{-5}$ -$2.8x10^{-4}$ M, dehulled seeds (13)

Kinetin: pre-applied, 24h, $2.5x10^{-6}$-$2x10^{-5}$ M, dehulled seeds (13)

C. plectostachyum

Alternating temperatures: 20°/30°C, 30°/20°C (6h/18h) (10)

Scarification: sulphuric acid, 75, 85%, 1 min (11); sandpaper (11)

IV. Partly-successful dormancy-breaking treatments

C. dactylon

Constant temperatures: 15°-40°C, dehulled seeds (13)

Alternating temperatures: 20°/30°C (16h/8h) (1); 22°-26°/33°C (18h/6h) (2); 15°/25°C, 15°/30°C, 15°/35°C, 20°/35°C, 25°/35°C (16.5h/7.5h) (5); 15°/35°C (16h/8h) (6); 20°/30°C, 20°/35°C, 30°/20°C, 35°/20°C (6h/18h) (10)

Pre-chill: 5°-10°C, 1-4w (1); 5°-10°C, 4w, dehulled seeds, germinate at 20°/30°C (16h/8h) in light (1)

Potassium nitrate: co-applied, 0.2% (1,6); co-applied, 0.1, 0.01 M (8); co-applied, 0.2%, dehulled seeds (1); co-applied, 0.1, 0.25% (10); pre-applied, 24h, 1% (2); pre-applied, 24h, 0.1, 1%, dehulled seeds (13)

Sodium nitrate: co-applied, 0.04, 0.01 M-(8)

Sodium nitrate: co-applied, 0.1%-1% (10)

Scarification: concentrated sulphuric acid, 1.5-9 min, dehulled seeds (8); concentrated hydrochloric acid, 5 min (4); concentrated sulphuric acid, 10 min (3); sulphuric acid, 75-100%, 1 min (11); nitric acid, 75-100%, 1 min (11); sandpaper (11)

Pre-soak: 24h (2); 24h, at 30°-40°C or 10°/40°C (16h/8h), germinate at 25°C (13)

Light: dark (12); fluorescent (12)

C. plectostachyum

Alternating temperatures: 20°/35°C, 35°/20°C (6h/18h) (10)

Pre-chill: 5°-10°C, 10d (10); 5°-10°C, 2-3w, plus potassium nitrate, co-applied, 0.2% (10)

Potassium nitrate: co-applied, 0.2% (10)

Light: dark (12)

Scarification: concentrated sulphuric acid, 1 min (11); sandpaper (11)

V. Successful dormancy-breaking treatments

C. dactylon

Light, Pre-chill, Potassium nitrate (AOSA, ISTA)

Alternating temperatures: 10°/38°C, 15°/38°C (18h/6h) (8); 10°-15°/40°C, 15°-20°/30°C, 20°/30°-40°C (16h/8h), dehulled seeds (13)

Potassium nitrate: co-applied, 0.2%, at 15°/35°C (16h/8h) (6); co-applied, 0.01 N, at 22°/32°C or 22°/38°C (18h/6h) in light (8); pre-applied, 24h, 10^{-3} M, plus GA_3, $3.5x10^{-5}$ M, plus kinetin, 10^{-5} M, pre-applied, 24h, dehulled seeds, germinate at 10°/40°C (16h/8h) (7,13)

Sodium nitrate: co-applied, 10^{-2} N, at 22°/32°C or 22°/38°C (18h/6h) in light (8)

Sodium nitrite: co-applied, 10^{-2} N, at 22°/32°C or 22°/38°C (18h/6h) in light (8)

Ammonium nitrate: co-applied, 10^{-2} N, at 22°/32°C or 22°/38°C (18h/6h) in light (8)

Oxygen: 8-12% (9)

C. plectostachyum

Pre-chill and then test at 25°/35°C (16h/8h), 21d (or 14d if dehulled), Potassium nitrate (AOSA)

VI. Comment

Even with non-dormant seeds of these species problems may arise. Potassium nitrate, co-applied, 0.2%, with germination in light at 20°/30°C (16h/8h) (1) or 15°/35°C (16h/8h) appear to be satisfactory regimes for some, but not all, seed lots. The general problem with most dormancy-breaking treatments reported here is that they may be very successful in promoting the germination of some seed lots but will reduce germination in others (e.g. 10). It is suggested that seeds of Cynodon spp. be tested for germination at 20°/35°C (16h/8h) in light with potassium nitrate, co-applied, 0.2%, with removal of the seed covering structures where required.

VII. References

1. Ahring, R.M. and Todd, G.W. (1978). Seed size and germination of hulled and unhulled bermudagrass seeds. Agronomy Journal, 70, 667 -670.

2. Akamine, E.K. (1944). Germination of Hawaiian range grass seeds. Hawaii Agricultural Experiment Station Technical Bulletin No. 2, 60 pp.

3. Bryan, W.E. (1918). Hastening the germination of Bermuda grass seed by the sulphuric acid treatment. Journal of the American Society of Agronomy, 10, 279-281.

4. Burton, G.W. (1939). Scarification studies on southern grass seeds. Journal of the American Society of Agronomy, 31, 179-187.

5. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

6. Heit, C.E. (1948). Report of subcommittee on dormancy in seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

7. Kay, B.L., Evans, R.A. and Young, J.A. (1977). Soaking procedures and hydroseeder damage to common Bermudagrass seeds. Agronomy Journal, 69, 555-557.

8. Morinaga, T. (1926). Effect of alternating temperatures upon the germination of seeds. American Journal of Botany, 13, 141-158.

9. Morinaga, T. (1926). The favorable effect of reduced oxygen supply upon the germination of certain seeds. American Journal of Botany, 13, 159-166.

10. Okigbo, B.N. (1964). Studies of seed germination in star grasses: I. The effect of nitrate and alternating temperature. Journal of the West African Science Association, 8, 141-158.

11. Okigbo, B.N. (1964). Studies of seed germination in star grasses: II. Effect of mechanical and acid scarification. Journal of the West African Science Association, 8, 159-166.

12. Okigbo, B.N. (1964). Studies of seed germination in star grasses: III. Effects of mulching on germination in soil and light quality and fungicides on germination in petri dishes. Journal of the West African Science Association, 8, 167-179.

13. Young, J.A., Kay, B.L. and Evans, R.A. (1977). Accelerating the germination of common Bermudagrass for hydroseeding. Agronomy Journal, 69, 115-119.

DACTYLIS

D. glomerata L. cocksfoot, orchard grass

I. Evidence of dormancy

Freshly harvested seeds of D. glomerata can show considerable dormancy (1,6-10,13-16). Dormancy may persist in the seeds after three years storage at room temperature (1) and is a problem in seed testing (1,9). Apparently non-dormant seeds have been reported to show great variation in repeated germination tests at 24°C (12).

II. Germination regimes for non-dormant seeds

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP; TS: 15°/25°C (16h/8h): 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 25°C (14); 20°C in light, 8h/d (9)

Alternating temperatures: 30°/25°C (12h/12h) (14); 20°/15°C (day/night) in light, 8h/d (9)

Light: dark, continuous (15); fluorescent, 8-24h/d (15)

Potassium nitrate: co-applied (1,7)

GA_3: co-applied, 100 ppm (7)

Germination in soil: (1)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 15°C, 20°C (1,14); 10°-30°C, in light, 1500 lux (6); 16°C in light (15); 20°C (7)

Alternating temperatures: 20°/30°C, 15°/25°C (16h/8h) (1); 5°/18°C, 27°/18°C, 24°/18°C (1-4h/20-23h) (6); 22°/28°C (18h/6h) (8); 15°/25°C, 15°/30°C, 20°/30°C, 15°/35°C (16.5h/7.5h) (5); 20°/30°C, 20°/25°C, 15°/20°C (night/day) (9); 20°/30°C (16h/8h) (10,13); 15°/10°C, 20°/15°C, 25°/20°C (12h/12h) (14); 21°/11°C (12h/12h) (15,16)

Pre-chill: (7); 4°C, 1-6w (6)

GA_3: co-applied, 50-1000 ppm (6); pre-applied, 24h, 800-1000 ppm (6)

Kinetin: co-applied, 200-1610 ppm (6)

6-Benzylaminopurine: co-applied, 200-1610 ppm (6)

Mercuric chloride: pre-applied, 16h, 0.05-0.5% (2)

Lead nitrate: pre-applied, 16h, 0.1-1% (2)

Oxalic acid: pre-applied, 16h, 0.5-2% (2)

Sodium chloride: pre-applied, 16h, 1-6% (2)

Copper sulphate: pre-applied, 16h, 0.25-2.5% (2)

Magnesium chloride: pre-applied, 16h, 1-6% (2)

Pre-soak: 17h, then pre-dry, 15°C, 24h (3,4)

Removal of seed covering structures: lemma and palea (6,7); lemma and palea, then pre-chill, 5°C, 7d (1)

Light: (7); fluorescent, 4h/d (15)

V. Successful dormancy-breaking treatments

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, test in soil (AOSA)

Alternating temperatures: 15°/35°C (16h/8h) in light (7); 15°/28°C, 10°/28°C, 5°/28°C (18h/6h) (8); 15°/25°C (16h/8h) in light (11,13)

Pre-chill: 5°C, 7d, germinate at 15°/25°C (16h/8h) (1); 5°C, 10°C, 15°C, 14d, germinate at 22°/28°C (18h/6h) (8); 5°C, 7-10d, germinate at 20°/30°C (16h/8h) (10); 5°C, 5d, germinate at 15°/25°C, 20°/30°C (16h/8h) (13); 2°C, 21d (14)

Pre-soak: 17h, then pre-dry, 15°C, 24h (2)

Uspulun: pre-applied, 16h, 0.05-0.25% (2)

Orthophosphoric acid: pre-applied, 16h, 0.08-1.6% (2)

Magnesium phosphate: pre-applied, 16h, 0.66-4% plus manganese sulphate, 0.33-2% (2)

Removal of seed covering structures: lemma and palea, germinate at 20°/30°C (16h/8h) (1)

GA_3: co-applied, 400-1000 ppm (6); pre-applied, 1000ppm (6)

VI. Comment

Dormant seeds of D. glomerata require alternating temperatures and light for germination (1,6,7,15,16). The optimum photoperiod is 4 hours light per day (15). The ISTA prescribed alternating temperature regime of 20°/30°C is unsatisfactory (1,9,10,13), even for after-ripened seed lots (1). The following AOSA/ISTA procedure - pre-chill at 5°C for 7 days, then test at 15°/25°C for 21 days - is satisfactory for moderately-dormant or non-dormant accessions (1,10,13). It is suggested that these treatments be applied, but with light applied for 4 hours per day during the germination test. For the more dormant accessions it is suggested that, in addition, the lemmas and paleas be removed from seeds which fail to germinate during the first 14 days of the test.

VII. References

1. Canode, C.L., Horning, E.V. and Maguire, J.D. (1963). Seed dormancy in Dactylis glomerata L. Crop Science, 3, 17-19.

2. Chippindale, H.G. (1933). The effect of some chemicals on germination in cocksfoot (Dactylis glomerata L.). Annals of Applied Biology, 20, 369-376.

3. Chippindale, H.G. (1933). The effect of soaking in water on the "seeds" of Dactylis glomerata L. Annals of Botany, 47, 841-849.

4. Chippindale, H.G. (1933). The effect of soaking in water on the "seeds" of some gramineae. Annals of Applied Biology, 21, 225-232.

5. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-3 32.

6. Junttila, O. (1977). Dormancy in disperal units of various Dactylis glomerata populations. Seed Science and Technology, 5, 463-471.

7. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

8. Sprague, V.G. (1940). Germination of freshly harvested seeds of several Poa species and of Dactylis glomerata. Journal of the American Society of Agronomy, 32, 715-721.

9. Bean, E.W. (1976). Problems of germination in ecotypes of Dactylis glomerata. Welsh Plant Breeding Station, Report for 1975, 53.

10. Fendall, R.K. and Canode, C.L. (1971). Dormancy-related growth inhibitors in seeds of orchard-grass (Dactylis glomerata L.) Corp Science, 11, 727-730.

11. Haight, J.C. and Grabe, D.F. (1972). Wetting and drying treatments to improve the

performancy of orchard grass seed. Proceedings of the Association of Official Seed Analysts, 62, 135-148.

12. Kummerow, J. (1963). Endogenous fluctuations of germination capacity in Dactylis glomerata. American Journal of Botany, 50, 915-920.

13. Maguire, J.D. and Canode, C.L. (1963). Germination of Latar and Pennlate orchardgrass. Proceedings of the Association of Official Seed Analysts, 53, 92-95.

14. Pannangpetch, K. and Bean, E.W. (1984). Effects of temperature on germination in populations of Dactylis glomerata from NW Spain and Central Italy. Annals of Botany, 53, 633-639.

15. Probert, R.J., Smith, R.D. and Birch, P. (1985). Germination responses to light and alternating temperatures in European populations of Dactylis glomerata L. I. Variability in relation to origin. New Phytologist, 99, 305-316.

16. Probert, R.J., Smith, R.D. and Birch, P. (1985). Germination responses to light and alternating temperatures in European populations of Dactylis glomerata L. II. The genetic and environmental components of germination. New Phytologist, 99, 317-322.

DIGITARIA

D. adscendens (HBK) Henrad.	
D. chinensis Hornem.	
D. didactyla	
D. exilis Stapf	hungry rice, fonio, fundi, acha
D. ischaemum (Schreber) Muhl.	smooth finger-grass
D. milanjiana (Rendle) Stapf	
D. pentzii Stent.	
D. sanguinalis (L.) Scop.	hairy finger-grass, crabgrass
D. scalarum (Schweif.) Chiov.	blue couch grass
D. smutsii	
D. violascens Link	

I. Evidence of dormancy

Dormancy has been reported in seed lots of D. adscendens (4,15-17,19), D. chinensis (17), D. didactyla (9), D. exilis (3), D. ischaemum (5,6), D. milanjiana (7,8), D. pentzii (8), D. sanguinalis (1,2,5,6,10,11), D. scalarum (12,13) and D. violescens (17). After-ripening periods required to remove dormancy in seed lots of Digitaria spp. can be considerable; for example 1300 days for D. adscendens (16) and 18 months for D. scalarum (12), whilst two-year-old seeds of D. didactyla can remain dormant (9). The severity of dormancy in Digitaria spp. causes problems in breeding programmes (8).

II. Germination regimes for non-dormant seeds

D. ischaemum

Alternating temperatures: 20°/35°C, 20°/40°C, 20°/30°C (18h/6h) (6)

D. sanguinalis

Alternating temperatures: 20°/35°C, 20°/30°C, 20°/40°C (18h/6h) in light (6)

D. smutsii

TP: 20°/30°C (16h/8h): 10d (ISTA)

III. Unsuccessful dormancy-breaking treatments

D. adscendens

Constant temperatures: 20°C, 30°C (16,17)

Pre-chill: 3°C, 30d (17)

GA_3: co-applied, 10, 25 ppm (20)

Scarification: concentrated sulphuric acid, 2,5 min (20)

Light: (17)

D. exilis

Pre-soak: 24h (3)

D. ischaemum

Light: (6)

Scarification: concentrated sulphuric acid, 2 min (6)

D. milanjiana

Alternating temperatures: 10°/20°C, 10°/30°C, 20°/30°C (12h/12h) in light (7)

GA_3: co-applied, 50-800 ppm (7,8)

Thiourea: co-applied, 10^{-2} M (7)

Potassium nitrate: co-applied, 10^{-2} M (7)

D. pentzii

GA_3: co-applied, 50-800 ppm (8)

D. sanguinalis

Oxygen: (1); 5-98% (2)

Potassium nitrate: co-applied, 0.2% (6)

IV. Partly-successful dormancy-breaking treatments

D. adscendens

Alternating temperatures: 20°/30°C (4); 20°/30°C (10h/14h) (17); 30°C/room temperature (10h/14h) (15,16); 25°±3°/35±3°C (17)

Warm stratification: 20°C, 30d, germinate at 20°/30°C (10h/14h) (17)

GA_3: co-applied, 5 ppm (20)

Removal of seed covering structures: dehull (16,19); dehull, then endosperm (16); cut off top

of hull (16)

Light: (4)

D. chinensis

Alternating temperatures: 25°±3°/35±3°C (17)

Warm stratification: 20°C, 30d, germinate at 20°/30°C (10h/14h) (17)

D. didactyla

Alternating temperatures: 20°/35°C, 15°/35°C (10h/14h) (9)

Light: 14h/d, at 35°C or 20°/35°C, 15°/35°C (10h/14h) (9)

D. exilis

Potassium cyanide: pre-applied, 24h, 10^{-3} M (3)

Sodium azide: pre-applied, 24h, 10^{-3} M (3)

Hydroxylamine hydrochloride: pre-applied, 24h, 10^{-3} M (3)

D. ischaemum

Alternating temperatures: 20°/40°C, 20°/35°C, 20°/30°C, 15°/25°C (18h/6h), 8w (6)

Pre-chill: 2°-5°C, 14,28d (6)

Ethanol: pre-applied, 7d, $50x10^{-6}$ 1 (in a 125 ml flask), in dark at 35°C, germinate at 20°/30°C (16h/8h) in red light, $3.3x10^{-9}$ mol cm^{-2} s^{-1} (5)

Potassium nitrate: co-applied, 0.2% (6)

Scarification: sand paper (6); concentrated sulphuric acid, 0.5, 1 min (6)

1,2-Dibromo-3-chloropropane: co-applied, 10 ppm (18)

D. milanjiana

Removal of seed covering structures: dehull (7,8); dehull then endosperm (7); chip (8)

GA_3: co-applied, 10-800 ppm, dehulled seeds (7,8)

Thiourea: co-applied, 10^{-2} M, dehulled seeds (7)

Potassium nitrate: co-applied, 10^{-2} M, dehulled seeds (7)

D. pentzii

Removal of seed covering structures: dehull (8); chip (8)

GA_3: co-applied, 50-800 ppm, dehulled seeds (8)

D. sanguinalis

Alternating temperatures: 15°/30°C (16h/8h) (1); 20°/40°C, 20°/30°C, 15°/25°C (18h/6h), 8w

(6)

Pre-chill: 10°C, 5d (1); 2°-5°C, 14-56d (6); 14°C, 2-3m (14)

Light: (6); 9h/d (1); 100-200 fc (2)

Potassium nitrate: co-applied, 0.25% (1)

Ethylene chlorohydrin: pre-applied, 24,48h, 0.5-0.125% (1); pre-applied, 48h, 25-250, 1000 ppm (10)

Pre-soak: (1)

Removal of seed covering structures: dehull (14); caryopses scarified (2); caryopses scarified plus oxygen, 40-98% (2)

Ethanol: pre-applied, 7d, $50x10^{-6}$1 (in a 125 ml flask), in dark at 35°C, germinate at 20°/30°C (16h/8h) in red light, $3.3x10^{-9}$ mol cm^{-2} s^{-1} (5)

GA_3: co-applied, 100, 1000 ppm (11)

1,2-Dibromo-3-chloropropane: co-applied, 10 ppm (18)

D. scalarum

Alternating temperatures: 20°/30°C (night/day) in diffuse light (13); 15°/23°C, 20°/29°C (night/day) (12)

Scarification: (12); concentrated sulphuric acid, 5 min (13); mechanical (13)

D. violascens

Alternating temperatures: 25°±3°/35±3°C (17)

Warm stratification: 20°C, 30d, germinate at 20°/30°C (10h/14h) (17)

V. Successful dormancy-breaking treatments

D. ischaemum

Alternating temperatures: 20°/35°C, 20°/40°C (18h/6h), 5m (6)

Pre-chill: 2°-5°C, 56d, germinate at 20°/35°C (18h/6h) (6)

D. sanguinalis

Alternating temperatures: 20°/30°C (18h/6h) in light, 3m (6); 20°/35°C (18h/6h), 3m (6)

Pre-chill: 2°-4°C, 56d, in light (1)

Ethylene chlorohydrin: pre-applied, 48h, 500 ppm (2, 10)

Removal of seed covering structures: (1); puncture (2, 10)

D. smutsii

Pre-chill, Potassium nitrate (ISTA)

VI. Comment

Two month pre-chill treatments at about 3°C appear to be satisfactory for D. ischaemum (6) and D. sanguinalis (1). Of those tested, the most suitable subsequent alternating temperature regimes for germination are between 20°/35°C and 20°/40°C (18h/6h) (6). However substantial periods in test may be required for full germination, viz. 140 days for D. ischaemum and 75d for D. sanguinalis (6).

The promotion of germination of the most dormant seeds of D. milanjiana and D. pentzii is likely to prove more difficult (7,8). Suggested additional treatments are dehulling plus co-application of gibberellic acid at 100 ppm. In addition prick and re-prick the firm seeds which remain in test.

VII. References

1. Delouche, J.C. (1956). Dormancy in seeds of Agropyron smithii, Digitaria sanguinalis, and Poa pratensis. Iowa State College Journal of Science, 30, 348-349.

2. Gianfagna, A.J. and Pridham, A.M.S. (1951). Some aspects of dormancy and germination of crabgrass seed, Digitaria sanguinalis Scop. Proceedings of the American Society for Horticultural Science, 58, 291-297.

3. Roberts, E.H. (1964). The distribution of oxidation-reduction enzymes and the effects of respiratory inhibitors and oxidising agents on dormancy in rice seed. Physiologia Plantarum, 17, 14-29.

4. Takabayashi, M. and Nakayama, K. (1981). [The seasonal change in seed dormancy of main upland weeds.] Weed Research, Japan, 26, 249-253.

5. Taylorson, R.B. and Hendricks, S.H. (1979). Overcoming dormancy in seeds with ethanol and other anesthetics. Planta, 145, 507-510.

6. Toole, E.H. and Toole, V.K. (1941). Progress of germination of seed of Digitaria as influenced by germination temperature and other factors. Journal of Agricultural Research, 63, 65-90.

7. Baskin, J.M., Shank, S.C. and West, S.H. (1967). Studies on germination and dormancy of Digitaria milanjiana (Rendle) Stapf from tropical Africa. Proceedings of Soil and Crop Science Society of Florida, 27, 90-96.

8. Baskin, J.M., Shank, S.C. and West, S.H. (1969). Seed dormancy in two species of Digitaria from Africa. Crop Science, 9, 58 4-586.

9. Febles, G. and Harty, R. (1973). Effect of light and alternate temperatures on the germination of Digitaria didactyla. Cuban Journal o f Agricultural Science, 7, 233-236.

10. Gianfagna, A.J. and Pridham, A.M.S. (1952). Some aspects of dormancy and germination of crabgrass seed, Digitaria sanguinalis Scop. Proceedings of the North Eastern Weed Control Conference, 6, 321-326.

11. Gray, R.A. (1958). Breaking the dormancy of peach seeds and crabgrass seeds with gibberellins. Plant Physiology, 33, 40-41.

12. Harker, K.W. (1957). A note on Digitaria scalarum seed. East African Agricultural Journal, 23, 109.

13. Huxley, P.A. and Turk, A. (1966). Factors which affect the germination of seeds of six common East African weeds. Experimental Agriculture, 2, 17-25.

14. Martin, J.N. (1943). Germination studies of the seeds of some common weeds. Proceedings of the Iowa Academy of Science, 50, 221-2 28.

15. Matumura, M. and Hirayoshi, I. (1961). [Physiological and ecological studies on germination of Digitaria seeds. II. Changes in germinability with elapsing of stored period on five lines of Mehisiba (D. adscendens Henrad) through successive generations.] Gifu University Faculty of Agriculture Research Bulletin, 14, 78-88.

16. Matumura, M. and Hirayoshi, I. (1962). [Physiological and ecological studies on germination of Digitaria seeds. III. A function of the caryopsis and hulls on appearing the individual difference of germinability.] Gifu University Faculty of Agriculture Research Bulletin, 16 104-111.

17. Matumura, M., Takase, N. and Hirayoshi, I. (1960). [Physiological and ecological studies on germination of Digitaria seeds. I. Differences in response to germinating conditions and dormancy among individual plants.] Gifu University Faculty of Agriculture Research Bulletin, 12, 89-96.

18. Miller, P.M., Ahrens, J.F. and Stoddard, E.M. (1965). Stimulation of crabgrass seed germination by 1,2-dibromo-3-chloropropane and ethylene dibromide. Weeds, 13, 13-14.

19. Shimizu, M. (1959). [Relation of the enclosing structure of the Digitaria adscendens spikelet to its germination. 2. The role of the enclosing structure (glumes and shell coat) of crabgrass (D. adscendens) and rice-plant spikelets in the absorption of water and water soluble substances.] Proceedings of the Crop Science Society of Japan, 28, 239-243. (From Horticultural Abstracts, 1960, 30, 1662.)

20. Singhal, B.K. and Sen, D.N. (1981). Seed germination in some grasses of Indian desert. Forage Research, 7, 27-30.

ECHINOCHLOA

E. colona (L.) Link [E. colonum Link; Panicum colonum L.]	jungle rice, shama millet
E. crus-galli (L.) Beauv. [Panicum crus-galli]	barnyard millet
E. frumentacea (Roxb.) Link [Panicum frumentaceum Roxb.]	japanese barnyard millet, sanwa millet, billion-dollar grass
E. utilis	

I. Evidence of dormancy

Seeds of E. colona (5,19), E. crus-galli (5,8,9,15-17,21-27) and E. frumentacea (1,6) can show considerable dormancy at harvest and may require 2-8 months after-ripening for dormancy to be lost (19).

II. Germination regimes for non-dormant seeds

E. crus-galli

TP: 20°/30°C (16h/8h); 25°C: 10d (ISTA)

Constant temperatures: 25°C (11); 30°C (14)

Alternating temperatures: 15°-20°/30°C, 15°/35°C, 15°-25°/40°C (16h/8h) (14)

E. frumentacea

TP: 20°/30°C (16h/8h): 10d (AOSA)

III. Unsuccessful dormancy-breaking treatments

E. colona

Light: dark (19)

Urea: co-applied, 0.5% (5)

E. crus-galli

Constant temperatures: 10°C (20); 20°C, dark (26); 30°C, dark (21)

Alternating temperatures: 20°/30°C (16h/8h) in light (24)

Warm stratification: 30°C, 7d (24)

Pre-soak: 24,48h (21)

Light: (21,27); dark (8,9,19,26)

Removal of seed covering structures: lemma and palea (27)

Oxygen: (17); 0%, scarified seeds (27); 100% (27)

Ammonium chloride: co-applied, 10^{-2} M (2)

Thiourea: co-applied, 0.2% (5); pre-applied, 24h, 10^{-1}-10^{-3} M (21,22)

Potassium nitrate: co-applied, 0.3% (5)

Indoleacetic acid: co-applied, 50, 100 ppm (7)

Kinetin: co-applied, 50, 100 ppm (7)

Sodium sulphide: pre-applied, 24h, 10^{-2}-10^{-4} M (21)

8-Hydroxyquinoline: pre-applied, 24h, 10^{-3}, 10^{-4} M (21)

Phenylthiourea: pre-applied, 24,48h, 10^{-2}, 10^{-3} M (22)

2,3-Dimercapto-1-propanol: pre-applied, 24,48h, 0.1, 0.01% (22)

Hydroxylamine: pre-applied, 24,48h, 10^{-2}, 10^{-3} M (22); pre-applied, 24h, 10^{-1}-10^{-3} M (21)

Salicylaldoxime: pre-applied, 24h, 10^{-1}-10^{-3} M (21)

Salicylic acid: pre-applied, 24h, 10^{-2} M (25)

Sodium diethyldithiocarbamate: pre-applied, 24h, 10^{-1}-10^{-3} M (21)

p-Nitrophenol: pre-applied, 24h, 10^{-2}-10^{-4} M (21)

Benzoquinone: pre-applied, 24h, 10^{-2}, 10^{-3} M (25); pre-applied, 48h, 10^{-4} M (25)

Malonic acid: pre-applied, 24h, 10^{-2} M (25)

Ascorbic acid: pre-applied, 24h, 10^{-1}, 10^{-2} M (21,23)

Cysteine: pre-applied, 24h, 10^{-1}, 10^{-2} M (23)

Glutathione: pre-applied, 24h, 10^{-2}, 10^{-3} M (23)

Ethrel: pre-applied, 24h, 10-1000 ppm (21)

Catechol: pre-applied, 24h, 10^{-2}, 10^{-3} M (21)

E. frumentacea

Pre-chill: 5°C, 7d (1,6)

Potassium nitrate: co-applied, 0.2% (6)

GA_3: co-applied, 100 ppm (6)

IV. Partly-successful dormancy-breaking treatments

E. colona

Light: continuous (19)

Potassium nitrate: co-applied, 0.3% (5)

Thiourea: co-applied, 0.25% (5)

E. crus-galli

Constant temperatures: 10°-42°C (9)

Alternating temperatures: (9); 30°/15°C (15); 20°/30°C in light (8,20); 5°/30°C (13); 5°/25°C (12); 5°/30°-35°C, 20°/30°-35°C (16); 8°/25°C in light (18)

Pre-chill: 5°C (9,21); 1°C, 5°C, 10°C, 2m (12); 10°C, 2m (26)

Potassium nitrate: co-applied, 10^{-2} M (2)

Sodium nitrate: co-applied, 10^{-3} M (2)

Hydroxylamine hydrochloride: co-applied, 3.2×10^{-4} M (2)

Potassium nitrite: co-applied, 10^{-5} M (2)

Urea: co-applied, 2.5×10^{-2}-10^{-1} M (17)

Scarification: sulphuric acid (9); sulphuric acid, 2 N, 15 min (27); sodium hydroxide, 2 N, 15-60 min (27)

Removal of seed covering structures: lemma and palea (9,21,25); lemma, palea and pericarp (27)

Light: (8,13,15,18,20); 1 min (9); 4×10^{-4} W m^{-2}, 5 min (12)

Ethanol: pre-applied, 3d, 0.5 M, at 35°C, 5 min red light, germinate at 20°/30°C (16h/8h) (10)

Pre-soak: 4-120h (16)

Pre-dry: 50°C, 14d, germinate at 20°/30°C (16h/8h) in light (24)

Oxygen: 20-100%, scarified seeds (27)

Calcium cyanamide: co-applied, 10^{-3}-10^{-1} M (17)

Potassium cyanide: pre-applied, 24h, 10^{-2} M (21,25); pre-applied, 24,48h, 10^{-2}, 10^{-3} M (22)

Sodium azide: pre-applied, 24h, 10^{-2} M (21,22)

Sodium cyanide: pre-applied, 24h, 10^{-2} M (25)

Sodium sulphide: pre-applied, 48h, 10^{-2}, 10^{-3} M (22)

Hydroquinone: pre-applied, 24h, 10^{-1} M (21,22,25)

8-Hydroxyquinoline: pre-applied, 24,48h, 10^{-2} -10^{-4} M (25)

Benzoquinone: pre-applied, 24h, 10^{-2} M (23); pre-applied, 48h, 10^{-2}, 10^{-3} M (25)

8-Oxyquinoline: pre-applied, 24,48h, 10^{-2} M (22,25)

Mercuric chloride: pre-applied, 24h, 10^{-2} M (21,22,25); pre-applied, 48h, 10^{-2}, 10^{-3} M (22)

2-4 Dinitrophenol: pre-applied, 24h, 10^{-2} M (21); pre-applied, 48h, 0.1% (25)

Sodium diethyldithiocarbamate: pre-applied, 48h, 10^{-1} M (22)

Salicylaldoxime: pre-applied, 48h, 10^{-2} M (22)

E. frumentacea

Alternating temperatures: (6); 10°/15°C, 20°/25°C, 25°/30°C (night/day) (3)

Thiourea: co-applied, 0.2% (6)

E. utilis

Alternating temperatures: 10°/15°C, 20°/25°C, 25°/30°C (night/day) (3)

V. Successful dormancy-breaking treatments

E. colona

Light: continuous (19)

E. crus-galli

Pre-dry (ISTA)

Alternating temperatures: 20°-30°/5°C, 30°/15°C (day/night) in light (15)

Pre-chill: 5°C, 6m (15); 1°C, 5°C, 2m (26)

Liquid nitrogen: 5 min, then thaw, 1h, 10 cycles (4)

Pre-dry: 50°C, 14d, then warm stratifiction, 30°C, 7d, germinate at 20°/30°C (16h/8h) in light

(24)

Light: 1 min (9)

Removal of seed covering structures: lemma, palea and pericarp (9); excise embryo, test on agar (27)

Potassium cyanide: co-applied, $5x10^{-3}$ -10^{-1} M (17)

Sodium cyanide: co-applied, $5x10^{-3}$ -10^{-1} M (17)

E. frumentacea

Alternating temperatures: 20°/30°C, 15°/25°C (16h/8h) in light (1)

Pre-dry: 35°C, 7d, germinate at 20°/30°C (16h/8h) (1)

VI. Comment

Although long pre-chill treatments - 2 to 6 months at 5°C for example - can promote the germination of dormant seeds of weedy Echinochloa spp., quite short pre-chill treatments - 7 days at 5°C for example - can be detrimental to less dormant or non-dormant seeds of the cultivated Echinochloa spp. (15,26). Consequently pre-chilling cannot be used as a general dormancy-breaking procedure for all Echinochloa accessions. Light and alternating temperatures are essential for germination (8-10,13,15,16,18,20,24): 20°/30°C (16h/8h) in light is a satisfactory regime for partly-dormant accessions (1), but does not promote full germination of dormant seeds of weedy Echinochloa spp. (16,20,24). In these cases lemma and palea removal or pricking near the embryo are suggested. Where this is inadequate pre-drying with subsequent warm stratification may be a useful additional procedure (24).

VII. References

1. Harper, L.W. (1970). Dormancy in Japanese millet (Echinochloa crus-galli var. Frumentacea (Roxb.) Wight) seed. Proceedings of the Association of Official Seed Analysts, 60, 132-137.

2. Hendricks, S.B. and Taylorson, R.B. (1974). Promotion of seed germination by nitrate, nitrite, hydroxylamine, and ammonium salts. Plant Physiology, 54, 304-309.

3. Hughes, R.M. (1979). Effects of temperature and moisture stress on germination and seedling growth of four tropical species. Journal of the Australian Institute of Agricultural Science, 45, 125.

4. Jordan, J.L. (1981). Seed dormancy in Pennsylvania smart weed and barnyard grass. Dissertation Abstracts International, B, 42, 1256-1257.

5. Moursi, M.A., Rizk, T.Y. and El-deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

6. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Asosciation, 27, 710-729.

7. Rizk, T.Y., Fayed, M.T. and El-Deepah, H.R. (1978). Effect of some promoters on weed seed germination. Research Bulletin, Faculty of Agriculture, Ain Shamo University, 818, 30pp.

8. Takabayashi, M. and Nakayama, K. (1981). [The seasonal change in seed dormancy of main upland weeds.] Weed Research, Japan, 26, 249-253.

9. Takahashi, H. (1978). Seed germination, ecology and cultivation of barnyard grass after italian ryegrass in unflooded paddy fields. Japan Agricultural Research Quarterly, 12, 44-48.

10. Taylorson, R.B. and Hendricks, S.B. (1979). Overcoming dormancy in seeds with ethanol and other anaesthetics. Planta, 145, 507-510.

11. Vanderzee, D. and Kennedy, R.A. (1981). Germination and seedling growth in Echinochloa crus-galli var. oryzicola under anoxic conditions: structural aspects. American Journal of Botany, 68, 1269-1277.

12. Watanabe, Y. (1978). [Physiological and ecological studies on upland weeds in Hokkaido.] Research Bulletin of The Hokkaido National Agricultural Experimental Station, 123, 17-77.

13. Watanabe, Y. (1981). [Ecological studies on seed germination and emergence of some summer annual weeds of Hokkaido.] Weed Research, Japan, 26, 193-199. (From Seed Abstracts, 1982 5, 2738.)

14. Arai, M. and Miyahara, M. (1963). [Physiological and ecological studies on barnyard grass (Echinochloa crus-galli Beauv. var oryzicola Ohwi.). V. On the germination of the seed.] Proceedings of the Crop Science Society of Japan, 31, 362-366.

15. Furya, S. and Kataoka, T. (1983). The effect of temperature and soil moisture on innate dormancy-breaking in Echinochloa spp. and temperature and light conditions for their germination. Aspects of Applied Biology, 4, 55-62.

16. Hayashi, M. and Kuroki, O. (1973). [Studies on the seed dormancy and breaking of seed dormancy of barnyard grass (Echinochloa crus-galli Beauv. var oryzicoia Ohwi.).] Japanese Journal of Tropical Agriculture, 16, 276-282.

17. Inoue, K., Higashi, T. and Yamasaki, K. (1970). [Control of barnyard grass using the dormancy breaking effect of calcium cyanamide. 1. The action of dormancy breaking of respiration inhibitory agents and gases to barnyard grass seeds.] Journal of the Science of Soil and Manure, 41, 377-382.

18. Popova, D. (1979). [Effect of light at constant and variable temperature conditions on the germination of green amaranth (Amaranthus retroflexus (L.) R. et S.) and barnyard grass (Echinochloa crus-galli L.) seeds.] Plant Science, 16, 39-48.

19. Ramakrishnan, P.S. (1960). Ecology of Echinochloa colonum Link. Indian Academy of Science Proceedings B, 52, 73-90.

20. Roché, B.F. Jr. and Muzik, T.J. (1964). Ecological and physiological study of Echinochloa crus-galli (L.) Beauv. and the response of its biotypes to sodium 2,2-dichloropropionate. Agronomy Journal, 56, 155-160.

21. Shimizu, N., Takahashi, H. and Tajima, K. (1974). [Effect of some artificial treatments and various chemicals as oxidase inhibitors on breaking seed dormancy in Echinochloa crus-galli var caudata.] Journal of Japanese Society of Grassland Science, 20, 173-180.

22. Shimizu, N. and Ueki, K. (1972). [Studies on the breaking of dormancy in barnyard grass seed. 3. Change of the dormancy-breaking effect of several inhibitors against oxidation-reduction system with dormancy stage.] Proceedings of the Crop Science Society of Japan, 41, 480-487.

23. Shimizu, N. and Ueki, K. (1972). [Studies on the breaking of dormancy in barnyard grass seed. 3. Change of the dormancy-breaking effect of various compounds concerned with the oxidation-reduction system by dormancy stage.] Proceedings of the Crop Science Society of

Japan, 41, 488-495.

24. Taylorson, R.B. (1980). Aspects of seed dormancy in fall panicum (Panicum dichotomiflorum). Weed Science, 28, 64-67.

25. Ueki, K. and Shimuzu, N. (1969). [Studies on the breaking of dormancy in barnyard grass seed. 1. The effects of various chemicals on the breaking of dormancy.] Proceedings of the Crop Science Society of Japan, 38, 261-272.

26. Watanabe, Y. and Hirokawa, F. (1979). [Ecological studies on the germination and emergence of annual weeds. 1. Effect of temperatures on the dormancy breaking in seeds of Chenopodium album, Echinochloa crus-galli var praticola and Polygonum lapathifolium.] Weed Research, Japan, 17, 24-28.

27. Yamasue, Y., Sudo, K. and Ueki, K. (1977). Physiological studies on seed dormancy of barnyard grass (Echinochloa crus-galli Beauv. var Oryzicola Ohwi.). Proceedings of the 6th Asian-Pacific Weed Science Society Conference, Indonesia 1977, 1, 42-51.

ELEUSINE

E. compressa	
E. coracana (L.) Gaertn. [Cynosurus coracanus, L.; E. coracan Aschers. & Graebn.]	finger millet, African millet, koracan, ragi, wimbi, bulo, telebun
E. indica (L.) Gaertn.	goose grass, fowl-foot grass
E. tristachya Lam.	

I. Evidence of dormancy

Germinating seeds of E. coracana as a routine procedure in seed testing stations can be particularly difficult (1). Variation in dormancy between cultivars can be considerable (11,12). In the more dormant cultivars dormancy may remain after seven months after-ripening at room temperature (8,11,12). As might be expected the weed/pasture Eleusine spp. can show considerably more dormancy than E. coracana.

II. Germination regimes for non-dormant seeds

E. coracana

TP: 20°/30°C (16h/8h): 8d (ISTA)

Constant temperatures: 30°C, 5d (2)

Alternating temperatures: 20°/30°C (16h/8h), 14d (A)

III. Unsuccessful dormancy-breaking treatments

E. compressa

Pre-dry: 110°C, 3-4h (5)

Scarification: concentrated sulphuric acid, 1 min (5)

Light: (5)

E. coracana

Alternating temperatures: (8)

Light: (2,8)

Potassium chloride: co-applied, 0.1% (8)

Ammonium chloride: co-applied, 0.2% (8)

Ammonium sulphate: co-applied, 0.1% (8)

Thiourea: co-applied, 0.2% (8)

Potassium nitrate: co-applied, 0.01% (8)

GA_3: co-applied, 100 ppm (8,9)

Ammonium thiocyanate: co-applied, 0.01% (8)

Ethylene chlorohydrin: co-applied, 0.0001% (8)

E. indica

Constant temperatures: 10°C, 15°C, 20°C (13); 15°-35°C in dark (4); 28°-50°C (3)

Alternating temperatures: 15°/25°C (17h/7h) (13)

Pre-chill: 4°C, 4w (10); 3°C, 2-8w (13)

Potassium nitrate:co-applied, 0.2%, in light (13)

Light: (3)

IV. Partly-successful dormancy-breaking treatments

E. compressa

Constant temperatures: 35°C in dark (5)

Pre-dry: 100°C, 2h (5)

E. coracana

Constant temperatures: 30°C in light, continuous (11,12)

Pre-chill: 5°C, 5d (8); 5°C, 7, 15d, plus potassium nitrate, co-applied, 0.2% (8)

Nitric acid: co-applied, 0.001-0.5% (8)

Sodium nitrate: co-applied, 0.01-0.5% (8)

Ammonium nitrate: co-applied, 0.01-0.5% (8)

Sodium nitrate: co-applied, 0.2% (8)

Aluminium nitrate: co-applied, 0.2% (8)

Magnese nitrate: co-applied, 0.2% (8)

Magnesium nitrate: co-applied, 0.1% (8)

Potassium nitrate: co-applied, 0.1% (8)

Ethylene chlorohydrin: co-applied, 0.1% (8)

Scarification: concentrated sulphuric acid, 4 min (8)

Removal of seed covering structures: lemma and palea (14)

E. indica

Alternating temperatures: 20°/30°C (16h/8h) in light (13); 4°C/ambient temperature (19h/5h) (10); 31.5°/23°C (12h/12h) in dark or light (6); 20°/28°C, 20°/30°C, 20°/40°C (16h/8h) with or without potassium nitrate, co-applied, 0.2% (3)

GA_3: co-applied, 0.01%, at 31.5°/23°C (12h/12h) in light (6)

Potassium nitrate: co-applied, 0.2%, at 31.5°/23°C (12h/12h) in light (6); co-applied, 0.2%, at 30°C (3)

Scarification: mechanical, with or without potassium nitrate, co-applied, 0.2% (13)

Removal of seed covering structures: lemma and palea (14)

E. tristachya

Removal of seed covering structures: lemma and palea (14)

V. Successful dormancy-breaking treatments

E. coracana

Potassium nitrate (ISTA)

Potassium nitrate: co-applied, 0.05-0.5%, at 25°C (8)

Calcium nitrate: co-applied, 0.1% (8)

Barium nitrate: co-applied, 0.2% (8)

Potassium nitrite: co-applied, 0.2% (8)

Scarification: concentrated sulphuric acid, 2 min, germinate at 25°C (8)

E. indica

Potassium nitrate: co-applied, 0.2%, at 30°C in light (4); co-applied, 0.2%, at 20°/30°C, 20°/35°C (16h/8h) in light (3,4); co-applied, 0.2% at 20°/35°C, 25°/40°C, 20°/40°C (17h/7h) (13)

GA_3: co-applied, 0.1%, at 31.5°/23°C (12h/12h) in light (7)

Removal of seed covering structures: prick (10)

Pre-soak: 7d (3)

VI. Comment

It has been suggested that a constant temperature of 30°C results in a greater proportion of seeds of E. coracana germinating than an alternating temperature of 20°/30°C (1), but this conclusion is possibly a result of the short test period, 5 days. For non-dormant seeds the latter regime is suitable (A). It has further been suggested that no procedure is satisfactory for

seed testing and that instead a tetrazolium test should be performed (1). However, it is suggested here that seeds of Eleusine spp. be tested for germination in an alternating temperature regime of 20°/30°-35°C (16h/8h) in light with potassium nitrate co-applied at 0.2% with pricking of ungerminated seeds near the embryo after a few days in test.

VII. References

1. Agrawal, P.K. and Kaur, S. (1975). Standardisation of the tetrazolium test for ragi (Eleusine coracana) seeds. Seed Science and Technology, 3, 565-568.

2. Arora, N. and Banerjee, S.K. (1978). Seed testing procedure for finger millet (Eleusine coracana). Seed Research, 6, 158-160.

3. Chin, H.F. and Raja Harum, R.M. (1979). Ecology and physiology of Eleusine indica seeds. Proceedings of the 7th Asian-Pacific Weed Science Society Conference, Sydney, Australia, 313-315.

4. Fulwider, J.R. and Engel, R.E. (1959). The effect of temperature and light on germination of seed of goosegrass, Eleusine indica. Weeds, 7, 359-361.

5. Gupta, R.K. and Saxena, S.K. (1980). Ecological studies on Eleusine compressa - a potential grass for sheep pasturage in the arid zone. Annals of Arid Zone, 19, 1-14.

6. Hawton, D. (1979). Temperature effects on Eleusine indica and Setaria anceps grown in association. Weed Research, 19, 279-284.

7. Hawton, D. and Drennan, D.S.H. (1980). Studies on the longevity and germination of seed of Eleusine indica and Crotalaria goreensins. Weed Research, 20, 217-223.

8. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

9. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

10. Popay, A.I. (1973). Germination and dormancy in the seeds of certain East African weed species. Proceedings of the 4th Asian-Pacific Weed Science Society Conference, 1, 77-81.

11. Shimizu, N. and Mochizuki, N. (1978). [Studies on dormancy and germination of seed in finger millet (Eleusine coracana). 2. Varietal differences of degree of dormancy and germination behaviour.] Bulletin of the National Grassland Research Institute (Japan), 12, 76-91.

12. Shimizu, N. and Tajima, K. (1979). [Studies on dormancy and germination of seed in finger millet (Eleusine coracana). 1. Effect of light, temperature and their interaction on germination.] Journal of Japanese Society of Grassland Science, 24, 289-295.

13. Toole, E.H. and Toole, V.K. (1940). Germination of seed of goosegrass, Eleusine indica. Journal of the American Society of Agronomy, 32, 320-321.

14. Hilu, K.W. and Wett, J.M.J. de (1980). Effect of artificial selection on grain dormancy in Eleusine (Gramineae). Systematic Botany, 5, 54-60.

ERAGROSTIS

E. abyssinica (Jacq.) Link [E. tef (Zucc.) Trotter; Poa abyssinica Jacq.] teff, t'ef

E. brizantha Nees

E. cilianensis	
E. curvula (Schrad.) Nees	weeping lovegrass
E. ferruginea Beauv.	
E. lehmanniana Nees	Lehmann lovegrass
E. leptoschachya (Steud.) Blake	lovegrass
E. secundiflora Presl	
E. trichodes (Nutt.) Wood	sand lovegrass

I. Evidence of dormancy

E. abyssinica seeds show some dormancy at harvest. This is most clearly seen from the duration of the germination test required at 30°C for full germination: freshly harvested seeds require 6-10 weeks, whereas old (after-ripened) seeds require only 3-7 days (6). Other Eragrostis spp. can exhibit considerable seed dormancy (1,3,5,8,9,16,18,20,21,24).

II. Germination regimes for non-dormant seeds

E. abyssinica

TP: 20°/30°C (16h/8h): 10d (ISTA)

Constant temperatures: 30°C (6)

Alternating temperatures: 20°/30°C (18h/6h) (13)

E. curvula

TP: 15°/30°C; 20°/35°C (16h/8h): 10d (ISTA)

TP: 20°/35°C (16h/8h): 14d (AOSA)

E. lehmanniana

Constant temperatures: 25°C, 30°C (16)

Alternating temperatures: 20°/30°C in light, 15°/25°C, 25°/35°C (16h/8h) (5,16)

E. trichodes

TP: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

E. abyssinica

Pre-chill: 3°-5°C, 4-8w (13)

Potassium nitrate: co-applied, 0.2% (13)

E. curvula

Constant temperatures: 15°-25°C (9)

Pre-chill: 3°-5°C, 4-8w (13)

Potassium nitrate: co-applied, 0.2% (9,13)

GA_3: co-applied, 100 ppm (9,10)

Thiourea: co-applied, 0.2% (9)

Light: (9); dark (14)

E. ferruginea

Light: dark, 6-12h, then red, 10 min, then dark 18-12h, then fluorescent, 12h (17); dark, 6-12h, then far red, 10 min, then dark 18-12h, then fluorescent, 12h (17); dark at 27°C (18,19,21)

5-Bromouracil: co-applied, 10^{-4}-$1.6x10^{-2}$ M (18)

5-Fluorouracil: co-applied, 10^{-4}-10^{-1} M (18)

E. lehmanniana

Pre-chill: 3°-5°C, 4-8w (13)

GA_3: (3,5,16)

Kinetin: (3,5,16)

Indoleacetic acid: (3,5,16)

Thiourea: (3,5,16)

Gamma radiation: (3,5,16)

High frequency electrical field: (3,16)

Sodium hydroxide: pre-applied, 24 min +, 1 N (5)

Pre-wash: (5)

Potassium nitrate: (3,16)

E. leptoschachya

Removal of seed covering structures: (8)

IV. Partly-successful dormancy-breaking treatments

E. abyssinica

Alternating temperatures: 20°/40°C (18h/6h) (13)

Constant temperatures: 30°C (6)

E. cilianensis

Ethanol: pre-applied, 0.5 M, 35°C, 3d, 5 min red light, germinate at 20°/30°C (16h/8h) (12)

E. curvula

Constant temperatures: 30°C (9,14)

Alternating temperatures: 30°/15°C (16h/8h) (9); 2°/7°C, 7°/13°C in light (15)

Pre-chill: 5°C, 4d (9)

Light: (11,14,15); dark (9); dark, 8h, then fluorescent, 60-400 fc, 2 min (25); dark, 8h, then fluorescent, 4000 fc, 0-32 min (25)

Potassium permanganate: pre-applied (11)

Sodium thiosulphate: pre-applied (11)

Sodium perborate: pre-applied (11)

Potassium iodate: pre-applied (11)

Chlorinated lime: pre-applied (11)

Potassium nitrate: co-applied, 0.2% (13)

E. ferruginea

Light: dark, 24h, then 1000-2000 lux, 12h (7,17,18,20,21); dark, 24h, then 100, 200 lux, 21h/d (22)

Methanol: pre-applied, 1-12h, germinate at 27°C in light (21)

Acetone: pre-applied, 6-48h, germinate at 27°C in light (21)

E. lehmanniana

Constant temperatures: 15°C (5,13); 20°C (5); 29°C (11)

Alternating temperatures: 20°/30°C (16h/8h) in light (3); 20°/30°C (18h/6h) in light (16); 15°/25°C, 20°/30°C, 25°/35°C, 25°/40°C (23)

Pre-chill: 5°-10°C, 2-15w (16)

Sodium hydroxide: pre-applied, 24 min, 1 N, (3,5,16)

Scarification: sulphuric acid, 1 N, 30-100 min (3,5,16); cylinder, 7-12 min (3,5,16); mechanical (4); needle (5,16)

Light: (11); dark, 24h, then light (3)

Potassium nitrate: co-applied, 0.2% (13)

Pre-soak: 16°C, 36h (2); 28°C, 18h (2); 20-100 min, with agitation (3,5,16)

Potassium permanganate: pre-applied (11)

Sodium thiosulphate: pre-applied (11)

Sodium perborate: pre-applied (11)

Potassium iodate: pre-applied (11)

Chlorinated lime: pre-applied (11)

E. leptoschachya

Constant temperatures: 20°-25°C (8)

Light: (8)

E. secundiflora

Alternating temperatures: 20°/40°C (18h/6h) (13)

Pre-chill: 3°-5°C, 14d (13)

Potassium nitrate: co-applied, 0.2% (13)

E. trichodes

Alternating temperatures: 20°/30°C (16h/8h) (1); 20°/40°C (18h/6h)(13)

Pre-chill: 5°-10°C, 14d (1); 3°-5°C, 4-8w (13)

Potassium nitrate: co-applied, 0.1% (1); co-applied, 0.2% (13)

Calcium nitrate: co-applied, 0.2% (1)

Ammonium nitrate: co-applied, 0.2% (1)

Pre-dry: 90°-100°C, 30-40 min (1); 50°-60°C, 12-24h (1)

V. Successful dormancy-breaking treatments

E. abyssinica

Pre-chill, Potassium nitrate (ISTA)

Constant temperatures: 30°C, 70d (6)

Alternating temperatures: 20°/30°C (16h/8h) in light (13)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C in light or 20°/40°C (18h/6h) (13); co-applied, 0.2%, plus pre-chill, 3°-5°C, 14d (13)

E. curvula

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C in light, 20°/40°C, 25°/40°C (18h/6h) (13)

Light: dark, 1-3d, then light (14); dark, 24h, then fluorescent, 60-4000 fc, 2 min (25); dark, 24h, then red, 600 erg cm^{-2} s^{-1}, 8 min (25)

E. ferruginea

Methanol: pre-applied, 24h, germinate in light (21)

Removal of seed covering structures: puncture (21)

Pre-dry: 6-18d, germinate at 27°C in light, continuous (21)

Nitrogen: 100%, 36h, then germinate in light (19)

E. lehmanniana

Constant temperatures: 25°C, 30°C, 35°C (5,16)

Alternating temperatures: 20°/30°C, 15°/25°C, 25°/35°C (16h/8h) (5,16)

Pre-chill: 3°-5°C, 28d, plus potassium nitrate, co-applied, 0.2%, at 20°/30°C (18h/6h) in light (13)

E. secundiflora

Potassium nitrate: co-applied, 0.2%, then pre-chill, 3°-5°C, 14d, germinate at 20°/40°C (18h/6h) (13)

E. trichodes

Light, Pre-chill, Potassium nitrate (AOSA)

Potassium nitrate: co-applied, 0.2%, then pre-chill, 14d, germinate at 20°/40°C (18h/6h) (13); co-applied, 0.2%, then pre-chill, 28d, germinate at 30°/5°-15°C in light (24)

VI. Comment

Light can both promote and inhibit the germination of dormant and slightly dormant seeds of Eragrostis spp. Light treatments are particularly promotory when applied after the seeds have imbibed in the dark for 24 hours (7,17-22,25), but can be inhibitory when applied during the first 8 hours of imbibition (17,25). Testing slightly dormant seeds of E. abyssinica in an alternating temperature regime of 20°/30°C (16h/8h) in the light (8h/d) with 0.2% potassium nitrate co-applied is very satisfactory: in our laboratory this regime, which involves combining 3 stimulatory agents, has been very successful in promoting the full germination of accessions showing residual dormancy (A). In view of the above comment on the light regime, however, it is suggested that the light treatment should not be applied during the first 24 hours of the germination test. For accessions of E. lehmanniana testing at 20°/30°C (16h/8h) in the light with 0.2% potassium nitrate co-applied is also proposed but after 28 days pre-chilling at 3°-5°C (13). It is suggested that the AOSA/ISTA prescriptions be applied for E. curvula and E. trichodes, but without light on the first day of the test. The AOSA recommend a 6 week pre-chill treatment at 5° to 10°C for dormant seeds of E. trichodes.

VII. References

1. Ahring, R.M., Dun, N.L. and Harlan, J.R. (1963). Effect of various treatments in breaking seed dormancy in sand lovegrass, Eragrostis trichodes (Nutt.) Wood. Crop Science, 3, 131-133.

2. Bleak, A.T. and Keller, W. (1972). Germination and emergence of selected forage species following preplanting seed treatment. Crop Science, 12, 9-13.

3. Brauen, S.E. (1967). Seed coat histology, germination dormancy and seedling drought tolerance of Lehmann lovegrass (Eragrostis lehmanniana Nees). Dissertation Abstracts, 28B, 436.

4. Haferkamp, M.R. (1975). Some physiological and physical changes exhibited by seeds of lehmann lovegrass (Eragrostis lehmanniana Nees) with presowing seed treatments of moistening and drying. Dissertation Abstracts, 36B, 1011.

5. Haferkamp, M.R., Jordan, G.L. and Matsuda, K. (1977). Pre-sowing seed treatments, seed coats and metabolic activity of Lehmann lovegrass seeds. Agronomy Journal, 69, 527-530.

6. Katayama, T.C. and Nakagama, A. (1972). Studies on the germination behaviour of teff seeds (Eragrostis abyssinica Schrad.) with the emphasis of storage condition. Japanese Journal of Tropical Agriculture, 16, 97-105.

7. Isikawa, S., Fujii, T. and Yokohama, Y. (1961). Photoperiodic control of the germination of Eragrostis seeds. Botanical Magazine (Tokyo), 74, 14-18.

8. Lodge, G.M. and Whalley, R.D.B. (1981). Establishment of warm- and cool- season native perennial grasses on the North-West slopes of New South Wales. I. Dormancy and germination. Australian Journal of Botany, 29, 111-119.

9. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

10. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

11. Shimizu, N., Tajima, K. and Ogata, R. (1970). [Studies on promotion of germination at low temperature in tropical grass seed. 1. Promotion of germination at low temperature in seeds of Chloris spp. and Eragrostis spp.] Bulletin of the National Grassland Research Institute, 11, 47-56. (From Seed Abstracts, 1978, 1, 2062.)

12. Taylorson, R.B. and Hendricks, S.B. (1979). Overcoming dormancy in seeds with ethanol and other anesthetics. Planta, 145, 507-510.

13. Toole, V.K. (1939). Germination requirements of the seed of some introduced and native range grasses. Proceedings of the Association of Official Seed Analysts, 30, 227-243.

14. Toole, V.K. and Borthwick, H.A. (1968). Light responses of Eragrostis curvula seed. Proceedings of the International Seed Testing Association, 33, 515-530.

15. Voigt, P.W. (1973). Induced seed dormancy in weeping lovegrass Eragrostis curvula. Crop Science, 13, 76-79.

16. Wright, L.N. (1973). Seed dormancy, germination environment, and seed structure of lehmann lovegrass, Eragrostis lehmanniana Nees. Crop Science, 13, 432-435.

17. Fujii, T. (1962). Studies on photoperiodic responses involved in the germination of Eragrostis seeds. Botanical Magazine (Tokyo), 75, 56-62.

18. Fujii, T. (1963). Inhibitory effect of 5-bromouracil and 5-fluorouracil on photoperiodically induced germination of Eragrostis seed. Plant and Cell Physiology, 4, 277-283.

19. Fujii, T. (1963). On the anaerobic process involved in the photoperiodically induced germination of Eragrostis seed. Plant and Cell Physiology, 4, 357-359.

20. Fujii, T. and Isikawa, S. (1962). Effects of after-ripening on photoperiodic control of seed germination in Eragrostis ferruginea Beauv. Botanical Magazine, Tokyo, 75, 296-301. (From Herbage Abstracts, 1963, 33, 854.)

21. Fujii, T. and Yokohama, Y. (1965). Physiology of light-requiring germination in Eragrostis seeds. Plant and Cell Physiology, 6, 135-145.

22. Isikawa, S. (1954). Light-sensitivity against the germination. I. "Photoperiodism" of seeds. Botanical Magazine (Tokyo), 64, 51-56.

23. Knipe, O.D. (1967). Influence of temperature on the germination of some range grasses. Journal of Range Management, 20, 298-299.

24. Sayers, R.L. (1969). Germination requirements of sand dropseed (Sporobolus cryptandrus)

and sand lovegrass (Eragrostis trichodes). Dissertation Abstracts International, 30B, 1535-1536.

25. Toole, V.K. and Borthwick, H.A. (1968). The photoreaction controlling seed germination in Eragrostis curvula. Plant and Cell Physiology, 9, 125-136.

FESTUCA

F. arizonica Vasey	Arizona fescue
F. arundinacea Schreber	tall fescue
F. elatior L. [F. pratensis Huds.]	meadow fescue
F. elatior L. var apennina (De Not.) Hack.	
F. idahoensis Elmer	Idaho fescue
F. megalura Nutt. [Vulpia megalura (Nutt.) Rydb.]	foxtail fescue
F. octoflora Walt.	sixweeks fescue
F. ovina L. var capillata Alef. [F. tenuifolia Hort.]	hair fescue
F. ovina L. var duriuscula Koch. [F. duriuscula L.; F. trachyphylla (Hack.) Krajina]	hard fescue
F. ovina L. var ovina [F. vulgaris Hort.]	sheep fescue
F. rubra L. var commutata Gaud. [F. rubra var fallax Hack.]	chewings fescue
F. rubra L. var rubra	red and creeping red fescue
F. scabrella Torr. ex Hook.	rough fescue

I. Evidence of dormancy

Freshly harvested seeds of Festuca spp. can present problems of dormancy (1,5-9,14,17-20).

II. Germination regimes for non-dormant seeds

F. arizonica

Constant temperatures: 15°C, 20°C (10)

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) (10)

F. arundinacea

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (ISTA)

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (AOSA)

Constant temperatures: 18°-26°C (13)

F. elatior

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (ISTA)

TP: 15°/25°C; 20°/30°C (16h/8h): 14d (AOSA)

F. idahoensis

Alternating temperatures: 15°/20°C, 20°/25°C (16h/8h) (10,11)

F. megalura

Constant temperatures: 15°C, 20°C (12)

Alternating temperatures: 5°/20°C, 15°/25°C (16h/8h) (12)

F. octoflora

Constant temperatures: 20°C (5)

Alternating temperatures: 15°/25°C (15h/9h) (5)

F. ovina var capillata

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 10°/25°C (16h/8h): 28d (AOSA)

F. ovina var duriuscula

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 15°/25°C (16h/8h): 21d (AOSA)

F. ovina var ovina

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 15°/25°C (16h/8h): 21d (AOSA)

TP: 20°/30°C (16h/8h): 28d (AOSA)

F. rubra var commutata, F. rubra var rubra

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 15°/25°C (16h/8h): 21d (AOSA)

F. scabrella

Constant temperatures: 15°C, 20°C (10)

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) (10)

III. Unsuccessful dormancy-breaking treatments

F. arundinacea

Potassium nitrate: co-applied, 0.2% (9,17)

Thiourea: co-applied, 0.2% (9)

GA_3: co-applied, 100 ppm (9)

Kinetin: co-applied, $5x10^{-5}$ M (14)

Sodium azide: co-applied (14)

F. elatior

GA_3: co-applied, 100 ppm (9)

F. elatior var apennina

Constant temperatures: 20°C (18)

F. octoflora

Constant temperatures: 20°C in light (5)

Alternating temperatures: 10°/30°C (15h/9h) in light (5,16)

Potassium nitrate: co-applied, 0.2% (5)

F. ovina var ovina

Constant temperatures: 3°C, 28d (4)

F. rubra var commutata

Potassium nitrate: co-applied, 0.2% (7,9)

GA_3: co-applied, 100 ppm (9)

Thiourea: co-applied, 0.2% (9)

Light: (7)

Pre-soak: 22°C, 17h, then pre-dry, 15°C, 24h (2)

F. rubra var rubra

Potassium nitrate: co-applied, 0.2% (9); co-applied, $2x10^{-3}$, $2x10^{-2}$ M (19)

Thiourea: co-applied, 0.2% (9)

GA_3: co-applied, 9000-35000 ppm (15)

IV. Partly-successful dormancy-breaking treatments

F. arundinacea

Constant temperatures: 15°C (1)

Alternating temperatures: 25°/30°C (16h/8h) (17)

Light: (3,9)

Pre-chill: 3°-5°C, 7d (6,9)

Potassium nitrate: co-applied, 0.2% (14)

GA_3: co-applied, $5x10^{-4}$ M (14)

Removal of seed covering structures: (14)

F. elatior

Constant temperatures: 15°C (6,7); 20°C (18)

Alternating temperatures: 10°/30°C, 15°/30°C, 20°/30°C, 10°/25°C (18h/6h) (6,7)

Pre-chill: 5°C, 7-14d (6,7); 0°-2°C, 14d (8)

Light: (6,7,9)

Potassium nitrate: co-applied, 0.2% (6,7,9)

Pre-soak: 22°C, 17h, then pre-dry, 15°C, 24h (2)

F. elatior var apennina

Warm stratification: 20°C, 15d, then pre-chill, 2°C, 14d, germinate at 20°C (18)

F. octoflora

Alternating temperatures: 15°/30°C, 20°/30°C, 15°/25°C (15h/9h) in light (16)

Warm stratification: 20°C, 21d, in light, then pre-chill, 3°-5°C, 7d (5); 20°C, 21d, in light, plus potassium nitrate, co-applied, 0.2%, then pre-chill, 3°-5°C, 7d, germinate at 20°C in light (5)

Potassium nitrate: co-applied, 0.2%, at 10°C, 15°C, 15°/25°C (15h/9h) in light (16)

F. ovina var capillata

Constant temperatures: 10°C, 15°C, 20°C (6,7)

Alternating temperatures: 15°/25°C, 10°/30°C, 20°/30°C (18h/6h) (6,7)

Pre-chill: 5°C, 7, 14d (6,7,9,20)

Light: (6,7)

F. ovina var ovina

Constant temperatures: 10°C (4)

Light: (9)

Potassium nitrate: co-applied, 0.2% (9)

GA_3: co-applied, 100 ppm (9); co-applied, 10^{-3} M (4)

F. rubra var commutata

Alternating temperatures: 10°/30°C, 15°/30°C, 20°/30°C (18h/6h) (6,7)

Pre-chill: 3°-5°C, 7d (6,7,9)

Pre-soak: 22°C, 17h, then pre-dry, 15°C, 24h (2)

Light: (9)

F. rubra var rubra

Constant temperatures: 10°C, 15°C (6,7); 20°C in light, red (19)

Alternating temperatures: 10°/30°C, 15°/30°C, 20°/30°C (18h/6h) (6,7)

Pre-chill: 5°C, 7,14d (6,7,9,20)

Potassium nitrate: co-applied, 0.2% (6,7); co-applied, 0.2%, at 20°C (20)

Light: (9); 5 min/d (20)

GA_3: co-applied, 100 ppm (9)

V. Successful dormancy-breaking treatments

F. arizonica

Constant temperatures: 15°C, 20°C (10)

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) (10)

F. arundinacea

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Constant temperatures: 1°C, 5°C, 48d (1); 10°C, 24d (1)

Alternating temperatures: 10°-15°/20°-25°C (16h/8h) (1); 15°/25°C (16h/8h) (3,6); 15°/30°C (16h/8h) in light (9); 18°/28°C, 15°/30°C, 20°/30°C (16h/8h) (17)

Pre-chill: 1°C, 5°C, 10°C, 12-24d, germinate at 15°/25°C (16h/8h) (14); 10°C, 7d, germinate at 20°/30°C (16h/8h) in light (17)

F. elatior

Potassium nitrate, Pre-chill (ISTA)

Light, Potassium nitrate (AOSA)

Constant temperatures: 20°C, 15d, then pre-chill remaining seeds, 2°C, 14d, then germinate at 20°C (18)

Alternating temperatures: 15°/25°C (18h/6h) (6,7); 15°/30°C (16h/8h) (9)

Pre-chill: 3°-5°C, 7d (9)

Thiourea: co-applied, 0.2% (9)

F. elatior var apennina

Constant temperatures: 20°C, 15d, then pre-chill remaining seeds, 2°C, 14d, then germinate at 20°C (18)

Pre-chill: 0°-2°C, 28d (8)

F. idahoensis

Alternating temperatures: 15°/20°C, 20°/25°C (16h/8h) (10,11)

F. megalura

Constant temperatures: 10°C, 15°C, 20°C (12)

Alternating temperatures: 5°/20°C, 10°/20°C, 15°/20°C, 10°/25°C, 15°/25°C, 20°/25°C, 10°/30°C, 15°/30°C (16h/8h) (12)

F. octoflora

Constant temperatures: 20°C in light, 9h/d (16)

Potassium nitrate: co-applied, 0.2%, at 20°C in light, 9h/d (16)

F. ovina var capillata

Potassium nitrate, Pre-chill (ISTA)

Potassium nitrate (AOSA)

Alternating temperatures: 10°/25°C (18h/6h) (6,7)

Potassium nitrate: co-applied, 0.2%, at 10°/25°C (18h/6h) in light (6,7)

F. ovina var duriuscula

Potassium nitrate, Pre-chill (ISTA)

Light, Potassium nitrate (AOSA)

Constant temperatures: 15°C, 20°C (10)

Alternating temperatures: 15°/20°C, 15°/25°C, 20°/25°C (16h/8h) (10)

F. ovina var ovina

Potassium nitrate, Pre-chill (ISTA)

Light, Alternating temperatures: 15°/30°C (16h/8h) in light (9); 10°/20°C, 15°/20°C, 10°/25°C, 15°/25°C, 5°/20°C (16h/8h) (10, 11)

Pre-chill: 3°C, 7d (4,9)

Thiourea: co-applied, 0.2% (9)

F. rubra var commutata

Potassium nitrate, Pre-chill (ISTA)

Light, Potassium nitrate, Pre-chill (AOSA)

Constant temperatures: 15°C in light (9)

Alternating temperatures: 15°/30°C (16h/8h) (9); 15°/25°C (18h/6h) (6,7)

F. rubra var rubra

Potassium nitrate, Pre-chill (ISTA)

Light, Potassium nitrate, Pre-chill (AOSA)

Alternating temperatures: 15°/30°C (16h/8h) (9); 15°/25°C (18h/6h) (6,7); 12°/20°C (12h/12h) (19); 10°/20°C (15h/9h) (20); 5°-16°/20°C (12h/12h) in light, red, 1.4×10^{-6} mol m^{-2} s^{-1}, 10 min (19)

Pre-chill: 4°C, 21,42d (20)

F. scabrella

Constant temperatures: 15°C, 20°C (10)

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h) (10)

VI. Comment

For dormant seeds of F. octoflora (5) and F. ovina var capillata (6,7) potassium nitrate can be promotory, but for other Festuca spp. potassium nitrate is of little benefit provided the seeds are tested in a suitable temperature regime (6,7,9,17,19,20): that is the germination test temperature regime is the major factor which must be specified in order to promote the germination of dormant seeds of Festuca accessions. Accessions of F. octoflora which show partial dormancy show greater germination in 42 days when tested at a constant temperature of 20°C in light than at alternating temperature regimes of 20°/30°C or 15°/25°C (15h/9h) (5,16); the successful regimes listed for F. octoflora (above) are not sufficient, however, to promote full germination in freshly harvested seed lots (5). Accessions of other Festuca spp. require alternating temperatures for germination (1,2,6,7,9-11,17-20), but the standard alternating temperature regime of 20°/30°C (16h/8h) is not the most suitable (6,7,16,17,19). In a major study of the response of seed lots of many Festuca spp. to alternating temperatures an optimum regime of 15°/20°C (16h/8h) was discerned (10). Other studies suggest that this or 15°/25°C (16h/8h) are most suitable for germination tests (1,3,6,7,11,12,14) with the possible exceptions of F. ovina var ovina - where a wider range of optimum regimes (5°-15°/20°-25°C) has been suggested (10) - and F. ovina var capillata - where 10°/25°C has been proposed (6,7). For very dormant accessions which fail to germinate fully in these regimes (given sufficient time in test) pre-chilling for a prolonged period with 0.2% potassium co-applied is proposed.

VII. References

1. Boyce, K.G., Cole, D.F. and Chilcote, D.O. (1976). Effect of temperature and dormancy on germination of tall fescue. Crop Science, 16, 15-18.

2. Chippindale, H.G. (1933). The effect of soaking in water on the "seeds" of some gramineae. Annals of Applied Biology, 21, 225-232.

3. Danielson, H.R. and Toole, V.K. (1976). Action of temperature and light on the control of seed germination in alta tall fescue (Festuca arundinacea Schreb). Crop Science, 16, 317-320.

4. Harmer, R. and Lee, J.A. (1978). The germination and viability of Festuca vivipara (L.) Sm. plantlets. New Phytologist, 81, 745-751.

5. Hylton, L.O. Jr. and Bass, L.N. (1961). Germination of sixweeks fescue. Proceedings of the Association of Official Seed Analysts, 51, 118-124.

6. Kearns, V. and Toole, E.H. (1938). Temperature and other factors affecting the germination of the seed of fescues. Proceedings of the International Seed Testing Association, 10, 337-341.

7. Kearns, V. and Toole, E.H. (1939). Temperatures and other factors affecting the germination of fescue seed. USDA Technical Bulletin No. 638, pp. 35.

8. Linnington, S., Bean, E.W. and Tyler, B.F. (1979). The effects of temperature upon seed germination in Festuca pratensis var. apennina. Journal of Applied Ecology, 16, 933-938.

9. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

10. Young, J.A. and Evans, R.A. (1982). Temperature profiles for germination of cool season range grasses. USDA Agricultural Research Service, Agricultural Research Results, Western Series, No. 27.

11. Young, J.A., Evans, R.A., Eckert, R.E. Jr. and Ensign, R.D. (1981). Germination-temperature profiles for idaho and sheep fescue and Canby bluegrass. Agronomy Journal, 73, 716-720.

12. Young, J.A., Evans, R.A. and Kay, B.L. (1973). Temperature requirements for seed germination in an annual-type rangeland community. Agronomy Journal, 65, 656-659.

13. Bean, E.W. (1977). Effect of temperature on germination in Festuca arundinacea Schreb. Welsh Plant Breeding Station, Annual Report for 1976, pp.88-89.

14. Boyce, K.G. (1973). Seed dormancy in tall fescue (Festuca arundinacea Schreb.); acquisition, effect on metabolic process and relief by temperature and growth regulators. Dissertation Abstracts International B, 33, 5615-5616.

15. Button, E.F. (1959). Effect of gibberellic acids on laboratory germination of creeping red fescue (Festuca rubra). Agronomy Journal, 51, 60-61.

16. Hylton, L.O. Jr. and Bement, R.E. (1961). Effects of environment on germination and occurrence of sixweeks fescue. Journal of Range Management, 14, 257-260.

17. Stanway, V. (1952). A study made on laboratory germination of tall fescue seed. Proceedings of the Association of Official Seed Analysts, 42, 84-88.

18. Tyler, B., Borrill, M. and Chorlton, K. (1978). Studies in Festuca. X. Observations on germination and seedling cold tolerance in diploid Festuca pratensis and tetraploid F. pratensis var apennina in relation to their altitudinal distribution. Journal of Applied Ecology, 15, 219-226.

19. Williams, E.D. (1983). Effects of temperature fluctuation, red and far-red light and nitrate on seed germination of five grasses. Journal of Applied Ecology, 20, 923-935.

20. Williams, E.D. (1983). Effects of temperature, light, nitrate and pre-chilling on seed germination of grassland plants. Annals of Applied Biology, 103, 161-172.

HORDEUM

H. glaucum Steud.	
H. jubatum L.	foxtail barley, squirrel-tail grass
H. leporinum Link	
H. marinum Huds. [H. maritimum Stokes]	sea barley
H. murinum L.	wall barley
H. pusillum Nutt.	little barley
H. spontaneum Koch	
H. vulgare L. [H. sativum Pers.; H. distichon L.; H. distichum L.; H. hexastichon L.; H. polystichon Hall.]	barley

I. Evidence of dormancy

Of the common temperate cereals dormancy in H. vulgare is probably the most pronounced. This can cause problems both in seed testing and the malting industry. Dormancy is also

common in H. geniculatum (30), H. glaucum (30), H. jubatum (34,36), H. leporinum (25,30,33), H. marinum (30), H. murinum (6,10,30), H. pusillum (38) and H. spontaneum (41,42).

II. Germination regimes for non-dormant seeds

H. vulgare

S; BP: 20°C: 7d (ISTA)

S; BP: 20°C; 15°C: 7d (AOSA)

III. Unsuccessful dormancy-breaking treatments

H. jubatum

Constant temperatures: 5°C, 22°C, 35°C (36); 20°C (2)

Alternating temperatures: 5°/35°C (14h/10h) (36)

Light: continuous (2)

H. leporinum

Alternating temperatures: 40°/15°C (13h/11h) (33)

Pre-soak: 38°C, 1-10h (7)

H. pusillum

Pre-chill: 5°-10°C, 1-6w, germinate at 20°C (38)

H. spontaneum

Constant temperatures: 20°C, 30°C (41); 20°C (42)

Pre-chill: 3°C, 7d (41)

GA_3: co-applied, 0.5-25 ppm (41)

H. vulgare

Pre-soak: 20h (4,19,28); 1-5h (16)

Sodium sulphide: pre-applied, 24h, 10^{-1} -10^{-4} M (20)

Dimercaprol: pre-applied, 24h, 10^{-3}, 10^{-4} M (20)

Iodoacetate: pre-applied, 24h, 10^{-3}, 10^{-4} M (20)

Monofluoroacetate: pre-applied, 24h, 10^{-2}, 10^{-3} M (20)

Carbon dioxide: co-applied, 10-80% (21)

Acetaldehyde: pre-applied, 24h, 10^{-5} -10^{-10} M (21)

Urea: pre-applied, 16h, 0.25-4% (27,28)

Oxygen: (26); 95%, 6d (20)

Ascorbic acid: pre-applied, 16h, 0.0625-0.25% (27,32)

p-Cresol: pre-applied, 16h, 0.0625-0.25% (27)

Resorcinol: pre-applied, 16h, 0.625-0.25% (27)

Protocatechuic acid: pre-applied, 16h, 0.0625-0.25% (27)

Sodium bisulphide: pre-applied, 16h, 0.0625-0.25% (27)

Sulphur dioxide: pre-applied, 16h, 0.0625-0.25% (27)

Indoleacetic acid: pre-applied, 16h, 0.25-1% (27)

Sodium tungstate: pre-applied, 16h, 0.25-1% (26)

Hydrogen sulphide: pre-applied, 16h, 31-1000 ppm (26)

Sodium hydroxide: pre-applied, 16h, 0.25-1% (26); pre-applied, 40 min, 0.5% (5)

Sodium chloride: pre-applied, 16h, 0.25-1% (26)

Trisodium phosphate: pre-applied, 16h, 0.25-1% (26)

Disodium hydrogen phosphate: pre-applied, 16h, 0.25-1% (26)

Sodium dihydrogen phosphate: pre-applied, 16h, 0.25-1% (26)

Sodium sulphate: pre-applied, 16h, 0.25-1% (26)

Sodium carbonate: pre-applied, 16h, 0.25-1% (26)

Potassium chloride: pre-applied, 24h, 10^{-2} M (32)

IV. Partly-successful dormancy-breaking treatments

H. geniculatum

Constant temperatures: 5°-15°C (30)

H. glaucum

Constant temperatures: 5°-20°C (30)

Alternating temperatures: 15°/20°C (16h/8h) (30)

Pre-chill: 5°C, 12d (30)

GA_3: co-applied, 10^{-4} -10^{-2} M (30)

H. jubatum

Constant temperatures: 20°C (34); 10°C, 15°C (2)

Alternating temperatures: 20°/30°C (18h/6h) (34); 10°/15°C (14h/10h) (2); 20°/25°C (14h/10h) (36); 15°/20°C (14h/10h) (36)

H. leporinum

Constant temperatures: 5°-15°C (30); 8°-14°C (7)

Alternating temperatures: 20°/25°C (12h/12h) (7); 32°/18°C, 35°/13°C (12h/12h) (33)

Pre-soak: 17°C, 10h, then pre-dry, 30°C, 24h (7)

H. marinum

Warm stratification: 35°C, 31d, germinate at 15°C (30)

H. murinum

Light: (30)

H. pusillum

Alternating temperatures: 20°/30°C in dark (38)

Light: (38)

H. spontaneum

Constant temperatures: 7.5°C, 42d (42)

Removal of seed covering structures: lemma, palea and testa (41,42)

Hydrogen peroxide: co-applied, 0.5, 1% (41)

Potassium cyanide: co-applied, $5x10^{-3}$ M (41)

Malonic acid: co-applied, $5x10^{-3}$, 10^{-2} M (41)

H. vulgare

Constant temperatures: 5°-15°C (35)

Pre-chill: 5°C, 5d (11); -1°C, 1-17d (15); -3°-(+)4°C, 3-10d (15); 12°C, 7d (18,19)

Calcium hydroxide: pre-applied, 4h, saturated solution, then sulphuric acid, pre-applied, 3.5h, 0.1% (5)

Nitric acid: pre-applied, 3-6h, 0.05-0.1% (5)

Sodium hydroxide: pre-applied, 1h, 0.5% (5)

Sulphuric acid: pre-applied, 5 min-18h, 0.01-10% (5)

Pre-dry: 35°C, 7d (8); 40°C, 5d (11,16)

Acetone: pre-applied, 5s (11)

GA_3: co-applied, $2.5x10^{-5}$ M (12); co-applied, $5x10^{-5}$ M (32); co-applied, 200 ppm (18); co-applied, 100-400 ppm (19); pre-applied, 16-20h, 100-200 ppm (14); 3-100 ppm (26)

Potassium nitrate: co-applied, 0.2% (19)

Antibiotics: chloramphenicol (20)

Oxygen: co-applied, 95%, 1d (20); 20 atmospheres (5)

Carbon monoxide: pre-applied, 90%, 3d (20)

Carbon dioxide: 2.5-5% (21)

Potassium cyanide: pre-applied, 24h, 10^{-2} -10^{-5} M (20); $8x10^{-4}$ M (32)

Hydrogen sulphide: pre-applied, 24h, 10^{-1}, 10^{-2} M (20); pre-applied, 16h, 0.00625-0.1% (27)

DIECA: pre-applied, 24h, 10^{-3}, 10^{-4} M (20)

Sodium fluoride: pre-applied, 24h, 10^{-2}, 10^{-3} M (20)

Sodium malonate: pre-applied, 10^{-1}, 10^{-2}, M (20)

Disophenol: pre-applied, 10^{-2} -10^{-5} M (20)

Ethanol: pre-applied, 10^{-8} -10^{-1} M (21)

Lactic acid: pre-applied, 24h, 10^{-8} -10^{-1} M (21)

Hydrogen peroxide: pre-applied, 16h, 0.25-5% (28)

Hydroquinone: pre-applied, 16h, 0.0625-0.25% (27)

Phenol: pre-applied, 16h, 0.0625-0.25% (27)

o-Cresol: pre-applied, 16h, 0.0625-0.25% (27)

m-Cresol: pre-applied, 16h, 0.0625-0.25% (27)

Catechol: pre-applied, 16h, 0.0625-0.25% (27)

Guaicol: pre-applied, 16h, 0.0625-0.25% (27)

Pyrogallol: pre-applied, 16h, 0.0625-0.25% (27)

Salicylic acid: pre-applied, 16h, 0.0625-0.25% (27)

Vanillic acid: pre-applied, 16h, 0.0625-0.25% (27)

m-Hydroxybenzoic acid: pre-applied, 16h, 0.0625-0.25% (27)

p-Hydroxybenzoic acid: pre-applied, 16h, 0.0625-0.25% (27)

8-Hydroxyquinone: pre-applied, 16h, 0.0625-0.25% (27)

Dimethylglyoxime: pre-applied, 16h, 0.0625-0.25% (27)

D-Threo-chloramphenicol: $2x10^{-3}$ M (32)

L-Threo-chloramphenicol: $2x10^{-3}$ M (32)

Thiourea: pre-applied, 16h, 0.25-4% (27)

Thioacetamide: pre-applied, 16h, 0.25-1% (27)

Thiosemicarbazide: pre-applied, 16h, 0.25-1% (27)

Methyl mercaptan: pre-applied, 16h, 0.0625-0.1% (27)

Ethyl mercaptan: pre-applied, 16h, 0.0625-0.1% (27)

Propyl mercaptan: pre-applied, 16h, 0.0625-0.1% (27)

Isopropyl mercaptan: pre-applied, 16h, 0.0625-0.1% (27)

Ethylene thioglycol: pre-applied, 16h, 0.0625-0.1% (27)

Ethylene dithioglycol: pre-applied, 16h, 0.0625-0.1% (27)

2-Thioglycerol: pre-applied, 16h, 0.0625-0.1% (27)

1,2-Dithioglycerol: pre-applied, 16h, 0.0625-0.1% (27)

Thioacetic acid: pre-applied, 16h, 0.0625-0.1% (27)

Thioglycollic acid: pre-applied, 16h, 0.0625-0.1% (27)

Thiosalicylic acid: pre-applied, 16h, 0.0625-0.1% (27)

Methyl thioglycollate: pre-applied, 16h, 0.0625-0.1% (27)

Ethyl thioglycollate: pre-applied, 16h, 0.0625-0.1% (27)

Propyl thioglycollate: pre-applied, 16h, 0.0625-0.1% (27)

Sodium bisulphide: pre-applied, 16h, 0.25-1% (26)

Sodium bicarbonate: pre-applied, 16h, 0.25-1% (26)

Sodium vanadate: pre-applied, 16h, 0.25-1% (26)

Potassium chlorate: pre-applied, 16h, 0.25-1% (26)

Potassium bromate: pre-applied, 16h, 0.25-1% (26)

Potassium iodate: pre-applied, 16h, 0.25-1% (26)

Kinetin: pre-applied, 16h, 6.25-25 ppm (26)

Sodium nitrite: pre-applied, 16h, 0.25-1% (26); $5x10^{-1}$, $8x10^{-3}$ M (32)

Sodium nitrate: pre-applied, 16h, 0.25-1% (26)

Removal of seed covering structures: (26)

Scarification: sulphuric acid, 0.5%, 40 min (5); sulphuric acid, 0.01-10%, 5 min-18h (5)

V. Successful dormancy-breaking treatments

H. geniculatum

Warm stratification: 35°C, 31d, germinate at 15°C (30)

H. glaucum

Warm stratification: 35°C, 31d, germinate at 15°C (30)

Removal of seed covering structures: lemma and palea or pierce palea, germinate at 15°C (30)

H. jubatum

Alternating temperatures: 10°/15°C (14h/10h) (36); 20°/30°C (18h/6h) (2)

H. leporinum

Constant temperatures: 17°C, 22°C (25)

Alternating temperatures: 22°/17°C, 27°/17°C (15h/9h) (25); 30°/20°C (12h/12h), 8d, then 21°C (33)

Warm stratification: 35°C, 31d, germinate at 15°C (30)

H. marinum

Constant temperatures: 5°-15°C (30)

H. murinum

Constant temperatures: 5°-15°C (29,30); 7.5°-30°C (10)

Pre-chill: 2°C, 21d (6)

Warm stratification: 35°C, 31d, germinate at 15°C (30)

H. pusillum

Alternating temperatures: 20°/30°C in light (38)

Potassium nitrate: co-applied, 0.2%, at 20°C, 20°/30°C (38)

H. spontaneum

Pre-chill: 2°C, 28d, germinate at 20°/15°C (16h/8h, 8h/16h) in light (39)

Removal of seed covering structures: lemma, palea and part of testa, germinate at 5°C (41); lemma, palea and testa, then pre-chill, 3°C, 7d (41); lemma, palea and cut endosperm, plus GA_3, co-applied, 1-25 ppm (41); lemma and palea, plus GA_3, co-applied, 25-50 ppm, then pre-chill, 3°C, 7d (41); lemma and palea, plus hydrogen peroxide, co-applied, 1% (41)

H. vulgare

Pre-chill, Pre-dry, GA_3 (ISTA)

Pre-chill, Pre-dry (AOSA)

Constant temperatures: 10°-13°C (1); 15°C (5,17,24); 10°C (8,9,12,13,15,32); 10°-12°C (16,22,23); 12°C (17); 7.5°C (42)

Pre-chill: 4°-6°C, 4d (14)

GA_3: co-applied, 500-1000 ppm (3,4); co-applied, 50-1500 ppm (11); co-applied, 0.1% (13); co-applied, $8x10^{-4}$ M (32); pre-applied, 1-5h, 100, 1000 mg/1 in acetone (11); 16h, 0.3-10 ppm, dehusked seeds (26); pre-applied, 16h, 12.5-100 ppm with hydrogen sulphide, 500, 1000 ppm (26)

Potassium cyanide: pre-applied, 24h, 10^{-2} M (20,32)

Kinetin: pre-applied, 16h, 3-25 ppm with hydrogen sulphide, 500, 1000 ppm (26)

Removal of seed covering structures: excision, piercing and/or scratching (5,8,9,12,13,16,26,28,32,40,42); deglume, plus potassium nitrate, co-applied, 0.2% (17)

Scarification: concentrated sulphuric acid, 0.5-5 min (16); sulphuric acid, 50%, 3h (28)

Oxygen: 1 atmosphere (5)

Ethanol: 0.5-1% (13); pre-applied, 30h, 3% (37)

Thiourea: pre-applied, 16h, 2% (26)

Hydrogen sulphide: pre-applied, 16h, 0.05, 0.1% (28)

Hydrogen peroxide: pre-applied, 24h, 1% (42)

Propyl mercaptan: pre-applied, 16h, 0.1% (28)

1,2-Dithioglycerol: pre-applied, 16h, 0.05% (28)

Dithiothreitol: pre-applied, 24h, 10^{-1} M (32)

2-Mercaptoethanol: pre-applied, 24h, $5x10^{-2}$ M (32)

Pre-dry: 40°C, 5d, then pre-chill, 5°C, 5d (11)

VI. Comment

Work with non-dormant aged seeds of H. vulgare has shown that between 7.5° and 12.5°C is the most suitable range of temperature for germination; at both higher and lower temperatures the germination of aged seeds is reduced (A). Fortunately this temperature range also results in the germination of virtually all dormant seeds provided the germination test period is sufficient - at least 21 days - (1,7-9,12,13,15-17,22,23,25,29, 42,A). Tests with 49 seed lots of a wide range of cultivars have confirmed that a 21 to 28 day test at 7.5°C is a suitable germination test regime for accessions of H. vulgare in gene banks and that it is unlikely that any further treatment to the seeds is required (A).

The same regime should be suitable for accessions of other Hordeum spp., but in addition removal of the lemma and palea may be required. For H. glaucum and H. geniculatum full germination was not always achieved at 10°C, and removal of the lemma and palea from ungerminated seeds which remained after 21 days in test plus a further period in test at 10°C were required (30); it is possible that this would also be required at 7.5°C.

Particular care should be taken to avoid excess moisture in seed germination tests with Hordeum spp. The germination of some seed lots will be reduced in the presence of excess moisture. The phenomenon is described as water sensitivity. See Chapter 9 for information on the correct level of moisture of germination test media.

VII. References

1. Atterberg, A. (1907). Die Nachreife des Getreides. Landwirtsch Versuchstat, 67, 129-143.

2. Banting, J.D. (1979). Germination emergence and persistence of foxtail barley. Canadian Journal of Plant Science, 59, 35-41.

3. Bekendam, J. (1975). Report of the working group on the application of gibberellic acid in routine germination testing to break dormancy of cereal seed. Seed Science and Technology, 3, 92-93.

4. Bekendam, J. and Bruinsma, J. (1965). The chemical breaking of dormancy of barley seeds. Proceedings of the International Seed Testing Association, 31, 779-787.

5. Bishop, L.R. (1944). Memorandum on barley germination. Journal of the Institute of Brewing, 50, 166-185.

6. Cocks, P.S., Boyce, K.G. and Kloot, P.M. (1976). The Hordeum murinum complex in Australia. Australian Journal of Botany, 24 651-662.

7. Cocks, P.S. and Donald, C.M. (1973). The germination and establishment of two annual pasture grasses (Hordeum leporinum Link. and Lolium rigidum Gand.). Australian Journal of Agricultural Research, 24, 1-10.

8. Corbineau, F. and Côme, D. (1980). Quelques caractéristiques de la dormance du caryopse d'orge (Hordeum vulgare L., varieté Sonja). Comptes Rendus de l'Académie des Sciences, Paris, 290, Série D, 547-550.

9. Corbineau, F. and Côme, D. (1982). Evolution de la dormance des semences de deux variétés d'orge (Hordeum vulgare L.) au cours de leur maturation et de leur conservation au sec. Comptes Rendus de l'Académie des Sciences, Paris, 294, Série III, 967-970.

10. Davidson, A.W. (1971). The ecology of Hordeum murinum L. 2. The ruderal habitat. Journal of Ecology, 59, 493-506.

11. Don, R. (1979). The use of chemicals, particularly gibberellic acid, for breaking cereal seed dormancy. Seed Science and Technology, 7, 355-367.

12. Dunwell, J.M. (1981). Dormancy and germination in embryo of Hordeum vulgare L. Effect of dissection, incubation temperature and hormone application. Annals of Botany, 48, 203-213.

13. Fischnich, O., Thielebein, M. and Grahl, A. (1961). Sekundäre Keimruhe bei getreide. Proceedings of the International Seed Testing Association, 26, 89-114.

14. Gaspar, S., Fazekas, J. and Petho, A. (1975). Effects of gibberellic acid (GA_3) and prechilling on breaking dormancy in cereals. Seed Science and Technology, 3, 555-563.

15. Grahl, A. (1970). Einfluss der Keimungstemperatur und Stratifikation auf die Keimruhe von getreide. Proceedings of the International Seed Testing Association, 35, 427-438.

16. Harrington, G.T. (1923). Forcing the germination of freshly harvested wheat and other cereals. Journal of Agricultural Research, 23, 79-100.

17. Heit, C.E. (1948). Thirty-eighth annual meeting. Report of subcommittee on dormancy of seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

18. Kahre, L., Kolk, H. and Fridz, T. (1965). Gibberellic acid for breaking of dormancy in cereal seed. Proceedings of the International Seed Testing Association, 30, 887-891.

19. Kåhre, L., Kolk, H. and Wiberg, H. (1962). Note on dormancy-breaking in seeds. (Cereals and timothy). Proceedings of the International Seed Testing Association, 27, 679-683.

20. Major, W. and Roberts, E.H. (1968). Dormancy in cereal seeds. I. The effects of oxygen

and respiratory inhibitors. Journal of Experimental Botany, 19, 77-89.

21. Major, W. and Roberts, E.H. (1968). Dormancy in cereal seeds. II. The nature of the gaseous exchange in imbibed barley and rice seeds. Journal of Experimental Botany, 19, 90-101.

22. Munerati, M.O. (1925). Existe-t-il une aprés maturation chez les céréales récémment recoltées? Comptes Rendus de l'Académie des Sciences, Paris, 181, 1081-1083.

23. Munerati, M.O. (1926). Possibilité de déterminer l'âge des graines de blé par la temperature de leur germination. Comptes Rendus de l'Académie des Sciences, Paris, 182, 535-537.

24. Munn, M.T. (1946). Germinating freshly harvested winter barley and wheat. Proceedings of the Association of Official Seed Analysts, 36, 151-152.

25. Piggin, C.M., Hallett, M.L. and Smith, D.F. (1973). The germination response of seed of some annual pasture plants to alternating temperatures. Seed Science and Technology, 1, 739-748.

26. Pollock, J.R.A. (1959). Studies in barley and malt. XV. Growth substances and other compounds in relation to dormancy in barley. Journal of the Institute of Brewing, 65, 334-337.

27. Pollock, J.R.A. and Kirsop, B.H. (1956). Studies in barley and malt. VI. Stimulation of the germination of freshly-harvested barley. Journal of the Institute of Brewing, 62, 323-327.

28. Pollock, J.R.A., Kirsop, B.H. and Essery, R.E. (1955). Some new observations on dormancy in barley. In European Brewery Convention, Proceedings of the Congress, Baden-Baden, pp.203-211. Elsevier, Amsterdam.

29. Popay, A.I. (1975). Laboratory germination of barley grass. Proceedings of the 28th New Zealand Weed and Pest Control Conference, 7-11.

30. Popay, A.I. (1981). Germination of seeds of five annual species of barley grass. Journal of Applied Ecology, 18, 547-558.

31. Pope. M.N. and Brown, E. (1943). Induced viviparity in three varieties of barley possessing extreme dormancy. American Society of Agronomy Journal, 35, 161-163.

32. Roberts, E.H. and Smith, R.D. (1977). Dormancy and the pentose phosphate pathway. In The Physiology and Biochemistry of seed dormancy and germination (ed. A.A. Khan), pp.385-411. Elsevier/North-Holland Biomedical Press, Amsterdam.

33. Smith, D.F. (1968). The growth of barley grass (Hordeum leporinum) in annual pasture. 1. Germination and establishment in comparison with other annual pasture species. Australian Journal of Experimental Agriculture and Animal Husbandry, 8, 478-483.

34. Stevens, O.A. (1960). Weed development notes. North Dakota Agricultural Experiment Station, Fargo, North Dakota, pp.6-7.

35. Strand, E. (1964). Studies on seed dormancy in barley. Meldinger fra Norges Landbrukshogskole, 44, 1-23.

36. Ungar, I.A. (1974). The effect of salinity and temperature on seed germination and growth of Hordeum jubatum. Canadian Journal of Botany, 52, 1357-1362.

37. Deunff, Y.L. (1983). Mise en évidence de l'influence bénéfique de l'alcool éthylique en

solution aqueuse sur la leveé de dormance des orges. Comptes Rendus Hebdomadaires des Séances de l'Académie des Science, Serie III, 296, 433-436.

38. Fischer, M.L., Stritzke, J.F. and Ahring, R.M. (1982). Germination and emergence of little barley (Hordeum pusillum). Weed Science, 30, 624-628.

39. Giles, B.E. and Lefkovitch, L.F. (1984). Differential germination in Hordeum spontaneum from Iran and Morocco. Zeitschrift für Pflanzenüchtung, 92, 234-238.

40. Lenoir, C., Corbineau, F. and Côme, D. (1983). Rôle des glumelles dans la dormance des semences d'orges. Physiologie Végétale, 21, 633-643. (From Seed Abstracts, 1984, 7, 1702.)

41. Ogawara, K. and Hayashi, J. (1964). Dormancy studies in Hordeum spontaneum seeds. Berichte d. Ohara Instituts Landwirtschaftliche, Biologia Okayama Universitat, 12, 159-188.

42. Urion, E. and Chapon, L. (1955). Contribution à l'étude de la dormance de l'orge. In European Brewery Convention, Proceedings of the Congress, Baden-Baden, pp. 172-202. Elsevier, Amsterdam.

LOLIUM

L. multiflorum Lam. (L. italicum A. Br.)	Italian ryegrass
L. multiflorum L. x L. perenne L. [L. x hybridum Hausskn.]	short rotation ryegrass
L. perenne L.	perennial ryegrass, English ryegrass
L. temulentum L. [L. persicum Boiss & Hoh.; L. rigidum Gaud.]	darnel, bearded ryegrass, persian ryegrass, annual ryegrass

I. Evidence of dormancy

Freshly harvested seeds of Lolium spp. show considerable dormancy (1-4,8,10,16-19,23-26). This causes substantial problems in seed testing (1,3,8,23,25).

II. Germination regimes for non-dormant seeds

L. multiflorum

TP: 15°/25°C; 20°/30°C (16h/8h); 20°C: 14d (ISTA)

TP: 15°/25°C (16h/8h): 14d (AOSA)

Constant temperatures: 20°C (14); 14°-25°C (22); 10°-25°C (24); 15°-30°C (12)

Alternating temperatures: (12); 20°/25°C in light (14,15); 15°/25°C (15); 5°/10°C, 5°/15°C, 10°/15°C, 10°/30°C, 15°/30°C, 15°/40°C (16h/8h) (24); 25°/18°C (day/night) in light (13)

L. multiflorum x L. perenne

TP: 15°/25°C; 20°/30°C (16h/8h); 20°C: 14d (ISTA)

L. perenne

TP: 15°/25°C; 20°/30°C; (16h/8h); 20°C: 14d (ISTA)

TP: 15°/25°C (16h/8h): 14d (AOSA)

L. temulentum

Constant temperatures: 10°-15°C (4,6); 17°-22°C (21); 12°C in dark (11); 24°C in light (11)

III. Unsuccessful dormancy-breaking treatments

L. multiflorum

Constant temperatures: 25°C, 30°C (26)

GA_3: co-applied, 100 ppm (19); pre-applied, 12-18h, 50-100 ppm (20)

L. perenne

Potassium cyanide: pre-applied, 24h, 10^{-2}-10^{-4} M (18)

Hydrogen sulphide: pre-applied, 24h, 10^{-1}, 10^{-2} M (18)

Sodium sulphide: pre-applied, 24h, 10^{-1}-10^{-4} M (18)

Ammonium hydroxide: pre-applied, 24h, 10^{-2}, 10^{-3} M (18)

GA_3: co-applied, 100 ppm (19)

L. temulentum

Pre-soak: 38°C, 1-10h (6)

IV. Partly-successful dormancy-breaking treatments

L. multiflorum

Alternating temperatures: 10°/30°C (16h/8h) (1,2,8); 20°/30°C (16h/8h) (1,2,9); 15°/30°C in light (19); 5°/15°C, 5°/20°C, 5°/25°C, 10°/15°C, 15°/25°C (16h/8h) (24)

Pre-chill: 5°C, 5d (3,8,19,23-26); 5°C, 5d, then again, 5°C, 2-3d, after 14d test (3,23); 5°C, 5d, plus potassium nitrate, co-applied, 0.2%, at 20°/30°C, 10°/30°C (16h/8h) (8); 5°C, 5d, plus potassium nitrate, co-applied, 0.2% at 15°/25°C (16h/8h) in light (8,24,25)

Light: (1,2,3,19)

Potassium nitrate: co-applied, 0.2% (1-3,7-9,19,23-26)

Thiourea: co-applied, 0.2% (19)

Pre-soak: 22°C, 17h, then pre-dry, 15°C, 24h (5)

Pre-dry: 35°C, 5d, plus potassium nitrate, co-applied, 0.2%, at 15°/25°C (16h/8h) in light (8)

L. perenne

Alternating temperatures: 20°/30°C (16h/8h) (9); 15°/30°C in light (19); 25°/18°C, 30°/18°C, 18°/25°C (day/night) (13)

Pre-chill: 5°C, 5d (19); 5°C, 5d, plus potassium nitrate, co-applied, 0.2% (25)

Pre-soak: 22°C, 17h, then pre-dry, 15°C, 24h (5)

Light: (19); 5 min (27)

Potassium nitrate: co-applied, 0.2% (19,27)

Potassium cyanide: pre-applied, 24h, 10^{-5} M (18)

Thiourea: co-applied, 0.2% (19)

L. temulentum

Alternating temperatures: 24°/12°C (12h/12h) (11); 10°/30°C (16h/8h) (4)

Light: 8h/d (4); 12h/d (11)

Pre-soak: 10h, then pre-dry, 30°C, 24h (6)

V. Successful dormancy-breaking treatments

L. multiflorum

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate, Pre-chill, further Pre-chill (AOSA)

Alternating temperatures: 15°/20°C, 15°/25°C, 20°/25°C, 20°/30°C, 25°/30°C (16.5h/7.5h) (12); 20°/30°C, 20°/25°C (16h/8h) in light (14); 10°/30°C (16h/8h) (17); 5°/10°C (16h/8h) (24); 18°/36°C, 10°/36°C (16h/8h) (10); 20°/30°C (16h/8h), 14d, then potassium nitrate, co-applied, 0.2%, at 20°/30°C (16h/8h), 5d (9)

Pre-chill: 5°C, 4d (14); plus further pre-chill (16); 5°C, 5d, plus potassium nitrate, co-applied, 0.2%, at 15°/25°C (16h/8h) in light (26); 5°C, 5d, plus potassium nitrate, co-applied, 0.2%, at 15°/25°C, 10°/30°C (16h/8h) in light, 14d, then further pre-chill, 5°C, 2-3d (8)

Pre-dry: test for 14d, then pre-chill (16); 35°C, 5d, then potassium nitrate, co-applied, 0.2%, at 15°/25°C (16h/8h) in light, 14d, then pre-chill, 5°C, 2-3d (8)

Potassium nitrate: co-applied, 0.2%, at 10°/30°C (16h/8h) in light, 100 fc (2); co-applied, 0.2%, at 15°/25°C (16h/8h) in light (7)

L. multiflorum x L. perenne

Pre-chill, Potassium nitrate (ISTA)

L. perenne

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate, Pre-chill, further Pre-chill (AOSA)

Alternating temperatures: 15°/20°C, 15°/25°C, 20°/25°C, 20°/30°C, 25°/30°C (16.5h/7.5h) (12); 10°/20°C (15h/9h) (27); 18°/36°C, 10°/36°C (16h/8h) (10); 20°/30°C (16h/8h), 10d, then potassium nitrate, co-applied, 0.2% at 20°/30°C (16h/8h), 5d (9); 5°C, 5d, plus potassium nitrate, co-applied, 0.2%, at 15°/25°C (16h/8h) in light (25,26)

Potassium nitrate: co-applied, 0.2%, at 20°C, 10°/20°C (15h/9h) in light (27)

L. temulentum

Constant temperatures: 12°C (11)

Alternating temperatures: 24°/12°C (12h/12h) (11); 10°/30°C (16h/8h) in light (4); 32°/22°C (15h/9h) (21)

VI. Comment

The earlier ISTA prescription (1976 rules) for germination tests with dormant seeds (light, pre-chill, potassium nitrate, and an alternating temperature of 10°/30°C) is not satisfactory for freshly harvested seeds (1,3,8,23). The AOSA prescription (potassium nitrate, pre-chill, and an alternating temperature of 15°/25°C with a further pre-chill if seeds remain ungerminated) appears to be more successful provided the change of temperature in the alternating temperature regime is rapid (8). However, rapid changes are rarely achieved in alternating temperature incubators. A Copenhagen tank where the water is completely changed between cycles would give a rapid temperature change, as would manual movement of germination tests twice daily between two constant temperature incubators.

There is some evidence that 15°/25°C may not be the most suitable alternating temperature regime (1,24). An alternation of 15°/25°C (16h/8h) has been reported to give higher germination than 10°/30°C (16h/8h) (3,8) which in turn is better than 20°/30°C (16h/8h) (17). However, 5°/10°C (16h/8h) was superior to all the above (24). Consequently it is suggested that this latter regime be applied, but with an extended test period compared to ISTA/AOSA prescriptions. If this does not completely break dormancy potassium nitrate could be co-applied and/or the seeds pre-chilled for 5 days. If it is not possible to provide an alternating temperature regime of 5°/10°C the following alternating temperatures have also been reported to give high germination: 5°/15°C, 5°/20°C, 5°/25°C, 10°/15°C (16h/8h) (24).

VII. References

1. Andersen, A.M. (1947). The effect of alternating temperatures, light intensities, and moistening agents of the substratum on the germination of freshly harvested seed of Oregon-grown rye-grass (Lolium spp.). Proceedings of the Association of Official Seed Analysts, 37, 152-161.

2. Andersen, A.M. (1954). Some factors affecting the germination of 1- and 2-year old ryegrass (Lolium) seed. Proceedings of the International Seed Testing Association, 19, 5-13.

3. Anonymous (1960). Dormancy in common ryegrass. Newsletter of the Association of Official Seed Analysts, 34, 31-33.

4. Banting, J.D. and Gebhardt, J.P. (1979). Germination, after-ripening, emergence, persistence and control of persian darnel. Canadian Journal of Plant Science, 59, 1037-1045.

5. Chippindale, H.G. (1933). The effect of soaking in water on the "seeds" of some gramineae. Annals of Botany, 21, 225-232.

6. Cocks, P.S. and Donald, C.M. (1973). The germination and establishment of two annual pasture grasses (Hordeum leporinium Link. and Lolium rigidum Gaud.). Australian Journal of Agricultural Research, 24, 1-10.

7. Colbry, V.L. (1956). Report of the subcommittee on germination. Proceedings of the Association of Official Seed Analysts, 46, 12-13.

8. Colbry, V.L., Wiseman, E.F. and Justice, O.L. (1961). Germination of freshly-harvested ryegrass seed grown in 1960. Proceedings of the Association of Official Seed Analysts, 51, 131-138.

9. Crosier, W. and Cullinan, B. (1941). Some observations in the germination of grass seeds. Proceedings of the Association of Official Seed Analysts, 33, 69-74.

10. Gadd, V. (1939). Uber Methoden zur Hebung mangelnder Keimreife in der

Samenkontrollarbeit. Proceedings of the International Seed Testing Association, 11, 96-118.

11. Gramshaw, D. (1972). Germination of annual ryegrass seeds (Lolium rigidum Gaud.) as influenced by temperature, light, storage environment and age. Australian Journal of Agricultural Research, 23, 779-787.

12. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

13. Harrison, C.S. (1954). The technique of ultra-violet testing in New Zealand. Proceedings of the International Seed Testing Association, 19, 44-49.

14. Johnston, M.E.H. and Miller, J.G. (1962). Investigation into germination techniques for ryegrass, Lolium spp. Proceedings of the International Seed Testing Association, 27, 345-356.

15. Johnston, M.E.H. and Tattersfield, J.G. (1970). Comparison of germination temperature treatments for ryegrass, Lolium spp. Proceedings of the International Seed Testing Association, 35, 325-340.

16. Justice, O.L. (1962). Discussion. Proceedings of the International Seed Testing Association, 27, 764.

17. Kahre, L. (1962). Discussion. Proceedings of the International Seed Testing Association, 27, 765.

18. Major, W. and Roberts, E.H. (1968). Dormancy in cereal seeds. I. The effects of oxygen and respiratory inhibitors. Journal of Experimental Botany, 19, 77-89.

19. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

20. Peacock, C.H., Dudeck, A.E. and Green, R.L. (1980). Effects of seed soaking and Gibberellic acid on the germination and establishment of annual ryegrass and Kentucky 31 tall fescue grass. Agronomy Abstracts, 72nd annual meeting American Society of Agronomy, 119.

21. Piggin, C. McE., Hallett, M.L. and Smith, D.F. (1973). The germination response of seed of some annual pasture plants to alternating temperatures. Seed Science and Technology, 1, 739-747.

22. Simon, J.C. (1981). Contribution à l'étude écophysiologique de la phase semis-levée du ray-grass d'Italie (Lolium multiforum Lam.) I. Etude en conditions controleés de l'influence du facteur thermique. Agronomie, 1, 339-344.

23. Weisner, M. and Kanipe, L.A. (1951). Delayed germination of Lolium multiflorum - common ryegrass. Proceedings of the Association of Official Seed Analysts, 41, 86-88.

24. Young, J.A., Evans, R.A. and Kay, B.L. (1975). Germination of Italian ryegrass seeds. Agronomy Journal, 67, 386-389.

25. Jensen, L.A. and Pierpoint, M. (1961). Survey of post-harvest dormancy in Oregon rye-grass samples. Proceedings of the Association of Official Seed Analysts, 51, 178-183.

26. Wiesner, L.E. and Grabe, D.F. (1972). Effects of temperature pre-conditioning and cultivar on ryegrass (Lolium spp.) seed dormancy. Crop Science, 12, 760-764.

27. Williams, E.D. (1983). Effects of temperature, light, nitrate and pre-chilling on seed germination of grassland plants. Annals of Applied Biology, 103, 161-172.

ORYZA

O. glaberrima Steud. African rice
O. sativa L. rice, red rice

I. Evidence of dormancy

O. glaberrima cultivars are generally the most dormant, followed by the indica, javanica and japonica cultivars of O. sativa, the latter being the least dormant (4). Seeds of wild rice (O. sativa var spontanea) show a similar level of dormancy to O. glaberrima (39).

II. Germination regimes for non-dormant seeds

O. sativa

BP; TP; S: 20°/30°C (16h/8h); 25°C: 14d (ISTA)

BP; TP; S: 20°/30°C (16h/8h): 14d (AOSA)

Constant temperatures: 28°-36°C (2); 30°-35°C (22); 27°-36°C (11-13); 32°C (5); 30°C (17,27,39)

III. Unsuccessful dormancy-breaking treatments

O. glaberrima

Removal of seed covering structures: (24); excise embryos, germinate at 30°C, dark (39)

Potassium cyanide: pre-applied, 24h, 10^{-3} M (10)

O. sativa

Alternating temperatures: 20°/26°C (15); 20°/30°C (26)

Removal of seed covering structures: dehull, germinate at 30°C, dark (39); excise embryos, germinate at 30°C, dark (39)

Potassium chlorate: pre-applied, 24h, 10^{-1} -10^{-3} M (34)

Potassium dichromate: pre-applied, 24h, 10^{-1} -10^{-3} M (34)

Calcium hypochlorite: pre-applied, 24h, 10^{-1} -10^{-3} M (34)

Potassium permanganate: pre-applied, 24h, 10^{-1} -10^{-3} M (34)

Dimercaprol: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

2,2-Dipyridyl: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

1,10 Phenanthroline: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

8-Hydroxyquinoline: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

Disodium edetate: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

Adenine: co-applied, 10^{-7} -10^{-2} M, at 30°C, dark, dehulled seeds (6)

Sodium hydroxide: pre-applied, 10,20,30 min, 0.1 N, germinate at 30°C, dark, dehulled seeds (39)

Sodium nitrate: co-applied, 10^{-2} M, at 30°C, light or dark, dehulled seeds (7)

Sodium diethyldithiocarbamate: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

Sodium malonate: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

Sodium monofluoroacetate: pre-applied, 24h, 10^{-2} M (34)

Sodium iodoacetate: pre-applied, 24h, 10^{-3} -10^{-4} M (33)

Sodium fluoride: pre-applied, 24h, 10^{-2} -10^{-3} M (34)

Sodium arsenite: pre-applied, 24h, 10^{-2} -10^{-3} M (34)

Sodium arsenate: pre-applied, 24h, 10^{-2} -10^{-3} M (34)

2,4 Dinitrophenol: pre-applied, 24h, 10^{-3} -10^{-6} M (34)

Sodium p-chloromercuribenzoate: pre-applied, 24h, 10^{-3} -10^{-4} M (34)

Sodium malate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Potassium sodium tartarate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium formate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium acetate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium lactate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium oxalate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium pyruvate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium citrate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium fumarate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Sodium succinate: pre-applied, 24h, 10^{-2}, 10^{-1} M (33)

Ammonium sulphate: pre-applied, 12-36h, 10^{-2} M (32)

Ammonium chloride: co-applied, 10^{-2} M, at 30°C in light or dark, dehulled seeds (7)

Urea: pre-applied, 24h, 10^{-2} -10^{-4} M (32)

Oxidised glutathione: pre-applied, 24h, 10^{-8} -10^{-4} M (33)

Reduced glutathione: pre-applied, 24h, 10^{-4} -10^{-2} M (33)

L-Cysteine: pre-applied, 24h, 10^{-4} -10^{-2} M (33)

Sodium thioglycollate: pre-applied, 24h, 10 -10 M (33)

L-Cystine: pre-applied, 24h, 10^{-4}, 10^{-3} M (33)

Sodium hypochlorite: pre-applied, 12h, 0.05% (23)

3-Indoleacetic acid: pre-applied, 24h, 10^{-5} -10^{-3} M (33)

Light: (9); fluorescent, continuous, $6x10^{-5}$ mol m^{-2} s^{-1}, dehulled seeds (6)

Sulphuric acid: pre-applied, 10,20,30 min, 0.1 N, germinate at 30°C, dark, dehulled seeds (39)

IV. Partly-successful dormancy-breaking treatments

O. glaberrima

Nitric acid: pre-applied, 12h, 0.7 M, germinate at 20°/30°C (16h/8h) (10); pre-applied, 24h, 0.4, 0.5 M, germinate at 20°/30°C (16h/8h) (10); pre-applied, 24h, 0.1, 0.2 M, then hydrogen peroxide, pre-applied, 24h, 0.25-1 M, germinate at 20°/30°C or 34°/11°C (16h/8h) (10); pre-applied, 24h, 0.1 M, then hydrogen peroxide, pre-applied, 24h, 0.25 M, with or without thiourea, co-applied, $2x10^{-2}$, $5x10^{-2}$ M, or sodium azide, co-applied, 10^{-4}, 10^{-3} M, or 2-mercaptoethanol, co-applied, 10^{-2}, $2.5x10^{-2}$ M, germinate at 34°/11°C (16h/8h) (10)

Hydrochloric acid: pre-applied, 10-15 min, 10-14%, germinate at 30°C, dark, dehulled seeds (39)

Sulphuric acid: pre-applied, 15 min, 15-35%, germinate at 30°C, dark, dehulled seeds (39)

GA_3: pre-applied, 24h, 10^{-4} -10^{-2} M, germinate at 20°/30°C (16h/8h) (10)

$GA_{4/7}$: pre-applied, 24h, 10^{-4} -10^{-2} M, germinate at 20°/30°C (16h/8h) (10)

O. sativa

Constant temperatures: 25°C (37); 27°C (31,35); 30°C (17,18,26,37); 31°C (13); 32°C (15)

Alternating temperatures: 30°/15°C (16h/8h) (26); 20°/32°C (15); 20°/30°C (16h/8h) (37)

Warm stratification: 40°C, 50°C (15)

Pre-dry: 47°C, 7d (3)

Removal of seed covering structures: dehull (9,20,26,28,30,40); pericarp and seed coat (38); cut in half (9); dehull, cut in half (9,30); clip one third of hull (16); dehull, germinate at 30°C, dark (8)

Oxygen: 100% (14,15,36)

Carbon monoxide: 90% (34)

Carbon dioxide: pre-applied, 30°C, 2-5d, 20-100% (40)

Thiourea: pre-applied, 2h, 0.5% (25); co-applied, 0.2% (26,40); co-applied, 10^{-2} M (33)

Potassium cyanide: pre-applied, 24h, 10^{-3} M (34)

Sodium sulphide: pre-applied, 24h, 10^{-2}-10^{-4} M (34)

Hydrogen sulphide: pre-applied, 24h, 10^{-1}-10^{-3} M (34)

Hydroxylamine hydrochloride: pre-applied, 24h, 10^{-2}-10^{-3} M (34)

Sodium azide: pre-applied, 10^{-3} M (34)

Methylene blue: pre-applied, 10^{-3} M (34)

Sodium hypochlorite: pre-applied, 24-72h, 20°-40°C, 0.25% (9)

Pre-soak: 45h, 3°C (31); 24h, 23°C (32); 24-72h, 20°-40°C (9)

Ethanol: 0.5-2.0% (16)

Nitric acid: pre-applied, 16-24h, 10^{-1} N (19); pre-applied, 12h, 10^{-1} N (21); pre-applied, 12-48h, 10^{-2} N (32)

Potassium nitrate: pre-applied, 24h, 10^{-2} M (32)

Sodium nitrate: pre-applied, 12-36h, 10^{-2} M (32); co-applied, 10^{-2} M (32)

Sodium nitrite: pre-applied, 12-36h, 10^{-2} M (32); co-applied, 10^{-2} M, pH3, at 30°C in light or dark, dehulled seeds (7)

Hydrogen peroxide: pre-applied, 24h, 1 M (34); 1% (41)

Sulphuric acid: pre-applied, 12-48h, 10^{-2} N (32); pre-applied, 4h, 10^{-1} N (36); pre-applied, 3h, 10^{-1} N (25)

Hydrochloric acid: pre-applied, 12-48h, 10^{-2} N (32)

GA_3: co-applied, 100ppm (26); pre-applied, 24h, 10^{-3} M (33)

Kinetin: pre-applied, 24h, 10^{-3} M (33); co-applied, $5x10^{-4}$, 10^{-3} M, at 30°C, dark, dehulled seeds (6)

Benzyladenine: co-applied, $5x10^{-4}$, 10^{-3} M, at 30°C, dark, dehulled seeds (6)

Isopentenyl adenine: co-applied, 10^{-7}-10^{-2} M, at 30°C, dark, dehulled seeds (6)

Zeatin: co-applied, 10^{-3} M, at 30°C, dark, dehulled seeds (6)

Light: (31)

V. Successful dormancy-breaking treatments

O. glaberrima

Alternating temperatures: 34°/11°C (16h/8h) with nitric acid, pre-applied, 24h, 10^{-1} M, then hydrogen peroxide, pre-applied, 24h, 0.25 M, plus 2-mercaptoethanol, co-applied, 10^{-2} M (10)

Removal of seed covering structures: excise embryos, plus sucrose, co-applied, 2%, at 30°C, dark (39)

After-ripening: 30°C, 11-12% moisture content, 80d, germinate at 20°/30°C (16h/8h) (10)

O. sativa

Pre-soak in water or Potassium nitrate, 24h, Pre-dry (ISTA)

Flood test (AOSA)

Alternating temperatures: 34°/11°C (16h/8h), with nitric acid, pre-applied, 24h, 10^{-1} M, then hydrogen peroxide, pre-applied, 24h, 0.25 M, plus 2-mercaptoethanol, co-applied, 10^{-2} M (10)

Removal of seed covering structures: dehull, plus GA_3, co-applied, 100ppm (26); dehull, plus thiourea, co-applied, 0.2% (26); prick near embryo (20); lemma (17); cut endosperm (28); kernels (36); puncture glumes (36); dehull, scarify pericarp and testa (30); dehull, nick pericarp (9); hull, pericarp and testa (16); excise embryos (8); excise embryos, plus sucrose, co-applied, 2%, at 30°C, dark (39)

Ethylene chlorohydrin: pre-applied, 24-72h, 0.1%, germinate at 20°-30°C (9)

Nitric acid: pre-applied, 23h, 10^{-1} N (1)

Hydrochloric acid: pre-applied, 15 min, 14%, germinate at 30°C, dark, dehulled seeds (39); pre-applied, 15 min, 14%, after 96h imbibition, germinate at 30°C, dark, dehulled seeds (39)

Alcohol: pre-applied, 10 min, 80%, germinate at 30°C, dark, dehulled seeds (39)

VI. Comment

Seed dormancy in O. sativa is a considerable problem in commercial seed testing (e.g. 9). In gene banks the problem is substantially greater: first accessions of O. sativa are likely, overall, to show considerably deeper dormancy than is the case for seed lots in commercial testing; second accessions of the considerably more dormant O. glaberrima will have to be germinated. In view of this and the importance of rice as a staple, a separate study with practical recommendations for those working in gene banks has been published elsewhere (10) - to which the reader is referred for detailed information.

The details of the AOSA flood test for rice are: plant the seeds in moist sand and test for 7 days; then add water to a depth of 7 mm above the sand and continue the test for a further 7 days. The dormancy-breaking procedure previously recommended by ISTA for O. sativa (pre-soak the seeds for 24 to 48 hours in water at 40°C) is questionable. Although this or similar procedures can be promotory in some cases (9,21,41), in other cases promotion may be small or non-existent (10,31), or the pre-treatment may damage the seeds and reduce germination (10). Moreover, in deeply dormant cultivars of O. glaberrima no promotory effect has been observed (A). The pre-soak treatment in hot water is no longer recommended by ISTA and should not be used.

Although dehusking can be successful with seeds of O. sativa - though apparently less successful for O. glaberrima (24) - particularly when combined with additional dormancy-breaking agents it is not a particulary useful treatment since aside from being extremely time-consuming there is a possibility of damage to the embryo resulting from the treatment and a tendency for the dehusked grains to succumb to bacterial and fungal attack (30).

A number of techniques have been developed for use in rice-breeding programmes (3) of which the most relevant is after-ripening. The treatment, 47°C for 7 days for seeds with less than 11% moisture content (3), is widely used (a similar treatment - pre-dry at 50°C - is now recommended as a dormancy-breaking procedure by the ISTA). It should not be applied to the entire accession, but its use on sub-samples can be sanctioned for moderately dormant lots of O. sativa provided these are of high quality. However, this procedure is not feasible for O.

glaberrima - since they require 30-60 day treatments (35) - and probably not for the more dormant O. sativa accessions. Another dormancy-breaking agent best avoided by gene banks is the use of gibberellins since their use can affect the growth and development of subsequent seedlings (29).

To avoid these problems and to enable gene bank staff to be able to germinate dormant seeds of rice required the development of procedures requiring five separate dormancy-breaking agents: viz, alternating temperature, hydrogen ions, nitrate ions, hydrogen peroxide and 2-mercaptoethanol (10). It was not possible to develop a single satisfactory procedure for seeds of all taxonomic groups (10). Nevertheless the procedures developed are easy to follow.

For japonica cultivars of O. sativa (which usually show only slight dormancy) a diurnal temperature alternation of 30°/20°C (16h/8h) is satisfactory. (Note that the periods spent at each temperature are the reverse of the ISTA/AOSA prescriptions.) Alternatively a regime of 34°/11°C (16h/8h) can be used. For O. glaberrima and indica and javanica cultivars of O. sativa the alternating temperature regime 34°/11°C (16h/8h) is best. In addition seeds of O. glaberrima and probably the more dormant indica and spontanea accessions of O. sativa require a pre-treatment in 0.1 M nitric acid for 24 hours followed by a further 24 hours pre-treatment in 0.25 M hydrogen peroxide with subsequent germination on filter paper moistened with 0.01 M 2-mercaptoethanol at 34°/11°C (16h/8h). Should operational constraints in the running of the laboratory preclude separate dormancy-breaking treatments according to taxonomic classification, then all rice seed accessions should be germinated according to this last method for the most dormant seeds. For most O. sativa accessions a 14 day test period is sufficient. However, for O. glaberrima and the most dormant O. sativa accessions the germination test period may have to be extended to 42 days, or more.

VII. References

1. Agrawal, P.K. and Nanda, J.S. (1969). A note on dormancy in rice. Riso, 18, 325-326.

2. Akemine, M. (1914). Zur Kenntnis der Keimungsphysiologie von Oryza sativa (Reis). Fühlings Landwirtschaftlich Zeitung, 63, 78-93. (Cited and re-analysed by Livingston and Haasis, 1933.)

3. Carpenter, A.J. and Roberts, E.H. (1962). Some useful techniques in speeding up rice breeding programmes. Empire Journal of Experimental Agriculture, 30, 127-131.

4. Chang, T.T. (1976). The rice cultures. Philosophical Transactions of the Royal Society of London, Series B, 275, 143-157.

5. Chaudhary, T.N. and Ghildyal, B.P. (1969). Germination response of rice seeds to constant and alternating temperatures. Agronomy Journal, 61, 328-330.

6. Cohn, M.A. and Butera, D.L. (1982). Seed dormancy in red rice (Oryza sativa). II. Response to cytokinins. Weed Science, 30, 200-205.

7. Cohn, M.A., Butera, D.L. and Hughes, J.A. (1983). Seed dormancy in red rice. III. Response to nitrite, nitrate, and ammonium ions. Plant Physiology, 73, 381-384.

8. Cohn, M.A. and Hughes, J.A. (1981). Seed dormancy in red rice (Oryza sativa). I. Effect of temperature on dry-afterripening. Weed Science, 29, 402-404.

9. Delouche, J.C. and Nguyen, N.T. (1964). Methods for overcoming seed dormancy in rice. Proceedings of the Association of Official Seed Analysts, 54, 41-49.

10. Ellis, R.H., Hong, T.D. and Roberts, E.H. (1983). Procedures for the safe removal of dormancy from, rice seed. Seed Science and Technology, 11, 77-112.

11. Hall, V.L. (1966). Temperature and the germinating rice seed. I. Minimum to maximum temperature for growth in four days. Rice Journal, 69, 40-42.

12. Hall, V.L. (1966). Temperature and the germinating rice seed. II. Effect of temperature on germination and eight days growth of aerated seed. Rice Journal, 69, 22-23.

13. Hall, V.L. (1966). Temperature and the germinating rice seed. III. Effect of temperature on germination and eight days growth of submerged seeds. Rice Journal, 69, 14-15.

14. Hayashi, M. (1980). [Studies on dormancy and germination of rice seed. IX. The effects of oxygen and moisture upon the release of the rice seed dormancy and upon the inactivation of inhibitors in the dormant seed.] Bulletin of the Faculty of Agriculture, Kagoshima University, 30, 1-9.

15. Hayashi, M. and Morifuji, N. (1972). [Studies on the dormancy and germination of rice seed. I. The influences of temperatures and gaseous conditions on dormancy and germination in rice seeds.] Japanese Journal of Tropical Agriculture, 16, 115-120.

16. Ikeda, M. (1963). [Studies on the viviparous germination of rice seed.] Bulletin of the Faculty of Agriculture, Kagoshima University, 13, 89-115.

17. Ikehashi, H. (1973). [Studies on the environmental and varietal differences of germination habits in rice seeds with special reference to plant breeding.] Journal of the Central Agricultural Experiment Station, Konosu, 19, 1-60.

18. Ikehashi, H. (1975). Dormancy formation and subsequent changes of germination habits in rice seeds. Japanese Agricultural Research Quarterly, 9, 8-12.

19. International Rice Research Institute (1968). Seed dormancy. IRRI Reporter, 4, 1-4.

20. International Rice Research Institute (1974). Annual Report for 1973, pp. 9-11. International Rice Research Institute, Los Baños, The Philippines.

21. Jalote, S.R. and Vaish, C.P. (1976). Dormancy behaviour of paddy varieties in U.P. Seed Research, 4, 187-190.

22. Livingston, B.E. and Haasis, F.W. (1933). Relations of time and maintained temperature to germination percentage for a lot of rice seed. American Journal of Botany, 20, 596-615.

23. Mikkelsen, D.S. and Sinah, M.N. (1961). Germination inhibition in Oryza sativa and control by preplanting soaking treatments. Crop Science, 1, 332-335.

24. Misra, P.K. and Misro, B. (1970). Seed dormancy in the African cultivated rice (Oryza glaberrima Steud.). Indian Journal of Agricultural Science, 40, 13-16.

25. Murty, K.S. and Raghavaiah, P. (1966). Observations on dormancy in rice seed. Current Science, 35, 548.

26. Nakamura, S. (1963). Short communication on dormancy of rice seed. Proceedings of the International Seed Testing Association, 28, 57-59.

27. Nishiyama, I. (1978). Further evidence for the break on the Arrhenius plot of germination activity in rice seeds. Japanese Journal of Crop Science, 47, 557-562.

28. Oka, H.I. and Tsai, K.H. (1955). [Dormancy and longevity of rice seed with regard to their

variations among varieties.] Japanese Journal of Breeding, 5, 22-26.

29. Roberts, E.H. (1959). Geotropic and morphological alterations in rice seedlings caused by plant growth regulators. Nature, 183, 1197-1198.

30. Roberts, E.H. (1961). Dormancy in rice seed. II. The influence of covering structures. Journal of Experimental Botany, 12, 430-445.

31. Roberts, E.H. (1962). Dormancy in rice seed. III. The influence of temperature, moisture and gaseous environment. Journal of Experimental Botany, 12, 75-94.

32. Roberts, E.H. (1963). The effects of inorganic ions on dormancy in rice seed. Physiologia Plantarum, 16, 732-744.

33. Roberts, E.H. (1963). The effects of some organic growth substances and organic nutrients on dormancy in rice seed. Physiologia Plantarum, 16, 745-755.

34. Roberts, E.H. (1964). The distribution of oxidation-reduction enzymes and the effects of respiratory inhibitors and oxidising agents on dormancy in rice seed. Physiologia Plantarum, 17, 14-29.

35. Roberts, E.H. (1965). Dormancy in rice seed. IV. Varietal responses to storage and germination temperatures. Journal of Experimental Botany, 16, 341-349.

36. Sikder, H.P. (1967). Dormancy of paddy seeds in relation to different seed treatments. Experimental Agriculture, 3, 249-255.

37. Singh, P.V., Singh, M.B. and Khanna, A.N. (1973). Note on the temperature requirements of germinating rice seeds under controlled conditions. Indian Journal of Agricultural Science, 43, 426-427.

38. Sugawara, T. (1973). On the dormancy of seeds in Oryza glaberrima. Bulletin of the College of Agriculture, Utsunomiya University, Japan, 8, 43-49.

39. Takahashi, N. (1963). Studies on the dormancy of wild rice seeds. Science Reports, Research Institutes, Tohoku University, Series D, 14, 75-85.

40. Tseng, S. (1964). Breaking dormancy of rice seed with carbon dioxide. Proceedings of the International Seed Testing Association, 29, 445-450.

41. Yasue, T. (1973). [Effect of moisture content of seeds and soaking in water on breaking dormancy in indica rice.] Research Bulletin of the Faculty of Agriculture, Gifu University, 34, 1-10.

ORYZOPSIS

O. hymenoides (Roem. & Schult.) Ricker Indian ricegrass
O. miliacea (L.) Ascherson & Schweinfurth smilo ricegrass, smilograss

I. Evidence of dormancy

O. hymenoides seeds show very deep dormancy at harvest (1,2,7,11,13), and seeds stored for six (11) or nine (19) years can remain dormant. Dormancy in seeds of O. miliacea, however, tends not to be so pronounced (3,5).

II. Germination regimes for non-dormant seeds

O. hymenoides

TP: 15°C: 42d (AOSA)

S: 5°/15°C; 15°/25°C (16h/8h); 15°C: 28d (AOSA)

O. miliacea

S: 15°C: 42d (ISTA)

TP: 20°/30°C (16h/8h): 42d (AOSA)

III. Unsuccessful dormancy-breaking treatments

O. hymenoides

Alternating temperatures: 15°/15°-35°C, 20°/25°-30°C, 20°/30°C (15h/9h) (1); -20°/43°C (freeze/thaw) (7)

Pre-chill: -18°C, in sand (12)

Radio frequency: 41 MHz, 2 Kv/cm, 8-36s (1)

Potassium nitrate: pre-applied, 24h, 0.2, 2% (1); co-applied, 0.2% (13)

Sodium nitrate: pre-applied, 24h, 0.2% (1)

GA_3: pre-applied, 72h, 10^{-6} M (7); pre-applied, 1.5h, 10^{-4} M (14)

Kinetin: pre-applied, 24h, 50 ppm (1)

Abscisic acid: pre-applied, 72h, 10^{-6}-10^{-4} M (7)

Thiourea: pre-applied, 3, 5% (12)

Hydrogen peroxide: pre-applied, 24h, 0.4% (1); 72h, 0.01-6% (7)

Light: 100 fc, 9h (1)

Pre-soak: 72h, aerated (7); 100°C, 0.5-6 min (7)

Acetone: pre-applied, 72h (7)

Ethanol: pre-applied, 72h (7)

Chloroform: pre-applied, 72h (7)

Pectinase: pre-applied, 72h (7)

Cellulase: pre-applied, 72h (7)

Tyrosinase: pre-applied, 72h (7)

Scarification: sulphuric acid, 40, 55%, 1h (9); concentrated sulphuric acid (13); sandpaper (13)

Sodium carbonate: pre-applied (12)

Hydrochloric acid: pre-applied, 10^{-3} N (12)

Butyric acid: pre-applied, $8x10^{-2}$ N (12)

Pre-dry: 80°C (12)

O. miliacea

Constant temperatures: 20°C, 26°C, 30°C, dark (3); 26°C, 30°C, continuous light (3,8)

Hydrogen peroxide: pre-applied, 90 min (4)

Calcium hypochlorite: pre-applied, 15 min, 10% (18)

IV. Partly-successful dormancy breaking treatments

O. hymenoides

Alternating temperatures: 5°/15°-30°C (15h/9h) (1); 15°/25°C, 20°/30°C (17h/7h) in light (13)

Pre-chill: 5°C, 4w (1,2,6,13); 4-10w (9)

Light: dark (1)

Calcium nitrate: pre-applied, 24h, 0.2% (1)

Nitric acid: pre-applied, 24h, 0.2% (1); pre-applied, 24h, 0.2%, then pre-chill, 5°C, 4w, germinate at 5°/15°C (15h/9h) (1)

GA_3: pre-applied, 24h, 100, 500, 1000 ppm (1); pre-applied, 24h, 10^{-6}-10^{-4} M (7); co-applied, 100 ppm (1)

Kinetin: pre-applied, 72h, 10^{-6}-10^{-4} M (7)

Removal of seed covering structures: (1,12,13); lemma and palea, then prick pericarp (19,20); lemma and palea, then prick pericarp, plus GA_3, co-applied, 100 ppm (19); lemma and palea, then prick pericarp, plus GA_3, co-applied, 100 ppm; plus pre-chill, 5°C, 4w (19)

Scarification: sulphuric acid, 98%, 0.5-1h (7); sulphuric acid, 98%, 0.25-1.25h (9); sulphuric acid, 98%, 0.5-1.25h (12); sulphuric acid, 98%, 0.75h (17); sulphuric acid, 98%, 0.5h (14); sulphuric acid, 67%, 40 min (7); sulphuric acid, 85%, 1h (9,13); sulphuric acid, 70%, 0.75-1h (9,13); sulphuric acid, 98%, 40 min, then GA_3, pre-applied, 70h, 10^{-5} M (15); sulphuric acid, 98%, 35 min, then GA_3, pre-applied, 1.5h, 10^{-4} M dissolved in acetone (6,14); sulphuric acid, 67%, then GA_3, co-applied, 10^{-6}-10^{-3} M dissolved in acetone (7); sulphuric acid (2); mechanical (2,9,12,15)

Ether: pre-applied, 72h (7)

Pre-soak: 2°-4°C, 40d (11)

Pre-wash: 1-5d (7)

O. miliacea

Alternating temperatures: 20°/30°C (16h/8h) in light (3)

Light: 100-120 fc, 5 min (3,8)

Pre-soak: (16)

Pre-wash: 1-4d (3)

Scarification: concentrated sulphuric acid, 1 min (4); sulphuric acid, 71%, 5-20, 60 min (4); sulphuric acid, 70%, 20-40 min (16)

Removal of seed covering structures: lemma and palea, then scarification, concentrated sulphuric acid, 5 min, germinate at 21°C in light, 12h/d (18)

Sodium hypochlorite: pre-applied, 1,3,4h, 2.5% (4)

Inoculum: Penicillum funiculosum (18)

V. Successful dormancy-breaking treatments

O. hymenoides

Pre-chill, or dark Pre-chill in soil (AOSA)

Constant temperatures: 3°C, 120d (13)

Pre-chill: 5°C, 4w, with GA_3, co-applied, 100 ppm, at 5°/15°C (15h/9h) in dark, 21d (1)

Scarification: sulphuric acid, 71%, 0.75-1h, germinate at 20°/30°C (17h/7h) (13)

Removal of seed covering structures: lemma and palea, then prick pericarp, germinate at 20°C, dark, 7d, then GA_3, co-applied, 50 ppm (20)

O. miliacea

Pre-chill (ISTA)

Light, Pre-chill (AOSA)

Scarification: sulphuric acid, 70%, 20-40 min, germinate at 20°/30°C (16h/8h) (3); sulphuric acid, 70%, 40 min (4)

VI. Comment

The AOSA directions for testing dormant seeds of O. hymenoides require pre-chilling at 5°C for 4 weeks and testing for an additional 3 weeks where paper is the germination test medium: a total germination test period of 13 weeks. This substantial test period is indicative of the dormancy problem in this species. If soil is used as the germination test medium then the direction is to pre-chill the seeds for 2 weeks at 5°C in the dark in soil prior to the subsequent germination test (AOSA): a total germination test period of 8 weeks.

Several of the AOSA prescriptions are, however, unlikely to be completely effective in promoting the germination of the very dormant seeds of O. hymenoides (1). Seeds tend to germinate better when tested in soil compared to paper substrata (1,14), and an alternating temperature regime is promotory compared to a constant temperature of 15°C (1). The following standard germination test procedure has been recommended: test in previously sterilized potting compost re-moistened with 100 ppm GA_3, pre-chill for 4 weeks at 5°C, then germinate at an alternating temperature of 5°/15°C in the dark (1). It is suggested here that the apparent requirement for testing in compost to avoid exposure to excess light may not be necessary, and that testing on a paper germination test medium may be satisfactory if the light regime specified in Chapter 6 is applied.

The AOSA prescribed alternating temperature regime of 20°/30°C (16h/8h) alone is unable to

promote the full germination of dormant accessions of O. miliacea (3), but pre-chilling - the AOSA directions suggest 2 weeks at 5°C - combined with lemma and palea removal should be sufficiently promotory. However, despite the AOSA prescription for light care with the light regime is also required for dormant accessions of O. miliacea: germination is inhibited by continuous light treatments but promoted by short light irradiations (8). Consequently testing in the dark is suggested with only a brief exposure to light: a single 4 minute exposure to red light (220 fc at source) 24 hours after imbibition in the dark began can be extremely promotory (8). Again the light regime described in Chapter 6 is suggested as a possible alternative.

VII. References

1. Clark, D.C. and Bass, L.N. (1970). Germination experiment with seeds of Indian Ricegrass, Oryzopsis hymenoides (Roem, and Schult.) Ricker. Proceedings of the Association of Official Seed Analysts, 60, 226-239.

2. Huntamer, M.Z. (1934). Dormancy and delayed germination of Oryzopsis hymenoides. Thesis, State College of Washington, Pullman, Washington.

3. Koller, D. and Negbi, M. (1959). The regulation of germination of Oryzopsis miliacea. Ecology, 40, 20-36.

4. Laude, H.M. (1951). Treatments to improve the emergence and stand of smilograss. Journal of Range Management, 4, 88-92.

5. Laude, H.M. (1956). Germination of freshly harvested seed of some Western Range species. Journal of Range Management, 9, 126-129.

6. McDonald, M.B. Jr. (1976). Improving the germination of Indian ricegrass seeds. Journal of Seed Technology, 1, 46-53.

7. McDonald, M.B. Jr. and Khan, A.A. (1977). Factors determining germination of Indian ricegrass seeds. Agronomy Journal, 69, 558-563

8. Negbi, M. and Koller, D. (1964). Dual action of white light in the photocontrol of germination of Oryzopsis miliacea. Plant Physiology, 39, 247-253.

9. Plummer, A.P. and Frischnecht, N.C. (1952). Increasing field stands of Indian ricegrass. Agronomy Journal, 44, 285-289.

10. Quinones, F.A. (1980). Seed germination and production of range species for use in revegetation. Bulletin, New Mexico Agricultural Experiment Station, Bulletin No. 670, 28pp.

11. Rogler, G.A. (1960). Relation of seed dormancy of Indian ricegrass (Oryzopsis hymenoides (Roem. and Schult.)) to age and treatment. Agronomy Journal, 52, 470-473.

12. Stoddart, L.A. and Wilkinson, K.J. (1938). Inducing germination in Oryzopsis hymenoides for range reseeding. Journal of the American Society of Agronomy, 30, 763-768.

13. Toole, V.K. (1940). The germination of seed of Oryzopsis hymenoides. Journal of the American Society of Agronomy, 32, 33-41.

14. Zematra, R.S., Havstad, C. and Cuany, R.L. (1983). Reducing seed dormancy in Indian ricegrass (Oryzopsis hymenoides). Journal of Rang Management, 36, 239-241.

15. Barton, L.V., Roe, C.H. and Khan, A.A. (1971). Imbibition and germination: influence of hard seed coats on RNA metabolism. Physiologia Plantarum, 25, 402-406.

16. Lapeyronie, A. (1968). Existence d'un cycle endogène concernant la faculté germinative de l' Oryzopsis miliacea. Comptes Rendus Hebdomadaires des Séances de l'Académie de Science, Paris, 267D, 1724-1726.

17. McDonald, M.B. Jr. and Khan, A.A. (1983). Acid scarification and protein synthesis during seed germination. Agronomy Journal, 75, 111-114.

18. Probert, R.J. (1981). The promotive effects of a mould, Penicillium funiculosum Thom. on the germination of Oryzopsis miliacea (L.) Asch. & Schw. Annals of Botany, 48, 85-88.

19. Young, J.A. and Evans, R.A. (1984). Germination of seeds of 'Paloma' and 'Nezpar' Indian ricegrass. Journal of Range Management, 37, 19-21.

20. Young, J.A., Evans, R.A. and Roundy, B.A. (1983). Quantity and germinability of Oryzopsis hymenoides seed in Lahontan sands. Journal of Range Management, 36, 82-86.

PANICUM

P. anceps Michx.	beaked panicum
P. antidotale Retz.	blue panic grass
P. bisulcatum Thunb.	
P. bulbosum HBK	
P. capillare L.	witch grass
P. clandestinum L.	deertongue grass
P. coloratum Stapf	kleingrass
P. dichotomiflorum Michx.	fall panicum
P. fasciculatum	brown top millet
P. maximum Jacq.	guinea grass, green panic
P. miliaceum L.	common millet, broom-corn millet, brown-corn millet, hog millet, proso millet, Russian millet
P. obtusum HBK	vine-mesquite
P. phillopogon	
P. prolutum	
P. ramosum L.	
P. simile Domin	
P. turgidum Forsk.	
P. virgatum L.	switch-grass

I. Evidence of dormancy

Freshly harvested seeds of Panicum spp. can show considerable dormancy and consequently can be difficult to germinate (1,2,4,5,7,10-13, 15,16,21,22,23,26,34,35,39,40,46). An indication of the degree of dormancy is provided by the large number of treatments listed below which failed to break dormancy and the observations that substantial periods of after-ripening are required to completely remove dormancy. For example, 10 (13), 12 (22), 18 (33) or 30 (43) months treatment has been required by various seed lots of P. maximum. A further example which indicates the severity of the problem is a failure to achieve more than 2-3% germination in high-viability lots of P. virgatum and P. bisulcatum after one year's storage despite eight different germination test environments (21).

II. Germination regimes for non-dormant seeds

P. antidotale

TP: 20°/30°C: 28d (ISTA)

TP; TS: 20°/30°C (16h/8h): 28d (AOSA)

P. bisulcatum

Constant temperatures: 15°-30°C (21)

P. bulbosum

Constant temperatures: 15°-25°C (21)

P. coloratum

TP: 20°/35°C (16h/8h): 28d (ISTA)

P. maximum

TP: 20°/30°C; 15°/35°C (16h/8h): 28d (ISTA)

TP: 15°/35°C (16h/8h): 28d (AOSA)

P. miliaceum

BP; TP: 25°C; 20°/30°C (16h/8h): 7d (ISTA)

BP; TP: 20°/30°C (16h/8h): 7d (AOSA)

P. ramosum

BP: 20°/30°C (16h/8h): 14d (ISTA)

P. virgatum

TP: 15°/30°C (16h/8h): 28d (ISTA)

TP; TS: 15°/30°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

P. anceps

Constant temperatures: 15°C, 20°C, 30°C (10)

Alternating temperatures: 10°/20°C, 20°/30°C (16h/8h) (10)

Potassium nitrate: pre-applied, 0.2% (10)

Sodium hydroxide: pre-applied, 35% (10)

Mercuric chloride: pre-applied, 0.025% (10)

Oxygen: pre-applied (10)

Ether: pre-applied (10)

Pre-soak: (10)

Pre-dry: (10)

Scarification: hydrochloric acid, 50% (10); disc, 25 min, 1150 rpm (18); concentrated sulphuric acid, 1,5,10 min (10); concentrated sulphuric acid, 30,45 min, then pre-chill, 5°C, 2,4,8w, germinate at 15°/30°C (16h/8h) (10); sulphuric acid, 71% (10)

Removal of seed covering structures: seed coat, then pre-chill, 5°C, 8w (10)

P. bisulcatum

Constant temperatures: 15°-30°C, dark, continuous (21)

Light: dark, continuous (21)

P. bulbosum

Constant temperatures: 15°-30°C, dark or light (21)

Light: continuous (21)

Potassium cyanide: pre-applied, 10^{-2} M (21)

P. coloratum

Hydrogen peroxide: pre-applied, 5 min, 21 M (46)

Potassium cyanide: pre-applied, 10^{-2} M (21)

Potassium nitrate: co-applied, 0.2% (40)

Ethanol: co-applied, $3x10^{-1}$ M (46)

Pre-dry: 70°C, 1d (46)

P. dichotomiflorum

Alternating temperatures: 15°/6°C, 20°/10°C, 25°/15°C, 30°/15°C, 35°/20°C (12h/12h) in light or dark (35)

Pre-dry: 50°C, 3,7,14d (27)

GA_3: pre-applied, 24h, $1.4x10^{-4}$ -$7x10^{-4}$ M (4)

Thiourea: pre-applied, 24h, 0.13, 0.32, 0.65 M (4)

Pre-wash: 24,48,96h (4)

Scarification: concentrated sulphuric acid, 10-30 min (4)

Ethanol: pre-applied, 7d, 10^{-4} 1 in 125ml flask, 35°C (29)

Acetone: pre-applied, 7d, 10^{-4} 1 in 125ml flask, 35°C (29)

Chloroform: pre-applied, 7d, 10^{-4} 1 in 125ml flask, 35°C (29)

Dark: (29)

Ethylene: co-applied, 1-100 ppm (26)

Carbon dioxide: pre-applied, 7d, 1-5%, dark, 35°C (26)

P. fasciculatum

Pre-chill: 5°C, 7d, plus potassium nitrate, co-applied, 0.2%, germinate at 20°/30°C or 20°/35°C (16h/8h) in light (2)

Potassium nitrate: co-applied, 0.2%, at 15°/25°C (16h/8h) in light (2)

P. maximum

Constant temperatures: 5°C, 35°C (12)

Alternating temperatures: 20°/30°C, 20°/35°C (16h/8h) (11)

Pre-chill: 5°C, 2-14d (11); -3°C, 4d (11)

Pre-dry: (23); 34°C, 3d (11); 40°C, 1-6h (11); 50°C, 1-4h (11); 90°C (1-4min)/2°C (3-7d) (9); 35°C, 13d (36)

Pre-soak: (23); 20°C, 1-7d (11); 50°C, 30,60 min (11)

Potassium cyanide: pre-applied, 10^{-2} M (21)

Scarification: (8,22); sulphuric acid, 50% (23); concentrated sulphuric acid, 5 min, then potassium nitrate, co-applied, 0.2%, at 30°C (22)

Potassium nitrate: co-applied, 2% (11); co-applied, 0.2% (13,22)

Uranyl nitrate: co-applied, 0.2, 1% (11)

Indoleacetic acid: co-applied, 10, 50, 100 ppm (22)

GA_3: co-applied, 10, 50, 100 ppm (22)

Kinetin: co-applied, 10, 50, 100 ppm (22)

Thiourea: co-applied, 100ppm (22)

2-Chloroethanol: pre-applied, 1% (23)

Light: (15,22); dark (36)

Inoculum: Rhizobium melilottii, $8x10^4/10^{-6}$ 1 (8)

Removal of seed covering structures: dehull (36); dehull, then pre-dry, 35°C, 13d (36)

P. miliaceum

Light: $180x10^{-6}$ mol $m^{-2}s^{-1}$, 12h/d (24)

P. prolutum

Constant temperatures: 4°C, 35°C (1)

Alternating temperatures: 33°/4°C (24h/24h) (1)

Pre-chill: 4°C, 7d, germinate at 33°C (1)

Warm stratification: 36°C, 7d, germinate at 4°C (1)

Potassium nitrate: co-applied, 0.2% (1)

Thyocyanate: pre-applied (1)

Hydrogen peroxide: co-applied, 1, 3, 30% (1)

Ether: pre-applied, 4 min (1)

Scarification: concentrated sulphuric acid, 25+ min (1)

P. ramosum

Kinetin: co-applied, 5ppm (3)

P. turgidum

Constant temperatures: 10°C in light (17)

Light: 10 min (17)

Panicum spp.

Sodium azide: pre-applied, 10^{-2} M (21)

Sodium sulphide: pre-applied, 10^{-3}, 10^{-2} M (21)

8-Hydroxyquinoline: pre-applied, $0.5x10^{-3}$, $0.5x10^{-2}$ M (21)

DIECA: pre-applied, 10^{-3}, 10^{-2} M (21)

Mercuric chloride: pre-applied, 10^{-4}, 10^{-3} M (21)

Hydroxylamine: pre-applied, 10^{-3} M (21)

Hydroquinone: pre-applied, $0.5x10^{-2}$, $0.5x10^{-1}$ M (21)

Catechol: pre-applied, $0.5x10^{-2}$, $0.5x10^{-1}$ M (21)

Pyrogallol: pre-applied, $0.5x10^{-2}$, $0.5x10^{-1}$ M (21)

Resorcinol: pre-applied, $0.5x10^{-2}$, $0.5x10^{-1}$ M (21)

p-Benzoquinone: pre-applied, $0.5x10^{-2}$, $0.5x10^{-1}$ M (21)

o-Cresol: pre-applied, 0.1% (21)

Guaiacol: pre-applied, 0.01% (21)

Ethylene chlorohydrin: pre-applied, 0.1% (21)

Pre-soak: (21)

IV. Partly-successful dormancy-breaking treatments

P. anceps

Constant temperatures: 25°C (10)

Alternating temperatures: 10°/30°C, 15°/30°C (10)

Pre-chill: 5°C, 56d (10); 7°C, 50d (18)

Scarification: concentrated sulphuric acid, 6 min (18); concentrated sulphuric acid, 30 min (10); concentrated sulphuric acid, 6 min, then pre-chill, 7°C, 50d (18); concentrated sulphuric acid, 15 min, then pre-chill, 5°C, 28d (10); sand paper (10)

Removal of seed covering structures: pericarp (10)

Potassium nitrate: pre-applied, 24h, 0.5%, then pre-chill, 5°-7°C, 42d (18)

P. antidotale

Constant temperatures: 20°-35°C in light (41)

Alternating temperatures: 10°/20°C, 10°/26°C, 20°/30°C (15-16h/8-9h) (41)

Pre-chill: 5°C, 7,14,21d (41)

Pre-dry: 5°C, 20°C, 30°C, 7,14,21d, over calcium chloride or sulphuric acid (41)

Light: 8h/d (42)

P. bisulcatum

Constant temperatures: 15°-30°C, continuous light (21)

P. bulbosum

Constant temperatures: 15°-25°C, continuous dark (21)

P capillare

Ethanol: pre-applied, 4h-3d, $1.6x10^{-1}$-$3.2x10^{-1}$ M, 35°C, dark (14)

Ethyl ether: pre-applied, 3d, $6x10^{-2}$-$2.4x10^{-1}$ M, 35°C, dark (14)

Chloroform: pre-applied, 3d, $1.5x10^{-2}$ M, 35°C, dark (14)

n-Propanol: pre-applied, 3d, $6x10^{-2}$-$1.2x10^{-1}$ M, 35°C, dark (14)

Pre-dry: 50°C, 7,14d (27)

P. clandestinum

Alternating temperatures: 15°/25°C, 20°/30°C, 10°/30°C, 5°/35°C (16h/8h) (5)

Pre-chill: 5°C, 10°C, 7-28d (5)

P. coloratum

Alternating temperatures: 20°/30°C (16h/8h) in light (37); 25°/35°C (12h/12h) in light, $5x10^{-6}$ mol m^{-2} s^{-1} (46); 20°/30°C, 30°/20°C (16h/8h) (40)

Pre-chill: 10°C, 7d (37); 10°C, 7d, plus potassium nitrate, co-applied, 0.2% (37)

Light: 8,16,24h/d (42)

Scarification: concentrated sulphuric acid, 3-60 min (60); concentrated sulphuric acid, 5-15 min (46); sand paper (7)

Potassium nitrate: co-applied, 0.2% (37); co-applied, $2x10^{-2}$, $5x10^{-2}$ M (46)

GA_3: co-applied, $5x10^{-5}$ M (46); co-applied, 100 ppm (40); co-applied, 100 ppm, plus thiourea, co-applied, 0.2% (40)

Thiourea: co-applied, 0.2% (40)

Ethrel: co-applied, $9.5x10^{-4}$ M (46)

Chloroethanol: pre-applied, 1h, 0.15, 0.75 M, in $6.7x10^{-2}$ M sodium hypochlorite (46)

Sodium azide: co-applied, 10^{-3} M (46)

Hydrogen peroxide: pre-applied, 15 min, 21 M (46)

P. dichotomiflorum

Alternating temperatures: 10°/30°C (16h/8h) (4)

Pre-chill: 10°C, 14d (4)

Warm stratification: 25°C, 35°C, dark, 3,7d (25,26)

Pre-dry: 50°C, 14d (26)

Ethanol: pre-applied, 35°C, 0.5 M (28); pre-applied, 7d, $10.75x10^{-6}$ 1 in 125 ml flask, 35°C (29)

Methanol: pre-applied, 7d, 10^{-6}-10^{-4} 1 in 125 mil flask, 35°C (29)

Acetone: pre-applied, 7d, $50x10^{-6}$ 1 in 125 ml flask, 35°C (29)

Chloroform: pre-applied, 7d, $50x10^{-6}$ 1 in 125 ml flask, 35°C (29)

Ethyl ether: pre-applied, 7d, 10^{-6}-10^{-4} 1 in 125 ml flask, 35°C (29)

Light: red, $3.3x10^{-9}$ mol m^{-2} s^{-1}, 590-680 nm, 5min (25,29); fluorescent, $2x10^{-5}$ mol m^{-2} s^{-1}, 14h/d (35)

Scarification: mechanical (4); concentrated sulphuric acid, 2-8 min (4)

P. fasciculatum

Alternating temperatures: 5°/35°C, 20°/35°C, 10°/35°C, 20°/30°C, 15°/35°C (16h/8h) in light (2)

Potassium nitrate: co-applied, 0.2% (2); co-applied, 0.2%, plus thiourea, 0.1%, co-applied, (2); co-applied, 0.2%, at 5°/35°C in light or dark (2); co-applied, 0.2%, at 20°/35°C, 10°/35°C, 20°/30°C, or 15°/35°C (16h/8h) in light (2); co-applied, 0.2%, plus thiourea, 0.1%, co-applied, at 5°/35°C (16h/8h) in light (2)

Thiourea: co-applied, 0.1% (2)

Removal of seed covering structures: glumes (2); glumes, germinate at 5°/35°C in light (2);

glumes, plus thiourea, co-applied, 0.1%, at 5°/35°C in light (2)

P. maximum

Alternating temperatures: 5°/30°C (16h/8h) (11,15,16); 15°/35°C (16h/8h) (6,11,12,13,16,31); 15°/30°C (16h/8h) (11,12,16,22); 5°/35°C, 10°/30°C, 30°/5°C, 35°/15°C (16h/8h) (11); 10°/35°C, 10°/20°C, 15°/25°C (16h/8h) (12); 20°/35°C, 20°/30°C (12,16); 15°/35°C (20h/4h) (44)

Pre-chill: 5°C, 2-14d (11); 5°C, 10°C, 1,3w (44)

Warm stratification: 15°C, 20°C, 25°C, 1,3w (44)

Pre-soak: then pre-dry (22); 24-72h, then pre-dry (19)

Pre-wash: 1-5h (22)

Removal of seed covering structures: bracts (22,44)

Pre-dry: 37°C, 50°C, 1-9d (9); 6°C, 1-9d, then 50°C, 1-9d (9); 9°C, 1-9d, then 37°C, 1-9d (9); 50°C, 1-9d, then 9°C, 1-9d (9); 37°C, 1-9d, then 9°C, 1-9d (9); 40°C, 50°C, 4-8w (44)

Potassium nitrate: co-applied, 0.2% (11,13,22,23); co-applied, 0.1, 0.2, 0.4% (38)

Uranyl nitrate: co-applied, 0.1% (11)

Hydrogen peroxide: pre-applied, 4,8h, 0.4, 0.8% (11)

GA_3: pre-applied (43); co-applied, 20-100 ppm (23); co-applied, 50 ppm, plus potassium nitrate, co-applied, 0.2% (23)

Scarification: mechanical (22); concentrated sulphuric acid, 2-4 min (11); concentrated sulphuric acid, 5 min (22,23); concentrated sulphuric acid, 4 min, plus potassium nitrate, co-applied, 0.2%, at 5°/30°C or 15°/35°C (16h/8h) (11); concentrated sulphuric acid, 5 min, plus potassium nitrate, co-applied, 0.2%, at 15°/30°C (16h/8h) in light (22,23); concentrated sulphuric acid, 4 min, plus hydrogen peroxide, pre-applied, 8h, 8%, germinate at 5°/30°C (16h/8h) (11); concentrated sulphuric acid, 4 min, plus uranyl nitrate, co-applied, 0.1%, at 15°/35°C (16h/8h) (11); concentrated sulphuric acid, 5 min, plus GA_3, co-applied, 50 ppm, with or without potassium nitrate, co-applied, 0.2% (23)

Light: 7000-8000 lux, 12, 18,24h/d (36)

Sodium peroxide: pre-applied, 24h, 0.2%, germinate at 22°/30°-32°C (night/day) in light, 4700 lux, 12h/d (36)

P. miliaceum

Pre-chill: 5°C (24)

P. obtusum

Alternating temperatures: 20°/30°C (32); 20°/30°C (17h/7h) in light (30); 20°/35°C, 20°/40°C, 25°/40°C, 10°/35°C, 35°/10°C, 15°/25°C (17h/7h) (30)

Pre-chill: 3°C, 10°C, 15°C, 14,28,56d (30)

Potassium nitrate: co-applied, 0.2% (30)

Scarification: sulphuric acid, 71%, 1.5h (30); sulphuric acid, 71%, 1.5h, plus potassium nitrate, co-applied, 0.2%, at 20°-25°/35°C (17h/7h) (30)

P. prolutum

Alternating temperatures: 4°/33°C (18h/6h,24h/24h) (1)

Pre-chill: 4°C, 7d, germinate at 36°C (1)

Warm stratification: 33°C, 7d, germinate at 4°C (1)

Pre-soak: 1-6d (1); 3d, then pre-dry, 3d (1); 3d, then pre-dry, 3d, then pre-soak, 1-3d (1)

Scarification: concentrated sulphuric acid, 3-20 min (1); concentrated sulphuric acid, 10 min, then pre-soak, 3d (1); concentrated sulphuric acid, 5 min, with re-scarification of remaining ungerminated seeds at 14d for 2 min, with further re-scarification at 28d if necessary (1)

P. simile

Alternating temperatures: 20°/30°C (8h/16h) in light, 16h/d (39)

GA_3: co-applied, 10^{-4} M, at 20°/30°C (8h/16h) in light, 16h/d (39)

Potassium nitrate: co-applied, 0.15%, at 20°/30°C (8h/16h) in light, 16h/d (39)

P. ramosum

Alternating temperatures: 5°/35°C, 20°/30°C (16h/8h) in light (3,34); 20°/30°C (20h/4h) (3)

Potassium nitrate: co-applied, 0.2% (3,34); co-applied, 0.2%, plus thiourea, co-applied, 0.1% (3,34)

GA_3: co-applied, 346, 692 ppm (3)

Pre-dry: 35°C, 7d (3,34); 35°C, 7d, plus GA_3, co-applied, 346, 692 ppm (3); 35°C, 7d, plus potassium nitrate, co-applied, 0.2%, plus thiourea, co-applied, 0.1%, at 5°/35°C (16h/8h) in light (34)

P. turgidum

Constant temperatures: 15°C, 20°C, 25°C, dark (17)

Alternating temperatures: 20°/26°C (16h/8h) (17)

Pre-dry: 30°C, 48d, over calcium chloride (17)

Light: 8h/d (42)

P. virgatum

Pre-chill: 3°-5°C, 14-54d (45)

Scarification: mechanical (45)

Panicum spp.

Potassium cyanide: pre-applied, 10^{-3}, 10^{-2} M (21)

Pre-soak: 30°C (21)

Sodium azide: pre-applied, 10^{-3} M (21)

Thiourea: pre-applied, 10^{-2}, 10^{-3} M (21)

Salicylaldoxime: pre-applied, $0.5x10^{-3}$, $0.5x10^{-2}$ M (21)

Hydroxylamine: pre-applied, 10^{-2} M (21)

2,4-Dinitrophenol: pre-applied, 10^{-4} M (21)

Cupferron: pre-applied, 10^{-2} M (21) o-Cresol: pre-applied, 0.01% (21)

Guaiacol: pre-applied, 0.01% (21)

Ethylene chlorohydrin: pre-applied, 0.01% (21)

V. Successful dormancy-breaking treatments

P. anceps

Scarification: mechanical, shake in glass bottle, 40 min, then pre-chill, 5°C, 4,8w, germinate at 15°/30°C (10)

P. capillare

Ethanol: pre-applied, 3d, 0.2, 0.5 M or $20x10^{-6}$, $50x10^{-6}$ l in 125 ml flask, 35°C, leave loosely capped for further 4d, then 5 min red light, $3.3x10^{-9}$ mol cm^{-2} s^{-1}, 590-680 nm, germinate at 20°/30°C (16h/8h) (29)

P. clandestinum

Potassium nitrate: co-applied, 0.2%, at 10°/30°C (16h/8h) in light (5); co-applied, 0.2%, then pre-chill, 10°C, 28d, germinate at 20°/30°C (16h/8h) (5)

P. coloratum

Removal of seed covering structures: then germinate at 30°/20°C (16h/8h) (40)

P. dichotomiflorum

Warm stratification: 35°C, 14d, in red light, 5 min, $3.3x10^{-9}$ mol cm^{-2} s^{-1}, 590-680 nm, germinate at 20°/30°C (16h/8h) (26)

Ethanol: pre-applied, 3d, 0.2, 0.5 M or $20x10^{-6}$, $50x10^{-6}$ l in 125ml flask, 35°C, leave loosely capped for further 4d, then red light, 5 min, $3.3x10^{-9}$ mol cm^{-2} s^{-1}, 590-680nm, germinate at 20°/30°C (16h/8h) (29)

P. fasciculatum

Removal of seed covering structures: glumes, plus potassium nitrate, co-applied, 0.2%, with thiourea, 0.1%, co-applied, at 5°/35°C (16h/8h) in light (2)

P. maximum

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Removal of seed covering structures: glumes, plus potassium nitrate, co-applied, 0.2%, at 35°/15°C (16h/8h) in light (6); dehull, germinate at 15°/35°C (20h/4h) (44)

P. prolutum

Removal of seed covering structures: cut, germinate at 4°/33°C (18h/6h) (1)

P. phillopogon

Removal of seed covering structures: (20)

P. ramosum

Pre-dry, Potassium nitrate (ISTA)

Removal of seed covering structures: lemma and palea, then potassium nitrate, co-applied, 0.2%, plus thiourea, co-applied, 0.1%, at 5°/35°C (16h/8h) in light (34)

P. simile

Removal of seed covering structures: dehull, germinate at 20°/30°C (8h/16h) in light (39); dehull, then GA_3, co-applied, 10^{-4} M, at 20°/30°C (8h/16h) in light (39); dehull, then potassium nitrate, co-applied, 0.15%, at 20°/30°C (8h/16h) in light (39)

P. turgidum

Polysorbate 80: co-applied, 0.01, 0.1%, at 20°/26°C (16h/8h) (17)

P. virgatum

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate, Pre-chill (AOSA)

VI. Comment

Obtaining full germination of seed accessions of Panicum spp. can be difficult. Much of the difficulty appears to stem from the relatively long after-ripening treatments - which gene banks will seek to avoid - commonly applied to remove dormancy but which can result in a single population containing both dormant and deteriorated seeds: subsequent treatments applied to such lots tend to result in the death of the non-dormant seeds. In general removal of the lemma and palea is not an advisable procedure since the seeds are easily damaged and viability reduced (8,22).

P. anceps Application of pre-chill or potassium nitrate treatments fail to result in full germination (18). The successful treatment described above for this species (10) is unfortunately somewhat long.

P. fasciculatum It is suggested that the potentially damaging removal of seed covering structures is avoided, but the remaining features of the treatment resulting in full germination described above (2) be applied for an extended test period - at least 42 days.

P. maximum Standard ISTA/AOSA procedures do not result in full germination, at least during 28 days tests (11,13,22,23,38). Several treatments combined with sulphuric acid scarification resulted in high, but not full germination (11,22,23). It is not suggested that acid scarification

treatments be applied to seed accessions of this species. In our laboratory the following germination test environments have been satisfactory for dormant seeds of P. maximum: alternating temperature regimes of 15°/30°C (16h/8h) or 10°/30°C (16h/8h or 20h/4h) in diffuse light applied for 42 to 56 days with or without potassium nitrate co-applied at 10^{-3} M (A); or an alternating temperature regime of 15°/30°C (20h/4h) in diffuse light with potassium nitrate, co-applied at 10^{-2} M, for 40 days (A). Where other recommendations are inadequate, it is suggested that these regimes may be useful for accessions of other Panicum spp., particularly since they avoid any need for the removal of seed covering structures.

P. ramosum Standard ISTA procedures, and variations thereof, did not result in full germination (3). The suggested procedure is to test in an alternating temperature regime of 5°/35°C (16h/8h) in light (during the 8 hour cycle) for at least 42 days with potassium nitrate (0.2%) and thiourea (0.1%) co-applied (34).

P. turgidum Polysorbate 80 is a surface tension reducing agent. If the successful treatment (17) is found to be unsatisfactory other treatments with a similiar effect could be tried, together with wider amplitudes of temperature alternation.

VII. References

1. Akamine, E.K. (1944). Germination of Hawaiian range grass seed. Hawaii Agricultural Experiment Station, Technical Bulletin, No. 2.

2. Andersen, A.M. (1958). A preliminary study of dormancy in brown top and cattail millets. Proceedings of the Association of Official Seed Analysts, 48, 85-92.

3. Andersen, A.M. (1962). Effect of gibberellic acid, kinetin-like substance, ceresan and phenacridane chlorite on the germination of Panicum ramosum seeds. Proceedings of the International Seed Testing Association, 27, 730-741.

4. Brecke, B.J. and Duke, W.B. (1980). Dormancy, germination and emergence characteristics of fall panicum (Panicum dichotomiflorum) seed. Weed Science, 28, 683-685.

5. Chirco, E.M., Goodman, J.R. and Clark, B.E. (1979). Germination of deertongue (Panicum clandestinum L.) seeds. Newsletter of the Association of Official Seed Analysts, 53, 40-42.

6. Cullinan, B. (1941). Germinating seeds of Southern grasses. Proceedings of the Association of Official Seed Analysts, 33, 74-76.

7. Edwards, D.C. (1933). 'Hard' seeds in Panicum coloratum Stapf. Nature, 132, 209.

8. Febles, G. and Padilla, C. (1970). The effect of Rhizobium melilottii, scarification and temperature in breaking dormancy in common guinea grass seed (Panicum maximum Jacq.). Revista Cubana Ciencia Agricola, 4, 71-78.

9. Febles, G. and Padilla, C. (1971). Effect of temperature on germination of guinea grass seed (Panicum maximum Jacq.) Revista Cubana Ciencia Agricola, 5, 77-87.

10. Garman, H.R. and Barton, L.V. (1946). Germination of seeds of Panicum anceps Michx. Contributions from Boyce Thompson Institute, 44, 117-122.

11. Hanssen, K.B. and Nicholls, E.B. (1965). Investigations into techniques for the germination of Panicum maximum Jacq. Proceedings of the International Seed Testing Association, 30, 715-722.

12. Harty, R.L. and Butler, J.E. (1975). Temperature requirements for germination of green panic, Panicum maximum var. trichoglum, during the after-ripening period. Seed Science and

Technology, 3, 529-536.

13. Harty, R.L., Hopkinson, J.M., English, B.H. and Alder J. (1983). Germination, dormancy and longevity in stored seed of Panicum maximum Jacq. Seed Science and Technology, 11, 341-351.

14. Hendricks, S.B. and Taylorson, R.B. (1980). Reversal by pressure of seed germination promoted by anesthetics. Planta, 149, 108-111.

15. Johnston, M.E.H. (1972). Report of the working group for the germination of tropical and sub-tropical seeds. Proceedings of the International Seed Testing Association, 37, 355-359.

16. Johnston, M.E.H. and Tattersfield, J.G. (1971). A preliminary report on germination techniques for Panicum maximum Jacq. Proceedings of the International Seed Testing Association, 36, 115-121.

17. Koller, D. and Roth, N. (1963). Germination regulating mechanisms in some desert seeds. VII. Panicum turgidum (Gramineae). Israel Journal of Botany, 12, 64-73.

18. Mathews, A.C. (1947). Observations on methods of increasing the germination of Panicum anceps Michx. and Paspalum notatum Flugge. Journal of the American Society of Agronomy, 39, 439-442.

19. Okada, T. (1980). [Studies of green panic seed. 4. The effects of soaking and wetting treatments on germination.] Journal of the Japanese Society of Grassland Science, 26, 126-130.

20. Placco, R. (1940). La germinazione dei semi di Panicum crusgalli e Panicum phillopogon. Risicoltura, 30, 101-113. (From Biology Abstracts, 1941, 15, 9403.)

21. Shimizu, N. (1979). [Studies on dormancy and germination of seeds in grasses of Panicum species. I. Light-temperature response in germination and dormancy-breaking effect of metabolic inhibitors.] Bulletin of the National Grassland Research Institute, 14, 94-101.

22. Smith, C.J. (1971). Seed dormancy in sabi panicum. Proceedings of the International Seed Testing Association, 36, 81-97.

23. Smith, R.L. (1979). Seed dormancy in Panicum maximum Jacq. Tropical Agriculture, 56, 233-239.

24. Striegel, W.L. and Boldt, P.F. (1981). Germination and emergence characteristics of wild proso millet. Proceedings of the North Central Weed Control Conference, 36, 22.

25. Taylorson, R.B., (1979). Control of fall panicum seed dormancy by light. Proceedings of the Northeastern Weed Science Society, 33, 330.

26. Taylorson, R.B. (1980). Aspects of seed dormancy in fall panicum (Panicum dichotomiflorum). Weed Science, 28, 64-67.

27. Taylorson, R.B. and Brown, M.N. (1977). Accelerated after-ripening for overcoming seed dormancy in grass weeds. Weed Science, 25, 473-476.

28. Taylorson, R.B. and Hendricks, S.B. (1979). Effects of ethanol and other anesthetics on seed dormancy. Plant Physiology, 63, 68.

29. Taylorson, R.B. and Hendricks, S.B. (1979). Overcoming dormancy in seeds with ethanol and other anesthetics. Planta, 145, 507-510.

30. Toole, V.K. (1940). Germination of seed of vine-mesquite, Panicum obtusum, and plains bristle-grass, Setaria macrostachya. Journal of the American Society of Agronomy, 32, 503-512.

31. Willersdorf, E. (1969). Germination tests on green panic. Australian Seed Testing Newsletter, 10, 9-12.

32. Wilson, C.P. (1931). Artificial reseeding on New Mexico ranges. New Mexico Agricultural Experiment Station Bulletin, 189, 3-37.

33. Winchester, W.J. (1954). Storing seed of green panic and buffel grass for better germination. Queensland Agricultural Journal, 79, 203-204.

34. Andersen, A.M. (1961). A study of dormant and firm seeds of brown-top millet. Proceedings of the Association of Official Seed Analysts, 51, 92-98.

35. Baskin, J.M. and Baskin, C.C. (1983). Seasonal changes in the germination responses of fall panicum to temperature and light. Canadian Journal of Plant Science, 63, 973-979.

36. Binrad, L. (1958). Resultats de quelques essais sur la germination de Panicum maximum. Agricultura, Louvain, 6, 305-310.

37. Butler, L., Helms, K. and Ogle, D. (1983). Establishing an official blowing method and germination method for kleingrass (Panicum coloratum). Newsletter of the Association of Official Seed Analysts, 57, 40-45.

38. Gonzalez, Y. and Torriente, O. (1983). [Effect of KNO_3 on dormancy breaking of Panicum maximum cv. Likoni. I. Storage at ambient temperature.] J. Pastas y Forrajes, 6, 59-72.

39. Heslehurst, M.R. and Peart, M.H. (1984). Germination and dormancy characteristics of Panicum simile. In Proceedings of the Australian Seeds Research Conference, pp. 225-234, personal communication.

40. Kijima, K. and Takei, K. (1971). [Germination test of tropical and sub-tropical grasses. 1. On the germination of coloured guineagrass (Panicum coloratum).] Journal of the Japanese Society of Grassland Science, 17, 170-175.

41. Koller, D. and Negbi, M. (1957). Hastening the germination of Panicum antidotale Retz. Bulletin of the Research Council of Israel, Section D, 5, 225-238.

42. Mukherjee, A. and Chatterji, V.N. (1970). Photoblastism in some of the desert grass seeds. Annals of Arid Zone, 9, 104-113.

43. Okada, T. (1982). [Studies on green panic seed. VII. Relation between time of heating at temperature of 30°C and improvement of germination.] Journal of the Japanese Society of Grassland Science, 28, 279-283.

44. Okada, T., Ochi, M. and Ohta, K. (1982). [Seed treatment to secure high germination percentage of fall panicum seed, soaking at room temperature.] Journal of the Japanese Society of Grassland Science, 28, 119-120.

45. Sautter, E.H. (1962). Germination of switchgrass. Journal of Range Management, 15, 108-109.

46. Tischler, C.R. and Young, B.A. (1983). Effects of chemical and physical treatments on germination of freshly-harvested kleingrass seed. Crop Science, 23, 789-792.

PASPALUM

P. dilatatum Poir. [P. racemosum Lam.]	dallis grass
P. guenoarum	
P. notatum Flügge	bahia grass
P. plicatulum Michx.	
P. scrobiculatum L. [P. commersonii Lam.]	kodo millet
P. urvillei Steud.	vasey grass
P. wettsteinii Hack.	

I. Evidence of dormancy

Dormancy in P. notatum can be particularly pronounced (10,12).

II. Germination regimes for non-dormant seeds

P. dilatatum

TP: 20°/35°C (16h/8h): 28d (ISTA)

TP: 20°/35°C (16h/8h): 21d (AOSA)

Alternating temperatures: 20°/35°C (16h/8h) (8)

P. notatum (cv. Pensacola only)

TP: 20°/35°C; 20°/30°C (16h/8h): 28d (ISTA)

TP; S: 20°/35°C (16h/8h): 28d (AOSA)

P. notatum (all other cvs.)

TP: 20°/35°C; 20°/30°C (16h/8h): 28d (ISTA)

TP; 30°/35°C (16h/8h): 21d (AOSA)

P. plicatulum

TP: 20°/35°C (16h/8h): 28d (ISTA)

P. scrobiculatum

TP: 20°/35°C (16h/8h): 28d (ISTA)

P. urvillei

TP: 20°/35°C (16h/8h): 21d (AOSA, ISTA)

P. wettsteinii

TP: 20°/35°C (16h/8h): 28d (ISTA)

III. Unsuccessful dormancy-breaking treatments

P. dilatatum

Pre-chill: -7°C, 1-20d (11)

Dry storage: -7°C, 10°C, 1-7d (11)

Removal of seed covering structures: glumes (5)

Scarification: concentrated sulphuric acid, 10-20 min (4)

P. notatum

Pre-dry: 70°C, 4h (4)

Pre-soak: 24h (1,4)

Removal of seed covering structures; palea (1,4)

Scarification: sulphuric acid, 50%, 5 min (13); concentrated hydrochloric acid, 5 min (4); disc, 1h, 1150 rpm (9)

Potassium nitrate: pre-applied, 1%, to scarified seeds (1)

Ammonium thiocyanate: pre-applied, 1%, to scarified seeds (1)

P. urvillei

Pre-dry: 70°C, 17h (4)

Scarification: concentrated hydrochloric acid, 5 min (4); concentrated sulphuric acid, 5 min (4); sandpaper (4)

IV. Partly-successful dormancy-breaking treatments

P. dilatatum

Alternating temperatures: 20°/35°C (16h/8h) in light (5,14); 35°/15°C (16h/8h) in light (5); 15°/35°C; 10°/35°C (16h/8h) in light (14)

Pre-chill: 5°C, 4d (8)

Removal of seed covering structures: lemma and palea (11); puncture (11)

Scarification: hydrochloric acid, 37%, 5 min (11); concentrated sulphuric acid, 5 min (4)

Pre-soak: 16h (8)

Sodium hydroxide: pre-applied, 35%, 5-10 min (4)

Potassium nitrate: co-applied, 0.2% (14)

P. notatum

Alternating temperatures: 30°/20°C (16h/8h) (10); 20°/35°C (16h/8h) (12)

Pre-chill: 5°C, 5d (10); 5°C, 5d, with potassium nitrate, co-applied, 0.2% (10)

Potassium nitrate: co-applied, 0.2% (2,10,12,13)

Potassium chlorite: co-applied, 0.2 M (13)

Sodium hydroxide: pre-applied, 35%, 10 min (4)

Removal of seed covering structures: lemma (1); glumes, then potassium nitrate, co-applied, 0.2% (12)

Pre-dry: 50°C, 60°C, 2-4d (6); 40°C, 7d (12); 50°C, 60°C, 2-4d, then scarification, concentrated sulphuric acid (6)

Scarification: disc, 30 min, 800 rpm (9); concentrated sulphuric acid, 5-15 min (4); concentrated sulphuric acid, 6 min (9); concentrated sulphuric acid, 20 min (3,12); concentrated sulphuric acid, 20-40 min (1); concentrated sulphuric acid, 1-5 min (10,13); concentrated sulphuric acid, 1-5 min, then potassium nitrate, co-applied, 0.2%, at 30°/20°C (16h/8h) (10); concentrated sulphuric acid, 1-5 min, then pre-chill, 5°C, 5d (10); concentrated sulphuric acid, 32 min, then pre-soak 24h (1); concentrated sulphuric acid, 32 min, then pre-soak 24h, then pre-dry 24h (1); sulphuric acid, 78%, 40-60 min (6); sulphuric acid, 60%, 23 min, then pre-soak, 15 min (15)

V. Successful dormancy-breaking treatments

P. dilatatum

Light, Potassium nitrate (AOSA, ISTA)

Potassium nitrate: co-applied, 0.2%, at 35°/15°C (16h/8h) in light (5); co-applied, 0.2%, at 20°/35°C (16h/8h) in light (8)

P. notatum

Light, Potassium nitrate, remove glumes, scratch caryopses (AOSA)

Potassium nitrate (ISTA)

Removal of seed covering structures: lemma and palea (1,2); lemma and palea, then potassium nitrate, co-applied, 0.2%, at 35°/15°C (16h/8h) in light (5); lemma and palea, then potassium nitrate, co-applied, 0.2%, at 20°/35°C (16h/8h) in light (2)

Scarification: concentrated sulphuric acid, 3 min, then potassium nitrate, co-applied, 0.2%, pre-chill, 5°C, 5d, germinate at 30°/20°C (16h/8h) (10); concentrated sulphuric acid, 5 min, then potassium nitrate, co-applied, 0.2%, at 35°-40°C (13)

P. plicatulum

Potassium nitrate, Light (ISTA)

P. scrobiculatum

Potassium nitrate (ISTA)

P. urvillei

Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

P. wettsteinii

Potassium nitrate (ISTA)

VI. Comment

The ISTA/AOSA procedures for germination tests and recommendations for breaking dormancy in P. notatum are not satisfactory (12). Alternating temperatures are an essential component of satisfactory germination test regimes, but in contrast to the ISTA/AOSA regimes

the higher temperature should be applied for the greater period (16h) in each daily cycle (5,10). It is suggested that the following regime - scarification in concentrated sulphuric acid for 3 minutes, pre-chill at 5°C for 5 days, with potassium nitrate, co-applied at 0.2%, and test for germination at 30°/20°C (16h/8h) (10) - be applied for dormant seeds. However, the scarification regime is possibly too harsh for less dormant or non-dormant seeds and, consequently, should be applied discriminatingly, if at all.

The ISTA procedures for seeds of P. scrobiculatum can be quite satisfactory (A). However, it is suggested that, where difficulties are encountered, the alternating temperature regime 35°/20°C (16h/8h) be tried with co-applied potassium nitrate, 0.2%.

Seeds of P. guenoarum germinate well in an alternating temperature regime of 18°/35°C (20h/4h) in diffuse light within a 30 day test (16). Co-applied potassium nitrate might result in further promotion of germination.

VII. References

1. Akamine, E.K. (1944). Germination of Hawaiian range grass seeds. Hawaii Agricultural Experiment Station Technical Bulletin No. 2.

2. Andersen, A.M. (1953). The effect of the glumes of Paspalum notatum Flugge on germination. Proceedings of the Association of Official Seed Analysts, 43, 93-100.

3. Andrade, R.V. De and Vaughan, E.C.E. (1980). [Evaluation of hard seed of Bahia grass cv. Pensacola and millet.] Revista Brasileira de Sementes, 2, 57-66.

4. Burton, G.W. (1939). Scarification studies on southern grass seeds. Journal of the American Society of Agronomy, 31, 179-187.

5. Cullinan, B. (1941). Germinating seeds of Southern grasses. Proceedings of the Association of Official Seed Analysts, 33, 74-76.

6. Hodgson, H.J. (1949). Effect of heat and acid scarification on germination of seed of Bahia grass, Paspalum notatum Flugge. Agronomy Journal, 41, 531-533.

7. Hoffman, W.D. (1948). Observations in testing Bahia grass (Paspalum notatum, Flügge) for germination in the Alabama laboratory. Newsletter of the Association of Official Seed Analysts, 22, 28.

8. Johnston, M.E.H. and Miller, J.G. (1964). Investigation into techniques for the germination of Paspalum dilatatum. Proceedings of the International Seed Testing Association, 29, 145-148.

9. Mathews, A.C. (1947). Observations on methods of increasing the germination of Panicum anceps Michx. and Paspalum notatum Flügge. Journal of the American Society of Agronomy, 39, 439-442.

10. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

11. Ray, C.B. and Stewart, R.T. (1937). Germination of seeds from certain species of Paspalum. Journal of the American Society of Agronomy, 29, 548-554.

12. Toledo, F.F. De, Marcos Filho, J., Silvarolla, M.B. and Batista Neto, J.F. (1981). [Maturation and dormancy of Paspalum notatum seeds.] Revista de Agricultura, Brazil, 56, 83-91.

13. Williams, R.C. and Webb, B.C. (1958). Seed moisture relationships and germination behaviour of acid scarified Bahia grass seed. Agronomy Journal, 50, 235-237.

14. Drake, V.C. (1951). Some factors influencing the germination of Dallis grass seed. Proceedings of the Association of Official Seed Analysts, 41, 66-71.

15. Gamboa, G.J.M. and Guerrero, S.D.N. (1969). [Scarification of Bahia grass (Paspalum notatum) to hasten the germination.] Agricultura Técnica en México, 2, 445-449. (From Herbage Abstracts, 1971, 41, 1888.)

16. Goedert, C. (1984). Seed dormancy of tropical forage grasses and implications for the conservation of genetic resources. Ph.D. Thesis, University of Reading.

PENNISETUM

P. ciliare L. (Link)	buffel grass
P. glaucum R. Br. [P. americanum Auth.; P. typhoideum Rich.;	bullrush millet, pearl millet, Indian millet,
P. typhoides (Burm.f.) Stapf & C.E. Hubb.; P. specatum (L.) Koern.;	African millet, spiked millet,
Panicum glaucum L.]	cat-tail millet, bajra
P. macrourum Trin.	African feather grass
P. pedicellatum Trin.	deenanath grass
P. polystachyon (L.) Schult.	
P. purpureum Schumacher	elephant grass, napier grass
P. setosum	

I. Evidence of dormancy

It is reported that seeds of P. macrourum are not dormant when harvested (15), but freshly harvested seeds of P. ciliare (3), P. glaucum (5,7), P. pedicellatum (16,17), P. polystachyon (14) and P. setosum (2) can exhibit considerable dormancy.

II. Germination regimes for non-dormant seeds

P. glaucum

TP; BP: 20°/30°C (16h/8h): 7d (AOSA,ISTA)

Constant temperatures: 30°-32°C (13); 18°-38°C (9)

Alternating temperatures: 30°/15°C, 28°/17°C, 26°/37°C, 33°/25°C (12h/12h) (9); 20°/25°C, 25°/30°C (10); 20°/30°C (16h/8h) (13)

P. macrourum

Constant temperatures: 30°C (15)

P. purpureum

BP: 20°/30°C (16h/8h): 10d (AOSA)

P. setosum

Constant temperatures: 20°-30°C (2)

III. Unsuccessful dormancy-breaking treatments

P. ciliare

Freezing and thawing: (2)

P. glaucum

Alternating temperatures: 20°/38°C (7)

Pre-chill: 5°C, 7d (5)

Pre-wash: 6,24h (7)

Pre-dry: 70°C, 3h (7)

Potassium nitrate: co-applied, 0.2% (5); pre-applied, 16h, 0.8% (7)

GA_3: pre-applied, 15,30 min, 200 ppm (7); pre-applied, 12h, 25-500 ppm (12)

Hydrogen peroxide: co-applied, 1% (7)

Scarification: sulphuric acid, 70%, 7 min (7)

P. pedicellatum

Nitric acid: pre-applied, 24h, 0.25, 1% (16)

GA_3: pre-applied, 24h, 500, 800 ppm (16); co-applied, 100 ppm (17)

Scarification: sulphuric acid, 5%, 5 min (16)

Removal of seed covering structures: dehull (17)

Morphactin: co-applied, 1-100 ppm (19)

P. polystachyon

Constant temperatures: 25°C, dark (18)

Light: dark blue, far red, to dehulled seeds (14)

P. setosum

Glycine: pre-applied, 24h (2)

Nicotinic acid: pre-applied, 24h (2)

Sodium thiocyanate: pre-applied, 24h (2)

1-Asparagine: pre-applied, 24h (2)

1-Leucine: pre-applied, 24h (2)

Ethyl alcohol: pre-applied, 24h (2)

Indoleacetic acid: pre-applied, 24h (2)

Thiourea: pre-applied, 24h (2)

Ammonium thiocyanate: co-applied, 0.5, 1, 2% (2)

Scarification: concentrated sulphuric acid, 2-5 min (2)

IV. Partly-successful dormancy-breaking treatments

P. ciliare

Alternating temperatures: 10°/30°C, 15°/30°C, 20°/30°C, 20°/35°C (16h/8h) in light (3)

Pre-chill: 5°-10°C, 7d (3)

Pre-dry: 40°C, 60°C, 28d (3); 66°C, 28d (6); 80°C, 7d (6); 40°C, 28d, then pre-chill, 5°C, 7d (3); 40°C, 21d, germinate at 20°/35°C (16h/8h) in light (3)

Scarification: concentrated sulphuric acid, 5-7 min (2)

Removal of seed covering structures: bristles (2); lemma and palea (3)

Potassium nitrate: co-applied, 0.2% (3)

P. glaucum

Alternating temperatures: 5°/35°C (16h/8h) (1,5); 10°/35°C, 15°/25°C, 15°/35°C, 20°/30°C, 20°/35°C (16h/8h) (5)

Thiourea: co-applied, 0.1% (5)

Potassium nitrate: pre-applied 3, 16h, 0.2, 0.4% (7); co-applied, 0.2% (7); co-applied, 0.2%, plus thiourea, 0.1%, co-applied (5)

GA_3: pre-applied, 1-3h, 100-1000 ppm (7)

Kinetin: pre-applied, 1h, 100 ppm (7)

Scarification: sulphuric acid, 70%, 3 min (7); sulphuric acid, 50%, 3,6 min (7); sulphuric acid, 50%, 5 min, then 2-chloroethanol, pre-applied, 1h, 1% (7)

2-Chloroethanol: pre-applied, 30,60 min, 1% (7); pre-applied, 30,60 min, 1%, plus sodium hypochlorite, pre-applied, 1h, 0.5% (7); 1%, plus 0.5% sodium hypochlorite, pre-applied, 1h, germinate at 38°C (7)

Sodium hypochlorite: pre-applied, 20 min, 5.25% (7); pre-applied, 20 min, 5.25%, then 2-chloroethanol, pre-applied, 1h, 1% (7)

Hydrogen peroxide: pre-applied, 3, 19h, 1, 5, 10% (7)

Removal of seed covering structures: glumes (7)

Pre-dry: 40°-80°C, 1d (11)

P. pedicellatum

Pre-dry: 50°-54°C, 4d (16)

Removal of seed covering structures: prick (16)

GA_3: co-applied, 1000 ppm (17); co-applied, 1-20 ppm (19)

Indoleacetic acid: co-applied, 1-50 ppm (19)

P. polystachyon

Light: 12h/d (18); daylight, red, at 25°C, to dehulled seeds (14)

P. setosum

Alternating temperatures: 22°-25°/33°C (2)

Potassium nitrate: pre-applied, 24h, 0.5, 1% (2)

Ammonium thiocyanate: pre-applied, 24h, 0.5, 1% (2)

Ascorbic acid: pre-applied, 24h, 0.5% (2)

Glucose: pre-applied, 24h, 2.5, 5% (2)

Pre-soak: 24h (2)

V. Successful dormancy-breaking treatments

P. ciliare

Removal of seed covering structures: excise caryopsis (2); excise caryopsis, then potassium nitrate, co-applied, 0.2% (3,4); excise caryopsis, then pre-chill, 5°C, 7d (3,4); excise caryopsis, scratch embryo, plus potassium nitrate, co-applied, at 30°C or 20°/35°C (16h/8h) in light (3,4)

P. setosum

Ammonium thiocyanate: pre-applied, 24h, 1%, germinate at 22°-25°/35°C (2)

VI. Comment

The lemma and palea are relatively easy to remove from seeds of Pennisetum spp., allowing the naked caryopses to be scratched and then tested for germination. This is recommended for dormant accessions. For non-dormant seeds of P. glaucum the AOSA/ISTA alternating temperature regime, 20°/30°C (16h/8h), is satisfactory (A) and an improvement over testing at constant temperatures provided sufficient time in the germination test is allowed (9). Ten days is generally sufficient (A). For dormant seeds the pre-application of 1% 2-chloroethanol plus 0.5% sodium hypochlorite for 1 hour appears to be both safe and comparatively successful (7), but alternating temperature regimes such as 5°/35°C, 10°/30°C, 10°/35°C, 15°/35°C, or 20°/35°C (16h/8h) are likely to be more suitable than the constant temperature of 38°C used by this reference. It is suggested here that these regimes combined with lemma and palea removal be used for testing dormant accessions of Pennisetum spp.

VII. References

1. Adams, C.E. (1956). Starr millet germination problems. Seed Technology News, 55, 17.

2. Akamine, E.K. (1944). Germination of Hawaiian range grass seeds. Hawaii Agricultural Experiment Station Technical Bulletin, No. 2.

3. Andersen, A.M. (1953). Germination of buffel grass seed. Proceedings of the Association of Official Seed Analysts, 43, 72-82.

4. Andersen, A.M. (1953). Germination of buffel grass, Pennisetum ciliare (L.) Link, seed. Newsletter of the Association of Official Seed Analysts, 27, 36-37.

5. Andersen, A.M. (1958). A preliminary study of dormancy brown top and cattail millets.

Proceedings of the Association of Official Seed Analysts, 48, 85-92.

6. Brown, E.O. (1952). Note on germination of buffel grass. Newsletter of the Association of Official Seed Analysts, 26, 17.

7. Burton, G.W. (1969). Breaking dormancy in seeds of pearl millet Pennisetum typhoides. Crop Science, 9, 659-664.

8. Garcia-Huidobra, J., Monteith, J.L. and Squire, G.R. (1982). Time, temperature and germination of pearl millet (Pennisetum typhoides S.& H.) I. Constant temperature. Journal of Experimental Botany, 33, 288-296.

9. Garcia-Huidobra, J., Monteith, J.L. and Squire, G.R. (1982). Time, temperature and germination of pearl millet (Pennisetum typhoides S.& H.) II. Alternating temperature. Journal of Experimental Botany, 33, 297-302.

10. Hughes, R.M. (1979). Effects of temperature and moisture stress on germination and seedling growth of four tropical species. Journal of the Australian Institute of Agricultural Science, 45, 125.

11. Raza, S.H. (1977). Effect of temperature pre-treatment on germination of seeds of Pennisetum typhoides var. HB1. Indian Journal of Agricultural Research, 11, 241-242.

12. Sandhu, A.S. and Husain, A. (1961). Effect of seed treatment with gibberellic acid on germination and growth of bajra (Pennisetum typhoides). Indian Journal of Agronomy, 5, 269-272.

13. Singh, A., Datta, D.D. and Singh, D. (1971). Laboratory germination findings on bajra seed (Pennisetum typhoides). Proceedings of the International Seed Testing Association, 36, 105-107.

14. Fernandez, D.B. (1980). Some aspects on the biology of Pennisetum polystachyon (L.) Schult. Philippine Journal of Weed Science, 7, 1-10.

15. Harradine, A.R. (1980). The biology of African feather grass (Pennisetum macrourum Trin.) in Tasmania. 1. Seedling establishment. Weed Research, 20, 165-169.

16. Maiti, S., Purkait, A. and Chatterjee, B.N. (1981). Seed dormancy in deenanath grass (Pennisetum pedicellatum). Forage Research, 7, 97-99.

17. Mott, J.J. (1980). Germination and establishment of the weeds Sida acuta and Pennisetum pedicellatum in the Northern Territory. Australian Journal of Experimental Agriculture and Animal Husbandry, 20, 463-469.

18. Pemadasa, M.A. and Amarasinghe, L. (1982). The ecology of a montane grassland in Sri Lanka. III. Germination of three major grasses. Journal of Ecology, 70, 483-490.

19. Varshney, K.A. and Baijal, B.D. (1978). Synergistic and antagonistic behaviour of some growth regulators on germination of seeds of Pennisetum pedicellatum. Comparative Physiology and Ecology, 3, 178-180.

PHALARIS

P. arundinacea L.	reed canary-grass, ribbon grass
P. canariensis L.	canary-grass
P. tuberosa L. [P. stenoptera Hack.]	harding grass

I. Evidence of dormancy

Seeds of P. arundinacea can show pronounced dormancy (1,4-6,8,10,11) which results in considerable problems for commercial seed testing. For example, 40% of commercial samples submitted for testing in one laboratory gave less than 60% germination (13). Seeds of P. tuberosa are thought to be comparatively less dormant (8).

II. Germination regimes for non-dormant seeds

P. arundinacea

TP: 20°/30°C (16h/8h): 21d (AOSA,ISTA)

P. canariensis

BP; TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

BP; TP: 20°/30°C (16h/8h): 7d (AOSA)

P. tuberosa

TP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

TP: 10°/30°C (16h/8h): 28d (AOSA)

TP: 15°/25°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

P. arundinacea

Constant temperatures: 10°-35°C (2); 10°-35°C, plus potassium nitrate, co-applied, 0.2% (2)

Pre-chill: 3°C, 14d (11)

Potassium nitrate: co-applied, 0.2% (8)

GA_3: co-applied, 100 ppm (8,9)

Kinetin: pre-applied (4)

2,4-Dinitrophenol: pre-applied, 24h, 10^{-5} -10^{-4}M, then GA_3, co-applied, 100 ppm (5)

Methylene blue: pre-applied, 24h, 10^{-2} M (5)

Thiourea: co-applied, 0.2% (8)

Ethyl alcohol: pre-applied, 15s, 70% (10)

Acetone: pre-applied, 15s, 3 min (10)

Scarification: sulphuric acid, 4 N, 1 min (10)

Ether: pre-applied, 15s (10)

Pre-soak: 50°C, 5,20 min (10)

Testing in aerated water: (11)

Oxygen: low partial pressure (6)

Light: (8)

Ethrel: 1-2 g/1 (6)

P. tuberosa

Light: (8)

Potassium nitrate: co-applied, 0.2% (8,14)

GA_3: co-applied, 100 ppm (8)

Thiourea: co-applied, 0.2% (8)

Ethyl alcohol: pre-applied, 15s, 70% (10)

Acetone: pre-applied, 15s, 3 min (10)

Scarification: sulphuric acid, 4 N, 1 min (10)

Ether: pre-applied, 15s (10)

Pre-soak: 50°C, 5,20 min (10)

IV. Partly-successful dormancy-breaking treatments

P. arundinacea

Alternating temperatures: 15°/25°C (16h/8h) (2); 15°/25°C (16h/8h) in light (1); 12°/27°C (4h/20h) (4,6); 20°/30°C (16h/8h) (7,8); 15°/30°C, 30°/20°C (16h/8h) (8); 12°/27°/12°/27°/12°/27°C (2h/2h/2h/2h/2h/14h) for 3d, then 27°C (5); 27°/12°/27°/12°/27°/12°/27°/12°/27°/12°/27°/12°C (24h/1h/1h/1h/1h/1h/1h/1h/1h/1h/1h/1h) then 27°C (6); 27°/12°/27°/12°/27°/12°C (24h/2h/2h/2h/2h/2h) then 27°C (6); 12°/27°/12°/27°/12°/27°C (2h/2h/2h/2h/2h/14h) for 1-5d, then 27°C (6)

Pre-chill: 2°-5°C, 28d (1); 4°C, 7-14d (4); 5°C, 7-28d in light (6); 10°C, 2-5d (7); 5°C, 6d (8)

Potassium nitrate: co-applied, 0.2% (7); pre-applied 24h, 10^{-4} -10^{-1} M (5); pre-applied, 24h, 10^{-4} -10^{-1} M, then GA_3, co-applied, 100 ppm (5)

GA_3: co-applied, 100, 1000 ppm (5); pre-applied, 24h, 2000 ppm (4)

Potassium cyanide: (4); pre-applied, 24h, 10^{-4} -10^{-2} M (5); pre-applied, 24h, 10^{-4} -10^{-2} M, then GA_3, co-applied, 100 ppm (5)

Sodium azide: pre-applied, 24h, 10^{-4} -10^{-2} M (5); pre-applied, 24h, 10^{-4} -10^{-2} M, then GA_3, co-applied, 100 ppm (5)

Sodium sulphide: pre-applied, 24h, 10^{-4} -10^{-2} M (5); pre-applied, 24h, 10^{-4} -10^{-2} M, then GA_3, co-applied, 100 ppm (5)

2,4-Dinitrophenol: pre-applied, 24h, 10^{-5} -10^{-3} M (5)

Hydrogen peroxide: (4); pre-applied, 24h, 10^{-2} -1 M (5); pre-applied, 24h, 10^{-2} -1 M, then GA_3,

co-applied, 100 ppm (5)

Methylene blue: pre-applied, 24h, 10^{-4}, 10^{-3} M (5); pre-applied, 24h, 10^{-4}, 10^{-3} M, then GA_3, co-applied, 100 ppm (5)

Ethrel: pre-applied, 24h, 250-500 mg l^{-1} (4,6)

Potassium cyanide: pre-applied, 24h, 10^{-2} M, then red light, $1.4x10^{-6}$ W cm^{-2} at 660 nm, 1h (5)

Pre-soak: 4d (6); aerated, 4d (6); nitrogen saturated, 4d (6); oxygen saturated, 4d (6)

Oxygen: 10-100% (6)

Scarification: sand paper (10)

Removal of seed covering structures: puncture (10); lemma and palea (4,10); lemma and palea, then GA_3, pre-applied, 24h, 500-1000 ppm (4)

Light: $5x10^{-4}$ W cm^{-2}, 400-700 nm, continuous, (4,5); 70-190 lux, continuous (11); $1.4x10^{-6}$ W cm^{-2}, 660 nm, 1-2d (5,6); $1.4x10^{-6}$ W cm^{-2}, 660 nm, 15-30 min after 24h dark imbibition (5,6); 3500 lux, 8h/d, during high temperature phase of alternating temperature regime (1); 100 fc, 8h/d (2)

P. tuberosa

Constant temperatures: 10°C, 15°C (12); 20°C, 25°C (8)

Alternating temperatures: 15°/20°C, 20°/25°C, 20°/30°C (16h/8h) (12)

Light: (8)

V. Successful dormancy-breaking treatments

P. arundinacea

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Pre-chill: 5°C, 10°C, 7d (2)

Removal of seed covering structures: scratch, pierce caryopses (4)

Pre-wash: 15°C, 4d (11)

Pre-dry: 35°C, 7d (2)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C, 15°/30°C, 10°/30°C, 20°/35°C, 10°/35°C (16h/8h) in light (2)

P. canariensis

Pre-chill, Potassium nitrate (ISTA)

P. tuberosa

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-soak, Potassium nitrate (AOSA)

Constant temperatures: 15°C (8)

Alternating temperatures: 15°/30°C (16h/8h) (8)

Pre-chill: 5°C, 7d (3,8)

VI. Comment

The choice of appropriate alternating temperature environments appears to be the most suitable approach for germinating dormant seeds of P. arundinacea in gene banks. In terms of relatively simple alternating temperatures environments 15°/30°C (16h/8h) is apparently more effective in promoting germination than 20°/30°C (16h/8h or 8h/16h). However, the most promising regime would appear to be 12°/27°/12°/27°/12°/27°C (2h/2h/2h/2h/2h/14h) for 5 days followed by a constant 27°C (6). It is suggested that this be carried out in the dark, but with an initial 24-48 hour exposure to red light ($1.4x10^{-6}$ W cm^{-2} at 660 nm) since this treatment appears to maximise photo-promotion and minimise photo-inhibition (6).

Apparently low constant temperatures are more effective in promoting the germination of dormant seeds of P. tuberosa than alternating temperatures (12). Accordingly it is suggested that the seeds be tested at a constant temperature of 10°C for an extended period (more than 28 days).

VII. References

1. Berg, T. (1982). Seed dormancy in local populations of Phalaris arundinacea L. Acta Agricultura Scandinavica, 32, 405-410.

2. Colbry, V.L. (1953). Factors affecting the germination of reed canary grass. Proceedings of the Association of Official Seed Analysts, 55, 50-53.

3. Easton, G.R. and Mullett, J.H. (1971). The duration of germination tests on Phalaris tuberosa. Proceedings of the International Seed Testing Association, 36, 75-80.

4. Junttila, O., Landgraff, A. and Nilsen, A.J. (1978). Germination of Phalaris seeds. Acta Horticulturae, 83, 163-166.

5. Junttila, O. and Nilsen, A.J. (1980). Stimulation of Phalaris seed germination by respiratory inhibitors and oxidising agents. Zeitschrift fur Pflanzen Physiologie, 97, 429-435.

6. Landgraff, A. and Junttila, O. (1979). Germination and dormancy of reed canary-grass seeds (Phalaris arundinacea). Physiologia Plantarum, 45, 96-102.

7. Myers, A. (1963). Germination of Phalaris seeds. Agricultural Gazette of New South Wales, 74, 635-637.

8. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

9. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

10. Vose, P.B. (1956). Dormancy of seeds of Phalaris arundinacea and Phalaris tuberosa. Nature, 1788, 1006-1007.

11. Vose, P.B. (1962). Delayed germination in reed canary-grass Phalaris arundinacea L.

Annals of Botany, 26, 197-206.

12. Young, J.A., Evans, R.A. and Kay, B.L. (1973). Temperature requirements for seed germination in an annual-type rangeland community. Agronomy Journal, 65, 656-659.

13. Griffeth, W.L. and Harrison, C.M. (1954). Maturity and curing temperatures and their influence on germination of reed canary-grass seed. Agronomy Journal, 46, 163-166.

14. Whalley, R.D.B., McKell, C.M. and Green L.R. (1966). Seed physical characteristics and germination of hardingrass (Phalaris tuberosa var. stenoptera (Hack.) Hitch.). Journal of Range Management, 19, 129-132.

PHLEUM

P. bertolonii DC. [P. nodosum L.] smaller cat's-tail
P. pratense L. timothy, cat's-tail

I. Evidence of dormancy

Seeds of P. pratense may exhibit dormancy (2,3,7,9,11). After-ripening for 25 days (2) to between 4 to 6 weeks (11) is required for dormancy to be lost.

II. Germination regimes for non-dormant seeds

P. bertolonii

TP: 20°/30°C; 15°/25°C (16h/8h): 10d (ISTA)

P. pratense

TP: 15°/25°C; 20°/30°C (16h/8h): 10d (ISTA,AOSA)

III. Unsuccessful dormancy-breaking treatments

P. pratense

Potassium cyanide: co-applied, 10^{-4} M (5)

Ammonium chloride: co-applied, 10^{-3} -10^{-2} M (5)

GA_3: co-applied, 100 ppm (9)

Potassium nitrate: co-applied, 10^{-1}, $3x10^{-3}$ M (11)

Potassium nitrite: co-applied, $2x10^{-2}$, $4x10^{-2}$ M (11)

Potassium chloride: co-applied, 10^{-2} M (11)

Manganese chloride: co-applied, 10^{-2} M (11)

Urea: co-applied, 10^{-2} M (11)

Pre-dry: 40°C, 50°C, 5,7d (11)

Light: dark (3)

IV. Partly-successful dormancy-breaking treatments

P. pratense

Constant temperatures: 15°C in light (3); 20°C (5,11); 12°C, 20°C, 30°C (8)

Alternating temperatures: (8); 20°/25°C (16h/8h) (7); 10°/20°C, 15°/25°C, 20°/30°C, 20°/35°C (16.5h/7.5h), dark (3); 20°/30°C, 15°/30°C, 10°/30°C, 15°/25°C (16h/8h) in light or dark (11)

Pre-chill: 10°C, 3-7d (11); 5°C, 6,9d (11)

Potassium nitrate: co-applied, 10^{-3} -10^{-2} M (5); co-applied, 0.2% (9); co-applied, 10^{-2} M (11)

Sodium nitrite: co-applied, 10^{-3} M (5)

Hydroxylamine hydrochloride: co-applied, $3.2x10^{-4}$ M (5)

Thiourea: co-applied, 0.2% (9)

GA_3: pre-applied, 20h, 200 ppm (7)

Pre-soak: 17h, 22°C, then pre-dry, 15°C, 24h (1)

Light: (3,9); 5-60 min (8); diffuse, fluorescent (11)

Silver nitrate: co-applied, 10^{-2} M (11)

Cadmium nitrate: co-applied, 10^{-2} M (11)

Nickel nitrate: co-applied, 10^{-2} M (11)

Cobalt nitrate: co-applied, 10^{-2} M (11)

Zinc nitrate: co-applied, 10^{-2} M (11)

Mercury nitrate: co-applied, 10^{-2} M (11)

V. Successful dormancy-breaking treatments

P. bertolonii

Pre-chill, Potassium nitrate (ISTA)

P. pratense

Light, Pre-chill, Potassium nitrate (AOSA)

Pre-chill, Potassium nitrate (ISTA)

Constant temperatures: 15°C in light (9)

Alternating temperatures: 10°/25°C (16h/8h) (7); 15°/30°C (16h/8h) in light (9); 10°/20°C, 15°/25°C, 20°/30°C, 20°/35°C (16.5h/7.5h) in light (3)

Pre-chill: 3°-5°C (9)

GA_3: co-applied, 200 ppm, at 10°/25°C (16h/8h) (7)

Potassium nitrate: co-applied, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

Potassium nitrite: co-applied, $5x10^{-4}$, $5x10^{-3}$ M, at 20°/30°C (16h/8h) in light (11)

Ammonium nitrate: co-applied, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

Sodium nitrate: co-applied, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

Calcium nitrate: co-applied, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

Magnesium nitrate: co-applied, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

Barium nitrate: co-applied, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

Manganese nitrate: co-applied, $2x10^{-3}$, 10^{-2} M, at 20°/30°C (16h/8h) in light (11)

VI. Comment

Non-dormant or slightly dormant seeds of P. pratense germinate over wide ranges of constant temperatures, viz. 15° to 30°C (3) and 10° to 30°C (12), and constant temperatures between 15° and 20°C have been reported to be as effective in promoting germination as alternating temperatures (4). Dormant seeds of P. pratense, however, require alternating temperatures and light for the promotion of germination (3,8,9,11): the regimes 10°/25°C, 15°/30°C or 20°/30°C (16h/8h) are suggested for use in gene banks. Additionally it is suggested that the seeds be tested on top of filter papers rather than between papers - since the former results in greater germination (11) - and that 0.2% potassium nitrate be co-applied - since potassium nitrate can have a major promotory influence on germination (5,9,11). It is suggested that seeds of P. bertolonii be tested in environments similar to those above or as prescribed by ISTA.

VII. References

1. Chippindale, H.G. (1933). The effect of soaking in water on the "seeds" of some gramineae. Annals of Biology, 21, 225-232.

2. Fisher, M.C. (1919). The dormant period of timothy seed after harvesting. Proceedings of the Indiana Academy of Science, 276-279.

3. Gordon, E.M. (1951). Light- and temperature-sensitiveness in germinating seed of timothy (Phleum pratense L.). Scientific Agriculture, 31, 71-84.

4. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

5. Hendricks, S.B. and Taylorson, R.B. (1974). Promotion of seed germination by nitrate, nitrite, hydroxylamine and ammonium salt. Plant Physiology, 54, 304-309.

6. Justice, O.L. and Reece, M.H. (1954). A review of literature and investigation on the effects of hydrogen-ion concentration on the germination of seeds. Proceedings of the Association of Official Seed Analysts, 44, 144-149.

7. Kahre, L., Kolk, H. and Wiberg, H. (1962). Note on dormancy-breaking in seeds. (Cereals and Timothy). Proceedings of the International Seed Testing Association, 27, 679-683.

8. Maier, W. (1933). Das Keimungsphysiologische Verhalten von Phleum pratense L., den Timotheegras. Jahrb. Wissen Bot., 78, 1-42. (Cited by Toole, 1939).

9. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed

Testing Association, 27, 710-729.

10. Schonfeld, M.A. and Chancellor, R.J. (1983). Factors influencing seed movement and dormancy in grass seed. Grass and Forage Science, 38, 243-250.

11. Toole, E.H. (1939). Observations on the germination of freshly harvested timothy seed. Proceedings of the International Seed Testing Association, 11, 119-139.

12. Yumoto, S., Shimamota, Y. and Tsuda, C. (1980). [Studies on ecotypic variations among natural populations of timothy (Phleum pratense L.). I. Variation in germination characteristics.] Journal of the Japanese Society of Grassland Science, 26, 243-250.

POA

P. alpina L.	alpine meadow-grass
P. ampla Merr.	big blue-grass
P. annua L.	annual blue-grass, annual meadow-grass
P. arachnifera Torr.	Texas blue-grass
P. artica R. Br.	arctic blue-grass
P. bulbosa L.	bulbous blue-grass, bulbous meadow-grass
P. canbyi (Scribn.) Howell	Canby blue-grass
P. compressa L.	Canada blue-grass, flattened meadow-grass, wire-grass
P. glaucantha Gaudin	glaucantha blue-grass
P. macrantha	Vasey seashore blue-grass
P. nemoralis L.	wood blue-grass, wood meadow-grass
P. nevadensis Scribn.	Nevada blue-grass
P. palustris L. [P. serotina Ehrh.; P. triflora Gilib.]	swamp meadow-grass, fowl meadow-grass
P. pratensis L.	Kentucky blue-grass, June-grass, smooth meadow-grass
P. sandbergii	Vasey sandberg blue-grass
P. trivialis L.	rough blue-grass, rough/rough-stalked meadow-grass

I. Evidence of dormancy

Freshly harvested seeds of P. pratensis can show pronounced dormancy (15,21,33,38,39,42) - particularly if seeds are harvested whilst immature, that is at a high moisture content (15,21,38). Dormancy is also common in P. annua (29,35,40), but tends to be easier to overcome than is the case for accessions of P. pratensis.

II. Germination regimes for non-dormant seeds

P. annua

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 20°/30°C (16h/8h): 21d (AOSA)

P. arachnifera

TP: 20°/30°C (16h/8h): 28d (AOSA)

P. bulbosa

TP: 15°/25°C (16h/8h): 35d (ISTA)

TP; S: 10°C: 35d (AOSA)

P. compressa

TP: 15°/25°C; 10°/30°C (16h/8h): 28d (ISTA)

TP: 15°/25°C; 15°/30°C (16h/8h): 28d (AOSA)

P. glaucantha

TP: 15°/25°C; 15°/30°C (16h/8h): 28d (AOSA)

P. nemoralis

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 28d (ISTA)

TP: 20°/30°C (16h/8h): 28d (AOSA)

P. nevadensis

TP: 20°/30°C (16h/8h): 21d (AOSA)

P. palustris

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 28d (ISTA)

P. pratensis

TP: 15°/25°C; 20°/30°C; 10°/30°C (16h/8h): 28d (ISTA)

TP: 15°/25°C (16h/8h): 28d (AOSA)

Alternating temperatures: 20°/30°C (18)

P. trivialis

TP: 15°/25°C; 20°/30°C (16h/8h): 21d (ISTA)

TP: 20°/30°C (16h/8h): 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

P. alpina

Alternating temperatures: 20°/30°C (18h/6h) (42)

P. annua

Constant temperatures: 30°C (40)

Alternating temperatures: 40°/30°C (12h/12h) (22); 25°C, 4-24h, then 40°/30°C (12h/12h) (22)

Pre-soak: 12h (49)

Ethanol: pre-applied, 7d, 10^{-5}-10^{-4} 1 in 125 ml flask, 35°C, red light, 5 min (44)

Pre-dry: 40°C, 2-5d (35)

GA_3: co-applied (41)

P. arachnifera

Alternating temperatures: 20°/30°C (18h/6h) (42)

P. compressa

Constant temperatures: 16°C, 20°C, 30°C, 35°C (25)

Light: (36,45)

Lead nitrate: co-applied, 0.01, 0.1% (36)

Lead nitrite: co-applied, 0.1% (36)

Sodium nitrite: co-applied, 0.1% (36)

Potassium nitrite: co-applied, 0.1% (36)

P. macrantha

Constant temperatures: 15°C (46)

Alternating temperatures: 20°/30°C, 15°/25°C, 20°/35°C (18h/6h) (46)

P. pratensis

Constant temperatures: (1,26,31,33); 15°C, 20°C (17)

Alternating temperatures: 20°/30°C, 5°/30°C (18h/6h) (42); 20°/35°C (18h/6h) (38); 20°/35°C (18h/6h) in light (39,56)

Pre-chill: -5°C, 7d (42)

Warm stratification: 43°C, 7d, plus potassium nitrate, co-applied, 0.1%, germinate at 22°-26°C (42)

Potassium nitrate: co-applied, 0.2% (45)

Thiourea: co-applied, 0.2% (33)

Acetone: pre-applied, 1h (39)

Ethephon: pre-applied, 1h, 500 ppm dissolved in acetone (39)

Kinetin: pre-applied, 1h, 10^{-4} M dissolved in acetone (39); pre-applied, 1h, 10^{-4} M, plus 500 ppm ethephon dissolved in acetone (39); pre-applied, 1h, 10^{-4} M, plus $GA_{,3}$, $0.5x10^{-3}$ M, plus 500 ppm ethephon dissolved in acetone (39)

Abscisic acid: pre-applied, 1h, 10^{-5} M dissolved in acetone (39)

Light: (17,45); blue (12); red (12); 2h/d or more, 4d, 1800 fc (47)

P. trivialis

Light: dark or light, $P_{fr}/P = 0.03$ (55)

IV. Partly-successful dormancy-breaking treatments

P. annua

Constant temperatures: 4°C (40); 10°C (41); 20°C, dark (35)

Alternating temperatures: 2°/20°C (16h/8h) in light (35); 10°/15°C, 10°/20°C (16h/8h) (41); 25°/9°C (16h/8h) (49); 34°/28°C (12h/12h) (22); 34°/28°C (12h/12h), 3d, then 25°/18°C (12h/12h) (22)

Pre-chill: 0°-2°C, 1d (35); 4°C, 12d (41); 4°C, 4-21d (40) Potassium nitrate; co-applied, 10^{-3} M (40)

Light: (22,35,40,49)

Pre-dry: 40°C, 1d (35); 50°C, 3-14d (43)

Removal of seed covering structures: lemma and palea (41); lemma and palea, plus GA_3, co-applied (41)

P. arachnifera

Pre-chill: 10°C, 10d, plus potassium nitrate, co-applied, 0.1%, at 20°/30°C (18h/6h) (42)

P. compressa

Alternating temperatures: 20°/30°C (18h/6h) in light (2,3,4,8,9,45); 15°/35°C, 12°/30°C, 20°/30°C (20h/4h) (8); 10°/30°C, 15°/30°C (16-20h/8-4h) (8); 15°/32°C (18h/6h) (31); 10°/35°C (18h/6h) (8); 20°/30°C, 20°/35°C, 16°/30°C, 16°/35°C (16h/8h) (25)

Potassium nitrate: co-applied, 0.2% (4,36,42,45)

Sodium nitrate: co-applied, 0.1% (36)

Calcium nitrate: co-applied, 0.1% (36)

Nitric acid: co-applied, $5x10^{-3}$-$1.5x10^{-3}$ N (2)

Removal of seed covering structures: glumes, germinate at 20°/30°C (18h/6h) in dark (3)

Light: (3,4,10,25); sunlight, 8h/d (25)

Ozone: pre-applied, 7d (4)

Nitrogen: pre-applied, 7d (4)

Oxygen: pre-applied, 7d (4)

P. ampla

Alternating temperatures: 15°/20°C, 15°/30°C, 20°/25°C, 20°/30°C (16h/8h) (52)

P. canbyii

Constant temperatures: 15°C, 20°C (52,53)

Alternating temperatures: 5°/15°C, 5°/20°C, 10°/15°C, 10°/20°C, 10°/25°C, 15°/20°C, 15°/25°C, 20°/25°C (16h/8h) (52,53)

P. pratensis

Alternating temperatures: 20°/30°C (16h/8h) (19,26,27,45,47); 20°/35°C (16h/8h) (26);

15°/30°C (15h/9h) (16); 15°/30°C (16h/8h) (19,28,33,42); 15°/30°C (18h/6h) (9); 15°/35°C (16h/8h) (26); 15°/35°C (20h/4h) (8); 15°/25°C (15h/9h) (16); 15°/25°C (16h/8h) (38,39,47,56); 15°/32°C (18h/6h) (31); 10°/25°C, 10°/30°C (16h/8h) (47); 10°/20°C (16h/8h) (38,39,56); 10°/35°C (20h/4h) (8); 20°/25°C (16h/8h) (26); 34°/28°C (12h/12h) (22); 20°-23°/35°-37°C (16h/8h) (36); 22°-26°/33°C (18h/6h) (1)

Pre-chill: 10°C, 5d (11,15,16,20); 3°-5°C, 7d (33); 7°-8°C, 3d (48); 10°C, 7d, plus potassium nitrate, co-applied, 0.1% (14,15); 0°-7°C, 7d, plus potassium nitrate, co-applied, 0.2% (42); 5°-15°C, 10d, germinate at 20°/30°C (16h/8h) (42); 10°C, 5d, plus potassium nitrate, co-applied, 0.2%, germinate at 15°/25°C (16h/8h) in light (11,21)

Pre-dry: 40°C, 1-7d (27); 43°C, 50°C, 1-3d (37); 40°-60°C, 1-4d (38)

Pre-soak: 48h (1); 14,34h (38)

Potassium nitrate: pre-applied, 48h, 0.2% (1); co-applied, 0.1% (14); co-applied, 0.2% (14,19,30,33,37,38,48); co-applied, 0.1%, at 15°/30°C (15h/9h) in light (14,15); co-applied, 0.1%, at 15°/30°C (18h/6h) in light (9); co-applied, 0.2%, at 15°/25°C, 15°/30°C, 20°/30°C (15h/9h) in light (54)

Scarification: mechanical (20); potassium hydroxide, 15-35%, 2-24 min (32)

GA_3: pre-applied, 24h, 200 ppm (51); pre-applied, 1h, $0.5x10^{-3}$ M dissolved in acetone (38,39); pre-applied, 1h, $0.5x10^{-3}$ M plus 10^{-4} M kinetin dissolved in acetone (38,39); pre-applied, 1h, $0.5x10^{-3}$ M plus 500 ppm ethephon dissolved in acetone (38,39); pre-applied, 1h, $0.5x10^{-3}$ M plus 10^{-4} M kinetin plus 500 ppm ethephon dissolved in acetone (38,39); co-applied, 100 ppm (33,34); co-applied,

300-500 ppm (48); co-applied, 1.3% (24); co-applied, 500 ppm plus 0.2% potassium nitrate (48)

Fusicoccin: pre-applied, 1h, 25 ppm dissolved in acetone (39)

Light: (9,12,20,21,33,50); orange (12); green (12); 150 fc, 9h during high cycle of alternating temperatures (15); 4000 fc, 10 min (47); 1800 fc, 1h (47); $6x10^{-4}$ W cm^{-2}, 660-680 nm, 2 min (47); 40-45 fc, 9h/d, at 15°/30°C (15h/9h) (13); 120-140 fc, 15h/d, at 15°/30°C (9h/15h) (13)

P. trivialis

Alternating temperatures: 10°/25°-40°C, 15°/20°-40°C, 20°/25°-35°C (16h/8h) (52)

Potassium nitrate: co-applied, 0.2%, at 10°/30°C, 15°/25°C, 15°/30°C (15h/9h) in light (54)

V. Successful dormancy-breaking treatments

P. alpina

Potassium nitrate: co-applied, 0.1%, plus pre-chill, 10°C, 10d, germinate at 20°/30°C (18h/6h) (42)

P. annua

Potassium nitrate, Pre-chill (ISTA)

Light (AOSA)

Alternating temperatures: 25°/18°C (12h/12h) (22); 15°/25°C (16h/8h) in light (35); 20°/30°C

(16h/8h) (35)

Pre-chill: 4°C, 4-7d (40)

GA_3: co-applied, 500 ppm (29)

Potassium nitrate: co-applied, 10^{-3} M, plus pre-chill, 4°C, 4-7d, in light, germinate at 10°/30°C (16h/8h) (40)

Removal of seed covering structures: palea and lemma, then pre-chill, 4°C, 12d (41)

P. arachnifera

Light, Potassium nitrate, Pre-chill (AOSA)

P. artica

Alternating temperatures: 10°/20°-30°C, 15°/15°-40°C, 20°/20°-40°C, 25°/25°-40°C (16h/8h) (52)

P. bulbosa

Potassium nitrate, test in soil, Pre-chill (AOSA)

Potassium nitrate (ISTA)

P. compressa

Pre-chill, Potassium nitrate (ISTA)

Light, Potassium nitrate, test at 10°/30°C (16h/8h) (AOSA)

Pre-chill: 10°C, 10d, plus potassium nitrate, co-applied, 0.1%, at 20°/30°C (18h/6h) (42)

Potassium nitrate: co-applied, 0.1% (36); co-applied, 0.2%, at 15°/30°C (18h/6h or 20h/4h) in light (8,10); co-applied, 0.2%, at 20°/30°C (18h/6h) in light (2,3,6,8,10)

Ammonium nitrate: co-applied, 0.1% (36)

Nitric acid: co-applied, 10^{-3}-$2x10^{-3}$ N, at 20°/30°C (18h/6h) in light (2)

Removal of seed covering structures: palea and lemma, germinate at 20°/30°C (18h/6h) in light (3)

Carbon dioxide: pre-applied, dark, 7d (4)

Moisten/dry: daily, 14-21d, germinate at 20°/30°C or 30°/20°C (18h/6h) (5,7)

P. glaucantha

Light, Potassium nitrate (AOSA)

P. macrantha

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (18h/6h) in light (46)

P. nemoralis

Light (AOSA)

Pre-chill, Potassium nitrate (ISTA)

Potassium nitrate: co-applied, 0.1%, at 20°-23°/35°-37°C (16h/8h) in light (36)

P. nevadensis

Light, Potassium nitrate (AOSA)

P. palustris

Potassium nitrate (ISTA)

Pre-chill: 10°C, 10d, plus potassium nitrate, co-applied, 0.1%, at 20°/30°C (18h/6h) (42)

P. pratensis

Pre-chill, Potassium nitrate (ISTA)

Light, Pre-chill, Potassium nitrate (AOSA)

Alternating temperatures: 20°/30°C (18h/6h) (17); 20°/30°C (18h/6h) in light (8); 10°/30°C (18h/6h) (42,51); 12°/30°C (20h/4h) in light (8); 25°/18°C (12h/12h) (22); 15°/25°C (16h/8h) in light, 4000 fc, 10 min, during second hour of 25°C cycle, 5d (47)

Pre-chill: 10°C, 5d, plus potassium nitrate, co-applied, 0.2%, at 15°/25°C (18h/6h) in light (11)

Potassium nitrate: pre-applied, 48h, 0.2%, germinate at 22°-26°/33°C (18h/6h) (1); pre-applied, 24h, 0.5% (51); co-applied, 0.1%, at 15°/30°C (16h/8h) in light (28); co-applied, 0.1%, at 20°/35°C (16h/8h) (36); co-applied, 0.1%, at 10°/30°C (18h/6h) (42)

Removal of seed covering structures: lema and palea, puncture (21)

P. sandbergii

Constant temperatures: 10°C (23)

Alternating temperatures: 5°-15°/20°C, 15°/25°C (16h/8h) (23)

P. trivialis

Pre-chill, Potassium nitrate (ISTA)

Light (AOSA)

Alternating temperatures: 15°/30°C, 15°/35°C (16h/8h) (52)

Potassium nitrate: co-applied, 0.1%, at 20°/35°C in light (36)

Light: P_{fr}/P = 0.4 or 0.6, 8h/d, at 15°C (55)

VI. Comment

Light is a particularly stimulatory factor in promoting the germination of dormant seeds of Poa spp. (12,13,15,21,40,55). This suggests that a light treatment is an essential feature of any germination test procedure.

For P. annua a test procedure combining four stimulatory agents is suggested. This combines potassium nitrate, co-applied, 10^{-3} M, a pre-chill treatment at 4°C for 4 to 7 days with subsequent germination at 10°/30°C (16h/8h) with daily light treatments of a few minutes

exposure to diffuse laboratory light during both the pre-chill and alternating temperature treatments (40).

For P. pratensis, however, the similar treatments prescribed and recommended by AOSA/ISTA - potassium nitrate, co-applied, 0.2%, pre-chill, 10°C, 5 days, with germination in light at any of the alternating temperatures listed - failed to promote full germination of freshly harvested seeds (15,21) or seeds after-ripened for as long as 9 months (30), although the treatments are effective for commercial seed lots which are only slightly dormant (15,21). It is suggested that the lemmas and paleas be removed from seeds of dormant accessions prior to the treatments described above (use an alternating temperature regime of 10°/30°C) with subsequent pricking of non-germinated seeds after 21 to 28 days in test, with the tests continued for a further 14 to 21 days after pricking.

VII. References

1. Akamine, E.K. (1944). Germination of Hawaiian range grass seeds. Hawaii Agricultural Experiment Station Technical Bulletin, No. 2.

2. Andersen, A.M. (1931). The use of dilute nitric acid in the germination of seeds of Poa compressa. American Journal of Botany, 18, 889.

3. Andersen, A.M. (1932). The effect of removing the glumes on the germination of Poa compressa. American Journal of Botany, 19, 835-836.

4. Andersen, A.M. (1933). The effect of carbon dioxide and some other gases on the germination of seeds of Poa compressa. American Journal of Botany, 20, 678-679.

5. Andersen, A.M. (1937). The effect of daily moistening and drying of seeds of Poa compressa prior to germination. American Journal of Botany, 24, 735.

6. Andersen, A.M. (1938). Comparison of methods used in germinating seeds of Poa compressa. Proceedings of the International Seed Testing Association, 10, 307-315.

7. Andersen, A.M. (1939). Moistening and drying as a pretreatment in germinating seeds of Poa compressa. Proceedings of the Association of Official Seed Analysts, 30, 246.

8. Andersen, A.M. (1939). Germination of seeds of Poa compressa L. and Poa pratensis L. at different alternating temperatures. American Journal of Botany, 26, 18S.

9. Andersen, A.M. (1941). Germination of freshly harvested seed of Kentucky bluegrass. Proceedings of the Association of Official Seed Analysts, 33, 96-98.

10. Andersen, A.M. (1947). Some factors influencing the germination of Poa compressa L. Proceedings of the Association of Official Seed Analysts, 37, 134-143.

11. Andersen, A.M. (1955). A germination study of Merion Kentucky bluegrass with special reference to the interfering fungi. Proceedings of the Association of Official Seed Analysts, 45, 94-101.

12. Bass, L.N. (1950). Effect of wavelength bands of filtered light on germination of seeds of Kentucky bluegrass (Poa pratensis). Proceedings of the Iowa Academy of Science, 57, 61-71.

13. Bass, L.N. (1951). Effect of light intensity and other factors on germination of seeds of Kentucky bluegrass (Poa pratensis L.). Proceedings of the Association of Official Seed Analysts, 41, 83-86.

14. Bass, L.N. (1953). Comparison of 0.1 per cent and 0.2 per cent KNO_3 as moistening

agents for Kentucky bluegrass germination tests. Proceedings of the Association of Official Seed Analysts, 43, 69-71.

15. Bass, L.N. (1954). Factors affecting germination of Kentucky bluegrass seed. Iowa State College Journal of Science, 28, 503-519.

16. Bass, L.N. (1955). Viability testing of Merion Kentucky bluegrass. Proceedings of the Association of Official Seed Analysts, 45, 55-57.

17. Brown, E. (1920). Germination of Kentucky bluegrass, U.S.D.A. Office of Experiment Stations Bulletins, No. 115, 105-110.

18. Brown, E.O. and Porter, R.H. (1935). An improved method of testing seeds of Kentucky bluegrass (Poa pratensis L.). Proceedings of the Association of Official Seed Analysts, 27, 44-49.

19. Crossier, W. and Cullinan, B. (1941). Some observations in the germination of grass seeds. Proceedings of the Association of Official Seed Analysts, 33, 69-74.

20. Delouche, J.C. (1956). Dormancy in seeds of Agropyron smithii, Digitaria sanguinalis and Poa pratensis. Iowa State College Journal of Science, 30, 348-349.

21. Delouche, J.C. (1958). Germination of Kentucky bluegrass harvested at different stages of maturity. Proceedings of the Association of Official Seed Analysts, 48, 81-84.

22. Eggens, J.L. and Ormrod, D.P. (1982). Creeping bentgrass, Kentucky bluegrass and annual bluegrass seed germination response to elevated temperature. HortScience, 17, 624-625.

23. Evans, R.A, Young, J.A. and Roundy, B.A. (1977). Seedbed requirements for germination of sandberg bluegrass. Agronomy Journal, 69, 817-820.

24. Falkowski, M., Kukulka, I. and Kozlowski, S. (1980). The question of gibberellic acid usefulness as stimulator in cultivation of seed grasses. Wissenschaftliche Beiträge, Martin-Luther-Universität, Halle-Wittenberg, 20, 460-469.

25. Fryer, J.R. (1922). The influence of light and of fluctuating temperature on the germination of Poa compressa (L.). Scientific Agriculture, 2, 225-230.

26. Harrington, G.T. (1923). Use of alternating temperature in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

27. Hite, B.C. (1919). Forcing the germination of bluegrass. Proceedings of the Association of Official Seed Analysts, 11, 53-58.

28. Justice, O.L. and Andersen, A.M. (1946). Germination of Kentucky bluegrass at two alternating temperatures. Newsletter of the Association of Official Seed Analysts, 20, 10-12.

29. Koch, W. (1968). Environmental factors affecting the germination of some annual grasses. Proceedings of the 9th British Weed Control Conference, 14-19.

30. Maguire, J.D. and Steen, K.M. (1971). Effects of potassium nitrate on germination and respiration of dormant and non-dormant Kentucky bluegrass (Poa pratensis L.) seed. Crop Science, 11, 48-50.

31. Morinaga, T. (1926). Effect of alternating temperatures upon the germination of seeds. American Journal of Botany, 13, 141-158.

32. Murray, J.J., Portz, H.L. and Yeam, D.Y. (1980). Enhancing germination of Kentucky bluegrass by KOH and light treatment. Agronomy Abstracts, 72nd Annual meeting American Society of Agronomy, 119.

33. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

34. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

35. Naylor, R.E.L. and Abdalla, A.F. (1982). Variation in germination behaviour. Seed Science and Technology, 10, 67-76.

36. Nelson, A. (1927). The germination of Poa spp. Annals of Applied Biology, 14, 157-174.

37. Phaneendranath, B.R. (1977). Effects of accelerated ageing and dry heat treatment on dormancy and viability of freshly harvested Kentucky bluegrass seed. Journal of Seed Technology, 2, 11-17.

38. Phaneendranath, B.R. (1978). Dormancy and viability of Kentucky bluegrass (Poa pratensis L.) seed as affected by stage of maturity, storage conditions and other treatments. Dissertation Abstracts International, B, 38, 5127.

39. Phaneendranath, B.R. and Funk, C.R. (1978). Germination stimulation of Kentucky bluegrass seed permeated with plant-growth regulators dissolved in acetone. Crop Science, 18, 1037-1039.

40. Roberts, E.H. and Benjamin, S.K. (1979). The interaction of light, nitrate and alternating temperature on the germination of Chenopodium album, Capsella bursa-pastoris and Poa annua before and after chilling. Seed Science and Technology, 7, 379-392.

41. Sgambatti-Araujo, L. (1978). Germination and dormancy studies in Poa annua L. Dissertation Abstracts International, B, 39, 526.

42. Sprague, V.G. (1940). Germination of freshly harvested seeds of several Poa species and of Dactylis glomerata. Journal of the American Society of Agronomy, 32, 715-721.

43. Taylorson, R.B. and Brown, M.M. (1977). Accelerated after-ripening for overcoming seed dormancy in grass weeds. Weed Science, 25, 473-476.

44. Taylorson, R.B. and Hendricks, S.B. (1979). Overcoming dormancy in seeds with ethanol and other anesthetics. Planta, 145, 507-510.

45. Toole, E.H. (1923). A preliminary report on bluegrass germination. Proceedings of the Association of Official Seed Analysts, 14/15, 119.

46. Toole, V.K. (1939). Germination requirements of the seed of some introduced and native range grasses. Proceedings of the Association of Official Seed Analysts, 30, 227-243.

47. Toole, V.K. and Borthwick, H.A. (1971). Effect of light, temperature and their interactions on germination of seeds of Kentucky bluegrass (Poa pratensis L.). Journal of the American Society for Horticultural Science, 96, 301-304.

48. Urbaniak, Z. (1978). [The application of gibberellic acid and potassium nitrate for shortening the period of dormancy in seeds of meadow grass (Poa pratensis L.).] Biuletyn Instytutu Hodowli i Aklimatyzacji Roslin, 133, 201-211. (From Seed Abstracts, 1981, 4, 1801.)

49. Wagenvoort, W.A. and Opstal, N.A.V. (1979). The effect of constant and alternating temperatures, rinsing, stratification and fertilizer on germination of some weed species. Scientia Horticulturae, 10, 15-20.

50. Waldron, C.H. (1921). Notes on germination of Kentucky bluegrass. Proceedings of the Association of Official Seed Analysts, 12/13, 14-15.

51. Wiberg, H. and Kolk, H. (1960). Effect of gibberellin on germination of seeds. Proceedings of the International Seed Testing Association, 25, 440-445.

52. Young, J.A. and Evans, R.A. (1982). Temperature profiles for germination of cool season range grasses. United States Department of Agriculture, Agricultural Research Service, ARR-W-27.

53. Young, J.A., Evans, R.A., Eckert, R.E. Jr. and Ensign, R.D. (1981). Germination-temperature profiles for Idaho and sheep-fescue and canby bluegrass. Agronomy Journal, 73, 716-720.

54. Cuddy, T.F. (1963). Germination of the bluegrasses. Proceedings of the Association of Official Seed Analysts, 53, 85-90.

55. Hilton, J.R., Froud-Williams, R.J. and Dixon, J. (1984). A relationship between phytochrome photoequilibrium and germination of seeds of Poa trivialis L. from contrasting habitats. New Phytologist, 97, 375-379.

56. Phaneendranath, B.R. and Funk, C.R. (1981). Effect of storage conditions on viability, after-ripening and induction of secondary dormancy of Kentucky bluegrass seed. Journal of Seed Technology, 6, 9-22.

SACCHARUM

S. aegyptiacum Willd.	wild sugar cane
S. barberi Jeswiet	sugar cane
S. officinarum L.	noble sugar cane
S. robustum Brandes & Jeswiet	wild sugar cane
S. sinense Roxb.	sugar cane
S. spontaneum L.	wild sugar cane

I. Evidence of dormancy

Seeds of S. aegyptiacum can show considerable dormancy (8), but seeds of other sugar cane species tend to show little dormancy and consequently viviparous germination can occur or be readily induced (10). In general the seeds of Saccharum spp. germinate quite rapidly showing little sign of dormancy, for example within 2 days (5), between 2 and 5 days (7,9) or within 11 days (3), but there is some evidence of low germination of freshly harvested seeds being increased by after-ripening for 6 to 8 months (6). Similarly we have observed that after-ripening treatments increased percentage germination in one of 17 seed lots (A) suggesting that dormancy is a problem for a minority of accessions. With the exception of S. aegyptiacum - which is more dormant - the information summarised below does not distinguish between the above Saccharum spp.

II. Germination regimes for non-dormant seeds

Saccharum spp.

Constant temperatures: 25°C, 5d (1); 28°-30°C (6); 35°C in light (3); 38°C (3)

III. Unsuccessful dormancy-breaking treatments

S. aegyptiacum

Constant temperatures: 15°-26°C in light or dark (8)

Thiourea: (8)

Kinetin: (8)

Removal of seed covering structures: then germinate at 15°C in light (8); then germinate at 15°-26°C in dark (8)

Saccharum spp.

Pre-soak: 15h (2)

Scarification: concentrated sulphuric acid, 5 min (2)

Orthophosphoric acid: pre-applied, 15h, 0.1% (2)

IV. Partly-successful dormancy-breaking treatments

S. aegyptiacum

Constant temperatures: 30°C, 37°C (8)

Pre-soak: 24h (8)

Light: continuous (8)

GA_3: pre-applied to dehusked seeds at 37°C in continuous light, then pre-dry (8)

Removal of seed covering structures: dehusk, germinate at 20°-26°C in light (8); dehusk, germinate at 30°-37°C in dark (8)

Saccharum spp.

Constant temperatures: 25°-40°C in light (4)

Light: continuous (4,9)

V. Successful dormancy-breaking treatments

S. aegyptiacum

Removal of seed covering structures: dehusk, germinate at 30°-37°C in light, continuous (8)

Saccharum spp.

Pre-dry: room temperature, 3-6d (6)

VI. Comment

Informal contacts suggest that large variations in germination test results of Saccharum accessions can occur. One problem may be the fuzz raising the seeds above the germination test substrate. When testing seeds ensure that a seed is present within the fuzz and able to imbibe. It is not necessary to remove the fuzz surrounding the seed. Indeed this action may damage the seed (A). One way of ensuring imbibition is to maintain high atmospheric humidity

above the substrate. A practical technique to achieve this when sowing out seeds for planting is to cover compost - on which the fuzz is placed - with black sand (volcanic ash). This can increase percentage germination and reduce the subsequent seedling mortality rate (7).

Despite reported optimum temperatures of 35°C (4) and 38°C (3), within the range 20°-35°C, 25°C has been optimal for germination (A). However, alternating temperatures of either 20°/30°C or 20°/35°C (16h/8h) in light were superior to both a constant temperature of 25°C and alternating temperatures of 38°/30°C or 34°/11°C (16h/8h) (A).

The view that alternating temperature regimes can increase percentage germination is reinforced by the observation that viviparous germination can be induced in a humid environment at 30.5°/10°C (day/night) (10). At 20°/30°C neither potassium nitrate, co-applied, 0.2%, nor thiourea, co-applied, $2.5x10^{-2}$ M affected germination, but thiourea, co-applied, $2.5x10^{-2}$ M, sodium azide, co-applied, 10^{-4} M, 10^{-3} M, or mercaptoethanol, co-applied, 10^{-2} M, $5x10^{-3}$ M, each reduced germination (A). Consequently for the present it is suggested that the seeds be tested at 20°/30°C with the standard light treatment (see Chapter 6). If further treatment is required potassium nitrate, co-applied, 0.2%, could be tried.

Breeders often remove seeds from the fuzz in order to be able to determine easily the number of seeds available and to be able to handle the seeds easily in nursery sowings - since the fuzz aggregates and, as a consequence, can be difficult to sow. However, defuzzing (particularly mechanical defuzzing) can damage the embryo. Correspondence suggests a minimum proportion of 5% of seeds are damaged sufficiently to prevent germination by mechanical defuzzing, but 5-10% is the more likely range of damage to accessions (A). Consequently it is suggested that seeds should not be defuzzed, particularly as it is not necessary for laboratory germination tests.

VII. References

1. Cazalet, K.R. and Berjak, P. (1983). Isolation of a seed storage fungus from sugarcane seeds. Proceedings of the South African Sugar Technologists' Association, June 1983, 1-4.

2. Dutt, N.L., Krishnaswami, M.K. and Rao, K.S.S. (1938). Seed setting and seed germination in certain sugar canes. Indian Journal of Agricultural Science, 8, 429-439.

3. Heinz, D.J. (1975). Temperature effect on fuzz (true seed) germination. 1974 Annual Report of the Experiment Station, Hawaiian Sugar Planters' Association, p. 7.

4. Itakura, M., Kudo, M., and Nakasone, S. (1981). [Effect of temperature on sugarcane seed germination.] Japanese Journal of Tropical Agriculture, 25, 47-51.

5. Jayasekera, E.W.H. (1956). Techniques of seed and seedling production with sugar cane. Tropical Agriculturist, 112, 262-266.

6. Lee, S. and Loo, Y.S. (1958). [Report of some experiments on the germination of true sugarcane seeds.] Report of the Taiwan Sugar Experiment Station, 18, 1-13.

7. Lennox, C.G. (1928). The effect of covering on the germination of sugar cane fuzz. Hawaiian Planters Record, 32, 14-17.

8. Poljakoff-Mayber, A. (1959). Germination of the seeds of Saccharum aegyptiacum Willd. Bulletin of the Research Council of Israel, Section D, 7, 93-94.

9. Purseglove, J.W. (1975). Tropical Crops. Monocotyledons, pp. 214-256. Longman, London.

10. Ragavan, K. (1960). Potential vivipary in Saccharum spontaneum and hybrid sugarcane.

Science and Culture, 26, 129-130.

SASA

S. senanensis Rehd. [Bambusa senanensis Franch. & Sav.] dwarf bamboo

I. Evidence of dormancy

Sasa is one of about 45 genera of bamboos. Freshly harvested seeds of S. senanensis can show considerable dormancy (1).

II. Germination regimes for non-dormant seeds

Constant temperatures: 20°C, 60-300d (1)

III. Unsuccessful dormancy-breaking treatments

Pre-chill: 3°-5°C, 30d (1)

Pre-dry: room temperature, 16,33,47,65d (1)

IV. Partly successful-dormancy breaking treatments

Pre-chill: 3°-5°C, 43-264d (1)

V. Successful dormancy breaking treatments

VI. Comment

Full germination was not achieved with pre-chill treatments alone despite considerable pre-chill and germination test periods (1). A 43 day pre-chill treatment at 3°-5°C gave the highest germination but only after a subsequent 300 days in the germination test - on top of filter papers - at 20°-25°/10°-15°C (9h/15h) (1). Moreover no seeds germinated before 150 days in the test (1).

VII. References

1. Matumura, M. and Nakajima, N. (1981). [Fundamental studies on artificial propagation by seeding useful wild grasses in Japan. VIII. Some observations concerning the seed propagation of the dwarf bamboo, Sasa senanensis Rehd.] Research Bulletin of the Faculty of Agriculture, Gifu University, 45, 289-297.

SECALE

S. cereale L. rye

I. Evidence of dormancy

Dormancy in rye has been observed by seed testers (1-3).

II. Germination regimes for non-dormant seeds

S; TP; BP: 20°C: 7d (ISTA)

S; BP: 20°C; 15°C: 7d (AOSA)

III. Unsuccessful dormancy-breaking treatments

-

IV. Partly-successful dormancy-breaking treatments

Potassium nitrate: co-applied, 0.2% (3)

GA_3: co-applied, 200 ppm (2)

V. Successful dormancy-breaking treatments

Pre-chill, GA_3 (ISTA)

Pre-chill, Pre-dry (AOSA)

Constant temperatures: 12°C, 15°C (1); 10°-12°C (4)

Pre-chill: 12°C, 7d (2,3)

GA_3: co-applied, 200 ppm (3)

Potassium nitrate: co-applied, 0.2%, at 15°C, deglumed seeds (1)

VI. Comment

A constant germination test temperature of 10°-12°C combined with a minimum 21 day test period is suitable for both deeply dormant and non-dormant seeds of S. cereale (4,A), and is marginally superior to a pre-chill treatment (3°-5°C, 7d) followed by testing at 20°C (A).

VII. References

1. Heit, C.E. (1948). Thirty-eighth annual meeting. Report of sub-committee on dormancy of seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

2. Kahre, L., Kolk, H. and Fridz, T. (1965). Gibberellic acid for breaking of dormancy in cereal seed. Proceedings of the International Seed Testing Association, 30, 887-891.

3. Kahre, L., Kolk, H and Wiberg, H. (1962). Note on dormancy-breaking in seeds. (Cereals & Timothy). Proceedings of the International Seed Testing Association, 27, 679-683.

4. Munerati. M.O. (1925). Existe-t-il une aprés-maturation chez les céréales récemment récoltées. Comptes Rendus de l'Académie des Sciences, Paris, 181, 1081-1083.

SETARIA

S. anceps Stapf	
S. chevalieri Stapf	ribbon bristle grass
S. faberii Herrm.	giant foxtail
S. glauca (L.) Beauv. [S. lutescens (Weigel) [Hubb.]	yellow bristle-grass, yellow foxtail
S. italica (L.) Beauv. [Panicum italicum L.; foxtail millet, Chaetochloa italica (L.) Scribn.] golden wonder millet, Turkestan millet	Italian millet, German millet, Hungarian millet, Siberian millet,
S. macrostachya HBK	plains bristle-grass
S. viridis (L.) Beauv.	green bristle-grass, green foxtail

I. Evidence of dormancy

Dormancy is comparatively slight in S. italica (8,9,21) but tends to be much deeper in S. chevalieri (22), S. faberii (8,15), S. glauca (11,12), S. macrostachya (19) and S. viridis (1). In

dry storage seed dormancy may persist in S. glauca for 4 to 8 months (20) and even 24 months (11) at room temperature, in S. faberii for 10 to 12 months or more at room temperature (8,15) and in S. italica for 3 to 6 months (21).

II. Germination regimes for non-dormant seeds

S. anceps

TP: 20°/35°C (16h/8h): 21d (ISTA)

S. chevalieri

Constant temperatures: 24°C in light, continuous (22)

S. italica

BP; TP: 20°/30°C (16h/8h): 10d (ISTA)

BP; TP: 15°/30°C; 20°/30°C (16h/8h): 10d (AOSA)

III. Unsuccessful dormancy-breaking treatments

S. chevalieri

Light: dark (22)

Sodium azide: pre-applied, 3h, 10^{-3} M, germinate at 24°C in dark (22)

S. faberii

Alternating temperatures: sub-zero/room temperature (8); 20°/30°C (16h/8h) (15)

Warm stratification: 35°C, 0.3-4d (17)

Sodium metaarsenite: pre-applied, 24h, 10% (6)

Pre-soak: 24h (6)

Removal of seed covering structures: fruit coat (6); fruit coat, then puncture (6); embryo excision (8)

Scarification: sulphuric acid (8)

Pre-dry: after imbibition, several cycles (8)

S. glauca

Constant temperatures: 20°C, 30°C, light or dark (13)

Alternating temperatures: 20°/30°C (18h/6h) in daylight (13)

Pre-chill: sub-zero, 1-12d (12)

Warm stratification: 35°C, 3d, plus 0.5 M ethanol, 5 min red light, germinate at 20°/30°C (16h/8h) (18)

Ammonium chloride: co-applied, 10^{-2} M (3)

Potassium cyanide: co-applied, 10^{-4} M (3)

GA_3: co-applied, 10^{-5}-10^{-4} M (7)

Pre-wash: (10)

Indoleacetic acid: pre-applied, 5-24h, 0.05-50 ppm, scarified seeds, sand paper (12)

Thiourea: pre-applied, 5-24h, 25-50 ppm, with scarified seeds, sand paper (12)

EPTC: pre-applied, 20,30h, 50, 500 ppm (12)

Methyl alcohol: pre-applied, 5-24h (12)

Magnesium nitrate: pre-applied, 76h, 2% (12)

Pre-soak: 12h (12); 54°C, 68°C, 78°C, 92°C, 1 min (12)

Light: dark (13)

S. italica

Alternating temperatures: (9)

Potassium nitrate: co-applied, 0.2% (9)

GA_3: co-applied, 100 ppm (9)

Light: (9)

S. viridis

GA_3: pre-applied, 24h, 250, 500 ppm (1)

Pre-dry: 60°C, 24h (1)

IV. Partly-successful dormancy-breaking treatments

S. anceps

Alternating temperatures: 20°/35°C (16h/8h) in light (5); 27°/20°C in light (2); 31.5°/23°C, 22.5°/16°C, 36°/26°C, 18°/12.5°C, 40°/30°C (12h/12h) (2)

Potassium nitrate: co-applied, 0.2% (5)

S. chevalieri

Light: continuous, at 24°C (22); dark, 10d, then light, continuous (22); red, 10^{-2} W m^{-2} min^{-1}, 15 min (22)

Sodium azide: pre-applied, 3,6h, 10^{-3} M, germinate at 24°C in light (22)

S. faberii

Alternating temperatures: 20°/30°C (16h/8h) (6,17); 21°/37°C (16h/8h) (6)

Pre-chill: 5°C, 10°C, 7d (6); 5°C, 28d (15)

Warm stratification: 21°C, 7d (6); 35°C, 2-3d, plus 0.01-0.5 M ethanol, 5 min red light, germinate at 20°/30°C (16h/8h) (17,18); 35°C, 2d, plus 0.05-2 M methanol, or 0.03-0.1 M 1-

propanol, or 0.03-0.1 M 1-propanol, or 0.03-1 M isopropanol, or 0.03-0.1 M acetaldehyde, or 0.01-0.1 M propionaldehyde, or 0.01-0.3 M ethyl acetate (17)

Potassium nitrate: pre-applied, 24h, 0.5-2% (6)

Sodium thiocyanate: pre-applied, 24h, 0.01-1% (6)

Removal of seed covering structures: prick (15); bracts (8); pierce, then pre-chill, 5°C, 28d (15)

Scarification: sand paper (8)

Light: $246x10^{-6}$ W cm^{-2}, 660-699 nm, 5 min (17)

S. glauca

Alternating temperatures: 20°/30°C (16h/8h) (11); 2°-3°/27°C, 5m (12)

Pre-chill: (10); 2°-5°C, 1-8d (12); 62d (11); 5m (12); 1°-7°C, 70d (13)

Potassium nitrate: co-applied (4); co-applied, 10^{-2} M (3); pre-applied, 15h, 0.5-2% (12); pre-applied, 76h, 1% (12)

Sodium nitrite: co-applied, 10^{-3} M (3)

Ammonium nitrate: pre-applied, 13,76h, 1, 2% (12)

Hydroxylamine hydrochloride: co-applied, $3.2x10^{-4}$ M (3)

Potassium azide: co-applied, 10^{-5} M (3)

GA_3: co-applied, (4); co-applied, 10^{-4}, 10^{-5} M, excised embryos (7)

Thiourea: co-applied (4)

EPTC: pre-applied, 1h, 0.5 ppm (12)

Scarification: sand paper (12); concentrated sulphuric acid, 30 min (7); concentrated sulphuric acid, 30,60 min (12); concentrated sulphuric acid, 30 min, then GA_3, co-applied, 10^{-4}, 10^{-3} M (7)

Removal of seed covering structures: lemma and palea (10,14); excise embryo (14)

Pre-soak: 12h, then pre-dry, room temperature, 4d (12)

Hydrogen peroxide: pre-applied, 24h, 0.03, 0.3, 3% (12)

S. italica

Pre-chill: 6°C, 28,42d (1)

S. macrostachya

Alternating temperatures: 35°/10°C, 10°/35°C, 20°/30°C in light, 15°/25°C, 20°/35°C, 20°/40°C, 25°/40°C (17h/7h) (19)

Pre-chill: 3°C, 10°C, 14-28d (19)

Potassium nitrate: co-applied, 0.2% (19)

Scarification: sulphuric acid, 71%, 15-60 min (19); sulphuric acid, 71%, 15-30 min, then potassium nitrate, co-applied, 0.2%, at 20°/30°C (17h/7h) in light (19)

S. viridis

Constant temperatures: 15°-20°C (1)

Pre-chill: 6°C, 28,42d (1)

V. Successful dormancy-breaking treatments

S. anceps

Potassium nitrate (ISTA)

Potassium nitrate: co-applied, 0.2%, at 20°/35°C (16h/8h) in light, 21d (5)

S. glauca

Removal of seed covering structures: lemma and palea (16)

S. italica

Alternating temperatures: 15°/30°C, 20°/30°C (16h/8h), 38-46d (21)

Thiourea: co-applied, 0.2% (9)

VI. Comment

Although the removal of seed covering structures can on occasion promote germination (8,10,14,16) it is an unreliable procedure since it can also damage the seeds (6,8,10,14). Thus, although it has been reported as a successful procedure in S. glauca (16), caution is required. It appears that alternating temperatures within the range 15°-20°/30°-35°C (16h/8h) are likely to be successful, but it should be noted that the first temperature experienced by the imbibing seeds should be the lower temperature of the alternation since 8 hours imbibition at 35°C has induced secondary dormancy in S. faberii (17). The absence of any ISTA/AOSA dormancy-breaking recommendations for S. italica is indicative of the comparatively slight dormancy in commercial seed lots of this species; for the majority of accessions an alternating temperature regime of 20°/30°C (16h/8h) is sufficient to promote germination (A) but a 42 day test at 15°/30°C (16h/8h) is suggested as an alternative for the more dormant accessions.

VII. References

1. Born, V.W.H. (1971). Green foxtail: seed dormancy, germination and growth. Canadian Journal of Plant Science, 51, 53-59.

2. Hawton, D. (1979). Temperature effects on Eleusine indica and Setaria anceps grown in association (I). Weed Research, 19, 279-284.

3. Hendricks, S.B. and Taylorson, R.B. (1974). Promotion of seed germination by nitrate, nitrite, hydroxylamine and ammonium salts. Plant Physiology, 54, 304-309.

4. Jennings, R.W., Collins, N.A., Bettis, R.B. and Biswas, P.K. (1968). Effects of several chemical stimulants and inhibitors on seed germination and oxygen consumption of selected weed species. Abstracts of the 1968 Meeting of the Weed Science Society of America, 23-24.

5. Johnston, M.E.H. (1981). Report of the germination committee working group on tropical and subtropical seeds (1977-1980). Seed Science and Technology, 9, 137-140.

6. King, L.J. (1952). Germination and chemical control of the giant foxtail grass. Contributions of the Boyce Thompson Institute, 16, 469-487.

7. Kollman, G.E. and Staniforth, D.W. (1972). Hormonal aspects of seed dormancy in yellow foxtail. Weed Science, 20, 472-477.

8. Moore, D.J. and Fletchall, O.H. (1963). Germination-regulating mechanisms of giant foxtail (Setaria faberii). Missouri Agricultural Experiment Station Research Bulletin, No. 829.

9. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

10. Nieto-Hatem, J. (1963). Seed dormancy in Setaria lutescens. Dissertation Abstracts, 24, 1360-1361.

11. Norris, R.F. and Schoner, C.A. Jr. (1980). Yellow foxtail (Setaria lutescens) biotype studies: dormancy and germination. Weed Science, 28, 159-163.

12. Peters, R.A. and Yokum, H.C. (1961). Progress report on a study of the germination and growth of yellow foxtail (Setaria glauca (L.) Beauv.). Proceedings of the North East Weed Control Conference, 15, 350-355.

13. Povilaitis, B. (1956). Dormancy studies with seeds of various weed species. Proceedings of the International Seed Testing Association, 21, 87-111.

14. Rost, T.L. (1975). The morphology of germination in Setaria lutescens (Gramineae): The effects of covering structures and chemical inhibitors on dormant and non-dormant florets. Annals of Botany, 39, 21-30.

15. Stanway, V. (1971). Laboratory germination of giant foxtail, Setaria faberii Herrm., at different stages of maturity. Proceedings of the Association of Official Seed Analysts, 61, 85-90.

16. Tao, K., Collins, N.A., Bettis, R.B. and Biswas, P.K. (1968). Studies on seed dormancy in selected weed species. Abstracts of the 1968 Meeting of the Weed Science Society of America, 25.

17. Taylorson, R.B. (1982). Anesthetic effects on secondary dormancy and phytochrome responses in Setaria faberii seeds. Plant Physiology, 70, 882-886.

18. Taylorson, R.B. and Hendricks, S.B. (1979). Overcoming dormancy in seeds with ethanol and other anesthetics. Planta, 145, 507-510.

19. Toole, V.K. (1940). Germination of seed of vine-mesquite, Panicum obtusum and plains bristlegrass, Setaria macrostachya. Journal of the American Society of Agronomy, 32, 503-512.

20. Torpornina, N.A. (1958). [New data on seed germination of Avena fatua and Setaria glauca.] Agrobiologiya, 3, 149-151.

21. Wright, W.G. and Kinch, R.C. (1962). Firm seeds in the foxtail millets. Proceedings of the Association of Official Seed Analysts, 52, 109-111.

22. Erasmus, D.J. and Van Staden, J. (1983). Germination of Setaria chevalieri caryopses.

Weed Research, 23, 225-229.

SORGHASTRUM

S. nutans (L.) Nash. Indian grass

I. Evidence of dormancy

Seeds of Indian grass can show pronounced dormancy at harvest (1-6). One to 2 years after-ripening may be required at room temperature for full germination (3,7).

II. Germination regimes for non-dormant seeds

TP; S: 20°/30°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Light: continuous dark (4)

Sodium hypochlorite: pre-applied, 80 min, 6%, germinate at 20°/30°C, dark (4)

IV. Partly-successful dormancy breaking treatments

Alternating temperatures: 20°/30°C (4); 30°/20°C (16h/8h) in light, 16h/d (7)

Pre-chill: 4°-6°C, 14d (2,4,5,6); 4°C, 14d, then pre-dry, dehull (5); 4°-6°C, 14d, then dehull non-germinated seeds (6); 4°-6°C, 14d, then dehull and scarify non-germinated seeds (6)

Light: daylight, 2h (4); red light (660 nm), 15 min, 2,24h (4)

GA_3: co-applied, 250-2000 ppm, dark (4); co-applied, 2000 ppm, light (4)

Sodium hypochlorite: pre-applied, 80 min, 6%, germinate at 20°/30°C, light (4)

Removal of seed covering structures: (2,5,6); dehull, then pre-chill, 4°-6°C, 14d (5,6)

V. Successful dormancy-breaking treatments

Light, Pre-chill, Potassium nitrate (AOSA)

Pre-chill: 4°-6°C, 28d (4)

GA_3: co-applied, 500-1500 ppm, at 20°/30°C in light (4)

Scarification: concentrated sulphuric acid, 10 min, germinate at 20°/30°C in light, 10h/d (4)

VI. Comment

Light is an essential promotory feature of the germination test environment. Diurnal treatments of either 10 hours daylight or 2 hours red light are suitable (4), but greater treatment periods (24 hours) are inhibitory (4). Gibberellin and concentrated sulphuric acid treatments are satisfactory for promoting the germination of partly after-ripened seeds (4), but very dormant seeds require a 28 day pre-chill treatment at 4°-6°C (4) - whereas AOSA recommend pre-chilling for 14 days. It is suggested that gene banks pre-chill the seeds for 28 days at 5°C and then transfer to the alternating temperature regime of 20°/30°C (16h/8h) prescribed by AOSA with 10 hours light per day or the light regime described in Chapter 6.

VII. References

1. Barnett F.L. (1964). Grass breeding investigations. Kansas Agricultural Experiment Station, Annual Report, 103-109.

2. Barnett, F.L. and Vanderlip, R.L. (1969). Criteria of field establishment capability in indiangrass, Sorghastrum nutans (L.) Nash. Crop Science, 9, 290-293.

3. Coukos, C.J. (1944). Seed dormancy and germination in some native grasses. Journal of the American Society of Agronomy, 36, 337-345.

4. Emal, J.G. and Conard, E.C. (1973). Seed dormancy and germination in indiangrass as affected by light, chilling, and certain chemical treatments. Agronomy Journal, 65, 383-385.

5. Geng, S. and Barnett, F.L. (1969). Effects of various dormancy-reducing treatments on seed germination and establishment of indiangrass, Sorghastrum nutans (L.) Nash. Crop Science, 9, 800-803.

6. Rafii, Z.E. (1967). Seed characteristics and field establishment in indian grass Sorghastrum nutans (L.) Nash. Dissertation Abstracts, 28, 1763-B.

7. Shaidaee, G., Dahl, B.E. and Hansen, R.M. (1969). Germination and emergence of different age seeds of six grasses. Journal of Range Management, 22, 240-243.

SORGHUM

S. almum Parodi	columbus grass, almum sorghum
S. arundinaceum (Desv.) Stapf [S. sudanense (Piper) Stapf]	Sudan grass, Tunis grass
S. bicolor (L.) Moench [S. vulgare Pers.;	sorghum, sorgo,
Andropogon sorghum (L.) Brot.; Holcus sorghum L.]	guinea corn, kafir
corn, milo, durra, mtama,jola jawa cholam	
S. intrans F. Muell. ex Benth.	
S. halepense (L.) Pers.	Johnson grass
S. plumosum	
S. 'Sorgrass'	sorgrass
S. stipoideum (Ewart & White) Gardn. & Hubb.	
S. verticilliflorum (Steud.) Stapf	

I. Evidence of dormancy

Grain sorghum seeds, S. bicolor, can show considerable dormancy when harvested (1-3,5-7,22,24,29) resulting in substantial problems for plant breeding and seed testing (6,7,22). Premature harvesting also increases dormancy (3), and drying seeds at high temperatures (39°C and 46°-48°C) down to 5-7% moisture content can induce dormancy (14,22). An indication of the degree of dormancy is provided by the substantial after-ripening treatments required to remove dormancy completely, e.g. 1-3 months at room temperature (3,20), 5 months at 40°C (1). Seeds of other Sorghum spp. show considerably more dormancy than S. bicolor which can be particularly difficult to remove, e.g. S. almum (24), S. intrans (23), S. halepense (8,9,18,19,21,26,27), S. stipoideum (23) and S. verticilliflorum (25).

II. Germination regimes for non-dormant seeds

S. almum

BP; TP: 20°/35°C; 20°/30°C (16h/8h): 21d (ISTA)

BP; TP; S: 20°/35°C; 15°/35°C (16h/8h): 21d (AOSA)

S. arundinaceum

BP; TP: 20°/30°C (16h/8h): 10d (ISTA)

BP; TP; S: 20°/30°C; 15°/30°C (16h/8h): 10d (AOSA)

S. bicolor

BP; TP: 20°/30°C (16h/8h); 25°C: 10d (ISTA)

BP; TP; S: 20°/30°C (16h/8h): 10d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (5,15)

S. halepense

TP; BP: 20°/35°C; 20°/30°C (16h/8h): 35d (ISTA)

TP: 20°/35°C (16h/8h): 35d (AOSA)

S. 'sorgrass'

BP; TP; S: 20°/35°C; 15°/35°C (16h/8h): 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

S. bicolor

Pre-chill: (6); 5°C, 5d (22); 5°C, 10°C, 5d (16,17)

Potassium nitrate: pre-applied (6)

Ammonium sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Magnesium sulphate: pre-applied, 24h, 10^{-6}-10^{-2} M (5)

Ferrous sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Silver sulphate: pre-applied, 24h, 10^{-8}-10^{-2} M (5)

Ferric chloride: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Copper sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Zinc chloride: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Cobalt chloride: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Nickel chloride: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Sodium nitrate: pre-applied, 24h, 10^{-4}, 10^{-3} M (5)

Sodium nitrite: pre-applied, 24h, 10^{-4}, 10^{-3} M (5)

Sodium chlorite: pre-applied, 24h, 10^{-2} M (5)

Urea: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

GA_3: co-applied, 100 ppm (7); co-applied, 8-500 ppm (22)

Thiourea: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

L-Cystine: pre-applied, 24h, 10^{-8}-10^{-4} M (5)

DL-Alanine: pre-applied, 24h, 10^{-6}-10^{-2} M (5)

Scarification: sulphuric acid (6)

Hydrochloric acid: pre-applied, 24h, 10^{-4}-10^{-1} N (5)

Pre-soak: 3d (22); 4 min, 70°-75°C (22); 1 min, 80°C, 85°C (6)

S. halepense

Constant temperatures: 20°-35°C (18); 15°-30°C in light or dark (11)

Pre-chill: 4°C (11); then GA_3, co-applied, 50,100 ppm (11); then thiourea, co-applied, $5x10^{-3}$, 10^{-2} M (11)

GA_3: co-applied, 50, 100 ppm (11)

Thiourea: co-applied, $5x10^{-3}$, 10^{-2} M (11)

Pre-wash: (11)

Removal of seed covering structures: glumes (11)

Light: continuous (18); red (18); red, $23x10^{-6}$ W cm^{-2}, 1s-16 min, then far red, $377x10^{-6}$ W cm^{-2}, 5 min, to pre-chilled seeds (28)

Pre-dry: (11)

Sodium hydroxide: pre-applied, 24h, 10^{-5}-10^{-1} M (9)

Potassium tartrate: pre-applied, 24h, 10^{-3} M (9)

Potassium citrate: pre-applied, 24h, 10^{-3} M (9)

Urea: pre-applied, 24h, 10^{-3} M (9)

Hydrochloric acid: pre-applied, 24h, 10^{-5} -10^{-1} N (9)

Oxalic acid: pre-applied, 24h, 10^{-5} -10^{-1} N (9)

Acetic acid: pre-applied, 24h, 10^{-5} -10^{-1} N (9)

Tartaric acid: pre-applied, 24h, 10^{-5} -10^{-1} N (9)

S. plumosum, S. stipoideum

Pre-chill: 0°-4°C, 4-8w (12)

Potassium nitrate: co-applied, 0.2% (12)

S. verticilliflorum

Alternating temperatures: 20°/30°C, 15°/30°C (night/day) in diffuse light (25)

Pre-dry: 40°C, 3d (25)

Pre-soak: (25)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (night/day) in diffuse light (25)

Scarification: concentrated sulphuric acid, 5 min (25)

IV. Partly-successful dormancy-breaking treatments

S. bicolor

Alternating temperatures: 20°/30°C (16h/8h), 28d (3-5,7,15,22,24); 30°/45°C (20-22h/4-2h) (22); 20°/35°C (16h/8h) (17)

Pre-chill: 10°C, 2d (5); 10°C, 5d (7); 5°-10°C, 5d (16)

Sodium nitrate: pre-applied, 24h, 10^{-2}, 10^{-1} M (5)

Sodium nitrite: pre-applied, 24h, 10^{-2}, 10^{-1} M (5)

Potassium nitrate: pre-applied (6); pre-applied, 24h, 10^{-2} M (5); co-applied, 0.2% (22)

Potassium nitrite: pre-applied, 24h, 10^{-2} M (5)

GA_3: co-applied, 1000 ppm (7); co-applied, 8-500 ppm (22)

Nitric acid: pre-applied, 24h, 10^{-4}-10^{-1} N (5)

Hydroxylamine hydrochloride: pre-applied, 24h, 10^{-4}-10^{-2} M (5)

Sulphuric acid: pre-applied, 24h, 10^{-4}-10^{-1} N (5)

Pre-soak: 30°C, 0.5,1d (5); 70°C, 1,2 min (6,7)

Hydrogen peroxide: pre-applied, 24h, 10^{-2}-1 M (5)

Storage: 40°C, 14d (5); 40°-50°C, 4d (22); 40°C, 80°C (20)

Removal of seed covering structures: cut or chip (14,22,29)

Scarification: 2.1-3.5 kg/cm^2, 1-3 min (7); 2.1 kg/cm^2, 3 min, then GA_3, co-applied, 100, 1000 ppm (7)

S. intrans

Pre-dry: 130°C, 1 min (23)

S. halepense

Alternating temperatures: 20°/35°C (16h/8h) (18,21,26,27); 20°/35°C (18h/6h) (8); 25°/40°C (18h/6h) (8); 30°/45°C (16h/8h) (21); 30°/45°C (22h/2h) (10); 25°/40°C, 25°/35°C, 20°/40°C, 20°/30°C, 20°/35°C (22h/2h) (18); 10°/40°/10°/40°/10°C (1h/1h/1h/1h/1h) then 25°C (9);

10°/40°/10°/40°/10°/40°C (1h/1h/1h/1h/1h/1h) then 30°C (9); 10°/40°/10°/40°/10°/40°/10°/40°C (1h/1h/1h/1h/1h/1h/1h/1h) then 25°C (9); 25°/40°/25°/40°/25°/40°C (1h/1h/1h/1h/1h/1h) then 25°C (9); 10°/20°/25°/30°/35°/40°/50°/25°/40°C (1h/1h/1h/1h/1h/2h/1h/20h/1h) then 25°C (9)

Pre-chill: 5°-10°C, 15d, then 40°C, 2h (18); 10°C, 7d (19)

Potassium nitrate: co-applied, 0.2%, at 20°/35°C (16h/8h) in dark or light (18); co-applied, 0.2%, at 20°/35°C (16h/8h) in light (19,21); co-applied, 0.2%, then pre-chill, 10°C, 7d, germinate at 20°/35°C (16h/8h) in light (19)

Removal of seed covering structures: (8,21)

Scarification: concentrated sulphuric acid, 5-20,40 min (27)

Hydrogen peroxide: pre-applied, 24h, 100% (9)

Carbon dioxide: pre-applied, 7d, 5-50%, then warm stratification, 25°C, 7d, germinate at 25°/40°C (17h/7h), 7d (9)

Pre-soak: 5d, then pre-chill, 10°C, 7d (19); 5d, then pre-chill, 10°C, 7d, plus potassium nitrate, co-applied, 0.2%, at 20°/35°C (16h/8h) in light (19)

S. plumosum, S. stipoideum

Removal of seed covering structures: dehull, germinate at 30°C in light (12); dehull, plus potassium nitrate, co-applied, 0.2% (12)

GA_3: co-applied, 1000 ppm (12)

Pre-dry: (12)

S. verticilliflorum

Alternating temperatures: 15°/40°C (night/day), dark, in soil (25)

Scarification: mechanical, hand (25)

V. Successful dormancy-breaking treatments

S. almum

Pre-chill (ISTA,AOSA)

S. arundinaceum

Pre-chill (AOSA, ISTA)

Alternating temperatures: 30°/20°C (16h/8h) (13)

S. bicolor

Pre-chill (ISTA)

Pre-chill, test at 30°/45°C (20-22h/2-4h) (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (5,15,16); 30°/20°C (16h/8h) (13); 20°/35°C (16h/8h) (17)

Pre-chill: 10°C, 4-8d (5)

Warm stratification: 28°C, 5d, germinate at 20°/30°C (16h/8h), 5d (20)

Potassium nitrate: pre-applied, 24h, 0.1-1.0%, germinate at 20°/30°C (16h/8h) (22)

Removal of seed covering structures: dehusk, bisect, scratch, file, prick (5,6,7,24); excise embryo, germinate on 1.4% agar at 20°/30°C (16h/8h) (3)

S. halepense

Light, Potassium nitrate (AOSA)

Removal of seed covering structures: then germinate at 25°/40°C or 30°/45°C (22h/2h) (10); dehull, then scarification, concentrated sulphuric acid, 0.75-2 min (8)

Pre-soak: then dehull, scratch (8)

Scarification: concentrated sulphuric acid, 30 min, germinate at 20°/35°C (16h/8h) in light (26,27); concentrated sulphuric acid, 30 min, then potassium nitrate, co-applied, 0.2%, at 20°/35°C (16h/8h) in light (27)

Carbon dioxide: pre-applied, 7d, 50-60%, then warm stratification, 25°C, 7d, germinate at 25°/40°C (17h/7h), 7d (9)

Ether: pre-applied, 6d, 0.5, 1, 2%, then warm stratification, 25°C, 7d, germinate at 25°/40°C (17h/7h), 7d (9)

Mercuric chloride: co-applied, 0.012-0.05%, at 25°C, 7d, then 25°/40°C (17h/7h), 13d (9)

S. plumosum

GA_3: co-applied, 1000 ppm, dehulled seeds (12)

Sorghum 'sorgrass'

Pre-chill: (AOSA)

S. stipoideum

GA_3: co-applied, 1000 ppm, dehulled seeds (12)

VI. Comment

Removal of the seed coats prior to testing for germination is an unreliable dormancy-breaking procedure (6,7,14,22) and often results in heavy mould infection (22). For dormant seeds of S. bicolor pre-chill treatments are not completely successful in promoting germination (6,7,27), and the ISTA/AOSA prescribed alternating temperature regime of 20°/30°C (16h/8h) is inadequate unless additional treatments are imposed (3,4,7,24). Suggested improvements are to co-apply 0.2% potassium nitrate and test at 20°/30°C, 20°/35°C, 30°/20°C (16h/8h), or 30°/45°C (22h/2h) and remove seedcoats from firm seeds which have not germinated within the first 10 days in test. The AOSA recommendation for seeds of S. halepense, 0.2% potassium nitrate co-applied at 20°/35°C (16h/8h) in light, is not completely successful (18,19,21). As an additional treatment it has been suggested that the non-germinated seeds be dehulled after 4 days in test, and that the surface of non-germinated seeds be scratched after a further 3 days in test (8).

VII. References

1. Brown, E., Stanton, T.R., Wiebe, G.A., Martin, J.H. (1948). Dormancy and the effect of storage on oats, barley, and sorghum. U.S.D.A., Technical Bulletin, No. 953.

2. Casey, J.E. (1947). Apparent dormancy in sorghum seed. Newsletter of the Association of Official Seed Analysts, 21, 34-36.

3. Clark, L.E., Collier, J.W. and Langston, R. (1967). Dormancy in Sorghum bicolor (L.) Moench. I. Relationship to seed development. Crop Science, 7, 497-500.

4. Clark, L.E., Collier, J.W. and Langston, R. (1968). Dormancy in Sorghum bicolor (L.) Moench. II. Effect of pericarp and testa. Crop Science, 8, 155-158.

5. Gaber, S.D., Abdalla, F.H. and Mahdy, M.T. (1974). Treatments affecting dormancy in sweet sorghum seed. Seed Science and Technology, 2, 305-316.

6. Goodsell, S.F. (1957). Germination of dormant sorghum seed. Agronomy Journal, 49, 387-389.

7. Gritton, E.T. and Atkins, R.E. (1963). Germination of sorghum seed as affected by dormancy. Agronomy Journal, 55, 169-174.

8. Harrington, G.T. (1916). Germination and viability tests of Johnson grass seed. Proceedings of the Association of Official Seed Analysts, 9, 24-28.

9. Harrington, G.T. (1917). Further studies of the germination of Johnson grass seeds. Proceedings of the Association of Official Seed Analysts, 10, 71-76.

10. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

11. Marbach, I. and Mayer, A.M. (1979). Germination, utilization of storage materials and potential for cyanide release in cultivated and wild sorghum. Physiologia Plantarum, 47, 100-104.

12. Mott, J.J. (1978). Dormancy and germination in five native grass species from savannah woodland communities of the Northern Territory. Australian Journal of Botany, 26, 621-631.

13. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

14. Nutile, G.E. and Woodstock, L.W. (1967). The influence of dormancy-inducing desiccation treatments on the respiration and germination of sorghum. Physiologia Plantarum, 20, 554-561.

15. Robbins, W.A. and Porter, R.H., (1946). Germinability of sorghum and soybean seed exposed to low temperatures. Journal of the American Society of Agronomy, 38, 905-913.

16. Stanway, V. (1958). Prechilled vs. non-prechilled germination of Sorghum vulgare Pers. Proceedings of the Association of Official Seed Analysts, 48, 93-95.

17. Stanway, V. (1959). Germination of Sorghum vulgare Pers. at alternating temperature of 20°-30°C and 20°-30°C. Proceedings of the Association of Official Seed Analysts, 49, 84-87.

18. Taylorson, R.B. and McWhorter, C.G. (1969). Seed dormancy and germination in ecotypes of Johnson grass. Weed Science, 17, 359-361.

19. Tester, W.C. and McCormick, G. (1954). Germination of Johnson grass: results of tests made by the Arkansas State Plant Board. Proceedings of the Association of Official Seed

Analysts, 44, 96-99.

20. Ujiihra, K. (1982). [Studies on the preharvest sprouting of grain sorghum.] Bulletin of the Chugoku National Agricultural Experiment Station, A, 30, 1-33.

21. Weir, H.L. (1959). Germination of Johnson grass. Proceedings of the Association of Official Seed Analysts, 49, 82-83.

22. Wright, W.C. and Kinch, R.C. (1962). Dormancy in Sorghum vulgare Pers. Proceedings of the Association of Official Seed Analysts, 52, 169-177.

23. Andrew, M.H. and Mott, J.J. (1983). Annuals with transient seed banks: the population biology of indigenous sorghum species of tropical north-west Australia. Australian Journal of Ecology, 8, 265-276.

24. Burnside, O.C. (1965). Seed and phenological studies with shattercane. Nebraska Agricultural Experiment Station, Research Bulletin 220, 37 pp.

25. Huxley, P.A. and Turk, A. (1966). Factors which affect the germination of seeds of six common East African weeds. Experimental Agriculture, 2, 17-25.

26. Tao, K.-L.J. (1982). The 10-day germination test of Johnsongrass seeds. Newsletter of the Association of Official Seed Analysts, 56, 20-25.

27. Tao, K.-L.J. (1982). Improving the germination of Johnsongrass seeds. Journal of Seed Technology, 7, 1-9.

28. Taylorson, R.B. (1975). Inhibition of pre-chill-induced dark germination in Sorghum halepense (L.) Pers. seeds by phytochrome transformations. Plant Physiology, 55, 1093-1097.

29. Wilson, R.D. (1973). Characterization of the dormancy of the seed of wild cane (Sorghum bicolor (L.) Moench.). Dissertation Abstracts International B, 33, 5099.

STIPA

S. bigeniculata Hughes	
S. leucotricha Trin. & Rupr.	Texas needlegrass
S. speciosa Trin. & Rupr.	needle-grass
S. variabilis Hughes	corkscrew grass
S. viridula Trin.	green-needle grass

I. Evidence of dormancy

Deep dormancy has been reported in seeds of all Stipa spp. (1-7,9-14). After-ripening periods of one (5), four (7), five (8) and seven years (9) at laboratory temperatures have been required for dormancy to be removed.

II. Germination regimes for non-dormant seeds

S. viridula

TP: 15°/30°C (16h/8h): 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

S. leucotricha

Pre-chill: 5°C, 10°C, 5d (12); 5°C, 10°C, 5d, plus potassium nitrate, co-applied, 0.2% (12)

Thiourea: pre-applied, 20,40,60h, 0.5, 1% (12)

S. viridula

Removal of seed covering structures: glumes (10)

Light: $4x10^{-4}$ W m^{-2} s^{-1}, 8h/d (13); continuous, at 20°C (14)

IV. Partly-successful dormancy-breaking treatments

S. bigeniculata

Alternating temperatures: 10°/20°C, 15°/25°C, 20°/30°C (16h/8h) (5)

Pre-chill: 1°-2°C, 1m (5)

Potassium nitrate: co-applied, 0.2% (5)

GA_3: co-applied, 100, 1000 ppm (5); co-applied, 1000 ppm, plus kinetin, co-applied, 10^{-4} M (5) kinetin: co-applied, 10^{-4} M (5)

Removal of seed covering structures: lemma and palea (5)

Light: (5)

S. leucotricha

Alternating temperatures: 15°/25°C (16h/8h) in light in soil or sand (12)

Potassium nitrate: co-applied, 0.2% (12); co-applied, 0.2%, plus thiourea, co-applied, 0.1% (12)

S. speciosa

Constant temperatures: 15°C (11)

Alternating temperatures: 10°/15°C (16h/8h) (11); 0°-30°C/2°-35°C, 2°-25°/40°C (16h/8h) (11)

S. variabilis

Light: 6.5-7.5 W m^{-2}, continuous (6)

Removal of seed covering structures: lemma and palea (6)

S. viridula

Alternating temperatures: 15°/20°C, 20°/15°C, 15°/25°C, 25°/15°C, 20°/25°C, 25°/20°C (16h/8h) (13)

Pre-chill: 4°C, 3w (1); 2°-4°C, 20,60d (9); 2°-4°C, 1m (13); 5°C, 21d (14)

Potassium nitrate: co-applied, 0.2% (10)

Removal of seed covering structures: lemma and palea (1,2,3,13); seed coat, then pre-chill, 4°C, 3w (1); prick (1,2,10,13); prick, then pre-chill, 4°C, 3w (1); clip, plus GA_3, co-applied, 100 ppm, at 20°/15°C (16h/8h) in dark (13); clip, then pre-chill, 2°-4°C, 1m (13)

GA_3: co-applied, 100 ppm, at 20°/15°C (16h/8h) in dark (13) Light: dark (13,14)

Scarification: mechanical (10); concentrated sulphuric acid, 2.5, 10 min (1); concentrated sulphuric acid, 2.5 min, then pre-chill, 4°C, 3w (1)

Sodium hypochlorite: pre-applied, 1,3,5h, 3.2% (3)

Oxygen: pre-applied, 100%, 2.5,5,10d (3)

V. Successful dormancy-breaking treatments

S. bigeniculata

Removal of seed covering structures: slit lemma (5); slit palea (5); lemma and palea, then GA_3, co-applied, 100 ppm, at 20°/30°C (16h/8h) in light (5)

S. leucotricha

Alternating temperatures: 15°/25°C (16h/8h) in light, 56d, deglume, initially or after 42d (12)

S. viridula

Potassium nitrate, Pre-chill, Dark (AOSA)

Removal of seed covering structures: seed coat, then pre-chill, 4°C, 3w (1); excise embryo (10); lemma and palea, then prick (4)

Potassium nitrate: co-applied, 0.2%, plus pre-chill, 2°-4°C, 12w, germinate at 15°/30°C (16h/8h) (10)

VI. Comment

Light inhibits the germination of dormant and slightly dormant seeds of S. viridula (13,14) and consequently the AOSA germination prescription includes a specific note to test the seeds in the dark. The inhibition of seed germination by light probably also occurs in S. leucotricha because an increase in germination is observed when seeds are tested in sand or soil rather than on top of paper (12). Gibberellic acid, co-applied, generally promotes germination in dormant seeds of all Stipa spp., particularly when this treatment is combined with lemma and palea removal (5,13).

The AOSA procedures for testing dormant seeds of S. viridula are not satisfactory (10), but can be improved in part by increasing the pre-chill period from the 2 weeks recommended by the AOSA to 12 weeks (10). Thus the procedure suggested is to combine potassium nitrate, co-applied, 0.2%, with a pre-chill treatment at 5°C for up to 12 weeks and to germinate at 15°/30°C (16h/8h) in darkness. After 10 to 14 days in the subsequent germination test remove the glumes from ungerminated seeds and continue the test for a further 14 days.

VII. References

1. Dawson, M.D. and Heinrichs, D.H. (1952). The effects of various germination techniques to overcome dormancy in green needlegrass seed. Scientific Agriculture, 32, 266-271.

2. Fendall, R.K. and Carter, J.F. (1965). New-seed dormancy of green needlegrass (Stipa viridula Trin.). I. Influence of the lemma and palea on germination, water absorption and oxygen uptake. Crop Science, 5, 533-536.

3. Frank, A.B. and Larson, K.S. (1970). Influence of oxygen, sodium hypochlorite, and

dehulling on germination of green needlegrass seed (Stipa viridula Trin.). Crop Science, 10, 679-682.

4. Grabe, D.F. (1963). Reliability of firm seed determination as an index of viability. Proceedings of the Association of Official Seed Analysts, 53, 100-106.

5. Hagon, M.W. (1976). Germination and dormancy of Themeda australis, Danthonia spp., Stipa bigeniculata and Bothriochloa macra. Australian Journal of Botany, 24, 319-327.

6. Lodge, G.M. and Whalley, R.D.B. (1981). Establishment of warm- and cool-season native perennial grasses on the North-west slopes of New South Wales. I. Dormancy and germination. Australian Journal of Botany, 29, 111-119.

7. McAlister, D.F. (1943). The effect of maturity on the viability and longevity of the seeds of Western range and pasture grasses. Journal of the American Society of Agronomy, 35, 442-453.

8. McWilliams, J.L. (1950). Mechanical treatment and age of seed affect germination of Western grasses. Crops and Soils, 2, 27.

9. Rogler, G.A. (1960). Relation of seed dormancy of green needlegrass (Stipa viridula Trin.) to age and treatment. Agronomy Journal, 52, 467-469.

10. Wiesner, L.E. and Kinch, R.C. (1964). Seed dormancy in green needlegrass. Agronomy Journal, 56, 371-373.

11. Young, J.A. and Evans, R.A. (1980). Germination of desert needlegrass. Journal of Seed Technology, 5, 40-46.

12. Andersen, A.M. (1963). Germination of seed of Texas needlegrass, Stipa leucotricha. Proceedings of the Association of Official Seed Analysts, 53, 74-79.

13. Fulbright, T.E., Redente, E.F. and Wilson, A.M. (1983). Germination requirements of green needlegrass (Stipa viridula Trin.). Journal of Range Management, 36, 390-394.

14. Niffenegger, D. and Schneiter, A.A. (1963). A comparison of methods of germinating green needlegrass seed. Proceedings of the Association of Official Seed Analysts, 53, 67-73.

THEMEDA

T. australis (R. Br.) Stapf
T. triandra Forsk. rooigras

I. Evidence of dormancy

Deep dormancy has been reported in seeds of Themeda spp. (1,3,4), requiring after-ripening periods of between 2 and 11 months to remove dormancy from the above species (3,7).

II. Germination regimes for non-dormant seeds

T. australis

Constant temperatures: 25°-30°C (3)

Alternating temperatures: 25°/35°C (16h/8h) (4); 20°/30°C (16h/8h) (3,4)

T. triandra

Constant temperatures: 25°C (1)

Light: (5)

III. Unsuccessful dormancy-breaking treatments

T. australis

Pre-chill: 4°C, 28,56d (6)

Potassium nitrate: co-applied, 0.2% (4,6); co-applied, 0.2%, dehulled seeds (6)

Pre-wash: 24h (6)

Pre-dry: after imbibition, several cycles (6)

T. triandra

Zinc: co-applied, up to 5 ppm (1)

Cobalt: co-applied, up to 5 ppm (1)

Copper/manganese: co-applied, up to 5 ppm (1)

Iron: co-applied, up to 5 ppm (1)

Molybdenum: co-applied, up to 5 ppm (1)

Molybdenum plus nitrate: co-applied, up to 5 ppm (1)

Molybdenum plus ammonia: co-applied, up to 5 ppm (1)

Light: (5)

Polyethylene glycol 6000: co-applied, 0.1 M (5)

IV. Partly-successful dormancy-breaking treatments

T. australis

Alternating temperatures: 20°/30°C (16h/8h) (4); 20°/30°C in light, 5°/15°C, 10°/20°C, 30°/40°C (16h/8h) (3)

Pre-chill: 4°C, 2-12w (3)

GA_3: co-applied, 100 ppm (3,4,6); co-applied, 1000 ppm (4,6); co-applied, 100 ppm, plus kinetin, co-applied, 10^{-5} M (4)

Removal of seed covering structures: lemma and palea (4,6); lemma and palea, plus GA_3, co-applied, 100 ppm (4,6)

Light: continuous, 400 lux (4,6)

Pre-dry: 39°/16°C, diurnal cycle, 28d (4); 45°/20°C, diurnal cycle, 15-120d (3); 60°/20°C, diurnal cycle, 8m (6)

T. triandra

Pre-chill: 0°C (7)

GA_3: co-applied, 0.1-100 ppm (1); co-applied, 1-30 ppm (5); co-applied, 0.1, 10, 100 ppm, plus boric acid, co-applied, 0.05 ppm (1)

Boric acid/sodium borate: co-applied, 0.0037-3.7 ppm (1)

Removal of seed covering structures: lemma and palea (5); longitudinal slit, lower glume (5); lemma and palea, plus GA_3, co-applied, 1, 3 ppm (5)

Pre-dry: 30°-40°C (7)

Scarification: concentrated sulphuric acid, 10 min (7)

V. Successful dormancy-breaking treatments

T. australis

Pre-chill: 1°-2°C, 1m (4)

Pre-dry: 62°/24°C, diurnal cycle, 1m (4)

T. triandra

Boric acid: co-applied, 0.05 ppm (1,2); co-applied, 0.05 ppm, plus GA_3, 1 ppm, co-applied (1,2)

VI. Comment

It is suggested that non-dormant seed accessions of Themeda spp. be tested for germination on the top of filter papers at a constant temperature of 25°C or at an alternating temperature of 20°/30°C (16h/8h) for at least 14 days. Although a one month pre-chill treatment was fully effective in promoting the germination of dormant seeds of one seed lot of T. australis (4) it is not completely effective for other seed lots (3) and may even have no promotory effect at all in some lots (6). Potassium nitrate appears to be ineffective (4,6), but gibberellic acid can promote germination (1,4-6), particularly where the seeds have been dehulled (4-6) and when combined with a boric acid treatment (1,2).

VII. References

1. Cresswell, C.F. and Nelson, H. (1972). The effect of boron on the breaking, and possible control of dormancy of seed of Themeda triandra Forsk. Annals of Botany, 36, 771-780.

2. Cresswell, C.F. and Nelson, H. (1973). The influence of boron on the RNA level, alpha-amylase activities, and level of sugars in germinating Themeda triandra Forsk. seed. Annals of Botany, 37, 427-438.

3. Groves, R.H., Hagon, M.W. and Ramakrishnan, P.S. (1982). Dormancy and germination of seed of eight populations of Themeda australis. Australian Journal of Botany, 30, 373-386.

4. Hagon, M.W. (1976). Germination and dormancy of Themeda australis, Danthonia spp., Stipa bigeniculata, and Bothriochloa macra. Australian Journal of Botany, 24, 319-327.

5. Martin, C.C. (1975). The role of glumes and gibberellic acid in dormancy of Themeda triandra spikelets. Physiologia Plantarum, 33, 171-176.

6. Mott, J.J. (1978). Dormancy and germination in five native grass species from savannah woodland communities of the Northern Territory. Australian Journal of Botany, 26, 621-631.

7. West, O. (1951). The vegetation of Weenen County. Natal Mem. Bot. Surv. S. Afr. No. 23, Govt. Printer, Pretoria. (Cited by Cresswell & Nelson, 1972.)

TRITICALE

Triticale triticosecale triticale

I. Evidence of dormancy

As in other temperate cereals, post-harvest dormancy - stronger than that observed in rye and similar to that of wheat - has been reported in seeds of triticale (2,3).

II. Germination regimes for non-dormant seeds

TP; BP; S: 20°C: 8d (ISTA)

BP; S: 20°C; 15°C: 7d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 0°C (3)

Sodium chloride: co-applied, 0.5-3% (3)

Potassium chloride: co-applied, 0.5-3% (3)

Calcium chloride: co-applied, 0.5-3% (3)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 20°C (2); 5°C, 25°-40°C (3)

Alternating temperatures: 10°/20°C, 7d (2)

Pre-chill: 3°-5°C, 3d (2); 4°C, 2d (3)

GA_3: co-applied (2)

Ethephon: pre-applied, 24h 10-100 ppm (1)

V. Successful dormancy-breaking treatments

Pre-chill, GA_3 (ISTA)

Pre-chill, Pre-dry (AOSA)

Constant temperatures: 10°C, 21d (2); 10°-20°C (3)

Pre-chill: 4°C, 2d (3)

VI. Comment

A 21 day germination test at 10°C (2) or 10° to 12°C (A) is satisfactory for dormant accessions and is marginally superior to a 7-day pre-chill treatment at 3° to 5°C with a subsequent constant temperature germination test at 20°C (A). Moreover, the use of a low constant temperature for germination tests avoids the excessive fungal growth that can occur when seeds are tested at higher temperatures (2), particularly when this follows a pre-chill treatment (A).

VII. References

1. Bisaria, A.K. and Paliwal, N.K. (1981). Effect of ethephon on seed germination, seedling growth and sugars in triticale. Acta Botanica Indica, 9, 148-150.

2. Grzelak, K. and Szyrmer, J. (1980). Evaluation of the germination capacity and microflora of triticale seed. Hodowla Roslin Aklimatyzacja I Nasiennictwo, 24, 625-627.

3. Szabo, L.G. (1972). The germination physiology of triticale. Acta Agronomica Academiae Scientiarum Hungaricae, 21, 219-222.

TRITICUM

T. aestivum L. [T. sativum Lam.; T. vulgare Vill.]	common wheat
T. dicoccum Schrank [T. aestivum var dicoccum Bailey]	emmer
T. durum Desf.	durum wheat
T. monococcum L. [T. aestivum var monococcum Bailey]	einkhorn
T. polonicum L. [T. aestivum var polonicum Bailey]	Polish wheat
T. spelta L. [T. aestivum var spelta Bailey]	spelt
T. turgidum L.	English wheat, poulard wheat

I. Evidence of dormancy

Although lack of dormancy in modern wheats is often a problem (viviparous germination occurring if pre-harvest conditions are wet) dormancy in these and other Triticum spp. is often present (4-7,10-12,14-17,22), particularly in the primitive wheats (A).

II. Germination regimes for non-dormant seeds

T. aestivum

S; TP; BP: 20°C: 8d (ISTA)

S; BP: 15°C; 20°C: 7d (AOSA)

T. durum

S; TP; BP: 20°C: 8d (ISTA)

S; BP: 15°C; 20°C: 10d (AOSA)

T. spelta

BP; S: 20°C: 8d (ISTA)

III. Unsuccessful dormancy-breaking treatments

T. aestivum

Pre-soak: 20h (14); 1-5h (11)

Pre-dry: 35°C, 3d (3)

IV. Partly-successful dormancy-breaking treatments

T. aestivum

Constant temperatures: 15°C, 20°C (21); 20°C (22)

Alternating temperatures: 5°/30°C (16h/8h) (10)

Pre-chill: 10°C, 3,5d (3); 12°C, 7d (13,14); 5°C, 0.5,1.5,3d (21); 4°-6°C, 2d (9)

Pre-dry: 35°C, 3d, then pre-chill, 10°C, 5d (3); 40°C, 5d (11)

Potassium nitrate: pre-applied, 16h, 0.2% (3); co-applied, 0.2% (12,14)

GA_3: pre-applied, 16h, 4, 40, 400 ppm (3); pre-applied, 16,20h, 200, 400 ppm (9); co-applied, 100 ppm (14)

$GA_{4/7}$: pre-applied, 16h, 4, 40, 400 ppm (3)

Hydrogen peroxide: pre-applied, 16h, 1, 3% (3); pre-applied, 17h, 1%, then co-applied, 1%, at 20°C (23)

Removal of seed covering structures: prick, germinate at 20°C (23)

Thiourea: pre-applied, 0.25 M (4)

V. Successful dormancy-breaking treatments

T. aestivum, T. durum, T. spelta

Pre-chill, Pre-dry, GA_3 (ISTA)

Pre-chill, Pre-dry (AOSA)

Triticum spp.

Constant temperatures: 4°C (23); 5°C, 10°C (21); 7°-17°C (1); 10°C (5-7,10) 9°-16°C (11); 15°C (17); 12°-15°C (12); 6°-14°C (15,16); 7°C, 15°C (18); 10°-15°C (20)

Pre-chill: 4°-6°C, 4d (9); 5°C, 6d, germinate at 20°/30°C (18h/6h) (19)

Pre-dry: 35°C, 6d (3)

Potassium nitrate: co-applied, 0.2%, germinate at 15°C, dehulled seeds (12)

Oxygen: co-applied, 36% (11)

Scarification: concentrated sulphuric acid, 0.5-5 min (11)

Removal of seed covering structures: (7); pierce over embryo (4); excise one-eighth of endosperm at distal end (8,11); scratch embryo (11); prick, germinate at 4°C (23); prick, then hydrogen peroxide, co-applied, 1%, at 4°C (23)

Hydrogen peroxide: co-applied, 1%, at 4°C (23)

GA_3: pre-applied, 16h, 1000 ppm (3); pre-applied, 16,20h, 800 ppm (9); co-applied, 200 ppm (13); co-applied, 200-800 ppm (14); co-applied, 500 ppm (2); 0.1% (7); co-applied, $2x10^{-6}$ M, at 13°C (21)

$GA_{4/7}$: pre-applied, 16h, 1000 ppm (3)

Ethanol: pre-applied, 0.5-1% (7)

VI. Comment

Gibberellic acid is unsuitable as a practical dormancy breaking agent for gene banks since the response is variable from year to year and varies with cultivar and provenance (2,3). If the temperature regime of the germination test is suitable then the need for special dormancy-breaking treatments is considerably reduced. Although pre-chill treatments (3° to 5°C, 7 days) with subsequent testing at 20°C are widely applied in commercial seed testing (AOSA/ISTA), testing dormant seeds at a single, low, temperature throughout is more effective in promoting germination (A). This is particularly true for seeds of the primitive wheats T. monococcum and T. dicoccum (A). Temperatures as low as 5° to 7°C can be damaging to aged seeds (16) but marginally higher temperatures are very satisfactory (A).

From tests on 54 seed lots of a number of Triticum spp. over a wide range of temperatures (A) it is recommended that testing at 10°C for 21 days, or more, is a suitable regime for gene banks. A further advantage of such a regime is the avoidance of the fungal growth on caryopses which can occur in germinations tests at 20°C (A,11,20), particularly where the seeds first received a pre-chill treatment (A).

VII. References

1. Atterberg, A. (1907). Die Nachreife des Getreides. Landwirtsch Versuch Stat, 67, 129-143.

2. Bekendam, J. (1975). Report of the working group on the application of gibberellic acid in routine germination testing to break dormancy of cereal seeds. Seed Science and Technology, 3, 92-93.

3. Bekendam, J. and Bruinsma, J. (1965). The chemical breaking of dormancy of wheat seeds. Proceedings of the International Seed Testing Association, 30, 869-886.

4. Belderok, B. (1961). Studies on dormancy in wheat. Proceedings of the International Seed Testing Association, 26, 697-760.

5. Ching, T.M. and Foote, W.H. (1961). Post-harvest dormancy in wheat varieties. Agronomy Journal, 53, 183-186.

6. Corbineau, F., Sanchez, A., Côme, D. and Chaussat, R. (1981). La dormance du caryopse de blé (Triticum aestivum L., var. champlein) en relation avec la temperature et l'oxygène. Comptes Rendus de l'Academie d'Agriculture de France, 67, 826-834.

7. Fischnich, O., Thielebein, M. and Grahl, A. (1961). Sekundäre Keimruhe bei getreide. Proceedings of the International Seed Testing Association, 26, 89-114.

8. Fitzgerald, P.H. (1959). Germination induced by excision of the endosperm of immature wheat grains. New Zealand Journal of Agricultural Research, 2, 735-740.

9. Gáspar, S., Fazekas, J. and Pethö, A. (1975). Effects of gibberellic acid (GA_3) and prechilling on breaking dormancy in cereals. Seed Science and Technology, 3, 555-563.

10. George, D.W. (1967). High temperature seed dormancy in wheat (Triticum aestivum L.). Crop Science, 7, 249-253.

11. Harrington, G.T. (1923). Forcing the germination of freshly harvested wheat and other cereals. Journal of Agricultural Research, 23, 79-100.

12. Heit, C.E. (1948). Thirty-eighth annual meeting. Report of sub-committee on dormancy of seeds. Proceedings of the Association of Official Seed Analysts, 38, 25-26.

13. Kåhre, L., Kolk, H. and Fridz, T. (1965). Gibberellic acid for breaking of dormancy in cereal seed. Proceedings of the International Seed Testing Association, 30, 887-891.

14. Kåhre, L., Kolk, H. and Wiberg, H. (1962). Note on dormancy-breaking in seeds. (Cereals & Timothy). Proceedings of the International Seed Testing Association, 27, 679-683.

15. Munerati, M.O. (1925). Existe-t-il une après-maturation chez les céréales récemment recoltées? Comptes Rendus de l'Academie des Sciences, Paris, 181, 1081-1083.

16. Munerati, M.O. (1926). Possibilité de déterminer l'âge des graines de blé par la temperature de leur germination. Comptes Rendus de l'Academie des Sciences, Paris, 182, 535-537.

17. Munn, M.T. (1946). Germinating freshly harvested winter barley and wheat. Proceedings of the Association of Official Seed Analysts, 36, 151-152.

18. Robertson, L.D. and Curtis, B.C. (1967). Germination of immature kernels of winter wheat. Crop Science, 7, 269-270.

19. Whitcomb, W.O. (1923). Germination of newly threshed grain. Proceedings of the Association of Official Seed Analysts, 14, 84-88.

20. Wilson, H.K. and Hottes, C.F. (1927). Wheat germination studies with particular reference to temperature and moisture relationships. Journal of the American Society of Agronomy, 19, 181-190.

21. Gosling, P.G., Butler, R.A., Black, M. and Chapman, J.M. (1981). The onset of germination ability in developing wheat. Journal of Experimental Botany, 32, 621-627.

22. Mares, D.J. (1983). Preservation of dormancy in freshly harvested wheat grain. Australian Journal of Agricultural Research, 34, 33-38.

23. Teich, A.H. (1980). Germinating immature winter wheat seed. Cereal Research Communications, 8, 495-499.

ZEA

Z. mays L.	corn, indian corn, maize, popcorn
Z. mexicana (Schrad.) Kuntze [Euchlaena mexicana Schrad.]	teosinte

I. Evidence of dormancy

Although seeds of Z. mays can be dormant (3), seed dormancy is rarely a problem. Rather the problem in cultivated accessions of this species tends to be insufficient dormancy, resulting in viviparous germination. Dormancy is more likely to be present in Z. mexicana (1,2) and in seeds of the interspecific hybrids, however.

II. Germination regimes for non-dormant seeds

Z. mays

BP; S: 20°/30°C (16h/8h); 25°C; 20°C: 7d (ISTA)

BP; S: 20°/30°C (16h/8h); 25°C: 7d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Z. mays

Pre-soak: 24h (3)

Potassium cyanide: pre-applied, 24h, 10^{-3} M (3)

Sodium azide: pre-applied, 24h, 10^{-3} M (3)

Z. mexicana

Scarification: mechanical, with or without pericarp removal (2)

IV. Partly-successful dormancy-breaking treatments

Z. mays

Hydroxylamine hydrochloride: pre-applied, 24h, 10^{-3} M (3)

Z. mexicana

Pre-soak: 48h (2)

GA_3: pre-applied, 24h, 500 ppm (2)

V. Successful dormancy-breaking treatments

Z. mexicana

GA_3: pre-applied, 24h, 1000 ppm (2)

VI. Comment

Although it has been reported that Z. mays is non-light requiring (5), that is seed germination is neither promoted nor inhibited by light, there is evidence that under sub-optimal germination test conditions (high osmotica) light (continuous red, blue or far red) can inhibit germination (4). The ISTA/AOSA prescribed germination test conditions are satisfactory for non-dormant seeds (presumably the majority of accessions), although it may often be necessary to extend the test period to 14 or 21 days (A). Germination has been reported to be considerably reduced when pericarps have been removed from dormant seeds of Z. mexicana (2). This may indicate a sensitivity of the pericarp-less seeds to the imbibition environment or damage to the embryo - particularly the primary root - occurring during the physical removal of the pericarp.

VII. References

1. Beadle, G.W. (1977). The origin of Zea mays. In Origins of Agriculture (ed. C.A. Reed), pp. 623-643. Mouton, The Hague.

2. Mondrus-Engle, M. (1981). Tetraploid perennial teosinte seed dormancy and germination. Journal of Range Management, 34, 59-61.

3. Roberts, E.H. (1964). The distribution of oxidation-reduction enzymes and the effects of respiratory inhibitors and oxidising agents on dormancy in rice seed. Physiologia Plantarum, 17, 14-29.

4. Thanos, C.A. and Mitrakos, K. (1979). Phytochrome-mediated germination control of maize caryopses. Planta, 146, 415-417.

5. Toole, V.K. (1973). Effects of light, temperature and their interactions on the germination of

seeds. Seed Science and Technology, 1, 339-396.

ZIZANIA

Z. aquatica L. indian wild rice, squaw rice
Z. palustris L. wild rice

I. Evidence of dormancy

Zizania is one of only two genera within the Gramineae that have been provisionally classified as possessing recalcitrant seed by M.W. King and E.H. Roberts (The Storage of Recalcitrant Seed, IBPGR, Rome, 1979). However, this classification may be erroneous due to misinterpretation of its pronounced dormancy. Dormancy is a severe problem for growers and plant breeders (1,5,11,15). Full germination results only when extreme treatments are applied, viz. 3 to 7 months storage in water at 3°C (1,2,4-6,9,10,12,13,15). This dormancy-breaking treatment provides one of the main reasons why the seed has been thought to be recalcitrant. In a comparison of wet and dry storage no germination resulted after dry storage (10). However, no dormancy-breaking treatment was applied after dry-storage whereas the wet storage treatment was in itself a dormancy-breaking treatment. Hence the classification as a recalcitrant species may be erroneous: failure of the seed to germinate after dry storage may have resulted from dormancy - not death. The suspicion that the classification of Zizania spp. as recalcitrant may be erroneous is greatly strengthened by the observation that seeds of Z. palustris were not killed by pre-dry treatments (to break dormancy) at 40°C, 55°C, or 70°C for 24, 48, and 72 hours (18). Greater attention to seed dormancy in future experimentation will assist in the classification of seed storage behaviour in this genus.

II. Germination regimes for non-dormant seeds

Z. aquatica

Constant temperatures: 15°C, 20°C (13)

Alternating temperatures: 15°/30°C, 30d (3,13)

III. Unsuccessful dormancy-breaking treatments

Z. aquatica

Constant temperatures: 30°C (13)

Pre-soak: 1°-3°C, 60d (10); 1°-3°C, 90d (7,16); 25°C, 55°C, 4h (7); 30°C, 14,28d (3); 30°C, 14,28d, then pre-chill, 5°C, 28d (3)

Removal of seed covering structures: (5,8,13); puncture pericarp (5,13); pericarp at dorsal or ventral side (5)

GA_3: co-applied, 0.1, 5, 50, 500 ppm (13)

Kinetin: co-applied, 10^{-8} -$5x10^{-6}$ M (5)

Ethanol: pre-applied, 4h, 10% (7)

Storage: 1°-3°C, 20°C, dry, 2-7m (10) pH: 6-8.7 (13)

Z. palustris

Pre-soak: 3°C, 120d (12)

GA_3: pre-applied, 24h (12); co-applied, 0.1-500 ppm (18)

$GA_{4/7}$: pre-applied, 24h (12)

Isopentenyl adenine: pre-applied, 24h (12)

6-Benzyladenine: pre-applied, 24h (12)

Kinetin: pre-applied, 24h (12)

Thiourea: pre-applied (12)

Potassium cyanide: pre-applied (12)

Sodium oxide: pre-applied (12)

Sodium nitrate: pre-applied (12)

Ethanol: pre-applied, 24h, 43-95% (12); pre-applied, 8h, 86, 95% (12); pre-applied, 7h, 95% (12)

Sodium hypochlorite: pre-applied, 1,2h, 5.25% (12)

Thiamine: co-applied (18)

Potassium hydroxide: pre-applied, 12,24,36h, 60°C (18)

Removal of seed covering structures: hulls (18)

Ultrasonics: 20 kc s^{-1}, 15-25 min, at 25°-30°C, 45°-50°C (18)

IV. Partly-successful dormancy-breaking treatments

Z. aquatica

Alternating temperatures: 15°/30°C (2,3,13); 14°/24°C (8h/16h) (5); 15.5°/24°C (9h/15h) (11)

Pre-soak: 0°-25°C, 14,28d, then 5°C, 28d (3); 45°C, 50°C, 10 min-8h (7)

GA_3: co-applied, 10^{-8}-$5x10^{-6}$ M (5); co-applied, $5x10^{-6}$ M, plus kinetin, $5x10^{-6}$ M (5)

Removal of seed covering structures: pericarp over embryo or scrape (5,11)

Scarification: mechanical, shake with crushed granite, 5-100 min (11)

Ethanol: pre-applied, 4h, 25-100% (7)

Ultrasonic: 70-100 kc/s, 10,15 min in water at 25°C, 50°C, 50°-70°C (7)

Oxygen: low partial pressure in water (9); 0.35-1 ppm (14)

Z. palustris

Alternating temperatures: 23°/18°C (16h/8h) (12)

Removal of seed covering structures: dehull, scrape or puncture pericarp (1,12); dehull, scrape over embryo, then GA_3, co-applied, 1, 10, 100 ppm, plus thiamine, co-applied, 0.05, 0.1, 1 ppm (18)

Pre-soak: 3°C, 120d (1); 45°C, 2,4,6h, then GA_3, 1 ppm, plus thiamine, pre-applied, 48h, 0.1, 1 ppm (18)

Pre-dry: 40°C, 55°C, 70°C, 24,48,72h, then GA_3, 1 ppm, plus thiamine, 1 ppm, pre-applied (18)

Ethanol: pre-applied, 0.5-5h, 28-95% (12); pre-applied, 6,7h, 28-86% (12); pre-applied, 8h, 28-71% (12); pre-applied, 4 min, 95% (12); pre-applied, 95%, 15s, then chloroform, pre-applied, 1 min, then ethanol, pre-applied, 15s (12)

Acetone: pre-applied, 1 min (12)

6-Benzyladenine: pre-applied, 24h, $6x10^{-5}$-$5x10^{-4}$ M, with mechanically scarified seeds (12)

GA_3: pre-applied, 24h, $5x10^{-6}$-$5x10^{-3}$ M, with mechanically scarified seeds (12); $5x10^{-6}$-$5x10^{-3}$ M, plus 6-Benzyladenine, $6x10^{-5}$-$5x10^{-4}$ M, pre-applied, 24h, with mechanically scarified seeds (12)

Hydrogen peroxide: pre-applied, 2,8h, 2.5, 5, 10% (12)

Sodium hypochlorite: pre-applied, 1,2h, 0.65, 1.3, 2.6% (12)

V. Successful dormancy-breaking treatments

Z. aquatica

Pre-soak: 5°C, 28d (2); 2°C, 60d (15); 1°-3°C, 90d (5); 1°-3°C, 150-210d (4,6,10,13); 1°-3°C, 180d, low oxygen partial pressure (13); sub-zero in ice, 150-180d (9); 25°C, 30d, then pre-chill, 5°C, 30d, germinate at 15°/30°C (3)

Removal of seed covering structures: excise embryo, culture on agar (8); dehull, scrape pericarp over embryo (15,17); dehull, scrape pericarp over embryo, germinate at 27°C in light, 16h/d (16)

VI. Comment

For non-dormant seeds a 30 day test period on top of filter paper is sufficient for germination to occur (13). The only satisfactory procedure available at present to remove dormancy from seeds of Z. aquatica enclosed within covering structures is the 2 to 7 month pre-soak at about 3°C (1,2,4-6,9,10,12,13,15). Similar treatments do promote germination in seeds of Z. palustris, but they are not completely effective in removing dormancy (12). However, removal of the hulls and subsequently scraping the pericarp above the embryo is completely successful (15-17) or almost completely successful (1,5,11,12) in removing seed dormancy in both species. Of the various chemical treatments applied, $5x10^{-3}$ M gibberellic acid combined with $5x10^{-4}$ M 6-benzyladenine either co-applied or pre-applied (5,12) or 1 ppm gibberellic acid plus 0.1 ppm thiamine co-applied (18) further promote germination of seeds previously dehulled and scraped as described above. Finally, an alternating temperature regime of 14°/24°C (8h/16h) promotes the germination of a greater proportion of dormant seeds than a constant temperature of 21°C (5).

Consequently it is suggested that seeds of Zizania spp. be tested in an alternating temperature regime of 25°/15°C (16h/8h) for 28 days with either 1 ppm gibberellic acid and 0.1 ppm thiamine or $5x10^{-3}$ M gibberellic acid and $5x10^{-4}$ M thiamine co-applied after the lemmas and paleas have been removed: after 7 days in test scrape the pericarp above the embryo and prick those seeds which have not germinated.

VII. References

1. Albrecht, K.A., Oelke, E.A. and Brenner, M.L. (1979). Abscissic acid levels in the grain of wild rice. Crop Science, 19, 671-676.

2. Barton, L.V. (1939). Experiments at Boyce Thompson Institute on germination and dormancy in seeds. Scientific Horticulture, 7, 186-193.

3. Barton, L.V. and Crocker, W. (1948). Twenty years of seed research at Boyce Thompson Institute for Plant Research. Faber and Faber, London.

4. Brown, E. and Scofield, C.S. (1903). Wild rice: its use and properties. U.S.D.A., Bureau of Plant Industry Bulletin, No. 50, 1-24.

5. Cardwell, V.B., Oelke, E.A. and Elliott, W.A. (1978). Seed dormancy mechanisms in wild rice (Zizania aquatica). Agronomy Journal, 70, 481-484.

6. Duvel, J.W.T. (1906). The germination and storage of wild rice seed. U.S.D.A., Bureau of Plant Industry Bulletin, No. 90, 1-13.

7. Halstead, E.H. and Vicario, B.T. (1969). Effect of ultrasonics on the germination of wild rice (Zizania aquatica). Canadian Journal of Botany, 47, 1638-1640.

8. LaRue, C.D. and Avery, G.S. Jr. (1938). The development of the embryo of Zizania aquatica in the seed and in artificial culture. Torrey Botanical Club Bulletin, 65, 11-21.

9. Moyle, J.B. and Krueger, P. (1964). Wild rice in Minnesota. Minnesota Department of Conservation, Division of Game and Fish, Special publication No. 18. (Cited by Simpson (1966).)

10. Muenscher, W.C. (1936). Storage and germination of seeds of aquatic plants. Cornell University Agricultural Experiment Station Bulletin, No. 652, 1-17.

11. Oelke, E.A. and Albrecht, K.A. (1978). Mechanical scarification of dormant wild rice seed. Agronomy Journal, 70, 691-694.

12. Oelke, E.A. and Albrecht, K.A. (1980). Influence of chemical seed treatments on germination of dormant wild rice seeds. Crop Science, 20, 595-598.

13. Simpson, G.M. (1966). A study of germination in the seed of wild rice (Zizania aquatica). Canadian Journal of Botany, 44, 1-9.

14. Svare, C.W. (1960). The effects of various oxygen levels on germination and early development of wild rice. Minnesota Department of Conservation, Division of Game and Fish, Game Investment Report No. 3.

15. Woods, D.L. and Gutek, L.H. (1974). Germinating wild rice. Canadian Journal of Plant Science, 54, 423-424.

16. Campiranon, S. and Koukkari, W.L. (1977). Germination of wild rice, Zizania aquatica, seeds and the activity of alcohol dehydrogenase in young seedlings. Physiologia Plantarum, 41, 293-297.

17. Gutek, L.H. (1976). Studies toward a breeding program in wild rice. Dissertation Abstracts International B, 36, 4774.

18. Huang, C.- S. (1978). Cytological and agronomical studies on American wild-rice, Zizania

palustris, and its related species. Journal of the Agricultural Association of China, 103, 20-42.

ZOYSIA

Z. japonica Steud. Korean or Japanese lawn grass
Z. matrella (L.) Merr. [Agrostis matrella L.] Manila grass

I. Evidence of dormancy

Seeds of Z. japonica and Z. matrella are particularly dormant at harvest (1,2,5).

II. Germination regimes for non-dormant seeds

Z. japonica

TP: 35°/20°C (16h/8h): 28d (AOSA, ISTA)

Z. matrella

TP: 35°/20°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Z. japonica

Alternating temperatures: 20°/30°C (16h/8h) (3)

Pre-dry: 35°C, 7d (2)

GA_3: co-applied, 100 ppm (5)

Thiourea: co-applied, 0.2% (5)

Scarification: sulphuric acid, 5%, 5,10,20 min, dehulled seeds (3)

IV. Partly-successful dormancy-breaking treatments

Z. japonica

Alternating temperatures: 20°/35°C (16h/8h) (3,4); 20°/35°C, 10°/35°C, 35°/10°C, 35°/20°C (16h/8h) in light, higher temperature phase (2); 35°/30°C (16h/8h) in light, 8h/d (2); 30°/20°C (16h/8h) (5); 20°/30°C (16h/8h) in light (6); 32°/42°C (3)

Light: (5,6); 500-1100 lux, during higher temperature phase of diurnal alternating temperature regimes (2); red, 660 nm, 0-36 kW m^{-2}, 5-30 min (1)

Potassium nitrate: co-applied, 0.2% (2,3,5,6)

Scarification: potassium hydroxide (1); sodium hydroxide (1); sulphuric acid (6); sulphuric acid, 75%, 5,10,20 min (3); sulphuric acid, 75%, 20,30 min (4); concentrated sulphuric acid, 2,3,5 min (5); concentrated sulphuric acid, 2,3,5 min, then potassium nitrate, co-applied, 0.2%, at 20°/30°C (8h/16h) in light (5); concentrated sulphuric acid, 5 min, then potassium nitrate, co-applied, 0.2%, pre-chill, 3°-5°C, 6,12d, germinate at 20°/30°C (8h/16h) in light (5)

Removal of seed covering structures: (1,2,3); dehull, then scarify (3); apex of glumes and tip of caryopses (2); dehull, then potassium nitrate, co-applied, 0.2%, at 20°/35°C (16h/8h) (3)
Potassium nitrate: co-applied, 0.2%, at 35°/20°C (16h/8h) in light, 16h/d (2); co-applied, 0.2%, then pre-chill, 3°-5°C, 6,12d, germinate at 30°/20°C (16h/8h) in light (5)

Pre-dry: 35°C, 7d, then potassium nitrate, co-applied, 0.2%, at 20°/35°C (16h/8h) in light (2)

Z. matrella

Potassium nitrate: co-applied, 0.2% (3)

Scarification: sulphuric acid, 75%, 10 min (3)

Removal of seed covering structures: (3)

V. Successful dormancy-breaking treatments

Z. japonica

Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Removal of seed covering structures: dehull, scratch caryopses, plus potassium nitrate, co-applied, 0.2%, at 35°/20°C (16h/8h) in light, 16h/d (2)

Scarification: potassium hydroxide, 25 min, then light, low intensity, 48h (7)

Z. matrella

Light, Potassium nitrate (AOSA)

VI. Comment

The ISTA/AOSA recommendations for removing dormancy in Z. japonica are not completely successful in promoting seed germination (2). The procedure given above which combines four promotory factors was successful for partially dormant seeds (2). Pre-chill treatments were apparently unnecessary for such seed lots (2). However, with deeply dormant seeds an additional pre-chill treatment can be beneficial (5), but even then full germination may not be promoted (5).

VII. References

1. Ahn, B.J., Portz, H.L. and Preece, J. (1981). The role of seed coverings on the dormancy of Zoysia grass. Agronomy Abstracts, 73rd Annual Meeting, 123.

2. Colbry, V.L. (1970). Laboratory germination of Zoysia japonica seed. Proceedings of the International Seed Testing Association, 35, 417-425.

3. Forbes, I. Jr. and Ferguson, M.H. (1948). Effect of strain differences, seed treatment, and planting depth on seed germination of Zoysia spp. Journal of the American Society of Agronomy, 40, 725-732.

4. Lefebvre, C.L. (1942). Claviceps yanagawaensis in imported seed of Japanese lawngrass. Phytopathology, 32, 809-812.

5. Nakamura, S. (1962). Germination of grass seeds. Proceedings of the International Seed Testing Association, 27, 710-729.

6. Nutile, G.E. and Hackett, J.E. (1953). Germination of Zoysia japonica seed under laboratory conditions. Newsletter of the Association of Official Seed Analysts, 27, 20-21.

7. Anonymous (1982). U.S.D.A. discovers fast method of propagating Zoysia by seed. Golf

Course Management, 50, 115.

CHAPTER 40. JUGLANDACEAE

The Juglandaceae comprise roughly 40 tree species within six genera which provide edible nuts. The fruits are usually drupes containing a large seed (nut). Seed storage behaviour is orthodox, at least in the genera Carya and Juglans, despite many previous comments to the contrary.

SEED DORMANCY AND GERMINATION

The seeds can exhibit dormancy, which varies considerably between accessions from only slight to very pronounced. Pre-chilling, sometimes for long durations, is the usual treatment applied to promote seed germination. Detailed information is provided in this chapter for the genera Carya (including synonyms within Hicoria and Juglans) and Juglans (including synonyms within Wallia).

CARYA

C. aquatica (Michx.f.) Nutt. [Hicoria aquatica (Michx.f.) Britt.]	water hickory, bitter pecan, swamp hickory
C. cordiformis (Wangh.) K. Koch. [C. amara Nutt.; Hicoria cordiformis (Wagh.) Britt.;	bitternut, bitternut hickory, swamp
Hicoria minima (Marsh.) Britt.; Juglans cordiformis Wangh.]	hickory, pignut
C. glabra (Mill.) Sweet [C. ovalis (Wangh.) Sarg.; Hicoria glabra (Mill.) Britt.]	pignut hickory, oval pignut hickory, pignut, red hickory
C. illinoiensis (Wangh.) K. Koch. [C. olivaeformis Nutt.; C. pecan Engler & Graebn. not Nott.; Hicoria pecan (Marsh.) Britt.; Juglans illinoensis Wangh.]	pecan, sweet pecan
C. l aciniosa (Michx.f.) Loud. [C. sulcata Nutt.; Hicoria laciosa (Michx.f.) Sarg.;	big or bottom shellbark hickory, bigleaf
Hicoria acuminata Dipp.; Juglans laciosa Michx.f.]	shagbark hickory, kingnut
C. myristicaeformis (Michx.f.) Nutt. [Hicoria myristicaeformis (Michx.f.) Britt.]	nutmeg hickory, bitter water hickory, swamp hickory
C. ovata (Mill.) K. Koch. [C. alba Nutt.; Hicoria ovata Britt.; Juglans ovata Mill.]	shagbark hickory, little shellbark hickory, scalybark hickory, southern shagbark hickory
C. tomentosa Nutt. [C. alba K. Koch. not Nutt.; Hicoria alba Britt.; Juglans tomentosa Poir.]	mockernut hickory, big-b ud hickory, white- heart hickory, bullnut, hognut, mockernut

I. Evidence of dormancy

Despite comments to the contrary Carya spp. have orthodox seed storage characteristics (10), which means that they can be stored at low moisture contents, e.g. 5% (4), and low temperatures (4,8). Viviparous germination can occur in pecan (25) - suggesting that lack of dormancy might be more of a problem than dormancy. Dormancy can be present, however: it appears to be more pronounced in C. aquatica, C. cordiformis, C. glabra, C. laciniosa, C. myristicaeformis, C. ovata and C. tomentosa (4,5,7) than in the cultivated C. illinoensis. It is reported that varieties of the latter species which have originated from the Southern United States show no or only slight dormancy, whereas those which have originated from the Northern United States can show considerable dormancy (16,17). Even with apparently non-

dormant seed lots pecan germination can be delayed with only low proportions of the seeds germinating (6,12,16,17,19,23,24,27,30,31).

II. Germination regimes for non-dormant seeds

C. aquatica

Alternating temperatures: 21°/27°-32°C (night/day), 63d, in soil (5)

C. cordiformis

Alternating temperatures: 20°/30°C (night/day), 250d, in sand, peat, or soil (1,5)

C. glabra

Alternating temperatures: 20°/30°C (night/day), 30-45d, in sand, peat, or soil (1,5)

C. illinoensis

TP: 20°/30°C (16h/8h): 28d (AOSA)

Constant temperatures: 27°C (16,17); 30°C (6,8,14,27,28,29,31)

Alternating temperatures: 20°/30°C (night/day), 45-60d, in sand or peat, or between papers (1,5)

C. laciniosa

Alternating temperatures: 20°/30°C (night/day), 45-60d, in sand, peat, or soil (1,5)

C. myristicaeformis

Alternating temperatures: 20°/30°C (night/day), 60d, between papers (5)

C. ovata

TP: 20°/30°C (16h/8h): 28d (AOSA)

Alternating temperatures: 20°/30°C (night/day), 45-60d, between papers (1,5)

C. tomentosa

Alternating temperatures: 20°/30°C (night/day), 93d, in sand, peat, or soil (1,5)

III. Unsuccessful dormancy-breaking treatments

C. illinoensis

Pre-soak: (18); hot, 2,5 min (18)

Pre-wash: 3-12d (27)

X-rays: 50 kv, 10mA, 80 min (26)

Benzylaminopurine: pre-applied, 24th, 300 ppm (12)

Ammonium hydroxide: pre-applied, 1-10 min (18)

Ammonium sulphate: pre-applied (18)

Calcium phosphate: pre-applied (18)

Calcium nitrate: pre-applied (18)

Potassium chloride: pre-applied (18)

Potassium sulphate: pre-applied (18)

Sodium nitrate: pre-applied (18)

Sodium hydroxide: pre-applied, 1-10 min (18)

Sugar: pre-applied (18)

Ether: fumigate dry or imbibed seed (18)

Chloroform: fumigate dry or imbibed seed (18)

Nitric acid: fumigate dry or imbibed seed (18)

Scarification: concentrated sulphuric acid, 10s-3 min (2); sulphuric acid, 20s (18)

C. ovata

Removal of seed covering structures: part of shell (7)

IV. Partly-successful dormancy-breaking treatments

C. aquatica

Pre-chill: 0°-3°C, 90-150d, germinate at 20°/30°C (night/day) (1)

C. cordiformis

Pre-chill: 0°-7°C, 90-120d, germinate at 20°/30°C (night/day) (1); 0°-5°C, 90d, germinate at 20°/30°C (night/day) (5)

C. glabra

Pre-chill: 0°-5°C, 90-120d, germinate at 21°/27°C (night/day) (5)

C. illinoensis

Constant temperatures: 20°C (6,8,27,29,31); 25°C (27,29,31)

Pre-chill: 3°C, 30d, germinate at 20°/30°C (night/day) (4); 0°-5°C, 30d, germinate at 21°/32°C (night/day) (5); 4°C, 90d, germinate at 20°C (8); 3°-5°C, 2,4w (19); 0°-2°C (26); 4.5°C, 17, 100d, germinate at 20°C, 25°C (31); 0°-5°C, 30-90d, germinate at 20°/30°C (night/day) (5); 4°C, 30d, then benzylaminopurine, pre-applied, 24h, 300 ppm (12); 3°-7°C, 6w, then pre-soak, 5d (13); 3°-5°C, 2,4w, then GA_3, pre-applied, 24h, 100, 200 ppm (19)

Warm stratification: 6w, then pre-soak, 5d (13); 6w, then GA_3, pre-applied, 5d, 1000 ppm (13)

Pre-soak: 0.5-4d (30); 1d (12); 5d (13); 7d (25)

GA_3: pre-applied, 1d, 1000 ppm (12); pre-applied, 5d, 1000 ppm (13); pre-applied, 1d, 100, 200 ppm (19); co-applied, 1-1000 ppm, at 20°C (8)

Kinetin: co-applied, 1-50 ppm, at 20°C (8)

Ammonium hydroxide: pre-applied, 10-20s (18); fumigate, 1-4d (18)

Sodium hydroxide: pre-applied, 10-20s (18)

C. laciniosa

Pre-chill: 0°-5°C, 90-120d, germinate at 20°/30°C (night/day) (5)

C. myristicaeformis

Pre-chill: 0°-5°C, 60-120d, germinate at 20°/30°C (night/day), in light, 8h/d (5)

C. ovata

Constant temperatures: 17°-35°C (7)

Pre-chill: 3°C, 10°C, 1-5m (3); 3°C, 30d (4); 0°-5°C, 90-150d, germinate at 20°/30°C (night/day) in light, 8h/d (5)

C. tomentosa

Pre-chill: 0°-5°C, 90-150d, germinate at 20°/30°C (night/day) (1,5)

V. Successful dormancy-breaking treatments

C. aquatica

Pre-chill: 0°-5°C, 30-90d, germinate at 21°/27°-32°C (night/day) (5)

C. cordiformis

Pre-chill: 3°-5°C, 13w (10)

C. glabra

Pre-chill: 0°-7°C, 90-120d, germinate at 20°/30°C (night/day) (1)

C. illinoensis

Pre-chill (AOSA)

Constant temperatures: 30°C (6,8,14,27,28,29,31); 35°C (27,28,29)

Pre-chill: (2,9,18,21);1°-5°C, 30-60d (32); 3°C, 60-120d (4); 4°C, 60-90d (6); 2°-3°C, 8-20w (15); 0°-2°C, 2-12w, germinate at 27°C (16,17); 5°C, 1-14w (20); 7.5°C, 1-10w (22); 4°C, 3m (29); 4.5°C, 17,100d, germinate at 30°C (31); 3°-7°C, 30-90d, germinate at 20°/30°C (night/day) (1); 4°C, 30d, then pre-soak, 24h, germinate at 30°C, in light, 120 mol m^{-2} s^{-1}, 15h/d (12); 4°C, 30d, then GA_3 pre-applied, 24h, 1000 ppm, germinate at 30°C, in light, 120 mol m^{-2} s^{-1}, 15h/d (12); 3°-7°C, 6w, then GA_3, pre-applied, 5d, 1000 ppm (13)

Pre-soak: (20); 2-3d (16); 4-5d (11,14); 4-15d (2); 8d (30); 1w, then pre-chill, 0°-7°C, then germinate at 27°C, in light, 15h/d (25)

GA_3: pre-applied, 0.5-8d, 50-5000 ppm (30)

Oxygen: 100%, 5 min/d flush, germinate at 30°C (27)

Removal of seed covering structures: shell (23,24,27); break shell (23,24,27); excise embryo

(27-29)

Scarification: concentrated sodium hydroxide, 2-4 min (2); concentrated ammonium hydroxide, 2 min (2)

Ammonia: fumigation, 1-3d (2)

C. ovata

Pre-chill (AOSA)

Pre-chill: 3°-7°C, 90-150d, germinate at 20°/30°C (night/day) (1); 3°C, 60-150d (4)

VI. Comment

Pecan seed germination and dormancy have been reviewed recently elsewhere (9). Not only is pre-chilling at 3°-5°C an effective dormancy breaking treatment for seeds of Carya spp., but it is also reported to result in the prompt germination of apparently non-dormant seeds when subsequently transferred to a higher temperature for germination (6,13,15,16,17,20,22). The AOSA recommended pre-chilling treatments for C. illinoensis and C. ovata are 60 days at 3° to 5°C.

An alternating temperature regime of 20°/30°C has usually been provided for germination. High constant temperatures, 30°-35°C, may also promote full germination for seeds of C. illinoensis and C. ovata provided that the test is continued for a long enough period (7,8,14,27,28,29,31). Pre-application of gibberellins after pre-chilling can provide a further promotion of germination (12,13,19).

It is suggested that gene banks test seed of Carya spp. for germination at an alternating temperature of 20°/30°C (16h/8h) or at a constant temperature of 30°C for at least 28 days after first pre-chilling the seeds at 30°-5°C for: 30-60 days for C. illinoensis; 30-90 days for C. aquatica; 60-120 days for C. myristicaeformis; 90-120 days for C. cordiformis, C. glabra and C. laciniosa; or 90-150 days for C. ovata and C. tomentosa. Where these treatments are insufficient to promote full germination try a 1 to 5 day pre-application of GA_3 at 100-1000 ppm.

VII. References

1. Anonymous (1948). Carya Nutt. Hickory. In Woody-plant Seed Manual, pp. 109-111, USDA Forest Service, Miscellaneous Publication No. 654.

2. Bailey, J.E. and Woodroof, J.G. (1932). Propagation of pecans. Georgia Agricultural Experiment Station, Bulletin 172, 4-19.

3. Barton, L.V. (1936). Seedling production in Carya ovata (Mill.) K.Koch, Juglans cinera L., and Juglans nigra L. Contributions from the Boyce Thompson Institute, 8, 1-5.

4. Bonner, F.T. (1976). Storage and stratification recommendations for pecan and shagbark hickory. UDSA Forest Service, Tree Planter's Notes, 27, 3-5.

5. Bonner, F.T. and Maisenhelder, L.C. (1974). Carya Nutt. Hickory. In Seeds of woody plants in the United States, pp. 269-272, USDA Agriculture Handbook 450.

6. Caminada, P. (1979). Germination of the pecan nut. Zimbabwe Rhodesia Agricultural Journal, 76, 237-238.

7. Crocker, W., Thornton, N.C. and Schroeder, E.M. (1946). Internal pressure necessary to

break shells of nuts and the role of the shells in delayed germination. Contributions from the Boyce Thompson Institute, 14, 173-201.

8. Dimalla, G.G. and Van Staden, J. (1977). The effect of temperature on the germination and endogenous cytokinin and gibberellin levels of pecan nut. Zeitschrift für Pflanzenphysiologie, 82, 274-280.

9. Dimalla, G.G. and Van Staden, J. (1978). Pecan nut germination - a review for the nursery industry. Scientia Horticulturae, 8, 1-9

10. Gordon, A.G. and Rowe, D.C.F. (1982). Seed Manual for Ornamental Trees and Shrubs, Forestry Commission Bulletin 59, 132 pp. HMSO, London.

11. Impey, R.L. (1971). Pecan nut propagation and nursery practices. Citrus and Sub-Tropical Fruit Journal, 451, 29-30.

12. Knox, C.A. and Smith, R.H. (1981). A method for rapid seed germination of pecan. Pecan Quarterly, 15, 23-24.

13. Laiche, A.J. (1976). Growth evaluation studies of one year pecan seedlings of selected varieties, seed treatments and growing methods. Pecan South, 3, 358-361, 382.

14. Madden, G., Brison, F.R. and McDaniel, J.C. (1969). Pecans. In Handbook of North American Nut Trees (ed. R.A. Jaynes), pp. 163, 180. Northern Nut Growers Association, Knoxville, Tennessee.

15. Madden, G., Roberts, D. and Campbell, D. (1977). Stratification and chilling. Pecan Quarterly, 11, 9-10.

16. Madden, G.D. and Tisdale, H.W. (1975). Effects of chilling and stratification on nut germination of northern and southern pecan cultivars. HortScience, 10, 259-260.

17. Madden, G.D. and Tisdale, H.W. (1975). Study examines chilling on pecan germination. Pecan Quarterly, 9, 16-17.

18. McHatton, T.H. and Woodroof, J.G. (1927). Some factors influencing pecan germination. Proceedings of the American Society for Horticultural Science, 24, 125-129.

19. Nasr, T.A. and Hassan, E.M. (1975). Effect of duration of after-ripening and gibberellic acid on germination of seeds and growth of seedlings of pecan in Egypt. Scientia Horticulturae, 3, 217-221.

20. O'Barr, R.D. (1976). Germination study and seedling performancy. Pecan South, 3, 424-427.

21. Pammel, L.H. and King, C.M. (1921). Studies in the germination of some woody plants. Proceedings of the Iowa Academy of Sciences, 28, 273-282.

22. Sparks, D., Chapman, J.W. and Lockwood, D.W. (1974). Stratification promotes germination. Pecan Quarterly, 8, 13.

23. Sparks, D. and Pokorny, F.A. (1967). Effect of the shell on germination of pecan nuts Carya illinoensis, Koch cv. Stuart. HortScience, 2, 145-146.

24. Sparks, D. and Pokorny, F.A. (1967). Germination of Stuart pecan nuts as affected by mechanical scarification and shell removal. Proceedings of the South Eastern Pecan Growers Association, 63, 73-76.

25. Tedders, W.L. Calcote, V.R. and Payne, J.A. (1970). A method for rapid germination of pecan seed. Pecan Quarterly, 4, 11.

26. Traub, H.P. and Muller, H.J. (1934). x-ray dosage in relation to germination of pecan nuts. Botanical Gazette, 95, 702-706.

27. Van Staden, J. and Dimalla, G.G. (1976). Regulation of germination of pecan, Carya illinoensis. Zeitschrift für Pflanzenphysiologie, 78, 66-75.

28. Van Staden, J. and Dimalla, G.G. (1977). High temperature incubation increases germination. Pecan Quarterly, 11, 14-15.

29. Van Staden, J., Wolstenholme, B.N. and Dimalla, G.G. (1976). Effect of temperature on pecan seed germination. HortScience, 11, 261-262.

30. Wiggans, S.C. and Martin, L.W. (1961). The effect of gibberellic acid on germination and seedling growth of pecans. Proceedings of the American Society for Horticultural Science, 77, 295-300.

31. Wolstenholme, B.W. (1974). Effect of stratification and temperature on germination of pecan nuts. Citrus and Sub-Tropical Fruit Journal, 489, 9-10.

32. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

JUGLANS

J. ailantifolia Carr. [J. sieboldiana Maxim.; J. cordiformia var ailantifolia (Carr.) Rehd.]	siebold walnut
J. californica S. Wats.	California walnut
J. cinera L. (Wallia cinerea (L.) Alef.]	butternut, oilnut, white walnut
J. hindsii Jeps. [J. californica var hindsii Jeps.]	Hinds walnut, Hinds black walnut
J. honorei	
J. major (Torr.) Heller [J. rupestris Engelm. var major Torr.]	Arizona walnut, Arizona black walnut
J. microcarpa Berlandier [J. nana Engelm.; J. rupestris Engelm. ex Torr.]	little walnut, Texas black walnut, nogal, river walnut
J. nigra L. [Wallia nigra (L.) Alef.]	black walnut
J. pyriformis	
J. regia L.	Persian walnut, English walnut

I. Evidence of dormancy

Seeds of all Juglans spp., which - despite some doubt in the literature - do show orthodox seed storage characteristics (9), can show pronounced dormancy (1,4,6,15).

II. Germination regimes for non-dormant seeds

J. cinera

Alternating temperatures: 20°/30°C (night/day), in sand, peat or soil, in light (4)

J. hindsii

Alternating temperatures: 20°/30°C (night/day), in sand, peat or soil (1,4)

J. major

Alternating temperatures: 20°/30°C (night/day), in sand, peat or soil, in light (4)

J. microcarpa

Alternating temperatures: 20°/30°C (night/day), in sand, peat or soil (4)

J. nigra

Alternating temperatures: 20°/30°C (night/day), in sand, peat or soil in light (1,4)

J. regia

Alternating temperatures: 20°/30°C (night/day), in sand, peat or soil (1,4)

III. Unsuccessful dormancy-breaking treatments

J. nigra

Warm stratification: 20°C, 45d (7)

GA_3: co-applied, 50-400 ppm (5)

Cycocel: co-applied, up to 1000 ppm (5)

Pre-soak: 5d (6)

IV. Partly-successful dormancy-breaking treatments

J. ailantifolia

Pre-soak: 10d (4)

J. californica

Pre-chill: (1); 1°-5°C, 156d (4); 1°-3°C, 5-6m (14)

J. cinera

Pre-chill: 3°-7°C, 90-120d (1); 3°C, 10°C, 4m (3); 1°-5°C, 90-120d (4); 1°-3°C, 5-6m (14)

Warm stratification: 60d, then pre-chill, 3°-7°C, 90-120d (1)

Removal of seed covering structures: part of shell over radicle, germinate at 20°C, 25°C (7)

J. hindsii

Pre-chill: (1); 1°-5°C, 156d (4); 1°-3°C, 5-6m (14)

J. honorei

Pre-chill: 1°-3°C, 5-6m (14)

J. major

Pre-chill: 5°-7°C, 90d (1); 1°-5°C, 120-190d (4)

J. microcarpa

Pre-chill: 1°-5°C, 190d (4); 1°-3°C, 5-6m (14)

J. nigra

Pre-chill; (6,12); 3°-10°C, 60-120d (1); 0°C, 10°C, 5m (3); 1°-5°C, 90-120d (4); 3°-5°C, 7°-10°C, 4m (6); 6°C, 15-100d (7); 1°-3°C, 5-6m (14)

Warm stratification: 19°-24°C, 4m (6); 20°C, 90d (7); 20°C, 45,90d, then pre-chill, 6°C, 15-100d (7)

Ethrel: co-applied, 100 ppm (5)

J. pyriformis

Pre-chill: 1°-3°C, 5-6m (14)

J. regia

Pre-chill: 5°C, 30-60d (1); 0°C, 1-6w (11); 1°-3°C, 5-6m (14)

Ethrel: pre-applied, 24h, 500-1500 ppm (16)

Thiourea: pre-applied, 24h, 500-1500 ppm (16)

Pre-soak: imbibe under vacuum (10)

Juglans spp.

Alternating temperatures: 5°/15°C, 15°/25°C (2)

Pre-wash: 7d (13)

V. Successful dormancy-breaking treatments

J. ailantifolia

Pre-chill: 1°-3°C, 5-6m (14)

J. cinera

Pre-chill: 3°C, 10°C, 2m (3)

Removal of seed covering structures: part of shell over radicle, germinate at 30°C, 35°C (7)

J. major

Pre-chill: 1°-3°C, 5-6m (14)

J. nigra

Constant temperatures: 15°C (7)

Pre-chill: 1°-5°C, 12-20w (9); 3°C, 10°C, 1-4m (3); 3°-5°C, 90-120d (17)

Warm stratification: 21°C, 1-2m, then pre-chill, 3°C, 10°C, 2m (3)

Removal of seed covering structures: part of shell over radicle, germinate at 6°-28°C (7)

J. regia

Pre-chill: 1°-5°C, 30-156d (4); 1°-5°C, 12-20w (9); 2°C, 6-8w (8); 0°C, 7,8w (11)

Juglans spp.

Pre-chill: 3°-5°C, 100-110d (13)

VI. Comment

Prolonged pre-chill treatments are required for breaking seed dormancy in Juglans spp. (1,3,4,6,7,9,14,17), whilst the removal of a small part of the shell over the radicle promotes prompt germination (7). Husks should be removed from the fruits before they dry (9). It is suggested that pre-chill treatments will be required for virtually all accessions of Juglans spp. maintained in gene banks. For most accessions 5 months pre-chilling at 3°-5°C may be required, but for accessions of J. nigra and J. regia 3 months pre-chilling may be satisfactory. Subsequent germination tests should be carried out in an alternating temperature regime of 20°/30°C (16h/8h) either on moist sand or between paper towels; the removal of a small part of the shell from the imbibed, pre-chilled, seeds may reduce the time taken to germinate.

VII. References

1. Anonymous (1948). Juglans L. Walnut. In Woody-Plant Seed Manual, pp. 201-204, USDA Forest Service, Miscellaneous Publication No. 654.

2. Baillon, H. (1882). Germination of walnut and almond. Botanical Gazette, 7, 91-92.

3. Barton, L.V. (1936). Seedling production in Carya ovata (Mill.) K.Koch., Juglans cinerea L., and Juglans nigra L. Contributions from the Boyce Thompson Institute, 8, 1-5.

4. Brinkman, K.A. (1974). Juglans L. Walnut. In Seeds of Woody-plants in the United States, pp. 454-459. United States Department of Agriculture, Agriculture Handbook No. 450.

5. Casini, E. and Salvadori, S. (1975/1976). [Observations and research on the use of various growth regulators in the germination of seeds of fruit trees.] La Nuova A.O.P.I., Dicembre 1975/Giugno 1976, 22pp. (From Horticultural Abstracts, 1977, 47, 12022.)

6. Chase, S.B. (1947). Eastern black walnut germination and seedbed studies. Journal of Forestry, 45, 661-668.

7. Crocker, W., Thornton, N.C. and Schroeder, E.M. (1946). Internal pressure cessary to break shell of nuts and the role of shells in delayed germination. Contributions from the Boyce Thompson Institute, 14, 173-202.

8. Forde, H.I. (1975). Walnuts. In Advances in Fruit Breeding (eds. J. Janick and J.N. Moore), pp. 439-455, Purdue University Press, West Lafayette, Indiana.

9. Gordon, A.G. and Rowe, D.C.F. (1982). Seed manual for Ornamental Trees and Shrubs, Forestry Commission Bulletin 59, 132 pp. HMSO, London.

10. Gutenev, V.I. and Bogoroditskii, I.I. (1975). [An effective new method.] Sadovodstvo, 12, 13-14. (From Horticultural Abstracts, 1976, 46, 8935.)

11. Martin, G.C., Mason, M.I.R. and Forde, H.I. (1969). Changes in endogenous growth substances in the embryos of Juglans regia during stratification. Journal of the American Society for Horticultural Science, 94, 13-17.

12. Matton, W.R. and Reed, C.A. (1924). Black walnut for timber and nuts. USDA Farmer's Bulletin No. 1392, 30 pp.

13. Mémmédov, B.A. (1976). [Preparation of walnut seeds for sowing.] Temat. sb. Tr. Azerb.

NII Sadovodstva, Vinogradarstva i subtrop. Kul'r, 9, 23-28. (From Horticultural Abstracts, 1977, 47, 11233.)

14. Muenscher, W.C. and Brown, B.I. (1944). Storage and germination of nuts of several species of Juglans. Northern Nut Growers Association Annual Report, 34, 61-62.

15. Sharma, S.D. and Chauhan, J.S. (1981). Effect of shell thickness on seed germination and growth of seedlings obtained from the nuts of seedling walnuts. South Indian Horticulture, 29, 87-89.

16. Sinha, M.M., Pal, R.S. and Koranga, D.S. (1977). Studies in the seed germination of walnut (Juglans regia L.). Progressive Horticulture, 8, 69-74.

17. Williams, R.D. (1980). Period in stratification hastens germination of black walnut seed. Proceedings of the Indiana Academy of Science, 89, 94.

CHAPTER 41. LABIATAE

The Labiatae comprise about 3000 species of herbaceous plants and shrubs within 160 genera which provide edible roots (e.g. Coleus tuberosus Benth.), flavourings, oils and medicines. The fruits comprise one-seeded nutlets and seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

The seeds (nutlets) generally exhibit dormancy: promotory treatments include a low germination test temperature or pre-chilling, alternating temperatures and, possibly, light. B.R. Atwater classifies seed morphology of the non-endospermic seeds into two groups: axile foliar embryos with thin, mucilaginous seed coats; and axile foliar embryos with woody seed coats and an inner semi-permeable layer. The exocarp may persist with the seeds. See Table 17.2, Chapter 17 for more information on these categories. Detailed information on seed germination is provided in this chapter for the genera Lavandula, Mentha, Ocimum, Origanum, and Salvia. Other recommended germination test procedures and dormancy-breaking treatments are summarised in Table 41.1. In addition the algorithm below may be helpful in developing germination test procedures for the more difficult accessions and other species.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 16°C, 21°C and 26°C with light applied for 12h/d.

If one of these regimes does not result in full germination then the second step of the algorithm is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test in the most successful regime determined from a comparison of the results of step one.

If this does not result in full germination then the third step of the algorithm is to chip the seeds and then test in the most successful regime determined from a comparison of the results of the steps one and two.

If this does not result in full germination then the fourth step of the algorithm is to test seeds at alternating temperatures of 23°/9°C (12h/12h) and 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature in each cycle for both regimes: co-apply 7×10^{-4} M GA_3 to the germination test substrate if a comparison of the results of steps one and two indicate this may be worthwhile; and chip the seeds before testing if a comparison of the results of step three with those of steps one and two indicates this may be worthwhile. Some experimentation with these conditions may be worth trying. For example, a different GA_3 concentration may be advantageous.

If full germination has not been promoted, the fifth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regime applied so far in the algorithm, then experiment with modifications to the

above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided for the five genera in this chapter and from Table 41.1.

TABLE 41.1 Summary of germination test recommendations for species within the Labiatae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Coleus blumei Benth.	TP; BP	20°/30°C; 20°C	21d	light	ISTA
	TP	20°/30°C	12d	light, avoid cool temperatures	AOSA
		20°/30°C	21d	light	Atwater
Galeopsis segetum Neck.	TP; BP	20°/30°C; 20°C	21d	pre-chill, scratch hard seeds	ISTA
Hyssopus officinalis L.	TP; BP	20°/30°C; 20°C	14d	light	ISTA
Leonurus cardiaca L.	TP	20°/30°C	42d	pre-chill	ISTA
Marrubium vulgare L.	TP	20°/30°C	21d	pre-chill	ISTA
	TP	20°/30°C		light	M&O
	TP	20°/30°C	21d	light reported to be inhibitory	Heit
Melissa officinalis L.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
	TP	20°/30°C	21d	light	AOSA/Heit
Molucella laevis L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP; BP	10°/30°C	21d	light, ensure good moisture supply	AOSA
		15°/30°C	4d	excise embryos	Atwater
		15°/30°C		activated charcoal, pre-soak, GA, 400ppm	Atwater
Nepeta cataria L.	TP; BP	20°/30°C; 20°C	28d	pre-chill	ISTA
	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	continue test for a further 5d if (reversible)	AOSA
				hard seeds have begun to imbibe	
	TP	20°/30°C	21d	hard seeds present	Heit
Perilla frutescens (L.) Britt.	TP; BP	20°/30°C; 20°C	21d	pre-chill	ISTA
Prunella vulgaris L.	TP	20°/30°C			M&O
Rosmarinus officinalis L.	TP	20°/30°C; 20°C	28d		ISTA
	TP	15°C	28d	light	AOSA
	TP	20°C	21d		Heit
Satureja hortensis L.	TP	20°/30°C	21d		ISTA
	BP	20°/30°C	21d		AOSA
	TP	20°C	14d		Heit
Stachys grandiflora Benth.	TP	20°C	14d		ISTA
Thymus serpyllum L.	TP; BP	20°/30°C; 15°C; 20°C	21d	light	ISTA
	TP	15°C	14d	light	AOSA

Thymus vulgaris L.	TP	20°/30°C; 20°C	21d		ISTA
	BP	14°C	21d		AOSA
	TP	15°C	21d		Heit

LAVANDULA

L. angustifolia Mill. [L. officinalis Chaix; L. spica L.; L. vera DC.] lavender

I. Evidence of dormancy

Lavender seeds can show considerable dormancy (3,4,7).

II. Germination regimes for non-dormant seeds

TP; BP; S: 20°C; 20°/30°C (16h/8h): 21d (ISTA)

BP: 20°/30°C (16h/8h); 20°C; 15°C: 35d (ISTA)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 20°C in light (7)

Alternating temperatures: 10°/30°C (16h/8h) in light (7); 15°/25°C (16h/8h) in light, 28d (1)

Scarification: sulphuric acid (2)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 10°/30°C (16h/8h), dark (7); 20°/30°C (16h/8h) in light (3,7)

Pre-chill: 5°C, 30d, germinate at 10°/30°C (16h/8h) in light or dark (7); 3°-5°C, 7-35d (4)

Potassium nitrate: co-applied, 0.2%, at 15°/25°C (16h/8h) in light, 28d (1)

GA_3: pre-applied, 24h, 100, 1000 ppm (6); pre-applied, 500-2000 ppm (8); co-applied, 25-100 ppm (3); co-applied, 200 ppm, at 10°/30°C (16h/8h) in light or 20°C in light (3); co-applied, 400 ppm (3); co-applied, 200 ppm, plus pre-chill, 3°-5°C, 7-35d (4); co-applied, 100 ppm, at 20°/30°C, 10°/30°C (16h/8h) in light (7); co-applied, 100, 200 ppm, at 10°/25°C (16h/8h) in light (7); co-applied, 400 ppm, at 15°/25°C (16h/8h) in light, 28d (1)

Fusicoccin: pre-applied, 24h, 5 ppm (6)

Ultrasonics: 830 kc, then GA_3, co-applied, 10 ppm (2)

V. Successful dormancy-breaking treatments

Pre-chill, GA_3 (ISTA)

GA_3: co-applied, 200 ppm, at 20°/30°C (16h/8h) in light, 2 W m^{-2} (3,4); co-applied, 200 ppm, at 20°/30°C (16h/8h) in light or at 20°C in light (7)

VI. Comment

The following procedure has been reported to break dormancy completely in seeds of L. angustifolia: test for germination in an alternating temperature regime of 20°/30°C (16h/8h) with light applied at 2 W cm^{-2} (at the seed surface) for 8 hours per day during the higher temperature phase of each diurnal cycle with GA co-applied at 200 ppm (3,4,7). A 56 day, or

longer, test may be necessary. Since some accessions may contain large numbers of empty seeds it has been suggested that all non-germinated seed-like structures be dissected at the end of each germination test (5).

VII. References

1. Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technology, 8, 523-573.

2. Cen, E.-Z. and Van, V.-C. (1965). [Trials on the propagation and cultivation of Lavandula vera.] Sborn. Statej. Introd. Akklim. Rast., Peking, 71-85. (From Horticultural Abstracts, 1967, 37, 7611.)

3. Chavagnat, A. (1978). Etude de la germination des semences de Lavandula angustifolia au laboratoire. Seed Science and Technology, 6, 775-784.

4. Chavagnat, A. (1978). Lavender seed dormancy and germination. Acta Horticulturae, 83, 147-154.

5. Laza, A. and Raianu, M. (1965). [A study on the germination of Lavandula angustifolia seed.] An. Inst. Cerc. Cereale Plante tehn., Fundulea, Ser. C, 33, 379-385. (From Horticultural Abstracts, 1968, 38, 6315.)

6. Menghini, A. and Venanzi, G. (1978). [The effect of growth regulators on the germination of seeds of various medicinal plants.] Annali della Facolta di Agraria, Perugia, 32, 771-783. (From Horticultural Abstracts, 1980, 50, 4582.)

7. Renard, H.A. and Clerc, P. (1978). Leveé de dormance par les gibberellines chez quatre espéces: Impatiens balsamina, Lavandula angustifolia, Brassica rapa et Viola odorata. Seed Science and Technology, 6, 661-677.

8. Ruminska, A., Suchorska, K. and Weglarz, Z. (1978). Effect of gibberellic acid on seed germination of some vegetable and medicinal plants. Acta Horticulturae, 73, 131-136. (From Horticultural Abstracts, 1979 49, 1458.)

MENTHA

M. aquatica L.
M. arvensis L. mint
M. piperita L. peppermint

I. Evidence of dormancy

Mint shows orthodox seed storage behaviour (3). Dormancy has been reported in freshly harvested seeds of M. aquatica and M. arvensis (2-4).

II. Germination regimes for non-dormant seeds

M. piperita

TP: 20°/30°C (16h/8h): 21d (ISTA)

TP: 20°/30°C (16h/8h): 16d (AOSA)

III. Unsuccessful dormancy-breaking treatments

M. aquatica, M. arvensis

Light: dark (2)

IV. Partly-successful dormancy-breaking treatments

M. aquatica

Light: light, diffuse light (2)

M. arvensis

Alternating temperatures: (2,3,4)

Pre-chill: (3); 2°C (4); 5°C (2)

Light: light, diffuse light (2); 1.846×10^{-3} W cm^{-2} (4)

V. Successful dormancy-breaking treatments

M. piperita

Pre-chill, Potassium nitrate (ISTA)

Light (AOSA)

Mentha spp.

Alternating temperatures: 15°/25°C (16h/8h), light, 28d (1)

VI. Comment

Alternating temperatures and light are required for the germination of seeds of Mentha spp. (1-4): an amplitude of 4.5°C has been reported to be partly-successful in breaking dormancy (4). It is suggested that the seeds of all Mentha spp. be tested for germination as recommended by the ISTA for M. piperita, that is on top of moist filter papers in light in an alternating temperature regime of 20°/30°C (16h/8h), with the additional suggestion that pre-chilling be used if the above regime does not promote germination sufficiently.

VII. References

1. Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous ornamental plants. Seed Science and Technology, 8, 523-573.

2. Grime, J.P., Mason, G., Curtis, A.V., Rodman, J., Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. Journal of Ecology, 69, 1017-1059.

3. Ikeda, N., Udo, S., Saisho, I. and Minakata, S. (1960). [Studies on the storage of mint seed.] Science Reports of the Faculty of Agriculture, Okayama, 16, 1-5.

4. Thompson, K., Grime, J.P. and Mason, G. (1977). Seed germination in response to diurnal fluctuations of temperatures. Nature, 267, 147-149.

OCIMUM

O. basilicum L. [O. americanum L.] sweet basil

O. canum

O. gratissimum

O. kilimandscharicum Guerke

O. tenuiflorum L. [O. sanctum L.]

I. Evidence of dormancy

Seeds of Ocimum spp. exhibit dormancy when tested for germination in the dark with germination being promoted by light (1,5,6). Secondary dormancy can be induced by prolonged, 10 to 20 days, dark imbibition treatments at 26°C (1,5).

II. Germination regimes for non-dormant seeds

O. basilicum

TP: 20°/30°C (16h/8h): 14d (ISTA)

BP: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

O. basilicum

Light: dark, at 25°C (5); dark, at 28°C, intact or scarified seeds (6); far red, 5 min (5); dark, 25°C, 10d, then light, 25°C (5); white, 35 W m^{-2}, 10 min-5h/d, after 48h dark, at 28°C (6)

O. tenuiflorum

Light: dark, at 14°-38°C (1); dark, at 22°C (2); red, 10 min, at 14°C (1); blue, 5h, at 26°C (1); dark, 26°C, 20,25d, then red, 10 min, germinate at 26°C (1)

GA_3: co-applied, 10^{-4} M, at 14°C, in light, red, 10 min, or dark (1); co-applied, 25, 50 ppm, at 22°C in light, 12h/d (2)

Kinetin: co-applied, 50, 100 ppm, at 22°C in light, 12h/d (2)

Ethrel: co-applied, 100, 200 ppm, at 22°C in light, 12h/d (2)

Boric acid: co-applied, 50, 75 ppm, at 22°C in light, 12h/d (2)

Ascorbic acid: co-applied, 25, 50 ppm, at 22°C in light, 12h/d (2)

Potassium nitrate: co-applied, 25, 50 ppm, at 22°C in light, 12h/d (2)

Storage: hermetic, dry, at -11°C, 8°C, 30°C, or 37°C, 7-30d (2)

IV. Partly-successful dormancy-breaking treatments

O. basilicum

Alternating temperatures: 15°/10°C, 18°/13°C, 21°/16°C, 33°/28°C, 36°/31°C (8h/16h) (7)

Warm stratification: 15°C, 1d, germinate at 25°C, dark (5)

Light: white, 10s-5 min, after 10h dark imbibition, germinate at 25°C in dark (5); white, 5 min, after 1-5d dark imbibition (5); red, 5 min, after 10h dark imbibition (5); white, 35 W m^{-2}, 5,8,24h/d, at 28°C (6); far red, 5.5 W m^{-2}, 6-11h/d, at 28°C (6)

Removal of seed covering structures: testa (5)

Scarification: sand paper, germinate at 28°C in light, 5, 13h/d (6)

O. tenuiflorum

Constant temperatures: 26°C, 32°C, light (1)

Warm stratification: 14°C, dark, 4d, germinate at 26°C, red light, 10 min (1); 14°C, dark, 12h, then red light, 10 min, then dark, 4d, germinate at 26°C in dark (1); 38°C, dark, 4d, germinate at 26°C, red light, 10 min (1); 38°C, dark, 12h, then red light, 10 min, then dark, 4d, germinate at 26°C in dark (1); 26°C, dark, 5-15d, germinate at 26°C, light, red, 10 min (1)

Light: white, 10 min (1); white, 5h (1); white, 12h/d (2); white, continuous (2); red, 10 min (1); red, 5h (1); far red, 10 min (1); far red, 5h (1)

GA_3: co-applied, 10 ppm, at 22°C in light, 12h/d (2); co-applied, 10^{-4} M, at 26°C, 38°C, dark or light, red, 10 min (1)

Kinetin: co-applied, 75 ppm, at 22°C in light, 12h/d (2)

Ethrel: co-applied, 50 ppm, at 22°C in light, 12h/d (2)

Boric acid: co-applied, 25 ppm, at 22°C in light, 12h/d (2)

Ascorbic acid: co-applied, 10 ppm, at 22°C in light, 12h/d (2)

Potassium nitrate: co-applied, 10 ppm, at 22°C in light, 12h/d (2)

V. Successful dormancy-breaking treatments

O. basilicum

Potassium nitrate (AOSA, ISTA)

Alternating temperatures: 20°/30°C (16h/8h) in light, continuous (3,4); 30°/25°C, 27°/22°C, 24°/19°C (8h/16h), dark (7)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) (3)

O. canum, O. gratissimum, O. kilimandscharicum, O. tenuiflorum

Alternating temperatures: 20°/30°C (16h/8h) in light (4)

VI. Comment

Light (1,2,3,6) and alternating temperatures (3,4,7) are reported to be required for the promotion of germination of dormant seeds of Ocimum spp. since seeds of O. basilicum and O. tenuiflorum tested at constant temperatures between 14° and 38°C in the dark failed to germinate (1,2,5). Alternating temperatures of 20°/30°C (16h/8h) (3,4) or 22°/27°C (16h/8h) (7) are reported to be promotory. During 14 day germination tests seeds of O. basilicum tested in the dark at 20°/35°C (16h/8h) or 20°C gave 74 and 54% normal germination, whereas those subjected to 8 hours light per day gave 76 and 32% respectively (A). Clearly alternating temperatures are required, but it does appear that light may not be as essential as has been reported provided a suitable alternating temperature regime is used. It is suggested that seeds of Ocimum spp. be tested for germination in an alternating temperature regime of 20°/35°C (16h/8h) with light applied during the period spent at the upper temperature of each cycle.

VII. References

1. Amritphale, D. and Mall, L.P. (1981). Germination of the photoblastic seeds of Ocimum. Plant Science Letters, 20, 263-271.

2. Dey, B.B. and Choudhuri, M.A. (1982). Seed germination as affected by plant age, growth and development stages of Ocimum sanctum. Seed Science and Technology, 10, 243-255.

3. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

4. Korsakova, O.M. (1970). [Determination of seed germination in basil.] Sbornik Trudov Aspirantov i Molodykh Nauchnykh Sotrudnikov, Leningrad, 17, 347-353. (From Horticultural Abstracts, 1972, 42, 4529.)

5. Varshney, C.K. (1968). Germination of the light-sensitive seeds of Ocimum americanum Linn. New Phytologist, 67, 125-129.

6. Amritphale, D., Mukhiya, Y.K., Gupta, J.C. and Iyengar, S. (1984). Effect of storage, photoperiod and mechanical scarification on seed germination in Ocimum americanum. Physiologia Plantarum, 61, 649-652.

7. Putievsky, E. (1983). Temperature and daylength influences on the growth and germination of sweet basil and oregano. Journal of Horticultural Science, 58, 583-587.

ORIGANUM

O. majorana L. [Majorana hortensis Moench]	sweet marjoram, annual marjoram
O. sativum	
O. vulgare L.	wild marjoram

I. Evidence of dormancy

There is indirect evidence that seeds of O. majorana and O. vulgare may exhibit dormancy (3,4).

II. Germination regimes for non-dormant seeds

O. majorana

TP: 20°C; 20°/30°C (16h/8h): 21d (ISTA)

BP: 15°C: 21d (AOSA)

O. sativum

TP: 20°C; 20°/30°C (16h/8h): 21d (ISTA)

III. Unsuccessful dormancy-breaking treatments

O. majorana

Potassium nitrate: co-applied, 0.2% (1)

O. vulgare

Alternating temperatures: 36°/31°C (8h/16h) (5)

Light: light or dark (3)

IV. Partly-successful dormancy-breaking treatments

O. majorana

Alternating temperatures: 10°/20°C, 20°/30°C (16h/8h) (1)

GA_3: pre-applied, 24h, 100-1000 ppm (4)

O. vulgare

Constant temperatures: 6°-10.5°C, 15°-31.5°C (3)

Alternating temperatures: 24°/19°C, 21°/16°C, 27°/22°C, 18°/13°C, 15°/10°C, 30°/25°C, 33°/28°C (8h/16h) (5)

V. Successful dormancy-breaking treatments

O. majorana

Constant temperatures: 15°C (1)

Fusicoccin: pre-applied, 24h, 5 ppm (4)

O. vulgare

Constant temperatures: 15°C (2); 12°-13.5°C (3)

VI. Comment

In a comparison of the germination of seeds of O. vulgare in seven different alternating temperature environments the regime 24°/19°C (8h/16h) was superior, but failed to promote full germination (5): in other investigations with seeds of O. vulgare constant temperatures of 15°C (2) and 12°-13.5°C (3) promoted full germination. Similarly, although an alternating temperature regime of 10°/20°C (16h/8h) was recommended in previous ISTA rules as a dormancy-breaking treatment for seeds of O. majorana a constant temperature of 15°C (also recommended previously by ISTA) is reported to be more promotory than this alternating temperature regime (1). Consequently it is suggested that seeds of Origanum spp. be tested at a constant temperature of 15°C (1,2,AOSA) with, if necessary, an extended test duration.

VII. References

1. Cseresnyes, Z. and Baleanu, M. (1978). [Improving the methods for germinating seed of Hypericum perforatum, Atropa belladonna, Majorana hortensis, Salvia Sclarea and Solanum laciniatum.] Analele Institutului de Cercetari pentru Cereale si plante Tehnice-Fundulea, 43, 111-116. (From Seed Abstracts, 1980, 3, 2371.)

2. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

3. Macchia, M., Benvenuti, A. and Angelini, L. (1983). [Germination characteristics of a series of medicinal species.] Revista della Ortoflorofrutticoltura Italiana, 67, 165-190.

4. Menghini, A. and Venanzi, G. (1977/1978). [The effect of growth regulators on the germination of seeds of various medicinal plants.] Annali della Facolta di Agraria, Perugia, 32, 771-783. (From Seed Abstracts, 1980, 3, 2391.)

5. Putievsky, E. (1983). Temperature and daylength influences on the growth and germination of sweet basil and oregano. Journal of Horticultural Science, 58, 583-587.

SALVIA

S. coccinea Juss. [S. rosea Vahl.]	
S. farinacea Benth.	mealycup sage
S. glutinosa L.	
S. officinalis L.	sage
S. patens Cav.	
S. pratensis L.	
S. reflexa Hornem	mintweed
S. Sclarea L. clary	
S. sonomensis	
S. splendens Sello [S. colorans Hort.]	scarlet sage
S. viridis	

I. Evidence of dormancy

Seeds of Salvia spp. can show considerable dormancy (4-6). Seeds of S. sclarea require 6 months after-ripening to remove dormancy (6).

II. Germination regimes for non-dormant seeds

S. coccinea

TP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

S. farinacea

TP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

TP: 20°/30°C (16h/8h): 10d (AOSA)

S. officinalis

TP: 20°/30°C (16h/8h): 21d (ISTA)

TP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

BP; S: 20°/30°C (16h/8h): 14d (AOSA)

S. patens, S. pratensis

TP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

S. Sclarea

TP; BP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

Constant temperatures: 30°C (2)

S. splendens

TP: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

TP: 20°/30°C (16h/8h): 12d (AOSA)

S. viridis

TP: 20°/30°C; 20°C: 21d (ISTA)

III. Unsuccessful dormancy-breaking treatments

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IV. Partly-successful dormancy-breaking treatments

S. officinalis

Constant temperatures: 15°C in light or dark (3); 20°C, dark (3)

Alternating temperatures: 20°/30°C (16h/8h), light (3)

S. reflexa

Constant temperatures: 12°-32°C (8)

S. Sclarea

Magnesium sulphate: co-applied, 0.5%, in sand (4)

S. sonomensis

GA_3: pre-applied, 200 ppm, germinate at 5°C (1)

V. Successful dormancy-breaking treatments

S. coccinea

Pre-chill (ISTA)

S. farinacea

Pre-chill (ISTA)

Light (AOSA)

S. glutinosa

Pre-chill: 4°C, 4-6w (7)

GA_3: co-applied, 10-1000 ppm, germinate at 25°C in light, 12h/d (7)

Removal of seed covering structures: (7); then GA_3, co-applied, 1000 ppm (7)

S. officinalis, S. patens, S. pratensis

Pre-chill (ISTA)

S. reflexa

Pre-chill: (8)

S. Sclarea

Pre-chill (ISTA)

Constant temperatures: 9°-30°C, light (5); 10.5°-31.5°C, dark (5)

Pre-dry: 40°C, 5d (6)

S. splendens

Pre-chill (ISTA)

Light (AOSA)

S. viridis

Pre-chill (ISTA)

VI. Comment

Removing the seed covering structures (7), pre-chilling (7,8), and treatment with GA_3 (1,7) are effective in overcoming seed dormancy in Salvia spp. Although it is reported that treatment with gibberellins can replace the requirement of a pre-chill treatment (7), it is suggested here that seeds be pre-chilled (note the treatment period given above for S. glutinosa) and then tested at 20°/30°C (16h/8h) in accordance with ISTA/AOSA rules.

VII. References

1. Chan, F.J. and Lambers, K.H.R. (1970). Influence of gibberellic acid on the germination of seeds of several native California plant species. Plant Propagator, 16, 9-12.

2. Cseresnyes, Z. and Baleanu, M. (1978). [Improving the methods for germinating seeds of Hypericum perforatum, Atropa belladonna, Majorana hortensis, Salvia Sclarea and Solanum lacinatum.] Analele Institutului de Cercetari pentru Cereale si Plante Tehnice-Fundulea, 43, 111-116. (From Horticultural Abstracts, 1980, 50, 5481.)

3. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

4. Luk'janov, I.A. (1959). The dormancy of the mucilaginous seeds of Salvia Sclarea. Agrobiologiya, 2, 294-296. (From Horticultural Abstracts, 1960, 30, 918.)

5. Macchia, M., Benvenuti, A. and Angelini, L. (1983). [Germination characteristics of a series of medicinal species.] Revista della Ortoflorofrutti coltura Italiana, 67, 165-190.

6. Shepetina, F.A. and Perestova, T.A. (1971). [On the varying quality of muscatel sage seeds.] Trudy Vsesoyuznogo Nauchno Isseledovatel' Skogo Instituta Efirnomaslichnykh Kul'tur, 3, 26-28. (From Horticultural Abstracts, 1972, 42, 8209.)

7. Thompson, P.A. (1969). Germination of species of Labiatae in response to gibberellins. Physiologia Plantarum, 22, 575-586.

8. Veerakoon, W.L. (1981). Studies on the autecology of Salvia reflexa Hornem (mintweed) with special reference to weed management. Journal of the Australian Institute of Agricultural Science, 47, 218.

CHAPTER 42. LECYTHIDACEAE

The Lecythidaceae comprise over 230 species of trees within 18 genera which provide edible nuts (e.g. Lecythis zabucajo Aubl., paradise nut). The fruits have hard, thick walls and generally contain about 12 to 24 nuts. Seed storage characteristics are unknown.

SEED DORMANCY AND GERMINATION

The shells of the nuts vary from leathery to woody and can act as a barrier to germination. Information is provided in this chapter for the genus Bertholletia only.

BERTHOLLETIA

B. excelsa HBK Brazil nut

I. Evidence of dormancy

Seeds of B. excelsa can show considerable dormancy due to the hard seed coat (1,2) and are reported to take between 12 and 15 months to germinate (1).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

Sodium hydroxide: pre-applied, 7,15h, 1.5, 3% (1); pre-applied, 18,24h, 5, 10% (1)

Scarification: mechanical, at striae (2)

IV. Partly-successful dormancy-breaking treatments

Pre-soak: 18,24h (1); 7d (2)

Scarification: mechanical, at micropyle end (2); mechanical, at striae and micropyle end (2); sulphuric acid, 25, 50%, 18,24h (1); sulphuric acid, 25%, 7h (1)

V. Successful dormancy-breaking treatments

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VI. Comment

Unfortunately we have not found any reports which describe precise environmental conditions suitable for germinating seeds of B. excelsa. It is suggested that the seeds be scarified by hand at the micropyle end and then tested for germination between moist rolled paper towels at a constant temperature of 30°C - although ultimately a more suitable alternating temperature regime may be found. A considerable germination test period may be necessary - see the first section.

VII. References

1. Barbosa, M.M.S. (1974). [Germination trials with Brazil nuts.] Boletim da Instituto Biologico

da Bahia, 13, 100-106.

2. Pereira, L.A.F., Muller, C.H., Muller, A.A., Figueriedo, F.J.C. and Frazao, D.A.C. (1980). [Mechanical scarification and imbibition (effect) on germination of Brazil nuts.] Boletim de Pesquisa, Centro de Pesquisa Agropecuaria do Tropico Umido, 10, 13 pp. (From Seed Abstracts, 1983, 6, 1130.)

CHAPTER 43. LEGUMINOSAE

The Leguminosae comprise about 18000 species of herbaceous plants, shrubs, trees and climbers within almost 700 genera. The Leguminosae are divided into three tribes, viz: Caesalpinoideae Mimosoideae, and Papilionoideae. Although several species within Caesalpinoideae and Mimosoideae provide useful products, the Papilionoideae (also described as Fabaceae, Faboideae, Lotoideae, or Papilionatae) is the most useful tribe to man and provides a very large number of important crop plants. The fruit is a pod, often a legume. Rarely the fruit may be single-seeded. Seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

With few exceptions, dormancy per se (that is innate or secondary dormancy as defined in Chapter 5, Volume I) is a comparatively slight problem in seed germination tests of Leguminosae accessions. The major problem preventing or delaying germination in such tests is that of hardseededness (see Chapter 4, Volume I).

Because dormancy is not a major problem, the layout of this chapter is slightly different from that of other chapters in this manual. No detailed information is provided for particular genera, with the exception of brief comments on a few genera where dormancy may be a problem in certain test regimes. Instead information on suitable germination test procedures and dormancy-breaking treatments (but see comment below) is summarised in tabular form. It will be seen that the majority of treatments listed as dormancy-breaking treatments are in fact treatments to remove hardseededness. This type of treatment is described in detail in Chapter 7, Volume I.

The structure of the testa (seed coat, see Chapter 3, Volume I) which may render a seed impermeable (hard) differs between the three tribes. Seeds of members of the Papilionoideae have a region of the testa described as the strophiole through which the imbibition of initially hard seeds may occur if treated appropriately - see Chapter 7, Volume I, for more details of testa structure in papilionate legumes. Percussion (shaking) treatments create a gap (the strophiolar cleft) in the impermeable testa through which moisture can enter seeds of species within this tribe. In contrast most authorities consider that seeds of the Caesalpinoideae and the Mimosoideae do not possess a strophiolar region; and accordingly percussion treatments are generally ineffective. In the Caesalpinoideae an initial treatment in absolute alcohol (see Chapter 7, Volume I) can be effective in rendering the seeds permeable, but this treatment is not so effective for seeds of either the Mimosoideae or the Papilionoideae. Finally, filing or chipping the testa is generally effective for seeds of all three tribes.

Thus the treatment which might be applied to render hardseeded accessions permeable may be dependent upon the tribe to which it belongs. For this reason we have divided the summary of germination test procedures and dormancy-breaking treatments in this chapter according to tribe - Caesalpinoideae in Table 43.1, Mimosoideae in Table 43.2, and Papilionoideae in Table 43.3.

A further problem in seed germination tests of the Leguminosae is that of imbition injury (see Chapter 4, Volume I). Imbibition injury is damage caused by very rapid imbibition of water by very dry seeds when they are set to germinate. It can be avoided by humidifying (also described as conditioning) the dry seeds until their moisture content is around 18% or more. A method of humidifying seeds is described in Chapter 7, Volume I. If the seeds are hard a

treatment to overcome hardseededness will be required before the humidification treatment. It is expected that a substantial proportion of Leguminosae accessions would benefit from a humidification treatment before the germination test.

For species not listed in Tables 43.1 to 43.3 and for accessions where the information tabulated is inadequate, the algorithm below may be helpful in devising a suitable germination test procedure. Note that the algorithm includes an obligatory treatment to overcome hardseededness and also an optional conditioning (humidification) treatment.

RBG Kew Wakehurst Place algorithm

The regimes tested in the first and second steps of the algorithm are dependent upon the accession's origin. All seeds to be tested for germination are chipped (part of the testa is removed) beforehand.

The first step of the algorithm is to test the chipped seeds of accessions of temperate origin at constant temperatures of 11°C and 16°C with light applied for 12h/d, or to test the chipped seeds of accessions of tropical origin at constant temperatures of 21°C and 26°C with light applied for 12h/d. If an accession's origin is unknown or doubtful then test chipped seeds at all four constant temperature regimes. If the results show a trend of germination with respect to temperature then test at more extreme constant temperatures. For example, if a temperate accession showed significantly greater germination at 11°C than at 16°C then test a further sample of chipped seeds at 6°C.

If the regimes applied in step one have not resulted in full germination then the second step of the algorithm is to test chipped seeds of accessions of temperate origin at an alternating temperature of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature of each cycle, and to test chipped seeds of accessions of tropical origin at an alternating temperature of 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature of each cycle. If an accession's origin is unknown or doubtful then test chipped seeds in both alternating temperature regimes.

If the second step of the algorithm does not result in full germination then the third step is to condition (humidify) the chipped seeds at 21°C and 100% relative humidity (i.e. over water) for 4d and then test in the temperature regime determined to be most successful from the results of steps one and two.

If the third step of the algorithm does not result in full germination then the fourth step is to experiment with the conditioning treatment by humidifying samples of the chipped seeds for more and less than 4d at 21°C with 100% relative humidity before testing in the temperature regime determined to be most successful from the results of steps one and two.

If full germination has not been promoted, the fifth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I). Note that chipping and humidification of the seeds prior to this test are likely to be required.

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from Tables 43.1 to 43.3 and the next section.

Innate dormancy?

In addition to hardseededness some legume accessions may exhibit innate seed dormancy. A clue as to which species are more likely to exhibit innate seed dormancy can be gained from Tables 43.1 to 43.3: if the additional directions include treatments which will not overcome hardseededness (e.g. pre-chill, or ethephon) then it is likely that some accessions may exhibit innate seed dormancy. The two most important genera in which innate seed dormancy is common are Arachis (groundnut) and Trifolium (clover). Other genera in which innate seed dormancy may be observed include Medicago and Trigonella.

In dormant seeds of Arachis hypogaea L. 100% oxygen in the germination test environment or an after-ripening treatment promote seed germination (11), whereas piercing the seed coat does not (11). Thus the problem of lack of germination in such cases is not hardseededness but dormancy. Of course, however, it is possible for dormant accessions to also be hardseeded (sometimes described as double dormancy, see Chapter 5, Volume I).

In general the lower the temperature of the germination test the less likely is seed dormancy to prevent, or delay germination. For example, in many lots of Trifolium subterraneum L. a greater proportion of dormant seeds germinate at 15°C than at 20°C (7,13) and a greater proportion germinate at 20°C than at 30°C (5). Similarly in several species pre-chill treatments promote the germination of the dormant seeds, e.g. in red clover (Trifolium pratense L.) (10).

Consequently the first suggestion to promote the germination of dormant legume seeds is to pre-chill (7 or 8d at 3° to 5°C) or test at a comparatively low temperature (10° to 15°C). Whilst the latter suggestion appears to be satisfactory in most cases, e.g. lupin (Lupinus albus L.) (10), there may be some exceptions, e.g. some lots of Trifolium pratense L. (10) and Trifolium subterraneum (13). The use of the algorithm, and in particular step one, would thus be advantageous since a trend of germination with respect to constant temperatures should be apparent from the initial results of step one and gene bank staff can act accordingly (see the algorithm).

A carbon dioxide enriched atmosphere can also promote the germination of dormant legume seeds, e.g. in Trifolium subterraneum L. (1-3,9,13), and Medicago hispida Gaertn., Medicago tribuloides Desr., Trifolium arvense L., Trifolium cherleri L., Trifolium glomeratum L., Trifolium hirtum All. and Trigonella ornithopodoides (L.) DC. (3,6). Promotion of germination is normally observed at concentrations between about 0.3 and 4.5% (by volume) (1,3) with inhibition of germination at CO_2 concentrations above about 5 to 10% (1,3). The beneficial effect of carbon dioxide is generally more enhanced the lower the germination test temperature (2,9) and also where the testas have been removed (3). In general treatment with carbon dioxide is more promotory than pre-chilling, e.g. compared with three days at 3°-5°C (6).

Although it is possible to artificially increase carbon dioxide concentration in germination tests, carrying out the tests in sealed or unsealed polyethylene envelopes is generally sufficient to overcome dormancy, e.g. in Trifolium hybridum L., Trifolium pratense L. and Trifolium repens L. (12). Consequently it is suggested that the seeds be tested for germination in this way. Similarly seeds of dormant accessions destined for field sowings can be imbibed in a sealed polyethylene bag for 24 hours prior to sowing out.

Ethylene (applied in various forms) has been shown to promote the germination of dormant seeds of several legumes. For example, in Trifolium subterraneum L. by co-application of 1-100 ppm ethephon (also known as ethrel and as 2-chloroethylphosphonic acid or CEPA) (5), in Medicago truncatula Gaertn. by co-application of 1-100 ppm ethephon (5), and in Arachis hypogaea L. by co-application of 5×10^{-4} M ethephon (8).

Thus co-application of ethephon (use concentrations within the ranges provided above) in

germination tests is another satisfactory potential dormancy-breaking treatment. Ethephon has also been successfully applied to promote seed germination in field sowings of Arachis hypogaea L., and the following treatments may be applicable to other species also. In the dry powder method 1 kg of seeds together with 2 g of a combined fungicide/insecticide and 0.02 g of ethephon are shaken in a polyethylene bag or mixed in a drum mixer (4). In the wet method a single layer of seeds is sprayed with a solution of 0.033 M ethephon (4). In both cases the seeds should be sown immediately after the treatment (4). These treatments may be useful when regenerating or multiplying dormant seed accessions of the Leguminosae.

Finally it is worth noting that several other growth regulators may also promote the germination of dormant legume seeds. For example, in Arachis hypogaea L. co-application of either 10^{-4} M kinetin or 10^{-4} M benzylaminopurine have resulted in a considerable promotion of germination (8).

References

1. Ballard, L.A.T. (1958). Studies of dormancy in the seeds of subterranean clover (Trifolium subterraneum L.). I. Breaking of dormancy by carbon dioxide and by activated carbon. Australian Journal of Biological Sciences, 11, 246-260.

2. Ballard, L.A.T. (1961). Studies of dormancy in the seeds of subterranean clover (Trifolium subterraneum L.). II. The interaction of time, temperature, and carbon dioxide during passage out of dormancy. Australian Journal of Biological Sciences, 14, 173-186.

3. Ballard, L.A.T. (1967). Effect of carbon dioxide on the germination of leguminous seeds. In Physiologie, Okologie und Biochemie der Keimung (ed. H. Borriss), pp. 209-219. Ernst-Moritz-Arndt-Universitat, Greifswald.

4. Gautreau, J. (1980). A new method of ending groundnut dormancy by using ethephon. Oléagineux, 35, 355.

5. Globerson, D. (1977). Germination and dormancy breaking by ethephon in mature and immature seeds of Medicago truncatula (Medic) and Trifolium subterraneum (Clover). Australian Journal of Agricultural Research, 29, 43-49.

6. Grant Lipp, A.E. and Ballard, L.A.T. (1959). The breaking of dormancy of some legumes by carbon dioxide. Australian Journal of Agricultural Research, 10, 495-499.

7. Johnson, M.E.H. and Tattersfield, J.G. (1970). Germination conditions for Trifolium subterraneum L. Proceedings of the International Seed Testing Association, 35, 343-347.

8. Ketring, D.L. and Morgan, P.W. (1971). Physiology of oilseeds. II. Dormancy release in Virginia-type peanut seeds by plant growth regulators. Plant Physiology, 47, 488-492.

9. Morley, F.H.W. (1958). The inheritance and ecological significance of seed dormancy in subterranean clover (Trifolium subterraneum L.). Australian Journal of Biological Sciences, II, 261-274.

10. Nakamura, S. (1962). Germination of legume seeds. Proceedings of the International Seed Testing Association, 27, 694-709.

11. Sharir, A. (1978). Some factors affecting dormancy breaking in peanut seeds. Seed Science and Technology, 6, 655-660.

12. Thomson, J.R. (1965). Breaking dormancy in germination tests of Trifolium spp. Proceedings of the International Seed Testing Association, 30, 905-909.

13. Young, J.A., Kay, B.L. and Evans, R.A. (1970). Germination of cultivars of Trifolium subterraneum L. Agronomy Journal, 62, 638-641.

TABLE 43.1 Summary of germination test recommendations for species within the Caesalpinoideae tribe of the Leguminosae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Ceratonia siliqua L.			30d	scarify, abrade with sand, or file or nick seed coat	Riley
Cercis canadensis L.		20°/30°C		scarify, then pre-chill, 5-8w	G&R
Cercis siliquastrum L.		20°/30°C		scarify	G&R
Gleditsia triacanthos L.	TP	20°C	21d	pierce, chip or file cotyledon end of testa, then pre-soak, 6h, or scarify, concentrated	ISTA
				sulphuric acid, then wash	
	BP	20°C	21d	clip, file testa, or scarify, concentrated sulphuric acid, 1h	AOSA
Tamarindus Indica L.			21d	pre-soak, 24h	Riley

TABLE 43.2 Summary of germination test recommendations for species within the Mimosoideae tribe of the Leguminosae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Acacia spp.	TP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h, or scarify,	ISTA
				concentrated sulphuric acid, 1h, then wash	
Inga paterno			21d	pre-soak, 24h	Riley
Leucaena leucocephala (Lam.) de Wit	TP; BP	25°C	10d		ISTA
		26°C	28d	pre-soak, hot water, 80°C, 2-5 min, or 100°C, 2-5s	Oakes
	BP		30d	pre-soak, boiling water, then allow to cool, 20 min	O&W
Mimosa pudica L.	TP; BP	20°/30°C; 20°C	28d	pre-soak, 24h	ISTA
	BP	20°/30°C	21d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA

TABLE 43.3 Summary of germination test recommendations for species within the Papilionoideae tribe of the Leguminosae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Amorpha fruticosa L.				percussion	Atwater
Anthyllis vulneraria	TP; BP	20°C	10d	pre-chill	ISTA

L.					
Arachis hypogaea L.	BP; S	20°/30°C; 25°C	10d	remove shells, pre-dry (40°C)	ISTA
	BP; S	20°/30°C; 25°C	10d	remove shells, or ethephon, or ethylene	AOSA
Astragalus cicer L.				scarify, mechanical	Atwater
Cajanus cajan (L.) Millsp.	BP; S	20°/30°C; 25°C	10d		ISTA
Calopogonium mucunoides Desv.	TP	25°C; 20°C	10d		ISTA
Caragana arborescens Lam.	TP	20°/30°C	21d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h	ISTA
Centrosema pubescens Benth.	TP	20°/35°C	10d		ISTA
				scarify, concentrated sulphuric acid, 15 min	Atwater
Cicer arietinum L.	BP; S	20°/30°C; 20°C	8d		ISTA
	BP; S	20°/30°C	7d		AOSA
Colutea istria L.				percussion, shake 6h, or scarify, concentrated sulphuric acid, 30 min	Atwater
Coronilla varia L.	TP; BP	20°C	14d		ISTA
	BP; S	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
				scarify, concentrated sulphuric acid, 30 min	Atwater
Crotalaria intermedia Kotschy.	BP	20°/30°C	10d		ISTA
	BP; S	20°/30°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Crotalaria juncea L.	BP; S	20°/30°C	10d		ISTA
	BP; S	20°/30°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Crotalaria lanceolata E. Mey.	BP	20°/30°C	10d		ISTA
	BP; S	20°/30°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Crotalaria mucronata Desv.	BP	20°/30°C	10d		ISTA
Crotalaria pallida Ait.	BP; S	20°/30°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Crotalaria spectabilis Roth	BP	20°/30°C	10d		ISTA
	BP; S	20°/30°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Cyamopsis tetragonoloba (L.)	BP	20°/30°C	14d		ISTA
	BP; S	20°/30°C; 30°C	14d	continue test for a further 5d	AOSA

Taub.				if (reversible) hard seeds have begun to imbibe	
Cytisus monspessulanus L.		20°/30°C	28d	clip hard seeds	Atwater
Cytisus scoparius (L.) Link	TP	20°/30°C	28d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h	ISTA
				scarify, boiling water, concentrated sulphuric acid, or mechanical	G&R
Desmodium intortum (Mill.) Urban	TP	20°/30°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
Desmodium tortuosum (Sweet) DC.	BP	30°C	28d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Desmodium uncinatum (Jacq.) DC.	TP	20°/30°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
Dolichos lablab L.	BP; S	20°/30°C; 25°C	10d		ISTA
		20°/30°C	21d		Atwater
Dolichos lignosis L.		20°/30°C	21d		Atwater
Galega officinalis L.	TP; BP	20°/30°C; 20°C	14d	imbibe 10d, then pre-soak, 24h	ISTA
Glycine javanica L.	TP	20°/30°C; 10°/35°C	10d		ISTA
Glycine max (L.) Merr.	BP; S	20°/30°C; 25°C	8d		ISTA
	BP; S	20°/30°C; 25°C	8d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Glycyrrhiza glabra L.	TP	20°/30°C	21d	scarify, concentrated sulphuric acid	Heit
Hedysarum coronarium L.	TP; BP	20°/30°C; 20°C	14d		ISTA
Indigofera hirsuta L.	BP	20°/30°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lablab purpureus (L.) Sweet	BP	20°/30°C	12d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Laburnum alpinum (Mill.) Bercht. & J.S. Presl.	TP	20°/30°C	21d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h, or scarify,	ISTA
				concentrated sulphuric acid, 1h, then wash	
Laburnum anagyroides Medic.	TP	20°/30°C	21d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h, or scarify,	ISTA
				concentrated sulphuric acid, 1h, then wash	

Lathyrus cicera L.	S	20°C	10d		ISTA
Lathyrus hirsutus L.	BP; S	20°C	14d		ISTA
	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lathyrus latifolius L.	BP; S; TP	20°C	21d	pre-chill, pierce, chip or file cotyledon end of testa	ISTA
	BP	20°C	30d	slow to germinate, continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
		20°C	21d	clip hard seeds	Atwater
Lathyrus odoratus L.	BP; S; TP	20°C	14d	pre-chill	ISTA
	BP; S	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
		20°C	14d		Atwater
Lathyrus sativus L.	BP; S	20°C	14d		ISTA
Lathyrus sylvestris L.	BP	15°/25°C; 20°C	28d	continue test at 15°/25°C for 14d or 20°C for 10d if (reversible) hard seeds have begun to imbibe	AOSA
Lens culinaris Medic.	BP; S	20°C	10d	pre-chill	ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lespedeza cuneata (Dumont) Don	BP; S	20°/35°C	21d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lespedeza hedysaroides (Pall.) Kitagawa	BP	20°/35°C	21d		ISTA
	BP; S	20°/35°C	21d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lespedeza stipulacea Maxim.	BP	20°/35°C	14d		ISTA
	BP; S	20°/35°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lespedeza striata (Murr.) Hook. & Arn.	BP	20°/35°C	14d		ISTA
	BP; S	20°/35°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lotononis bainesii Baker	TP	20°/30°C	21d		ISTA
Lotus corniculatus L.	TP; BP	20°/30°C; 20°C	12d	pre-chill	ISTA
	BP	20°C	12d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lotus scoparius (Nutt.) Ottley		20°C	21d	pre-soak, hot water	Atwater
Lotus uliginosus	TP; BP	20°/30°C; 20°C	12d	pre-chill	ISTA

Schk.	BP	20°C	12d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lupinus albus L.	BP; S	20°C	10d	pre-chill	ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lupinus angustifolius L.	BP; S	20°C	10d	pre-chill	ISTA
	BP; S	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lupinus hartwegii Lindl.	BP; S; TP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa, or pre-chill	ISTA
Lupinus hybridus	BP; S; TP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa, or pre-chill	ISTA
Lupinus luteus L.	BP; S	20°C	21d	pre-chill	ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lupinus nanus Dougl.	BP; S; TP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa, or pre-chill	ISTA
		20°C	14d	clip hard seeds	Atwater
Lupinus polyphyllus Lindl.	BP; S; TP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa, or pre-chill	ISTA
	BP	20°/30°C	30d	slow to germinate, continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lupinus subcarnosus Hook.	BP	20°/30°C	21d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Lupinus succulentus Dougl.		20°C	50d	pre-soak, 7h, 100°C, then cool	Atwater
Lupinus texensis Hook.		20°C	14d	clip hard seeds	Atwater
Lupinus spp.	BP	20°/30°C	18d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Macroptilium atropurpureum (DC.) Urban.	TP	25°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
Macroptilium axillare (E. Mey.) Verdc.	BP	25°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
Macroptilium lathyroides (L.) Urban	TP	25°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
Medicago arabica (L.) Huds.	TP; BP	20°C	14d		ISTA
	BP	20°C	14d	remove seeds from bur,	AOSA

				continue test for a further 5d if (reversible) hard seeds have begun to imbibe,	
				test at 17°-18°C	
Medicago littoralis Rohde ex Lois	TP	20°C	14d		ISTA
Medicago lupulina L.	TP; BP	20°C	10d	pre-chill	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 17°-18°C	AOSA
Medicago orbicularis (L.) Bartal	TP; BP	20°C	10d	pre-chill	ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C,	AOSA
				or 17°-18°C	
Medicago polymorpha L.	TP; BP	20°C	14d		ISTA
	BP	20°C	14d	remove seeds from bur, continue test for a further 5d if (reversible) hard seeds have begun to imbibe,	AOSA
				test at 17°-18°C	
Medicago rugosa Desr.	TP; BP	20°C	14d		ISTA
Medicago sativa L.	TP; BP	20°C	10d	pre-chill	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 17°-18°C	AOSA
Medicago scutellata (L.) Mill.	TP; BP	20°C	14d		ISTA
Medicago truncatula Gaertn.	TP; BP	20°C	10d		ISTA
Medicago x varia T. Martyn.	TP; BP	20°C	10d	pre-chill	ISTA
Melilotus alba Medic.	TP; BP	20°C	7d	pre-chill	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Melilotus indica (L.) All.	TP; BP	20°C	14d		ISTA
	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Melilotus officinalis (L.) Pall.	TP; BP	20°C	7d	pre-chill	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Mucuna deeringiana (Bort.) Merr.	TP; S	20°/30°C; 32°C	14d	cut seed	ISTA
	BP; S	20°/30°C	14d	continue test for a further 5d if (reversible) hard seeds	AOSA

				have begun to imbibe	
Onobrychis viciifolia Scop.	TP; BP; S	20°/30°C; 20°C	14d	pre-chill	ISTA
	BP	20°/30°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Ornithopus sativus Brot.	TP; BP	20°C	14d		ISTA
Pachyrhizus tuberosus (Lam.) A. Spreng		20°/30°C	14d		Atwater
Phaseolus angularis (Willd.) W.F. Wight	BP; S	20°/30°C	10d		ISTA
Phaseolus aureus Roxb.	BP; S	20°/30°C; 25°C	7d		ISTA
Phaseolus coccineus L.	BP; S	20°/30°C; 20°C	9d		ISTA
	BP; S	20°/30°C	9d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Phaseolus limensis Macf.	S	25°C	9d		ISTA
Phaseolus lunatus L.	BP; S	20°/30°C; 25°C	9d		ISTA
	BP; S	20°/30°C	9d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Phaseolus mungo L.	BP; S	20°/30°C; 25°C; 20°C	7d		ISTA
Phaseolus vulgaris L.	BP; S	20°/30°C; 25°C; 20°C	9d		ISTA
	BP; S	20°/30°C; 25°C	8d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Pisum sativum L.	BP; S	20°C	8d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	ISTA/AOSA
Psophocarpus tetragonolobus (L.) DC.	BP; S	20°/30°C; 30°C	14d		ISTA
	BP	20°/30°C	28d	scarify with emery paper	A
Pueraria lobata (Willd.) Ohwi	BP	20°/30°C	14d		ISTA
	BP	20°/30°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Pueraria phaseoloides (Roxb.) Benth.	TP	25°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
		20°C	40d	pre-soak, 26h	Atwater
Robinia pseudoacacia L.	TP	20°/30°C	14d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h, or scarify, concentrated sulphuric	ISTA

				acid, then wash	
	BP	20°C	21d	clip, file testa, or scarify, concentrated sulphuric acid, 1h	AOSA
				file or percussion, shake 20 min	Atwater
				scarify, boiling water, concentrated sulphuric acid, or mechanical	G&R
Sesbania exaltata (Raf.) Rydb.	BP	20°/30°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Sophora spp.				chip, then pre-soak	G&R
Spartium junceum L.	TP	20°C	14d	pierce, chip or file cotyledon end of testa, then pre-soak, 3h	ISTA
		20°C	21d	pre-soak	Atwater
Stylosanthes fructicosa	TP	25°C; 30°/25°C;	14d	dark, dehull, scarify	McIvor
		25°-35°/20°C			
Stylosanthes guianensis (Aubl.) Sw.	TP	20°/35°C; 20°/30°C	10d	scarify, concentrated sulphuric acid, extend test 7d if hard seeds have begun to imbibe	ISTA
	TP	25°C; 30°/20°-25°C;	14d	dark, dehull, scarify	McIvor
		35°/20°C			
Stylosanthes hamata (L.) Taub.	TP	20°/35°C; 10°/35°C	10d		ISTA
	TP	25°C; 25°-40°/20°C	14d	dark, dehull, scarify	McIvor
	TP	25°C	10d	pre-dry, 75°C, 85°C, 1,2h	M&M
Stylosanthes humilis HBK	TP	20°/30°C; 10°/35°C	5d	cut seed	ISTA
	TP	25°C	14d	scarify, if necessary scarify again subsequently	Cameron
	TP	25°C	10d	pre-dry, 75°C, 85°C, 1,2h	M&M
	TP	25°C; 25°-35°/20°C;	14d	dark, dehull, scarify	McIvor
		30°/25°C			Ballard
	TP	20°/30°C(2h/6h,	14d	dehull, scarify	
		2-6h/18-22h, 18h/6h)			
	TP	30°C	3d	scarify, thiourea, co-applied, 0.1 M, 0.2 M	B&B
(pods)	TP	25°C	10d	after 7d cut off proximal 1/3rd of ungerminated pods	Holm
(pods)	TP	10°/35°C(1.5h/4.5h);	10d	cut off proximal end of pods	Butler
		20°/35°C(16h/8h)			
Stylosanthes scabra Vog.	TP	20°/35°C	10d		ISTA
	TP	25°C; 25°-35°/20°C;	14d	dark, dehull, scarify	McIvor
		30°/25°C			
	TP	25°C	10d	pre-dry, 75°C, 85°C, 1,2h	M&M

Stylosanthes subsericea	TP	25°C; 35°/25°C;	14d	dark, dehull, scarify	McIvor
		25°-40°/20°C			
Stylosanthes viscosa Sweet	TP	25°C; 30°-35°/25°C;	14d	dark, dehull, scarify	McIvor
		25°-40°/20°C			
	TP	25°C	10d	pre-dry, 75°C, 85°C, 1,2h	M&M
Tephrosia vogellii Hook,				presoak, 54°C, 5 min	Atwater
Trifolium alexandrinum L.	TP; BP	20°C	7d		ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium campestre Schreber	TP; BP	20°C	14d		ISTA
	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium dubium Sibth.	TP; BP	20°C	14d	pre-chill	ISTA
	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium fragiferum L.	TP; BP	20°C	7d		ISTA
	BP	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium glomeratum L.	TP; BP	20°C	10d		ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium hirtum All.	TP; BP	20°C	10d		ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium hybridum L.	TP; BP	20°C	10d	pre-chill, sealed polythene envelope	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium incarnatum L.	TP; BP	20°C	7d	pre-chill, sealed polythene envelope	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium lappaceum L.	TP; BP	20°C	7d	pre-chill	ISTA

	BP	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium pratense L.	TP; BP	20°C	10d	pre-chill	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium repens L.	TP; BP	20°C	10d	pre-chill, sealed polythene envelope	ISTA
	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium resupinatum L.	TP; BP	20°C	7d		ISTA
	BP	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trifolium semipilosum Fresenium	BP; S	20°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Trifolium squarrosum L.	TP; BP	20°C; 15°C	14d	pre-chill	ISTA
Trifolium subterraneum L.	TP; BP	20°C; 15°C	14d	no light	ISTA
	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, test at 15°C, 17°-18°C	AOSA
Trigonella foenum-graecum L.	TP; BP	20°/30°C; 20°C	14d		ISTA
Ulex europaeus L.		20°C		light, 8h/d	G&R
Vicia articulata Hornem.	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vicia augustifolia L.	BP; S	20°C	14d	pre-chill	ISTA
Vicia benghalensis L.	BP	20°C	10d		ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vicia ervilia (L.) Willd.	BP; S	20°C	8d		ISTA
Vicia faba L.	BP; S	20°C	14d	pre-chill	ISTA
	BP; S	20°C	14d	test at 17°-18°C, pre-chill, 10°C, 3d	AOSA
Vicia narbonensis L.	BP; S	20°C	10d		ISTA
Vicia pannonica Crantz.	BP; S	20°C	10d	pre-chill	ISTA
	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vicia sativa L.	BP; S	20°C	14d	pre-chill	ISTA

	BP	20°C	10d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vicia sativa L. subsp. nigra	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vicia villosa Roth	BP; S	20°C	14d	pre-chill	ISTA
	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vicia villosa var varia (Host.) Corbiere	BP	20°C	14d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe, pre-chill, 10°C, 5d,	AOSA
				and test at 10°C	
Vigna angularis (Willd.) Ohwi & Ohashi	BP; S	20°/30°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vigna marina (Burm. f.) Merr.	BP	20°/30°C	8d		ISTA
Vigna radiata (L.) Wilczek.	BP; S	20°/30°C	7d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
Vigna unguiculata (L.) Walp.	BP; S	20°/30°C; 25°C	8d		ISTA
	BP; S	20°/30°C	8d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
subsp. sesquipedalis (L.) Verdc.	BP; S	20°/30°C	8d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA
subsp. unguiculata	BP; S	20°/30°C	8d	continue test for a further 5d if (reversible) hard seeds have begun to imbibe	AOSA

CHAPTER 44. LILIACEAE

In this handbook the Liliaceae is deemed to include the Alliaceae. It should also be noted that some authorities have classified the Alliaceae as the Amaryllidaceae. From the point of view of seed germination and dormancy, however, it is convenient to adopt the widest classification of the Liliaceae.

The Liliaceae, by this definition, comprise roughly 2500 species of herbaceous plants within about 200 genera. The most important genus for crop production is Allium. The fruits of Liliaceae are small capsules or berries and, mostly, many-seeded. Seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

Seed dormancy is common in the Liliaceae, but unfortunately often not detected. The seeds are endospermic, the endosperm surrounding the embryo. Low germination test temperatures and/or pre-chill treatments generally promote the germination of the dormant seeds. Detailed information on seed dormancy and germination is provided for the genera Allium and Asparagus in this chapter. A brief summary of additional recommended germination test procedures is provided in Table 44.1. In addition the algorithm below may be helpful in developing suitable germination test-procedures for some accessions.

RBG Kew Wakehurst Place algorithm

The first step of the algorithm is to test seeds at constant temperatures of 11°C and 26°C with light applied for 12/d. If full germination has not been achieved and the results of the tests at 11°C and 26°C indicate a trend of the response of germination to constant temperatures then test a further sample of seeds at a more extreme constant temperature. For example, if a greater proportion of seeds germinate at 11°C than at 26°C then test a further sample of seeds at 6°C with light applied for 12h/d. If no trend is apparent test a further sample of seeds at a constant temperature of 31°C with light applied for 12h/d.

If the first step has not resulted in full germination then the second step of the algorithm is to pre-chill a further sample of seeds at 2° to 6°C for 8w and then test for germination in the most suitable constant temperature regime determined from the results of step one.

If the second step has not resulted in full germination then the third step of the algorithm is to chip a fresh sample of seeds so that the embryo is exposed and then test for germination in the most suitable regime determined from the results of steps one and two. This may include a pre-chill treatment if the proportion of seeds germinating in step two was significantly greater than that in step one.

If full germination has not been promoted, the fourth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to

the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided in this chapter for the genera Allium and Asparagus.

TABLE 44.1 Summary of germination test recommendations for species within the Liliaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Kniphofia uvaria (L.) Hook.	TP	20°/30°C	21d		ISTA
Kniphofia spp.	TP	20°/30°C	18d		AOSA
Lilium regale Wils.	TP; S	20°/30°C; 20°C	28d		ISTA
	TP	20°C	21d		AOSA

ALLIUM

A. albo-pilosum W. Right	
A. ampeloprasum L.	great-headed garlic, wild leek
A. ampeloprasum L. var porrum (L.) Gray [A. porrum L.]	leek
A. angulosum L.	
A. asclepiadeum Bornm.	
A. atropurpureum W. & K.	
A. cepa L.	onion
A. curtum Boiss. & Gaill	
A. cyanthophorum var farreri Stearn	
A. fistulosum L.	Welsh onion, spring onion, Japanese bunching onion
A. flavum L.	
A. giganteum Regel	
A. heldreichii Boiss.	
A. hirstum Zucc.	
A. ledebourianum Schult.	
A. neapolitanum Cyr.	
A. pulchellum G. Don	
A. rosenbachianum Regel	
A. sativum L.	garlic
A. schoenoprasum L.	chive
A. schubertii Zucc.	
A. senescens L.	
A. tanguticum Regel	
A. tel-avivense Eig.	
A. ursinum L.	
A. victorialis L. var platyphylum Mak.	

I. Evidence of dormancy

Freshly harvested seeds of the above Allium spp. may be dormant (1,5,7,11,14,15,17,18,22,27,29). Within the above, seeds of A. albo-pilosum, A. ampeloprasum, A. curtum, A. flavum, A. giganteum, A. hirstum, A. neapolitanum, A. pulchellum, A. rosenbachianum, A. schubertii and A. tel-avivense are likely to be the more dormant (1). In A. cepa seed dormancy is comparatively weak requiring, for example, between 2 weeks (14) and 2 months (18) after-ripening at room temperature to remove dormancy.

Seed dormancy in A. ampeloprasum var porrum can be more pronounced (18) and the seeds may require, for example, 3 years after-ripening at room temperature to remove dormancy (5). Seeds of A. ursinum are reported to be very dormant, failing to germinate within 14 months of harvest (29).

II. Germination regimes for non-dormant seeds

A. ampeloprasum var porrum

BP: TP: 20°C; 15°C: 14d (ISTA)

BP: 20°C: 14d (AOSA)

Alternating temperatures: 10°/20°C (16h/8h) (7)

A. cepa

BP; TP: 20°C; 15°C: 12d (ISTA)

BP: 20°C: 10d (AOSA)

S: 20°C: 12d (AOSA)

Constant temperatures: 15°-22°C (10); 20°-25°C (21); 18°C (16)

Alternating temperatures: 20°/30°C (15h/9h) (12)

A. fistulosum

BP; TP: 20°C; 15°C: 12d (ISTA)

A. schoenoprasum

BP; TP: 20°C; 15°C: 14d (ISTA)

BP: 20°C: 14d (AOSA)

Constant temperatures: 20°C (13)

III. Unsuccessful dormancy-breaking treatments

A. albo-pilosum

Constant temperatures: 13°C, 20°C, 50d (1)

A. ampeloprasum var porrum

Constant temperatures: above 27°C (5)

Pre-chill: 3°-4°C, 7-28d, germinate at 20°C, 20°/30°C (16h/8h) (9); -1°C, 7-28d, germinate at 30°C (9)

Light: continuous, 1000 lux (18)

A. atropurpureum

Constant temperatures: 5°C, 50d (1)

A. cepa

Constant temperatures: above 28°C (19)

Alternating temperatures: 28°/33°C (8h/16h) (19)

Light: (19); continuous, 1000 lux (18)

GA_3: pre-applied, 6h, 50 ppm (20)

Naphthaleneacetic acid: pre-applied, 6h, 50 ppm (20)

A. curtum

Constant temperatures: 20°C, 30d (1)

A. fistulosum

Constant temperatures: above 28°C (19)

Alternating temperatures: 28°/33°C (8h/16h) (19)

Light: (19)

A. giganteum

Constant temperatures: 20°C, 50d (1)

A. hirstum

Constant temperatures: 5°C, 20°C, 50d (1)

A. neapolitanum

Constant temperatures: 20°C, 30d (1)

A. rosenbachianum

Constant temperatures: 13°C, 50d (1)

A. sativum

B-Naphthoxyacetic acid: pre-applied, 6h, 75 ppm (22)

A. senescens

Constant temperatures: 13°C, 30d (1)

A. victorialis var platyphylum

Constant temperatures: 10°C, 50d (1)

A. ursinum

Constant temperatures: 20°C in light or dark (29)

Pre-chill: 2d (29)

IV. Partly-successful dormancy-breaking treatments

A. albo-pilosum

Constant temperatures: 5°C, 50d (1)

A. ampeloprasum

Constant temperatures: 20°C, 30d (1)

A. ampeloprasum var porrum

Constant temperatures: 7°C, 15°C, 23°C (3); 12°-24°C (5); 15°C, 20°C (15, 18)

Alternating temperatures: 20°/25°C, 15°/28°C (16h/8h) (18)

Pre-chill: 3°-4°C, 14-28d, germinate at 25°C, 30°C (9); 5°C, 1d (17); 12°C, 3d (17); 5°C, 4d, germinate at 15°/28°C (18); 10°C, 5d, germinate at 10°/30°C (16h/8h) (7)

Warm stratification: 18°C, 3d (5); 12°C, 5d (5); 30°C, 14d (9)

Light: dark (18)

A. angulosum

Constant temperatures: 5°C, 13°C, 30d (1)

A. atropurpureum

Constant temperatures: 10°C, 20°C, 50d (1)

A. cepa

Constant temperatures: 12°C, 20°C (14); 15°C, 20°C (18); 20°C in light (28)

Alternating temperatures: 20°/25°C, 15°/28°C (16h/8h) (18); 12°/20°C (15h/9h) (14); 25°/33°C (8h/16h) (19)

Pre-chill: 12°C, 3d (17); 5°C, 1d (17); 5°C, 4d (18); 1.5°C, 6w, germinate at 7.5°C (27)

Light: dark (18)

GA_3: pre-applied, 6h, 30-75 ppm (22)

3-Indolepropionic acid: pre-applied, 6h, 30-75 ppm (22)

B-Naphthoxyacetic acid: pre-applied, 6h, 30-75 ppm (22)

Calcium peroxide: seed coating, 125-375 g/kg, germinate at 10°C, 20°C, light (28)

A. cyathophorum

Constant temperatures: 5°C, 13°C, 20°C, 50d (1)

A. fistulosum

Alternating temperatures: 25°/33°C (8h/16h) (19)

A. flavum

Constant temperatures: 5°C, 13°C, 20°C, 50d (1)

A. giganteum

Constant temperatures: 5°C, 110d (1)

A. heldreichii

Constant temperatures: 5°C, 10°C, 15°C, 30d (1)

A. ledebourianum

Constant temperatures: 15°C, 20°C, 25°C, 50d (1)

A. neapolitanum

Constant temperatures: 5°C, 13°C, 30d (1)

A. pulchellum

Constant temperatures: 5°C, 13°C, 20°C, 15d (1)

A. sativum

GA_3: pre-applied, 6h, 30, 75 ppm (22)

3-Indolepropionic acid: pre-applied, 6h, 30, 75 ppm (22)

B-Naphthoxyacetic acid: pre-applied, 6h, 30, 50 ppm (22)

A. schoenoprasum

Constant temperatures: 5°C, 110d (1)

A. schubertii

Constant temperatures: 20°C, 30d (1)

A. senescens

Constant temperatures: 5°C, 30d (1)

A. tanguticum

Constant temperatures: 20°C, 25°C, 50d (1)

A. tel-avivense

Constant temperatures: 5°C, 110d (1); 13°C, 20°C, 50d (1)

A. victorialis var platyphyllum

Constant temperatures: 15°C, 20°C, 50d (1)

V. Successful dormancy-breaking treatments

A. ampeloprasum

Constant temperatures: 5°C, 30d (1); 6°-15°C (24); 13°C, 15d (1)

A. ampeloprasum var porrum

Pre-chill (ISTA)

Constant temperatures: 5°C, 13°C, 20°C, 15d (1); 3°-17°C (2); 6°-15°C (24); 8°-22°C (10); 15°C (11); 7.5°-15°C (23,24); 12°-18°C (5)

Warm stratification: 27°C, 7d, germinate at 15°C (5); 20°C, 2d, then pre-chill, 1°C, 12d, germinate at 20°C (6)

A. angulosum

Constant temperatures: 20°C, 10d (1)

A. asclepiadeum

Constant temperatures: 10°C, 26d (26)

A. atropurpureum

Constant temperatures: 15°C, 10d (1)

A. cepa

Pre-chill (ISTA)

Constant temperatures: 3°-17°C (2); 4°-15°C (4); 10°C (27); 10°C in light (28); 18°C in dark (8, 16); 8°-22°C (10, 11, 25)

Pre-chill: 5°C, 4d, germinate at 20°/25°C (16h/8h) (18)

A. curtum

Constant temperatures: 5°C, 50d (1); 13°C, 20d (1)

A. fistulosum

Pre-chill (ISTA)

A. hirstum

Constant temperatures: 13°C, 15d (1)

A. rosenbachianum

Constant temperatures: 5°C, 110d (1)

A. sativum

GA_3: pre-applied, 6h, 50 ppm (22)

3-Indolepropionic acid: pre-applied, 6h, 50 ppm (22)

A. schoenoprasum

Pre-chill (ISTA)

Constant temperatures: 13°C, 20°C, 15d (1)

A. schubertii

Constant temperatures: 5°C, 30d (1); 10°C (26); 13°C, 30d (1)

A. senescens

Constant temperatures: 20°C, 25°C, 10d (1)

A. tanguticum

Constant temperatures: 15°C, 50d (1)

VI. Comment

The following constant temperatures or range of constant temperatures have been described as optimum for germinating seeds of Allium spp.: 2°-7°C for A. albo-pilosum, A. giganteum and A. rosenbachianum (1); 5°-13°C for A. ampeloprasum, A. curtum, A. heldreichii, A. pulchellum, A. neapolitanum, and A. schubertii (1); 5°-20°C for A. ampeloprasum var porrum, A. flavum and A. schoenoprasum (1,3); 10°-20°C for A. atropurpureum (1); 13°C for A. hirstum and A. tel-avivense (1); 13°-20°C for A. cyathophorum (1); 15°-20°C for A. ledebourianum and A. victorialis var platyphyllum (1); 20°C for A. angulosum (1); and finally 20°-25°C for A. senescens and A. tanguticum (1). However, for the more dormant seeds of the above species a constant temperature germination test regime alone may be insufficient to promote the germination of all dormant seeds.

When compared with certain constant temperatures there may be an advantage in testing the seeds for germination in alternating temperature regimes, or at least no disadvantage: with seeds of A. ampeloprasum var porrum and A. cepa alternating temperature regimes of 15°/28°C (16h/8h) (18) or 10°/20°C (16h/8h) (7) were reported to provide greater promotion of germination than constant temperatures of 15°C or 20°C; in other investigations with A. cepa there was no difference between germination at a constant temperature of 20°C and at alternating temperature regimes of 20°/30°C (16h/8h) (12,13) or 12°/20°C (15h/9h) (14). However, it is suggested here that lower constant temperatures - combined with an extended test period - may be preferable.

Seed dormancy in Allium spp. tends to delay germination, rather than completely preventing it. For dormant seeds of most Allium species cultivated as vegetables, 49-day - or more - germination tests at 10°C in the dark are likely to be successful (4,27). In some accessions only a minority of seeds may germinate during a 63-day test at 10°C (A). Should full germination not be observed in this regime then it is suggested that the seeds then be transferred to 20°C for a further 14 days: in other words the original test regime is treated as a pre-chill treatment, during which some germination may occur. In A. schoenoprasum such transfers have been extremely promotory (A). As an alternative to this somewhat lengthy test, combining potassium nitrate (0.2%, co-applied) and pre-chilling treatments (3°-5°C, 7 days) enables the subsequent germination test period at 15°C for seeds of A. schoenoprasum to be reduced from 77 days to between 14 and 21 days (A). Consequently we suggest this regime as an alternative procedure to shorten overall germination test periods. Where dormancy is not a problem - as may often be the case in A. cepa for example - testing at 15°C for a much shorter period with no additional treatments is adequate.

VII. References

1. Aoba, T. (1967). [Effects of different temperatures on seed germination of garden ornamentals in Allium.] Journal of the Japanese Society for Horticultural Science, 36, 333-338.

2. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticultures, 2, 213-219.

3. Bremer, A.H. (1927). Oppspiring av hagefro under unlike temperaturer. Nord. Jordbr.

Forsk., 9, 377-390.

4. Dowker, B.D., Winarno, J.F. and Fennell, J.F.M. (1981). Germination studies on onion seed lots. Horticultural Research, 21, 41-48.

5. Dragland, S. (1972). Germination of leek seed at different temperatures. Meldinger fra Norges Landbrukshogskole, 51, 1-9.

6. Finch-Savage, W.E. and Cox, C.J. (1982). A cold-treatment technique to improve the germination of vegetable seeds prior to fluid drilling. Scientia Horticulturae, 16, 301-311.

7. Fornerod, C. (1975). Remarques sur la germination des semences potageres en laboratoire. Revue Horticole Suisse, 48, 6-9.

8. Gadd, I. (1939). On methods for the elimination of seed dormancy in seed control work. Proceedings of the International Seed Testing Association, 11, 96-118.

9. Gelmond, H. (1965). Pre-treatment of leek seed as a means of overcoming superoptimal temperatures of germination. Proceedings of the International Seed Testing Association, 30, 737-742.

10. Guy, R. (1980). Quelques exemples des effets de la temperature sur la germination des plantes potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 12, 35-37.

11. Guy, R. (1981). Influence de la tempèrature sur la durèe de germination des semences de dix espèces potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 13, 219-225.

12. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

13. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

14. Ingold, M. (1960). Contribution à l'ètude de la germination des semences d'Allium cepa L. et Cucurbita pepo L. Proceedings of the International Seed Testing Association, 25, 787-799.

15. Klitgård, K. (1969). Report of the working group on the germination of Beta, Brassica and Allium. Proceedings of the International Seed Testing Association, 34, 609-612.

16. Kotowski, F. (1926). Temperature relations to germination of vegetable seed. Proceedings of the American Society for Horticultural Science, 23, 176-184.

17. Lovato, A. and Amaducci, M.T. (1964). Examination of the problem of whether dormancy exists in seeds of onion (Allium cepa L.) and leek (Allium porrum L.). I. A comparative test of different tetrazolium test techniques. Proceedings of the International Seed Testing Association, 29, 17-26.

18. Lovato, A. and Amaducci, M.T. (1965). Examination of the problem of whether dormancy exists in seeds of onion (Allium cepa L.) and leek (Allium porrum L.). II. Effect of temperature, prechilling and light on germination. Proceedings of the International Seed Testing Association, 30, 803-820.

19. Nakamura, S., Okasako, Y. and Yamada, E. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

20. Sandhu, J.S., Nandpuri, K.S. and Thakur, J.C. (1972). Studies on the germination of

freshly harvested mature and immature onion seeds. Indian Journal of Horticulture, 29, 339-341.

21. Singh, H. and Kumar, A. (1979). Germination studies on vegetable crops onion, pea and spinach. Journal of Research, India, 16, 164-168. (From Horticultural Abstracts, 1982, 52, 2137.)

22. Srivastava, R.P. and Adhikari, B.S. (1968). Influence of growth substances on the germination of onion and garlic. Allahabad Farmer, 42, 103-104.

23. Thompson, P.A. (1972). Geographical adaptation of seeds. In Seed Ecology (ed. W. Heydecker), pp. 31-58, Butterworths, London.

24. Thompson, P.A. and Cox, D.J.C. (1976). The germination responses of vegetable seeds in relation to their history of cultivation by man. Scientia Horticulturae, 4, 1-14.

25. Wagenvoort, W.A., Boot, A. and Bierhuizen, J.F. (1981). Optimum temperature range for germination of vegetable seeds. Gartenbauwissenschaft, 46, 97-101.

26. Wallerstein, I. (1981). [Propagation of Allium asclepiadeum and Allium schubertii from seeds.] Hassadeh, 61, 1678-1681. (From Seed Abstracts, 1982, 5, 1266.)

27. Whitwell, J.D. and Davies, A.C.W. (1976). Some effects of temperature on the emergence of bulb onion seed stocks. Experimental Horticulture, 28, 41-46.

28. Brocklehurst, P.A. and Dearman, J. (1983). Effects of calcium peroxide as a supplier of oxygen for seed germination and seedling emergence in carrot and onion. Seed Science and Technology, 11, 293-299.

29. Tutin, T.G. (1957). Biological flora of the British Isles. Allium ursinum L. Journal of Ecology, 45, 1003-1010.

ASPARAGUS

A. densiflorus (Kunth) Jessop [A. Sprengeri Regel]	sprenger asparagus
A. officinalis L.	garden asparagus
A. setaceus (Kunth) Jessop [A. plumosus Baker]	fern asparagus

I. Evidence of dormancy

Seeds of A. officinalis may show slight dormancy at harvest (3,4,7), which can be removed by 3 weeks storage (3). However, secondary dormancy may be induced during drying, or in germination tests where the medium is allowed to dry out, or where the concentration of carbon dioxide is increased (4). Problems of hardseededness may arise in A. densiflorus (5) and A. setaceus.

II. Germination regimes for non-dormant seeds

A. densiflorus

BP; TP; S: 20°/30°C (16h/8h); 20°C: 35d (ISTA)

BP; TP: 20°/30°C (16h/8h): 30d (AOSA)

A. officinalis

BP; TP; S: 20°/30°C (16h/8h): 28d (ISTA)

BP; S: 20°/30°C (16h/8h): 21d (AOSA)

A. setaceus

BP; TP; S: 20°/30°C (16h/8h); 20°C: 35d (ISTA)

TP; BP: 20°/30°C (16h/8h): 30d (AOSA)

III. Unsuccessful dormancy-breaking treatments

A. densiflorus

Pre-soak: 12h (5)

Ultrasonics: 0-1000 kHz, 30s-5 min, with or without pre-soak, 12h (5)

A. officinalis

Pre-chill: -10°C, -10°/4°C (7d/7d), 4°C, -10°/4°/21°C (7d/7d/7d), moist sand, 2m, germinate at 26°C ± 4°C in light, 12000 lux, 14h/d (8)

Pre-soak: 6-110h, 22°-38°C (2); 6-86h, 45°C (2); 6-40h, 50°C (2); 110h, 45°C (2); 12h, 20°C, 30°C (2); 12-48h, 30°C, germinate at 30°C (3); 2m, -10°C, -10°/4°C (7d/7d), 4°C, germinate at 26°C ± 4°C in light, 12000 lux, 14h/d (8)

IV. Partly-successful dormancy-breaking treatments

A. densiflorus

Constant temperatures: 30°C (6)

Ultrasonics: 0-1000 kHz, 5s, then pre-soak, 12h (5) pH: 5.6 (6)

A. officinalis

Constant temperatures: 15°C, 30°C (3,4); 26°C ± 4°C in light, 12000 lux, 14h/d (8)

Pre-chill: 0°-5°C, 10-40d, germinate at 15°C (3); 0°-5°C, 10-60d, germinate at 10°C (4); 0°-5°C, 30d, germinate at 15°C, 20°C (4); 10°-12°C, 10-30d, germinate at 15°C (3); 10°-12°C, 10,20d, germinate at 30°C (3)

Pre-soak: 1-6d, 20°C, 30°C (2)

V. Successful dormancy-breaking treatments

A. densiflorus

Pre-soak (ISTA)

A. officinalis

Pre-chill: 5m (1); 10°-12°C, 30d, germinate at 30°C (3); 10°-12°C, 10-30d, then 15°C, 30d, germinate at 30°C (3); 0°-5°C, 30d, germinate at 30°C (3,4); 0°-5°C, 50-60d, germinate at 15°C, 20°C, 30°C (3,4); 0°-5°C, 10-40d, then 15°C, 30d, germinate at 30°C (3)

Scarification: concentrated sulphuric acid, 10 min, germinate at 15°C (4)

A. setaceus

Pre-soak (ISTA)

VI. Comment

It is important that the germination test substratum be prevented from drying out and that it be kept moist throughout the germination test (4, AOSA). Germination tests may have to be extended beyond the 21 to 35 days prescribed by ISTA/AOSA to as many as 71 days (1). Pre-soak treatments are not particularly beneficial (3), and although pre-chill treatments are effective in promoting the germination of dormant seeds, considerable treatment periods may be required (1,3,4).

It is suggested that the seeds be tested for germination at 20°/30°C (16h/8h) for up to 60 days following pre-chill treatments: either at 3°-5°C for 10 to 30 days; or at 10°C for 30 days. In addition check for hardseededness after 7 days or so in test (that is during the pre-chill treatment) and scarify (by hand) any seeds remaining hard at this time.

VII. References

1. Adams, J. (1927). The germination of the seeds of some plants with fleshy fruits. American Journal of Botany, 14, 415-428.

2. Borthwick, H.A. (1925). Factors influencing the rate of germination of the seed of Asparagus officinalis. University of California Agricultural Experiment Station, Technical Paper, 18, 1-17.

3. Komoti, S. (1956). [Studies on temperature treatments of seeds. I. Effects of temperature treatments on germination of garden asparagus seeds.] Hokkaido National Agricultural Experiment Station Research Bulletin, 70, 42-49.

4. Komoti, S. (1957). [Studies on temperature treatments of seeds. II. Dormancy and germinating temperature in garden asparagus seeds.] Hokkaido National Agricultural Experiment Station Research Bulletin, 73, 9-19.

5. Perry, L.P. and Boodley, J.W. (1980). Germination of foliage plant seeds in response to pre-sowing, ultrasonic exposures, water soaks and fungicides. HortScience, 15, 192-194.

6. Perry, L.P. and Boodley, J.W. (1980). Germination of foliage plant seeds in response to sowing media, depths of sowing, pH levels, and medium temperatures. HortScience, 15, 194-196.

7. Wright, W.N. (1945). Hard seed of asparagus. Newsletter of the Association of Official Seed Analysts, 19, 5.

8. Dufault, R.J. and Greig, J.K. (1983). Production potential and survival of fall- and spring-seeded asparagus. Journal of the American Society for Horticultural Science, 108, 763-767.

CHAPTER 45. LINACEAE

The Linaceae comprise about 150 species of herbaceous plants and shrubs within 14 genera which provide fibre and oils (e.g. Linum usitatissimum L., flax). The fruits are usually capsules, but sometimes drupes. The seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

The seeds can show considerable dormancy. B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos within thin, mucilaginous seed coats (see Table 17.2, Chapter 17). Potassium nitrate, low germination test temperatures, alternating temperatures, and pre-chilling are generally promotory treatments. Detailed information is provided in this chapter for the genus Linum only, but the algorithm below may be helpful in developing suitable germination test procedures for difficult accessions of Linum and other species.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test the seeds at constant temperatures of 16°C, 21°C and 26°C with light applied for 12h/d. If full germination has not been achieved and the results of these tests indicate a trend in the response of germination to constant temperatures then test a further sample of seeds at a more extreme constant temperature. For example, if the greatest proportion of seeds germinates at 16°C, then test a further sample of seeds at a constant temperature of 11°C with light applied for 12h/d.

If the first step of the algorithm has not resulted in full germination then the second step is to test a fresh sample of seeds in an alternating temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If the second step of the algorithm has not resulted in full germination then the third step is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test a fresh sample of seeds in the most appropriate temperature regime determined from the results of steps one and two.

If the third step of the algorithm has not resulted in full germination then the fourth step of the algorithm is to pre-chill a fresh sample of seeds at 2° to 6°C for 8w and then test in the most appropriate regime determined from the results of steps one to three. This may include a GA_3 treatment if a comparison of the results of step three with those of steps one and two indicate that the GA_3 treatment is promotory.

LINUM

L. flavum L.	golden flax
L. grandiflorum Desf.	flowering flax
L. narbonense L.	
L. perenne L.	perennial flax
L. usitatissimum L.	flax

I. Evidence of dormancy

Freshly harvested seeds of L. usitatissimum can be dormant (5,6), and after-ripening for 3-4 (6) or 6 (5) months is required to remove this dormancy.

II. Germination regimes for non-dormant seeds

L. flavum

TP; BP: 20°/30°C (16h/8h); 15°C; 20°C: 21d (ISTA)

TP: 20°/30°C (16h/8h): 18d (AOSA)

Constant temperatures: 20°C, 21d (1)

L. grandiflorum

BP; TP: 15°C; 10°C; 20°C: 21d (ISTA)

TP: 15°C: 12d (AOSA)

Constant temperatures: 15°C, 14d (1)

L. narbonense

TP; BP: 20°/30°C (16h/8h); 15°C; 20°C: 21d (ISTA)

L. perenne

BP; TP: 15°C; 10°C; 20°C: 21d (ISTA)

TP: 15°C: 14d (AOSA)

Constant temperatures: 15°C, 21d (1)

L. usitatissimum

BP; TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

BP, S: 20°/30°C (16h/8h): 7d (AOSA)

Constant temperatures: 15°C (8); 20°C (3,5); 22°-25°C (7); 28°C in dark (10); 30°C (4,14)

Alternating temperatures: 15°/31°C (12h/12h) (15); 20°/30°C, 25°/35°C (18h/6h) (4); 20°/30°C (16h/8h) (3,4,9,13)

III. Unsuccessful dormancy-breaking treatments

L. usitatissimum

Constant temperatures: 1°C, 40°C (12)

Alternating temperatures: 25°/40°C, 40°/20°C, 40°/25°C (18h/6h) (4)

Pre-dry: 40°C, 50°C, 65°C, 1h (15)

Deuterium oxide: co-applied, 25-100% (1)

Boric acid: co-applied, 10^{-4}, 10^{-2} M (10)

Sodium metaborate: co-applied, 10^{-4}, 10^{-2} M (10)

Sodium tetraborate: co-applied, 10^{-4}, 10^{-2} M (10)

IV. Partly-successful dormancy-breaking treatments

L. perenne

Constant temperatures: 15°C, 25°C, 30°C, in light, $155x10^{-6}$ mol m^{-2} s^{-1} (11)

L. usitatissimum

Alternating temperatures: 20°/30°C (16h/8h) (9)

Pre-chill: 10°C, 4d, germinate at 20°C (5)

Potassium nitrate: co-applied, 0.2%, plus pre-chill, 10°C, 4d, germinate at 20°C (5)

Boric acid: co-applied, 10^{-6} M (10)

Sodium metaborate: co-applied, 10^{-6} M (10)

Sodium tetraborate: co-applied, 10^{-6} M (40)

V. Successful dormancy-breaking treatments

L. flavum, L. grandiflora

Potassium nitrate (AOSA, ISTA)

L. narbonense

Potassium nitrate (ISTA)

L. perenne

Potassium nitrate (AOSA, ISTA)

Constant temperatures: 20°C, in light, 155 x 10^{-6} mol m^{-2} s^{-1} (11)

L. usitatissimum

Pre-chill (ISTA)

Constant temperatures: 5°C, 15°C, 25°C, in dark (8); 4°C, 14°C, 16°C (16)

Pre-chill: 5°C, 5d, germinate at 20°/30°C (16h/8h) (9)

VI. Comment

The optimum range of constant temperatures for the germination of seeds of L. usitatissimum is 4° to 20°C (8,16). Pre-chilling (9) or pre-chilling plus co-applied potassium nitrate (5) are very effective dormancy-breaking treatments. It is suggested that the ISTA rules are satisfactory for germination but it may prove worthwhile to investigate whether the pre-chill regime should be extended and considered as the germination test regime - rather than subsequently transferring to a higher temperature.

VII. References

1. Atwater, B.R. (1980). Germination, dormancy and morphology of the seeds of herbaceous

ornamental plants. Seed Science and Technology, 8, 523-573.

2. Blake, M.I., Crane, F.A., Uphaus, R.A. and Katz, J.J. (1968). Effect of heavy water on the germination of a number of species of seeds. Planta, 78, 35-38.

3. Decker, A.E. and Reitz, L.P. (1948). Germination tests with flax stored at different moisture and temperature levels. Proceedings of the International Seed Testing Association, 14, 27-34.

4. Dillman, A.C. and Toole, E.H. (1937). Effect of age, condition, and temperature on the germination of flax seed. Journal of the American Society of Agronomy, 29, 23-29.

5. Doyle, E.J., Robertson, E. and Lewis, N.G. (1952). The effect of potassium nitrate on the germination of freshly harvested wheat, oats, barley and flax seed. Proceedings of the Association of Official Seed Analysts, 42, 93-101.

6. Frederiksen, P.S. (1955). [Germination tardiness of fibre-flax seed.] Lin, 9, 85-87. (From Field Crops Abstracts, 1957, 10, 248.)

7. Gupta, D. and Basak, S.L. (1983). Genetics of germination and seedling growth of flax (Linum usitatissimum). Seed Science and Technology, 11, 251-256.

8. Harper, J.L. and Obeid, M. (1967). Influence of seed size and depth of sowing on establishment and growth of varieties of fiber and oil seed flax. Crop Science, 7, 527-532.

9. Higgins, E.C. (1951). Flax germination - crops of 1950. Proceedings of the Association of Official Seed Analysts, 41, 88-89.

10. Jensen, W. (1951). Effect of boron on germination of flax seed and on respiration of flax seedlings. Botanical Gazette, 113, 180-185.

11. Kaspar, M.J. and McWilliams, E.L. (1982). Effects of temperature on the germination of selected wild flower seeds. HortScience, 17, 595-596.

12. Mandy, G.Y., Szabo, L. and Papp, E. (1971). [Examination of cardinal points of germination in poppy and flax varieties.] Agrobotanika, 11, 169-174. (From Field Crop Abstracts, 1973, 26, 1912.)

13. Reitz, C.P. Hansing, E.D., Davidson, F.E. and Decker, A.E. (1947). Viability and seed treatment of flax. Journal of the American Society of Agronomy, 39, 959-970.

14. Salehuzzaman, M. and Pasha, M.K. (1979). Effects of high and low temperatures on the germination of seeds of flax and sesame. Indian Journal of Agricultural Sciences, 49, 260-261.

15. Siegel, S.M. (1950). Effects of exposures of seeds to various physical agents. 1. Effects of brief exposures to heat and cold on germination and light sensitivity. Botanical Gazette, 112, 57-70.

16. Trifonov, N.P. (1980). [Temperature and germination of flax seed.] Len i Kinoplya, 1, 26-27. (From Field Crop Abstracts, 1981, 34, 10443.)

CHAPTER 46. MALVACEAE

The Malvaceae comprise more than 1000 species of herbaceous plants, shrubs and trees within about 50 genera which provide fibres (e.g. Gossypium hirsutum L., cotton) and edible fruits (e.g. Hibiscus esculentus L., okra). The fruits are usually dry single-seeded schizocarps or capsules, but are sometimes berry-like. The seeds exhibit orthodox storage characteristics.

SEED DORMANCY AND GERMINATION

The seeds may possess an endosperm, but the major food storage organ is the cotyledons. The seed coats are often hard and the embryo can be slow to develop during germination. B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos within hard seed coats (see Table 17.2, Chapter 17). Consequently treatments to seed coats which overcome hardseededness generally promote germination (see Chapter 7, Volume I).

In addition dormancy per se (that is innate seed dormancy, see Chapter 5, Volume I) can also prevent germination. Secondary dormancy may be induced when the seeds are tested for germination at low temperatures. Dormancy is minimised if the seeds are tested in alternating temperature regimes. The presence of both hardseededness and innate seed dormancy is sometimes described as double dormancy (see Chapter 5, Volume I).

Detailed information on seed dormancy and seed germination for the genera Gossypium, Hibiscus (including synonyms within Abelmoschus and Trionum), and Urena is provided in this chapter. Recommendations for germination test procedures and dormancy-breaking treatments for other species are summarised in Table 46.1. In addition the algorithm below may be helpful in developing suitable germination test procedures for some accessions.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 11°C, 21°C and 31°C with light applied for 12h/d.

If the above regimes do not promote full germination then the second step in the algorithm is to chip a fresh sample of seeds and then test at the constant temperature regime which gave the greatest germination in step one: test at 21°C if no significant differences in germination were observed in step one. Imbibition injury (see Chapter 4, Volume I) may occur in malvaceous species, particularly where the seed coats have been chipped. Consequently it may advantageous to humidify (condition) the seeds after chipping the seed coats and before imbibition. Chapter 7, Volume I, provides details of a suitable humidification treatment.

If the second step of the algorithm does not result in full germination then the third step of the algorithm is to experiment with the above conditions and test fresh samples of seeds in darkness and/or in alternating temperature regimes. The alternating temperature regimes 20°/30°C (16h/8h) and 15°/35°C (16h/8h) are suggested. If a comparison of the results of steps one and two shows chipping to be beneficial, then chip (and possibly humidify) the seeds before testing in darkness and/or alternating temperatures.

If full germination has not been promoted, the fourth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to

the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided in this chapter for the genera Gossypium, Hibiscus and Urena and from Table 46.1.

TABLE 46.1 Summary of germination test recommendations for species within the Malvaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Abutilon x hybridum Hort.	TP; BP	20°/30°C; 20°C	21d		ISTA
Abutilon theophrasti Medic.	TP; S	3°/35°C	7d	pre-soak, 100°C, 0.5-1 min, or pre-chill, 2°-5°C, 2d	Everson
				pre-soak, 70°C, 30s, or pre-dry, 95°C, 6 min	Atwater
Alcea rosea L.	TP; BP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa	ISTA
	BP	20°C	18d	continue test for a further 5d if (reversible) hard	AOSA
				seeds have begun to imbibe	
		20°C	21d	remove calyx, clip hard seeds	Atwater
Althaea x hybrida Hort.	TP; BP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa	ISTA
Althaea officinalis L.	TP; BP	20°/30°C; 20°C	21d	pierce, chip or file cotyledon end of testa	ISTA
Lavatera trimestris L.	TP; BP	20°/30°C; 20°C	21d	pre-chill	ISTA
	BP	20°C	21d	continue test for a further 5d if (reversible) hard	AOSA
				seeds have begun to imbibe	AOSA
Malope trifida Cav.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA

GOSSYPIUM

G. anomalum Wawra & Peyr.	wild cotton
G. arboreum L. [G. obtusifolium Roxb.; G. Nanking Meyen; G. indicum Lam.]	Ceylon cotton, Chinese cotton, tree cotton
G. armourianum Kearney	wild cotton
G. barbadense L. [G. peruvianum Cav.; G. vitifolium Lam.]	sea-island cotton
G. barbadense L. var darwinii Hutch.	wild cotton
G. herbaceum L.	Levant cotton, asiatic cotton
G. hirsutum L. [G. mexicanum Tod.]	upland cotton
G. hirsutum L. var marie-galante (Watt) Hutch.	tree cotton
G. hirsutum L. x G. barbadense L.	American-Egyptian cotton
G. klotzschianum Anders. var davidsonii Hutch.	wild cotton
G. raimondii Ulb.	wild cotton
G. thurberi Tod.	wild cotton

I. Evidence of dormancy

Standard germination tests on seeds of Gossypium spp. are often plagued by low, delayed and/or erratic germination with additional problems from fungi (1,8,9,12,16). Freshly harvested seeds and those dried below 10% moisture content are generally the more difficult to germinate since they are extremely sensitive to the conditions of the germination test (16). These germination test difficulties result from both dormancy and hardseededness.

At harvest seeds of the cultivated Gossypium spp. can show considerable dormancy, viz. G. barbadense (17), G. herbaceum (9), G. hirsutum (3-6,10-12,14,16,17) and G. hirsutum x G. barbadense (5). Dormancy is reported to be lost after 1 (6,11), 1-5 (5), 2-3 (10) or 24 months (15) after-ripening. In addition secondary dormancy may be induced at low germination test temperatures (7,15), under high salt concentrations (15), or if there is excess moisture during imbibition (16). In the latter case the reported secondary dormancy may be increased hardseededness in the population.

Hardseededness is induced in the majority of seeds of the cultivated Gossypium spp. when dried to 5 or 6% moisture content (16). In addition all wild forms of the cultivated spp. and most wild Gossypium spp. have impermeable seed coats at low moisture contents (3,14,17). In general the wild spp. have much thicker seed coats than the cultivated spp. (14) and consequently greater proportions of individual seeds of the former are hardseeded than the latter (17). Thus gene banks must assume that hardseededness is present in all cases and take steps to make the seed coats permeable, with more severe treatments being necessary for the wild spp. than for the cultivated spp.

II. Germination regimes for non-dormant seeds

Gossypium spp.

BP; S: 20°/30°C (16h/8h); 25°C: 12d (ISTA)

BP; S: 20°/30°C (16h/8h): 12d (AOSA)

BP; S: 30°C: 8d (AOSA)

III. Unsuccessful dormancy-breaking treatments

G. hirsutum

Constant temperatures: 13°C (15)

Light: white, continuous (13); red, 1,4,8 min, after 8,12,16h dark imbibition (13)

Sodium chloride: co-applied, 9000 ppm, plus calcium chloride, 9000 ppm, at 25°C (15)

Scarification: mechanical, after acid delint (12)

IV. Partly-successful dormancy-breaking treatments

G. barbadense

Pre-soak: shake, drain, blot (7); 1h, after acid delint, then calcium chloride, co-applied, 10^{-5} M, at 15°C (8)

G. herbaceum

Pre-chill: 5°C, 71d (9)

G. hirsutum

Constant temperatures: 20°C, dark (1)

Alternating temperatures: 20°/30°C (16h/8h) (1); 18°/32°C (16h/8h, 8h/16h) (16); 13°/15°-21°C (16h/8h), after acid delint (2)

Pre-soak: shake, drain, blot (7); 1h, after acid delint, then calcium chloride, co-applied, 10^{-5} M, at 15°C (8)

Pre-dry: (11)

Ultrasonics: 90 kc/s, 30 min, germinate at 20°/30°C (16h/8h) (1)

Light: dark (13); far red, 4,8, min, after 8,12,16h dark imbibition (13)

V. Successful dormancy-breaking treatments

G. anomalum

Removal of seed covering structures: chip (14)

Pre-soak: hot water (14)

G. arboreum

Constant temperatures: 25°-30°C, after acid delint (7)

G. armourianum

Removal of seed covering structures: chip (14)

Pre-soak: hot water (14)

G. barbadense

Constant temperatures: 25°-30°C, after acid delint (7)

Alternating temperatures: 16°/21°C, 16°/27°C, 16°/30°C, 19°/21°C, 19°/27°C, 19°/30°C, 13°/27°C, 13°/30°C (16h/8h), after acid delint (2)

Pre-soak: 85°C, 1 min (17); 80°-90°C, 0.5-2 min (17); 1h, after acid delint, then calcium chloride, co-applied, 10^{-5} M, at 25°C (8)

G. barbadense var darwinii

Pre-soak: hot water (14)

Removal of seed covering structures: chip (14)

G. hirsutum

Constant temperatures: 20°C, 25°C, (16); 25°-30°C, after acid delint (7)

Alternating temperatures: 20°/30°C (16-18h/8-6h) (16); 15°/35°C (18h/6h) (16); 16°/21°C, 16°/27°C, 16°/30°C, 19°/21°C, 19°/27°C, 19°/30°C, 13°/27°C, 13°/30°C (16h/8h), after acid delint (2)

Pre-soak: 85°C, 1 min (17); 80°-90°C, 0.5-2 min (17); shake, drain, blot, germinate at

20°/30°C (16h/8h) (16); 1h, after acid delint, then calcium chloride, co-applied, 10^{-5} M, at 25°C (8)

Scarification: concentrated sulphuric acid, 5-8 min (12); ethanol (3); ether (3)

Removal of seed covering structures: seed coat (12); prick (3)

G. hirsutum var marie-galante, G. klotzschianum var davidsonii, G. raimondii

Pre-soak: hot water (14)

Removal of seed covering structures: chip (14)

G. thurberi

Pre-soak: hot water (14); 85°C, 1 min (17); 80°-90°C, 0.5-2 min (17)

VI. Comment

The term acid delint is used by many authors to describe a procedure which dissolves the lint and fuzz fibres of the seed coat and also removes other external contamination: it is frequently recommended as a means of seedling disease control (12). A typical treatment is 5 to 8 minutes immersion in sulphuric acid. Such treatments dissolve the cotton fibres and their basal cells, and in addition the epidermal and outer pigment layers of the seed coat are broken and distorted. The subsequent rate of imbibition (and hence germination) is increased, mainly due to closer contact between seeds and the germination test substratum in the absence of the fuzz. However, some accessions are damaged by acid delint treatments (12).

As an alternative to the acid delint treatment AOSA, ISTA (1976 Rules) and others (16) have recommended saturating the lint with moisture (pre-wetting) - by soaking and/or shaking the seeds in water or by subjecting seeds to a moist atmosphere using mist propagation equipment, with excess moisture being removed by the use of blotting paper. Whilst this increases the rate of imbibition (at least if the seeds are not hard), the germination of seeds of Gossypium spp. is very sensitive to excess moisture (8,12,16). Moreover, neither acid delinting nor pre-wetting can totally avoid the problem of hardseededness which, in seeds at 5% moisture content, is likely to be pronounced.

Consequently the following sequence of pre-germination test treatments is recommended for use in gene banks where seeds have been dried to low moisture contents: first scarify the seeds by chipping or sanding away a piece of the seed coat, or by piercing the seed coat with a needle; then humidify the seeds at ambient temperature and 95-100% relative humidity. A 24-48 hour humidification treatment for scarified seeds is sufficient to raise seed moisture content from around 6 to 12% moisture content (4). Provided seed moisture content is at or above 12% moisture content there should be no problems in the subsequent germination test (16). Seeds destined for field or glasshouse sowings should also be pre-treated as described.

Provided low temperatures are avoided - at which secondary dormancy may be induced (7,15) - full germination occurs over a fairly wide range of alternating and constant temperatures, viz. 20°/30°C (16h/8h), 15°/35°C (18h/6h), 20°C, 25°C (16). The major effect of seed dormancy appears to be one of delay to germination under such regimes rather than a failure to germinate (12). Thus it is suggested that the pre-treated seeds be tested for germination at the alternating temperature regime prescribed by AOSA/ISTA - 20°/30°C (16h/8h) - for at least 14 days.

VII. References

1. Andersen, A.M., Hart, J.R. and French, R.C. (1964). Comparison of germination techniques

and conductivity tests of cotton seeds. Proceedings of the International Seed Testing Association, 29, 81-96.

2. Anderson, W.K. (1971). Emergence and early growth response of cotton to controlled temperature regimes. Cotton Growing Review, 48, 104-115.

3. Christiansen, M.N. and Moore, R.P. (1959). Seed coat structural differences that influence water uptake and seed quality in hard seed cotton. Agronomy Journal, 51, 582-584.

4. Christiansen, M.N., Moore, R.P. and Rhyne, C.L. (1960). Cotton seed quality preservation by a hard seed coat characteristic which restricts internal water uptake. Agronomy Journal, 52, 81-84.

5. Christidis, B.G. (1955). Dormancy in cotton seed. Agronomy Journal, 47, 400-403.

6. Hsi, D.C.H. and Reeder, H.M. (1953). Dormancy of upland and American-Egyptian cottonseed. Agronomy Journal, 45, 454.

7. Ludwig, C.A. (1932). The germination of cotton seed at low temperatures. Journal of Agricultural Research, 44, 367-380.

8. Powell, R.D. and Morgan, P.W. (1973). A test system for the germination of cotton seed. Cotton Growing Review, 50, 268-273.

9. Prathapasenan, G., Kamalavalli, D. and Pathak, C.H. (1966). Retarded rate of germination in Digvijay cotton. Journal of Maharaja Sayajirao University, Baroda, 15, 1-3. [From Field Crop Abstracts, 1972, 25, 2423.]

10. Purseglove, J.W. (1968). Malvaceae, pp. 333-376. In Tropical Crops. Dicotyledons Longmans, London.

11. Simpson, D.M. (1935). Dormancy and maturity of cotton seed. Journal of Agricultural Research, 50, 429-434.

12. Simpson, D.M., Adams, C.L. and Stone, G.M. (1940). Anatomical structure of the cotton seed coat as related to problems of germination. U.S.D.A. Technical Bulletin 734, pp. 1-23.

13. Singh, G. and Garg, O.P. (1971). Effect of red, far-red radiations on germination of cotton seed. Plant and Cell Physiology, Japan, 12, 411-415.

14. Stephens, S.G. (1958). Salt water tolerance of seeds of Gossypium species as a possible factor in seed dispersal. American Naturalist, 92, 83-92.

15. Taylor, R.M. and Lankford, M.K. (1972). Secondary dormancy in cotton. Crop Science, 12, 195-196.

16. Toole, E.H. and Drummond, P.L. (1924). The germination of cotton seed. Journal of Agricultural Research, 28, 285-292.

17. Walhood, V.T. (1956). A method of reducing the hard seed problem in cotton. Agronomy Journal, 48, 141-142.

HIBISCUS

H. acetosella Welw.	
H. cannabinus L.	kenaf, bimli, bimlipatum, jute, Deccan hemp

H. coccineus Walt.	
H. esculentus L. [Abelmoschus esculentus (L.) Moench]	okra, lady's finger, gumbo, bhindi
H. gossypinus Thunb.	
H. militaris Cav.	
H. moscheutos L. [H. oculiroseus Britt.]	
H. mutabilis L.	cotton rose, confederate rose
H. pedunculatus L.	
H. sabdariffa L.	roselle, Jamaican sorrel
H. trionum L. [H. africanus Hort.; Trionum trionum Woot. & Standl.]	flower of an hour, shoo fly

I. Evidence of dormancy

No reports of dormancy, hardseededness or other problems in germinating seeds of H. cannabinus and H. sabdariffa have been found in the literature. Apparently, most of the annual cultivated Hibiscus spp. produce few hard seeds (16), whereas hardseededness can be prevalent in seeds of the wild Hibiscus spp., viz. H. trionum (5,9,11,16), H. acetosella, H. gossypinus, H. militaris, H. pedunculatus, H. moscheutos, H. coccineus and H. mutabilis (16). Hardseededness can, however, be a problem for seeds of H. esculentus, causing slow and erratic germination (1,7,13): seeds of H. esculentus at 13% moisture content tend to show little or no hardseededness, but once the seeds have been dried to 4-6% moisture content hardseededness becomes prevalent (A). This suggests that hardseededness is a potential problem in seeds of all Hibiscus spp. dried to low moisture contents for long-term storage. In addition to hardseededness, seed dormancy is also a problem in germination tests of H. esculentus (A).

II. Germination regimes for non-dormant seeds

H. cannabinus

BP; S: 20°/30°C (16h/8h): 8d (ISTA)

BP: 20°/30°C (16h/8h): 8d (AOSA)

H. esculentus

BP; TP; S: 20°/30°C (16h/8h): 21d (ISTA)

BP: 20°/30°C (16h/8h): 14d (AOSA)

H. sabdariffa

Alternating temperatures: 25°/30°C, light, 24h/d, 16d (17)

H. trionum

TP; BP: 20°/30°C (16h/8h): 28d (ISTA)

Hibiscus spp.

BP: 20°/30°C (16h/8h): 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

H. esculentus

Warm stratification: 13°C, 10d, germinate at 15°/29°C (1)

Pre-soak: 12h (14); 24h, then 13°C, 10d, germinate at 15°/29°C (1); 38°-54°C, 3 min (4)

Scarification: concentrated sulphuric acid, 5-15 min (7); mechanical (4)

Acetone: pre-applied, 1h (14); pre-applied, 30 min, 95%, then 13°C, 10d, germinate at 15°/29°C (1); pre-applied, 20,40 min, 95% (2,4) Glycerine: pre-applied, 5-60 min, 5% (1)

H. pedunculatus

Scarification: concentrated sulphuric acid, 1-60 min (16)

H. trionum

Thiourea: co-applied, 0.25% (11)

IV. Partly-successful dormancy-breaking treatments

H. acetosella

Scarification: concentrated sulphuric acid, 1 min-8h (16)

H. coccineus

Scarification: concentrated sulphuric acid, 1-15 min, 2-8h (16)

H. esculentus

Pre-soak: 24h (10)

GA_3: pre-applied, 12h, 100-400 ppm (12)

Indoleacetic acid: pre-applied, 12h, 10-40 ppm (12)

Napthaleneacetic acid: pre-applied, 12h, 5-30 ppm (12)

Sodium bicarbonate: pre-applied, 24h, 0.1 M (10)

Calcium phosphate: pre-applied, 24h, 0.1 M (10)

Scarification: concentrated sulphuric acid, 0.5-3h (3,4); concentrated sulphuric acid, 30,60 min (7); concentrated sulphuric acid, 60 min (14); sulphuric acid, 50%, 30 min (1,10,14); hydrochloric acid, 50%, 1h (14); concentrated nitric acid, 1h (14); nitric acid, 50%, 30 min (14); hydrochloric acid, 50%, 1h (14); buttermilk, 30,60 min (14); acetone, 95%, 20,40 min (3); acetone, 95%, 30 min (10); alcohol, 95%, 30 min (10); mechanical (13)

H. gossypinus, H. militaris, H. moscheutos, H. mutabilis

Scarification: concentrated sulphuric acid, 1 min-8h (16)

H. pedunculatus

Scarification: concentrated sulphuric acid, 2-8h (16)

H. trionum

Constant temperatures: 25°C, 30°C (9)

Removal of seed covering structures: seed coat (9)

V. Successful dormancy-breaking treatments

H. coccineus

Scarification: concentrated sulphuric acid, 30 min (16)

H. esculentus

Constant temperatures: 15°-35°C (6); 25°C, dark (8, 15)

Alternating temperatures: 15.5°/29°C, 15.5°/32°C (night/day) (1)

Pre-soak: 24h (1, 14)

Removal of seed covering structures: part of testa (7)

Scarification: concentrated sulphuric acid, 30 min (14); concentrated sulphuric acid, 3h (7); sulphuric acid, 50%, 1h (14); concentrated hydrochloric acid, 0.5, 1h (14); hydrochloric acid, 50%, 30 min (14); concentrated nitric acid, 30 min (14); nitric acid, 50%, 1h (14); acetone, 95%, 5 min (1); acetone, 30 min (14); alcohol, 95%, 5 min (1); alcohol, 0.5, 1h (14)

H. sabdariffa

Pre-soak: 24h (18)

H. trionum

Scarification: concentrated sulphuric acid, 20 min, germinate at 20°C/30°C (16h/8h) (5)

VI. Comment

Seed scarification is reported to be necessary to allow germination to occur in H. esculentus and the wild Hibiscus spp. (1-3,5,7,9,10, 13,14,16). The rules of the AOSA note that hard seeds may be present when seeds of the Hibiscus spp. cultivated as flowers are tested for germination and direct that germination tests be continued for an additional 5 days. Although hardseededness does not appear to be a major problem in H. cannabinus, it is possible that seeds dried to 5% moisture content for long-term storage may exhibit hardseededness. Acetone or sulphuric acid are commonly used in scarification treatments and are generally successful, but appropriate concentrations and treatment durations vary considerably between species and between accessions within a single genotype (3,4,16); with concentrated sulphuric acid 30 minute treatments are probably the most satisfactory (16), although 2 hour treatments are required for H. mutabilis and H. pedunculatus (16). In view of these differences and the difficulty in obtaining full germination with such treatments it is not suggested that gene banks acid scarify seeds of Hibiscus spp.

For H. esculentus 25°C is the most suitable constant temperature germination test regime (6,8,15), but - as with other species in which hardseededness is a problem - alternating temperature regimes are preferable to constant temperatures (1). It is suggested that the seeds be tested for germination under the ISTA/AOSA prescribed alternating temperature regime of 20°/30°C (16h/8h), and that these tests be inspected after 4 or 5 days and the non-imbibed seeds scarified by hand and then returned to the germination test. Where a high proportion of seeds with impermeable seed coats is expected, it is suggested that all seeds be scarified by hand and then humidified at 95 to 100% relative humidity for 24 hours prior to the germination test.

VII. References

1. Anderson, W.H., Carolus, R.L. and Watson, D.P. (1953). The germination of okra seed as influenced by treatment with acetone and alcohol. Proceedings of the American Society for Horticultural Science, 62, 427-432.

2. Edmond, J.B. and Drapala, W.J. (1958). The effect of temperature, sand and soil, and acetone on germination of okra seed. Proceedings of the American Society for Horticultural Science, 71, 428-434.

3. Edmond, J.B. and Drapala, W.J. (1959). The effect of temperature, immersion in acetone, and sulphuric acid on germination of five varieties of okra seed. Proceedings of the American Society for Horticultural Science, 74, 601-606.

4. Edmond, J.B. and Drapala, W.J. (1960). Studies of the germination of okra seed. Mississipi Agricultural Experiment Station Technical Bulletin, 47, 1-15.

5. Everson, L. (1949). Preliminary studies to establish laboratory methods for the germination of weed seed. Proceedings of the Association of Official Seed Analysts, 39, 84-89.

6. Harrington, J.F. (1963). The effect of temperature on the germination of several kinds of vegetable seeds. Proceedings of the 16th International Horticultural Congress, 2, 435-441.

7. Johnston, A. (1949). The germination of malvaceous seeds. Tropical Agriculture, Trinidad, 26, 63.

8. Manohar, M.S. (1969). Pod development and germination of bhindi (Abelmoschus esculentus). Experimental Agriculture, 5, 249-255.

9. Martin, J.N. (1943). Germination studies of the seeds of some common weeds. Proceedings of the Iowa Academy of Science, 50, 221-22 8.

10. Medina, P.V.L., Medina, R.M.T. and Shimoya, C. (1972). [Okra seedcoat anatomy and the use of chemicals to hasten germination.] Revista Ceres, 19, 385-394. (From Horticultural Abstracts, 1974, 44, 475.)

11. Moursi, M.A., Rizk, T.Y. and El-Deepah, H.R. (1977). Weed seed germination responses to some chemical treatments. Egyptian Journal of Agronomy, 2, 197-209.

12. Omran, A.F., El-Bakry, A.M. and Gawish, R.A. (1980). Effect of soaking seeds in some growth regulator solutions on the growth, chemical constituents and yield of okra. Seed Science and Technology, 8, 161-168.

13. Rose, D.H. (1915). A study of delayed germination in economic seeds. Botanical Gazette, 59, 425-444.

14. Singh, K. and Singh, A. (1969). Effect of various chemicals on the germination of some hard-coated vegetable seeds. Journal of Research, Ludhiana, 6, 801-807.

15. Solanki, S.S., Singh, R.D. and Yadav, J.P. (1980). Studies on the temperature and media relations and coefficient velocity of germination of vegetable seeds. II. Summer squash (Cucurbita pepo L.) and okra (Abelmoschus esculentus (L.) Moench.). Progressive Horticulture, 12, 59-65.

16. Tachibana, Y. (1961). [Studies in Hibiscus. IV. Further studies on the method of promoting seed germination.] Journal of the Japanese Society for Horticultural Science, 30, 183-188.

17. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

18. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

URENA

U. lobata L. aramina fibre, Congo jute

I. Evidence of dormancy

Germination of seeds of U. lobata is slow, erratic and low (1,4-8). Field sowings take 2-3 months to germinate (1). Hardseededness is reported to be the cause of these problems (4-8).

II. Germination regimes for non-dormant seeds

Constant temperatures: 30°C in light (2,3,9,10)

Alternating temperatures: 20°/30°C (night/day) (7)

III. Unsuccessful dormancy-breaking treatments

Pre-chill: 5°-10°C, 3d (4)

Pre-soak: 12h (4); 12-48h, then pre-chill, -10°C, 6h (7); 36,48h, then pre-chill, -10°C, 2h (7)

Ethanol: pre-applied, 2,3h, 95% (7); pre-applied, 5 min-3h, 95%, to dehulled seeds (7)

Ethyl ether: pre-applied, 5 min-3h, 1.5% (7); pre-applied, 5 min-3h, 1.5%, to dehulled seeds (7)

Scarification: concentrated sulphuric acid, 5-15 min, 12,24h (7)

Removal of seed covering structures: dehull, then concentrated sulphuric acid scarification, 2 min (7); dehull, then concentrated sulphuric acid scarification, 5,6h, then pre-soak, 48h (6)

IV. Partly-successful dormancy-breaking treatments

Removal of seed covering structures: carpel (7); carpel, then pre-soak, 1,2d (6,8)

Pre-soak: 12,24h, then pre-chill, -10°C, 2h (7)

Ethanol: pre-applied, 4h, 95% (4); pre-applied, 5 min-1h, 95% (7)

Formol: pre-applied, 2h, 40% (4)

Acetone: pre-applied, 4h, 95% (4)

Sodium hypochlorite: pre-applied, 24h, 1% (4)

Potassium nitrate: pre-applied, 12h, 0.2% (4); co-applied, 0.3% (4)

Scarification: nitric acid, 10^{-2} N, 10 min (4); concentrated hydrochloric acid, 15 min (4); concentrated sulphuric acid, 0.5-2h (7); concentrated sulphuric acid, 5 min-1.5h, 4-6h, then pre-soak, 48h (6); sulphuric acid, 0.1%, 12h (4); mechanical, 1425-1725 rpm, 10s (4); concentrated sulphuric acid, 30 min, germinate at 20°C, 25°C, 35°C, 20°/30°C, 20°/35°C (16h/8h), dark or light, 8h/d, 4d (2)

Removal of seed covering structures: small part of testa, germinate at 21°/31°C (night/day) (5); dehull, then concentrated sulphuric acid scarification, 0.5-2h (7); dehull, then concentrated sulphuric acid scarification, 5-30 min, 1.5-4h, then pre-soak, 48h (6)

Light: 5 min (4)

Pre-dry: 90°C, 2h (4); 90°/2°C (2h/2h) (4)

V. Successful dormancy-breaking treatments

Pre-soak: 100°C, then 30°C, 40 min (4)

Scarification: concentrated sulphuric acid, 30 min, then pre-wash, 10 min, germinate at 30°C, light, 8h/d (2,3,4,9,10); concentrated sulphuric acid, 3,4h (7); concentrated sulphuric acid, 2,3h, then pre-soak, 48h (6)

Removal of seed covering structures: dehull, then concentrated sulphuric acid scarification, 1h, then pre-soak, 48h (6)

VI. Comment

It is suggested that the carpel (hull) be removed from seeds, a small portion of the testa be removed or scarified by hand, and the seeds then tested for germination in an alternating temperature regime of 20°/30°C (16h/8h) in light.

VII. References

1. Crane, J.C. and Acuna, J.B. (1945). Effect of planting rate on fiber yield of Urena lobata L. as compared with kenaf, Hibiscus cannabinus L. Journal of the American Society of Agronomy, 37, 245-250.

2. Figueiredo, F.J.C. and Popinigis, F. (1978). Temperature de germinaçáo para sementes de malva (Urena lobata L.). EMBRAPA/ CPATU, Comunicado Tecnico No. 14, 20 pp.

3. Figueiredo, F.J.C. and Popinigis, F. (1978). Substrato de germinaçáo para sementes de malva (Urena lobata L.). EMBRAPA/CPATU, Comunicado Tecnico No. 18, 10 pp.

4. Figueiredo, F.J.C. and Popinigis, F. (1979). Superaçáo da dormencia de sementes de malva. Revista Brasileira de Sementes, 1, 1-13.

5. Harris, P.J.C. (1981). Seed viability, dormancy, and field emergence of Urena lobata L. in Sierra Leone. Tropical Agriculture, 58, 205-213.

6. Horn, C.L. and Colon, J.E.N. (1942). Acid scarification of the seed of two cuban fiber plants. Journal of the American Society of Agronomy, 34, 1137-1138.

7. Juillet, A. (1952). Etude de la germination d'Urena lobata. Agronomie Tropicale, 7, 487-507.

8. Kirby, R.H. (1963). Vegetable fibres: Botany, cultivation and utilization, Leonard Hill, London.

9. Figueiredo, F.J.C. and Popinigis, F. (1980). Substrato de germinaçáo para sementes de malva. Revista Brasileira de Sementes, 2, 11-17.

10. Figueiredo, F.J.C. and Popinigis, F. (1980). Duraçáo de teste de germinaçáo do sementes de malva. Revista Brasileira de Sementes, 2, 53-57.

CHAPTER 47. MENISPERMACEAE

The Menispermaceae comprise several genera of climbers and, rarely, trees and shrubs. Whilst several species are cultivated for ornament, one species (Dioscoreophyllum cumminsii Diels, serendipity berry) provides a powerful proteinaceous sweetener. The fruits are drupes or drupe-like and seed storage behaviour is probably orthodox. The information on seed dormancy and germination provided here is limited to the genus Dioscoreophyllum.

DIOSCOREOPHYLLUM

D. cumminsii Diels serendipity berry

I. Evidence of dormancy

Seeds of D. cumminsii can show considerable dormancy (1-3). There can be a delay of 6 months before sown seeds germinate and emerge (2).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

Light: sunlight (1,2)

Pre-soak: 1h (1,2); 55°-60°C; 10 min (1,2)

Potassium nitrate: pre-applied, 24h, 0.25% (3)

Scarification: sulphuric acid, 0.05, 0.1, 0.2 N, 1h (1,2); concentrated sulphuric acid, 3 min (3); concentrated sulphuric acid, 3 min, then pre-chill, 5°C, 14d (3); acetic acid, 0.05, 0.1, 0.2 N, 1h (1,2)

IV. Partly-successful dormancy-breaking treatments

Pre-soak: 24h (3)

Potassium permanganate: pre-applied, 24h, 0.5% (3)

Indoleacetic acid: pre-applied, 24h, 250-1500 ppm (3)

Naphthalene acetic acid: pre-applied, 24h, 250-1500 ppm (3)

GA_3: pre-applied, 24h, 1000-2000 ppm (3); pre-applied, 24h, 0.01-0.1% (2); pre-applied, 2h, 0.05, 0.1% (1,2)

V. Successful dormancy-breaking treatments

Light: dark, at 23°-26°C (1,2)

GA_3: pre-applied, 2h, 0.5% (1,2); pre-applied, 24h, 500 ppm (3)

VI. Comment

Light, or at least direct sunlight, inhibits the germination of seeds of D. cumminsii (1,2). Pre-treatment with gibberellins can, however, promote full germination in light (1-3), but the response depends upon the concentration applied and the duration of pre-treatment. On the basis of the evidence available at present it is suggested that the seeds be tested for germination at 25°C in dark after a 24 hour pre-treatment with 500 ppm GA_3 (3) or a 2 hour pre-treatment with 5000 ppm GA_3 (1,2). However, it should be noted that there are some contradictions in the literature concerning suitable promotory pre-treatments. Consequently the above pre-treatments may require modification. Note also that even where GA_3 has been applied there may be a considerable delay before the seeds begin to germinate. For example, in one investigation no germination was observed until 68 days after the test had commenced (3). Consequently a germination test duration of 90 days, or more, may be required.

VII. References

1. Adansi, M.A. and Holloway, H.L.O. (1977). Seed germination and establishment of the serendipity berry (D. cumminsii Diels). Acta Horticulturae, 53, 407-411.

2. Holloway, H.L.O. (1977). Seed propagation of Dioscoreophyllum cumminsii, source of an intense natural sweetener. Economic Botany, 31, 47-50.

3. Uzo, J.O. (1983). Studies on the nature of seed dormancy of the serendipity berry Dioscoreophyllum cumminsii Diels. Acta Horticulturae, 123, 197-205.

CHAPTER 48. MORACEAE

The Moraceae comprise more than 1000 species of trees and shrubs and, rarely, herbaceous plants and climbers which provide edible fruits (e.g. Artocarpus altilis (Park.) Fosber, breadfruit) and other products (e.g. Broussonetia papyrifera (L.) Vent., paper mulberry). The fruits are often compound and fleshy. Seed storage behaviour is generally orthodox (e.g. Ficus, Humulus, Morus), but some genera possess recalcitrant seeds (e.g. Artocarpus).

SEED DORMANCY AND GERMINATION

The seeds may or may not possess an endosperm. Seed dormancy can be a difficult problem to overcome and the seedcoats may also prevent germination in some accessions. Promotory treatments include pre-chilling, some disruption of the seed coat and light in germination tests. Detailed information is provided for seed dormancy and germination in the genera Ficus, Humulus and Morus in this chapter. Additional information on recommended germination test procedures and dormancy-breaking treatments is summarised in Table 48.1.

TABLE 48.1 Summary of germination test recommendations for species within the Moraceae

Species and Authority	Substrate	Temperature	Durationo	Additional directions	Source
Antidesma spp.			21d	pre-soak, 24h	Riley
Artocarpus heterophyllus Lam.	S	25°-30°C	21d	light, continuous	CHML
Artocarpus spp.			21d	pre-soak, 24h, then warm stratification	Riley
Cannabis sativa L.	TP; BP	20°/30°C; 20°C	7d		ISTA
	BP	20°/30°C	7d		AOSA
	BP; S	20°/30°C	7d		Everson
Cudrania tricuspidata			21d	scarify, abrade with sharp sand, or file or nick seed	Riley
				coat, then pre-chill, 1°-5°C, 30-60d	

FICUS

F. aurea Nutt.
F. carica L. common fig
F. populnea Willd.
F. religiosa L. pipal-tree, bodh-tree, peepul
F. roxburghii
F. septica Burm. f.

I. Evidence of dormancy

Seeds of F. carica are reported to germinate readily in glasshouse sowings (2,3,5,8), but full germination in laboratory tests is more difficult to achieve.

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

F. aurea

Light: dark (1)

F. religiosa

Constant temperatures: 15°C (4); 25°C in dark (4)

Light: dark (4)

IV. Partly-successful dormancy-breaking treatments

F. roxburghii

Constant temperatures: 15°C, 20°C (9)

F. septica

Soil: in glasshouse (6)

V. Successful dormancy-breaking treatments

F. aurea

Potassium nitrate: co-applied, plus calcium nitrate, magnesium sulphate, and monobasic potassium phosphate (Knop's solution), at room temperature in light (1)

F. carica

Soil: in glasshouse or warm room (2,3,5,8)

Pre-soak: 24h (10)

F. populnea

Potassium nitrate: co-applied, plus calcium nitrate, magnesium sulphate, and monobasic potassium phosphate (Knop's solution), at room temperature in light or dark (1)

F. religiosa

Constant temperatures: 25°C in white light (4)

F. roxburghii

Constant temperatures: 25°C, 30°C, in soil (9)

Ficus spp.

Constant temperatures: 28°C in unsterilized vermiculite or on top of filter papers with bacterium added (7)

VI. Comment

Seeds of F. aurea and F. religiosa are reported to require light for germination (1,4), whereas seeds of F. populnea will germinate in light or dark (1). Seeds of F. religiosa are sensitive to

drying out of the germination test substratum; germination is reduced if this occurs (4). It is suggested that seeds of Ficus spp. be tested for germination on top of filter papers at 25°C or 30°C in the light; the filter papers should not be allowed to dry out.

VII. References

1. Bessey, E.A. (1908). The Florida strangling figs. Annual Report, Missouri Botanic Garden, 19, 23-33.

2. Condit, I.J. (1947). The Fig Waltham, Massachusetts.

3. Eisen, G. (1901). The fig. USDA Division of Pomology Bulletin No. 9, 317 pp. (Cited by Condit, 1947.)

4. Galil, J. and Meiri, L. (1981). Drupelet germination in Ficus religiosa L. Israel Journal of Botany, 30, 41-47.

5. Pammel, L.H. and King, C.M. (1926). Studies on germination of trees and woody plants (continued). Proceedings of the Iowa Academy of Science, 33, 97-119.

6. Piatos, P., Knight, R.J. Jr. and Burditt, A.K. Jr. (1976). Seed production in an exotic Ficus species. Proceedings of the Florida State Horticultural Society, 88, 462-464.

7. Ramirez, W.B. (1976). Germination of seeds of New World Urostigma (Ficus) and of Morus rubra L. (Moraceae). Revista De Biologia Tropical, 24, 1-6.

8. Storey, W.B. (1975). Figs. In Advances in fruit breeding (eds. J. Janick and J.N. Moore), pp. 568-589. Purdue University Press, Indiana.

9. Zimmer, K. (1981). [Germination conditions for some rare ornamental plants.] Deutscher Gartenbau, 36, 863-869.

10. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

HUMULUS

H. lupulus L. hop

I. Evidence of dormancy

It is reported to be difficult to germinate seeds of H. lupulus (2,4-6,8,9); typically only 15% of seeds may germinate in tests immediately after harvest (6,7).

II. Germination regimes for non-dormant seeds

Constant temperatures: 20°C (2,5,7,9)

Alternating temperatures: 15°/25°C, dark/light (16h/8h) (3)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 6°-10°C, 66d (4); 6°-12°C (8); 15°-23°C (7); 20°C (9); 20°-25°C, 66d (4); 30°C (8)

Pre-chill: -2°C, 3,6d (5)

Warm stratification: 15°-23°C, 2-15d, then pre-chill, 5°C, 1w (7); 15°-23°C, 10d, then pre-chill,

-12°C, 1-4w (7); 15°-23°C, 15d, then pre-chill, -12°C, 1,2w (7); 15°-23°C, 2,5d, then pre-chill, -12°C, 1-5w (7)

Pre-soak: 24h, then pre-chill, 4.4°C, 1w, with or without scarification (9)

Scarification: concentrated sulphuric acid, 3 min (5); concentrated sulphuric acid, 1,3,30 min (9); concentrated hydrochloric acid, 3 min (5); methyl alcohol, 3 min (5); acetone, 3 min (5); ether, 3 min (5); xylene, 3 min (5); shake, 3 min (5)

Ethylene chlorohydrin: pre-applied, 12h, to imbibed seeds (5)

GA_3: pre-applied, 15 min, 50-4000 ppm (9); co-applied, 50, 100, 4000 ppm (9); co-applied, 50 ppm (8)

GA_7: co-applied, 20 ppm (8)

Potassium nitrate: pre-applied, 15 min, 0.2% (9); co-applied, 0.2% (9)

Thiourea: pre-applied, 15 min, 2, 5% (9)

Hydrogen sulphide: pre-applied, 15 min (9); co-applied (9)

Hydrogen peroxide: co-applied (8)

Bis-cyclohexanoneoxalyldihydrazone: pre-applied, 15 min, 0.5% (9); co-applied, 0.5% (9)

Ethylenediaminetetracetic acid: pre-applied, 15 min, 1% (9); co-applied, 1% (9)

Malic acid: pre-applied, 15 min, 0.5% (9); co-applied, 0.5% (9)

Indoleacetic acid: co-applied, 15 ppm (8)

2-4,Dichlorophenoxyacetic acid: co-applied, 20 ppm (8)

Ultrasonics: 5-240s, dry seeds (8)

Sulphuric acid: co-applied, 0.05, 0.5% (9)

Dimethylglyoxime: pre-applied, 15 min, 0.1% (9); co-applied, 0.1% (9)

Removal of seed covering structures: prick (8)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: -2°/22°C (6d/1d), 42d (5); 2°/-2°C (7d/7d), 42d (5); 20°-25°C/6°-10°C (1d/1d, 3d/3d, 5d/5d) (4); 6°-10°C/20°-25°C (3d/3d, 5d/5d) (4)

Pre-chill: -2°C, 9, 12d (5); -2°C, 6w (5); 2°C, 6w (5); -9.5° to -1°C, 6w (5); 0°-1°C, 21,42d (8); 1°-3°C, 21-56d (8)

Warm stratification: 15°-23°C, 5-15d, then pre-chill, 5°C, 2-5w (7); 15°-23°C, 2d, then pre-chill, 5°C, 3-5w (7); 15°-23°C, 15d, then pre-chill, -12°C, 3-5w (7); 15°-23°C, 10d, then pre-chill, -12°C, 5w (7)

Pre-soak: 24h, then pre-chill, 4.4°C, 2-6w (9); 24h, then pre-chill, 4.4°C, 2-4w, then remove outer seed coat (9); 5d, 6°-10°C, germinate at 20°C or 25°C (3); 1°-3°C (8)

Thiourea: co-applied, 2, 5% (9)

Removal of seed covering structures: chip (4,9); operculum (6); operculum, then pre-chill, 0°C, 16-72d (6)

Scarification: concentrated sulphuric acid, 6-15 min (9); concentrated sulphuric acid, 10 min, then pre-chill, 4.4°C, 2w (9); sandpaper (9)

V. Successful dormancy-breaking treatments

Pre-chill: 0°C, 10d, then scarify, sandpaper (1); 2°C, 8-10w (5); 2°-3°C, 6-8w, germinate at 15°/25°C, dark/light (16h/8h) (3); 2°-10°C, 6w (5)

Pre-soak: 24h, then pre-chill, 4.4°C, 5-6w (2); 24h, then pre-chill, 4.4°C, 5-6w, then remove outer seed coat, germinate at 20°C (9)

Removal of seed covering structures: seed coat (8); chip, germinate at 6°-10°/20°-25°C (5d/5d), 37d (4); chip (8)

VI. Comment

Pre-chilling at 0°-5°C for between 5 and 10 weeks (2,3,5,9) is required to promote full germination of dormant seeds. Although scarification treatments can be promotory, they fail to promote full germination in the more dormant seeds, although they may reduce the duration of pre-chill treatment required to promote full germination. It is suggested that seeds of H. lupulus be pre-chilled at 3°-5°C for 6 weeks, and then tested for germination at 15°/25°C (16h/8h) with light applied during the period spent at the higher temperature (3). The seed coats of seeds which fail to begin to germinate within a week or so can be chipped or rubbed with sand paper; this should result in more rapid, uniform and complete germination (1,4,8,9).

VII. References

1. Bressman, E.N. (1931). Developing new varieties of hops. Science, 74, 202-203.

2. Burgess, A.H. (1964). Hops. Botany, cultivation and utilization. Leonard Hill, London.

3. Haunold, A. and Zimmermann, C.E. (1974). Pollen collection, crossing and seed germination of hop. Crop Science, 14, 774-776.

4. Holubinsky, I.N. (1941). Influence of temperature alternation on the germinable power of hop seeds (Humulus lupulus L.). Comptes Rendus (Doklady) de l'Académie des Sciences de l'URSS, 32, 85-86.

5. Keller, K.R. (1953). Seed germination in hop, Humulus lupulus L. Agronomy Journal, 45, 146-150.

6. Paine, J. (1950). The treatment of hop seed to improve germination. East Malling Research Station Report, 139-140.

7. Smith, D.C. (1939). Influence of moisture and low temperature on the germination of hop seeds. Journal of Agricultural Research, 58, 369-381.

8. Suciu, T., Salontai, A., Muntean, L., Felecan, V. and Vaida, L. (1977-1978). Recherches concernant la germination des semences de houblon (Humulus lupulus L.). Institutum Agronomicum "Dr. Petru Groza" Cluj-Napoca (Romania) Notulae Botanicae Horti Agrobotanici, 9, 79-83.

9. Williams, I.H. and Weston, E.W. (1958). Hop propagation. The germination of hop seeds. Annual Report 1957, Department of Hop Research, Wye College, 108-118.

MORUS

M. alba L.	white mulberry
M. alba var tatarica Loud. [M. tatarica L.]	Russian mulberry
M. indica L.	mulberry
M. latifolia var rotundiloba	mulberry
M. Lhou (Ser.) Koidz.	mulberry
M. nigra L.	black mulberry
M. rubra L.	red or American mulberry

I. Evidence of dormancy

Although viviparous germination has been reported in seeds of M. latifolia var rotundiloba (4), dormancy can be exhibited in freshly harvested seeds of M. alba (3) and M. Lhou (7,8,9). At room temperature 2 years dry storage (over calcium chloride) is required to remove dormancy from the latter species (7).

II. Germination regimes for non-dormant seeds

Morus spp.

TP: 20°/30°C (16h/8h): 28d (ISTA)

III. Unsuccessful dormancy-breaking treatments

M. alba

Scarification: concentrated sulphuric acid, 15 min (3)

M. Lhou

Constant temperatures: below 21°C or above 39°C (8)

Light: indigo, violet, bluish-violet (8,9)

M. rubra

Sterile substratum: (5)

IV. Partly-successful dormancy-breaking treatments

M. alba

Pre-chill: 5°C, 90d (3)

M. alba var tatarica

Constant temperatures: 20°C (2)

Pre-chill: 1m (2)

M. indica

Pre-soak: 24h (6)

GA_3: pre-applied, 24h, 10, 25 ppm (6)

Irradiation: gamma rays, 2500-15000 R (1)

M. Lhou

Constant temperatures: 24°-36°C in light or dark (8,9)

Light: diffuse, 700-680 nm, 560-520 nm (8,9)

M. nigra

Constant temperatures: 20°C (2)

Pre-chill: 1m (2)

V. Successful dormancy-breaking treatments

M. alba

Pre-chill: (11); 1°-5°C, 4-12w (10)

Scarification: abrade with sharp sand (11); file or nick seed coat (11)

M. alba var tatarica

Alternating temperatures: 20°/30°C in light (2)

M. indica

GA_3: pre-applied, 24h, 50, 100 ppm (6)

M. Lhou

Constant temperatures: 32°C in light (7)

Sodium nitrate: pre-applied, 24h, 0.04% (8,9)

M. nigra

Alternating temperatures: 20°/30°C in light (2)

Pre-chill: (11); 1°-5°C, 4-12w (10)

M. rubra

Constant temperatures: 28°C, non-sterile substratum (5)

Alternating temperatures: 20°/30°C in light (2)

Pre-chill: (11)

Scarification: abrade with sharp sand (11); file or nick seed coat (11)

VI. Comment

Alternating temperatures (2) and light (2,8,9) are required for germination, although it is reported that the promotive effect of sodium nitrate is sufficient to avoid the requirement for light (8,9). It is suggested that the ISTA germination test procedure - 20°/30°C (16h/8h) in light - is satisfactory for all Morus spp., but if difficulties are encountered also co-apply 0.2% potassium nitrate and pre-chill for 4 to 12 weeks.

VII. References

1. Das, B.C. (1970). Effects of gamma radiation on germination and seedling development of mulberry. Science and Culture, 36, 60-61. (From Horticultural Abstracts, 1971, 41, 3312.)

2. Heit, C.E. (1969). Propagation from seed. Part 15: Fall plantings of shrub seeds for successful seedling production. American Nurseryman, 128, 8-10, 70-80.

3. Krefting, L.W. and Roe, E.I. (1949). The role of birds and mammals in seed germination. Ecological Monographs, 19, 269-286.

4. Mukherjee, S.K. (1960). Vivipary in mulberry. Science and Culture, 26, 234. (From Horticultural Abstracts, 1961, 31, 1986.)

5. Ramirez, W.B. (1976). Germaniation of seeds of New World Urostigma (Ficus) and of Morus rubra L. (Moraceae). Revista De Biologi Tropical, 24, 1-6.

6. Rao, L.S.P., Rao, T.P. and Narayanan, E.S. (1963). Response of mulberry seeds to gibberellic acid treatment. Current Science, 32, 348-349.

7. Takagi, I. (1939). [On the storage of mulberry seeds.] Research Bulletin of the Imperial Tokyo Sericultural College, 2, 1-22.

8. Takagi, I. (1940). [The effect of temperature and light on the germination of mulberry seeds.] Research Bulletin of the Imperial Tokyo Sericultural College, 2, 1-26.

9. Takagi, I. (1940). The effect of the temperature and the light conditions upon the germination of mulberry seed. Japanese Journal of Botany, 10, 73-74.

10. Gordon, A.G. and Rowe, D.C.F. (1982). Seed Manual for Ornamental Trees and Shrubs. Forestry Commission Bulletin 59, HMSO, London.

11. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 49. MUSACEAE

The Musaceae comprise about 100 species of partly woody plants within about six genera which provide edible fruits (e.g. Musa accuminata Colla, banana) and fibres (e.g. Musa textilis Nee, Manila hemp). The fruits are berries and seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

The seeds have linear embryos, copious endosperm and a thick hard testa. Dormancy per se (that is innate seed dormancy, see Chapter 5, Volume I) is a problem (sometimes severe) in germination tests and in addition the thick hard testa can act as a barrier to germination. Chipping the testa and testing in alternating temperature regimes promote seed germination. Detailed information on seed dormancy and germination is provided in this chapter for the genus Musa only, although a comment on Ensete is also included in this section.

MUSA

M. acuminata Colla	banana
M. balbisiana Colla	banana
M. textilis Née	abaca, Manila hemp

I. Evidence of dormancy

Promoting the germination of banana seeds is difficult in plant breeding (1,4-6). The germination of intact seeds is either unsuccessful (1), or erratic with only low proportions of seeds germinating (4). The low germination reported for banana seeds is due to the degree of maturity of the seed when extracted from the fruit (5,6), and in particular to dormancy - as the following examples of after-ripening demonstrate. Storage of seeds of M. balbisiana in a desiccator at room temperature for 3 months resulted in an increase in germination from 73% to 95% (5). In M. acuminata and M. balbisiana germination increased from 28% to 84% and 86% respectively, after 6 months storage in an atmosphere of 5% carbon dioxide at room temperature (6). Whilst 2 year old seeds of M. balbisiana did not germinate at all at any constant temperatures after 5 months in test, 99% of seeds germinated in satisfactory alternating temperature regimes (7). Moreover seeds buried in the soil can remain dormant for a year (6) or more (4). Seeds of the closely related Ensete spp. may survive for up to 25 years in soil and still germinate after disturbance (6). The above examples of loss in dormancy with after-ripening treatments also demonstrate that Musa spp. seeds show orthodox storage characteristics.

II. Germination regimes for non-dormant seeds

M. balbasiana

Alternating temperatures: 20°/35°C, 27°/32°C (19h/5h) (7)

III. Unsuccessful dormancy-breaking treatments

M. acuminata

Pre-dry: sun, desiccator, 1w (5)

Pre-soak: 1-4w, in light or dark (5)

M. balbisiana

Constant temperatures: 28°C, 32°C, 38°C (7); 18°-35°C (8); 25°-40°C (9)

Alternating temperatures: 4°/27°C, 4°/32°C, 4°/35°C, 27°/4°C, 32°/4°C, 27°/12°C, 35°/12°C, 27°/15°C, 35°/15°C, 27°/18°C, 32°/27°C (19h/5h) (7)

Pre-chill: (9); 10°C, 4d (5); 4°C, 80d (7)

Pre-dry: sun, desiccator, 1w (5); 60°C, 4d (5); scorch (5)

Pre-soak: 12h (2); 2d (5); 1-4w, in light or dark (5); 2d, then dry, 2d (5); 2-192h (9)

Pre-wash: 2-192h (9)

Scarification: chip (5); concentrated sulphuric acid, 8-64 min (5)

Ethanol: (6); 5, 30, 95, 100%, 5s (9)

Carbon tetrachloride: 5s (9)

Mercuric chloride: pre-applied, 1-50 min, 10^{-4}, 10^{-2} M (6)

Acetone: 5s (9)

Ethyl acetate: 5s (9)

Hydrogen peroxide: pre-applied, 24,48h, 1% (9)

Ultrasonics: 5,60,300s (2)

M. textilis

Pre-dry: sun, 24-72h (10)

Pre-soak: 30°C, 40°C, 50°C, 1-20 min (10); 60°C, 5, 10 min (10); 70°C, 5-15 min (10); 80°C, 100°C (10)

Scarification: hand (11); concentrated sulphuric acid, 0.5-3h (10); sulphuric acid, 3, 6 N, 0.5-3h (10); concentrated hydrochloric acid, 0.5-3h (10); hydrochloric acid, 3, 6 N, 0.5-3h (10); concentrated nitric acid, 0.5-3h (10); nitric acid, 3, 6 N, 0.5-3h (10)

Sodium hydroxide: pre-applied, 24h, 0.5-5% (11)

IV. Partly-successful dormancy-breaking treatments

M. acuminata

Pre-dry: sun, 3d (5)

M. balbisiana

Alternating temperatures: 12°-18°/27°-35°C, 27°/32°C, 27°/35°C, 35°/4°C, 35°/18°C, 35°/27°C, 32°/12°C, 32°/15°C, 32°/18°C (19h/5h) (7); 24°/37°C, 18°/32°C (19h/5h) (8)

Pre-chill: 15°C, 4m (7); 12°C, 3,4m, germinate at 20°/35°C (16h/8h) (7)

Warm stratification: 28°C, 32°C, 38°C, 6w, germinate at 19°/28°C, 19°/32°C, 19°/38°C (19h/5h) (7)

Pre-dry: whole fruit, 45°C, 4d (6)

Scarification: concentrated sulphuric acid, 2,4 min (5); sulphuric acid, 50%, 30 min (9); concentrated nitric acid, 15 min (9); sodium hydroxide, 10%, 2,4h (9); hydrogen chloride, 20%, 1h (9); mechanical (8,9)

Ultrasonics: 30s (2) pH: 5.2-6.3 (3)

Light: daylight (5); 12h/d (9)

M. textilis

Warm stratification: 2-4m (11)

Pre-soak: 16h (4)

V. Successful dormancy-breaking treatments

M. balbisiana

Alternating temperatures: 18°/35°C (12-19h/12-5h) (7)

Warm stratification: 27°C, 32°C, 4m, germinate at 20°/35°C (19h/5h) (7)

Pre-soak: 24h (12); 24h, then warm stratification (12)

Removal of seed covering structures: excise embryo (1,8); chip (9); chip, germinate at 27°/32°C, 18°/32°C (19h/5h) (7)

Scarification: concentrated sulphuric acid, 2-16 min, continue test for 5m (5)

VI. Comment

It is essential that banana seeds be tested for germination in alternating temperature regimes. Constant temperatures outside the range 10°-37°C result in seed death (7). Within this range virtually no germination occurs in dormant seeds(7), but the seeds will subsequently germinate after transfer to a suitable alternating temperature regime (7). A fairly large amplitude is required for full germination: 12°/35°C or 15°/35°C (19h/5h) are probably the most suitable (7), but 18°/35°C (19h/5h) could be used provided the germination test period is extended to 49 days (7). Chipping imbibed seeds in the germination test may result in more rapid germination (7,9). Where the seeds do not exhibit dormancy they will germinate within about 3 weeks when tested in sand at 25° to 30°C.

VII. References

1. Cox, E.A., Stotzky, G. and Goos, R.D. (1960). In vitro culture of Musa balbisiana Colla embryos. Nature, 185, 403-404.

2. Perry, L.P. and Boodley, J.W. (1980). Germination of foliage plant seeds in response to pre-sowing ultrasonic exposures, water soaks and fungicides. HortScience, 15, 192-194.

3. Perry, L.P. and Boodley, J.W. (1980). Germination of foliage plant seeds in response to sowing media, depths of sowing, pH levels and medium temperatures. HortScience, 15, 194-196.

4. Purseglove, J.W. (1972). Tropical Crops. Monocotyledons, pp. 361, Longman, London.

5. Simmonds, N.W. (1952). The germination of banana seeds. Tropical Agriculture, Trinidad, 29, 35-49.

6. Simmonds, N.W. (1959). Experiments on the germination of banana seeds. Tropical Agriculture, Trinidad, 36, 259-274.

7. Stotzky, G. and Cox. E.A. (1962). Seed germination studies in Musa. II. Alternating temperature requirement for the germination of Musa balbisiana. American Journal of Botany, 49, 763-770.

8. Stotzky, G., Cox, E.A., and Goos, R.D. (1961). Alternating temperature requirements for the germination of Musa balbisiana Colla seeds. Plant Physiology, 36, 21-22.

9. Stotzky, G., Cox, E.A. and Goos, R.D. (1962). Seed germination studies in Musa. I, Scarification and aspetic germination of Musa balbisiana. American Journal of Botany, 49, 515-520.

10. Ferrer, L.G. and Espino, R.B. (1923). A study on the germination of abaca seeds. Philippine Agriculturist, 12, 101-110.

11. Ricahuerta, J.R. (1952). Germination and viability study of seven abaca varieties. Philippine Agriculturist, 35, 504-511.

12. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 50. MYRTACEAE

The Myrtaceae comprise 3000 species of woody plants within about 75 genera which provide edible fruits (e.g. Feijoa sellowiana Berg., feijoa), spices (e.g. Pimenta dioica (L.) Merr., pimento), oils (e.g. Pimenta racemosa (Mill.) J.W. Moore, bay), and timber and firewood (e.g. Eucalyptus spp.). The fruits vary from a pulpy berry or drupe to a woody capsule or nut. The seeds generally show orthodox storage behaviour. For example, Callistemon and Melaleuca spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank. Eugenia brasiliensis Lam., however, is reported to show recalcitrant seed storage behaviour.

SEED DORMANCY AND GERMINATION

The embryos are either curved or linear, the cotyledons generally large, and the seed coats hard - thereby delaying or preventing germination. Dormancy per se (that is innate dormancy, see Chapter 5, Volume I) can also prevent or delay germination. Treatments to overcome the barrier provided by the hard seed coat (see Chapter 7, Volume I), gibberellins and warm germination test temperatures (roughly 25°C) tend to result in the promotion of seed germination. Detailed information on seed dormancy and germination is provided in this chapter for the genera Eugenia (including synonyms within Syzygium and Myrtus) and Psidium, and information on recommended germination test procedures and dormancy-breaking treatments for other species is summarised in Table 50.1. In addition the algorithm below may be helpful in developing suitable germination test procedures for other species.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 21°C and 26°C with light applied for 12h/d. If the results of these tests indicate a trend in the response of germination to constant temperatures then a further sample of seeds is tested at a more extreme constant temperature. For example, if germination at 26°C is greater than at 21°C then test a further sample of seeds at a constant temperature of 31°C with light applied for 12h/d.

If the above constant temperature regimes do not result in full germination then the second step in the algorithm is to test further samples of seeds at an alternating-temperature regime of 23°-26°/9°-11°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

TABLE 50.1 Summary of germination test recommendations for species within the Myrtaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Eucalyptus deglupta Blume	TP; BP	20°/30°C	14d		AOSA
Eucalyptus grandis Sieber ex Benth.	TP; BP	25°C	14d	light	AOSA
Eucalyptus spp.				rules state that seed replicates should be weighed	ISTA
				out for testing rather than being counted	
				pre-chill, 1°-5°C, 4w	G&R
Feijoa sellowiana Berg.			21d	pre-chill, 1°-5°C, 30-60d	Riley

Myrciaria cauliflora Berg.			21d	pre-soak, 24h	Riley
Myrtus communis L.			21d	pre-chill, 1°-5°C, 30-60d	Riley
Rhodomyrtus tomentosa			21d	pre-soak, 24h	Riley
Syzygium spp.			21d	pre-soak, 24h	Riley

EUGENIA

E. brasiliensis Lam. [E. dombeyi (Spreng.) Skeels]

E. jambolana Lam. [E. cuminii Druce.; E. jambolanum DC.; Syzygium cuminii Skeels; Myrtus cuminii L.] — jambolan, jambolan-plum

E. jambos

I. Evidence of dormancy

Poor and delayed germination has been reported for seeds of E. jambolana (2,3). Freshly harvested seeds of E. brasiliensis germinate readily, although it is reported to be possible to induce secondary dormancy (1). E. brasiliensis is reported to show recalcitrant seed storage behaviour (1).

II. Germination regimes for non-dormant seeds

E. brasiliensis

Constant temperatures: 25°C, 14d (1)

E. jambos

Alternating temperatures: 25°/30°C, light, 24h/d, 22d (4)

III. Unsuccessful dormancy-breaking treatments

-

IV. Partly-successful dormancy-breaking treatments

E. jambolana

GA_3: pre-applied, 48h, 100-400 ppm (2)

V. Successful dormancy-breaking treatments

E. brasiliensis

GA_3: co-applied, 10^{-4} M, plus kinetin, co-applied, 10^{-4} M (1)

E. jambolana

GA_3: pre-applied, 48h, 500 ppm (2)

Eugenia spp.

Pre-soak: 24h (5)

VI. Comment

It is suggested that seeds of Eugenia spp. be tested for germination at 25°C; at 15°C secondary dormancy may be induced (1). A 60-day germination test period may be required.

Treatment with gibberellins is an effective dormancy-breaking treatment (1,2) and is suggested as an additional treatment where dormancy is a problem.

VII. References

1. Goldbach, H. (1979). Imbibed storage of Melicoccus bijugatus and Eugenia brasiliensis (E. dombeyi) using abscisic acid as a germination inhibitor. Seed Science and Technology, 7, 403-406.

2. Shanmugavelu, K.G. (1970). Effect of gibberellic acid on seed germination and development of seedlings of some tree plant species. Madras Agricultural Journal, 57, 311-314.

3. Singh, R.K. and Thakur, S. (1977). Seed germination and seedling growth of jamum (Syzygium [Eugenia] cuminii Skeels) types. Proceedings of the Bihar Academy of Agricultural Sciences, 25, 139-142.

4. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

5. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

PSIDIUM

P. araca		
P. cattleianum	Sabine [P. littorale Raddi]	strawberry guava
P. guajava	L.	guava
P. pumilum		

I. Evidence of dormancy

P. guajava and P. cattleianum show orthodox seed storage behaviour (1,2,9). Poor and delayed germination has been reported in P. araca (8), P. cattleianum (8), P. guajava (3,5-8), and P. pumilum (8). The cause of this problematic germination has been ascribed to the hard seed coat characteristic (6). Dormancy can be removed by after-ripening for 4 months (9).

II. Germination regimes for non-dormant seeds

P. cattleianum

Alternating temperatures: 20°/30°C (12h/12h) (1)

P. guajava

Constant temperatures: 28°-30°C (2)

Alternating temperatures: 20°/30°C (12h/12h) (1); 25°/30°C, light, 24h/d, 14d (10)

III. Unsuccessful dormancy-breaking treatments

P. guajava

Pre-soak: 24h (4); 14d (7); 100°C (3); 100°C, 5 min (7)

Scarification: concentrated nitric acid, 6-12 min (6); concentrated sulphuric acid, 5 min (7)

Hydroxylamine: pre-applied, 24h, 10^{-3} M (4)

Indoleacetic acid: pre-applied, 8h, 500, 1500 ppm (7)

IV. Partly-successful dormancy-breaking treatments

P. guajava

Pre-soak: (3)

Potassium cyanide: pre-applied, 24h, 10^{-3} M (4)

Sodium azide: pre-applied, 24h, 10^{-3} M (4)

Ethrel: pre-applied, 8h, 500-1500 ppm (7)

Indoleacetic acid: pre-applied, 8h, 1000 ppm (7)

Scarification: concentrated sulphuric acid, 3-12 min (6); concentrated hydrochloric acid, 6-12 min (6); concentrated nitric acid, 3 min (6)

V. Successful dormancy-breaking treatments

P. guajava

Pre-soak: 12-72h (6)

Scarification: concentrated hydrochloric acid, 3 min (6)

Psidium spp.

Pre-soak: 24h (11)

VI. Comment

Scarification of the seeds with subsequent testing in an alternating temperature regime are required for germination to occur. It is suggested for hard-seeded accessions of Psidium spp. that the seeds be scarified for 3 minutes only in either concentrated sulphuric acid or concentrated hydrochloric acid. All accessions can be tested at 20°/30°C (16h/8h), but a test duration of at least 3 months is necessary. Details of a suitable tetrazolium staining procedure for assessing seed viability have been provided by reference (5) - bisected seeds should be stained for 12-14 hours at room temperature in a 1% solution.

VII. References

1. Becwar, M.R., Stanwood, P.C. and Leonhardt, K.W. (1983). Dehydration effects on freezing characteristics and survival in liquid nitrogen of desiccation-tolerant and desiccation-sensitive seeds. Journal of the American Society for Horticultural Science, 108, 613-618.

2. Chacko, E.K. and Singh, R.N. (1971). Studies on the longevity of papaya, phalsa, guava and mango seeds. Proceedings of the International Seed Testing Association, 36, 147-158.

3. Haq, F., Khan, M.S. and Faridullah, I. (1973). Germination trial on guava seed. Journal of Agricultural Research, Pakistan, 11, 121.

4. Roberts, E.H. (1964). The distribution of oxidation-reduction enzymes and the effects of respiratory inhibitors and oxidising agents on dormancy in rice seeds. Physiologia Plantarum, 17, 14-29.

5. Shanker, G. and Ranganathi, A.S. (1974). A quick test for aonla, ber and guava seed viability. Current Research, 3 18-19.

6. Singh, S. and Soni, S.L. (1974). Effect of water and acid soaking periods on seed germination in guava. Punjab Horticultural Journal, 14, 122-124.

7. Sinha, M.M., Verma, J.P. and Koranga, D.S. (1973). Studies on the seed germination of guava (Psidium guajava L.) I. Effect of scarification and plant growth regulation treatments. Progressive Horticulture, 5, 37-40.

8. Teaotia, S.S. and Singh, R.D. (1973). Standardization of rootstocks of guava. I. Studies on seed germination, congeniality and vigour of various guava species and varieties. Progressive Horticulture, 4, 23-24.

9. Teng, Y.T. and Hor, Y.L. (1976). Storage of tropical fruit, seeds. In Seed Technology in the Tropics (eds. H.F. Chin, I.C. Enoch and R.M. Raja Harun) pp. 135-146. Universiti Pertanian Malaysia, Serdang, Selangor, Malaysia.

10. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

11. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 51. OLEACEAE

The Oleaceae comprise over 500 species of trees and shrubs within about 20 genera which provide edible fruits (Olea europaea L., olive) and timber (Fraxinus spp., ash). The fruit may be a drupe (e.g. Olea spp.), a berry (e.g. Jasminum spp.), a capsule (e.g. Syringa spp.) or a samara (e.g. Fraxinus spp.). Seed storage behaviour is orthodox. For example, Jasminum beesianum Forrest & Diels. and Syringa spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

Seed covering structures are often hard, thereby delaying or preventing germination. Dormancy per se (that is innate seed dormancy, see Chapter 5, Volume I) may also prevent or delay germination. Treatments to the seed covering structures (see Chapter 7, Volume I), pre-chill treatments, and warm stratification/pre-chill treatments tend to promote germination. Detailed information on seed dormancy and germination is provided for the genus Olea in this chapter, and recommendations for suitable germination test procedures and dormancy-breaking treatments for other species are summarised in Table 51.1.

TABLE 51.1 Summary of germination test recommendations for species within the Oleaceae.

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Fraxinus spp.	TP	20°/30°C	56d	excise embryos, or pre-treat, 20°C, 2m, then pre-chill, 3°-5°C, 7m	ISTA
	TP	18°-22°C	10-14d	excise embryos, or pre-chill, 3°-5°C, 3m	AOSA
				warm stratification, 20°-25°C, 0-12w, then pre-chill, 1°-5°C, 2-12w	G&R
Syringa reflexa Schneid.	TP	20°C	21d	two tests: with and without pre-chill, 3°-5°C, 27d	ISTA
Syringa villosa Vanl.	TP	20°/30°C	21d		ISTA
Syringa vulgaris L.	TP	20°C	21d		ISTA/AOSA

OLEA

O. cuspidata

O. europaea L. olive

O. welwitschii loliondo

I. Evidence of dormancy

Olea spp. show orthodox seed storage behaviour (10,17,19), but freshly harvested intact seeds show poor germination (1,4,9,14,18-20). Although the seed covering structures (endocarp and testa) contribute to dormancy (1,4,9,11,12,16,18-20), the excised seeds also show dormancy (7,20). After-ripening for 22 months (8) or 3 years (17) is reported to result in loss of seed dormancy.

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

O. cuspidata

Pre-soak: 100°C, allow to cool, 24h (9)

O. europaea

Constant temperatures: 15°C (11); 15°C, 25°C, dark or light/dark (12h/12h) (20); 25°C (2,11); 35°C (19)

Pre-chill: 13°C, 5-15d, germinate at 25°C (6)

Pre-soak: 2d, or more (19)

Light: light or dark (19); red, 3 W m^{-2}, 2 min/h (20); far red, 5 W m^{-2}, 2 min/h (20)

Scarification: sulphuric acid (16)

Removal of seed covering structures: excise embryos, germinate at 4°C, 25°C (7); excise embryos, germinate at 18°-20°C in dark (8); excise embryos, then GA_3, co-applied, 100 ppm (18)

GA_3: co-applied, $1.45x10^{-4}$ -$5.8x10^{-4}$ M, at 15°C, 25°C, dark (20)

$GA_{4/7}$: pre-applied, 36h, 10-1000 ppm, then 5°C, 10°C, 15°C, 20°C, 35°C, dark, 30d, then germinate at 25°C in light, 16h/d (18)

6-Benzylaminopurine: pre-applied, 36h, 10-1000 ppm, then 5°C, 10°C, 15°C, 20°C, 35°C, dark, 30d, then germinate at 25°C in light, 16h/d (18)

Abscisic acid: pre-applied, 36h, 10, 100 ppm, then 5°C, 10°C, 15°C, 20°C, 35°C, dark, 30d, then germinate at 25°C in light, 16h/d (18); co-applied, $2x10^{-5}$ -$8x10^{-5}$ M, at 15°C, 25°C, dark (20)

Kinetin: pre-applied, 30s, 25-100 ppm (3); co-applied, $4.6x10^{-6}$ -$9.2x10^{-6}$ M, at 15°C, 25°C, dark (20)

Zeatin: co-applied, $4.5x10^{-6}$ -$9.1x10^{-6}$ M, at 15°C, 25°C, dark (20)

Ethrel: pre-applied, 30s, 50-200 ppm (3)

4-Chloro-5-2-3-pyridazinone: co-applied, $3.3x10^{-6}$ -$66x10^{-6}$ M, at 15°C, dark (20)

IV. Partly-successful dormancy-breaking treatments

O. cuspidata

Scarification: concentrated sulphuric acid, 5 min (9)

Pre-soak: 7,15d (9)

O. europaea

Constant temperatures: 15°C (18)

Pre-chill: 13°C, 20-30d, germinate at 25°C (6); 15°C, dark, 30d, germinate at 25°C in light, 16h/d (18)

Pre-soak: 5-6d, then warm stratification, 1m (12)

Removal of seed covering structures: endocarp (15,16); excise embryo, germinate at 25°C (2); excise embryo, germinate at 10°C, 15°C, 18°C, in dark (7)

Potassium hydroxide: pre-applied, 6h, 0.5, 0.75% (15,16)

Sodium hydroxide: pre-applied, 6h, 0.5, 0.75% (15,16)

Sodium carbonate: pre-applied, 5h, 0.5, 0.75% (15,16); pre-wash, 5%, then warm stratification, 1m (12)

Scarification: sulphuric acid, 10%, 30s (3); sulphuric acid, 2% (15)

4-Chloro-5-2-3-pyridazinone: co-applied, 16.5×10^{-6} -33×10^{-6} M, at 25°C (20)

O. welwitschii

Pre-soak: then removal of seed covering structures (10)

V. Successful dormancy-breaking treatments

O. europaea

Constant temperatures: 13°C, 48d (6)

Pre-soak: 1d, germinate at 15°C, dark, 56d (12)

Removal of seed covering structures: endocarp and testa, germinate at 13°C, in light or in dark (5); excise embryo, germinate at 13°C in dark (5,7,8); excise embryo, germinate at 18°-20°C in light (8); excise embryo, germinate at 25°C (11,18,20); excise embryo, germinate at 15°C, 25°C, dark (19)

VI. Comment

The endocarp and testa of Olea spp. restrict imbibition (4,5). Consequently their removal promotes germination (5,10,11,19,20). Intact dormant seeds will not germinate at 25°C or higher (2,6,11,18-20), but embryos excised from slightly dormant seeds will germinate at 25°C (2,11,18-20). Germination of dormant and non-dormant intact seeds and excised embryos occurs at about 13°C in both light and dark (5-8,18,19), but at slightly supra-optimal temperatures, 15°-20°C, light can be promotory (8). Fluorescent, red, and far red light, however, have no effect on germination (19,20). Plant growth regulators have either no positive effect or may inhibit germination (3,18,20). It is suggested that gene banks test seeds of Olea spp. for germination at a constant temperature of 13°C in diffuse light after removing endocarps and pricking, or chipping away a part of the testa. Allow at least 7 weeks (6) for these tests.

VII. References

1. Basso, M. (1962). [Observations on the germinating capacity of olive seeds.] Agri. Ital., 7. (From Horticultural Abstracts, 1963, 33, 6063.)

2. Diamantoglou, S. and Mitrakos, K. (1979). Sur la culture in vitro de l'embryon d'olivier (Olea

europaea L. var. oleaster). Comptes Rendus Hepdomadaires des Séances de l'Académie des Sciences (Paris), D, 288, 1537-1540.

3. Diana, G. and Gaetani, F.R. (1979/1980). [The germination of olive seeds in relation to pre-sowing treatments and to different harvesting dates.] Annali dell' Istituto Sperimentale per l'Olivicoltura, 6, 81-97.

4. Istanbouli, A. (1974). Etude de la "dormance" des semences d'olivier (Olea europaea L.). I. Rôle des enveloppes dans l'imbibition de la graine et de l'embryon. Revue Générale de Botanique, 81, 215-221.

5. Istanbouli, A. and Neville, P. (1974). Etude de la "dormance des semences d'olivier (Olea europaea L.). Mise en évidence d'une inhibition excerceé par l'albumen. Comptes Rendus Hepdomadaires des Séances de l'Academie des Sciences (Paris), D, 279, 1441-1442.

6. Istanbouli, A. and Neville, P. (1977). Distinction entre germination physiologique (ou activation) et germination morphologique chez l'olivier (Olea europaea L.). Comptes Rendus Hepdomadaires des Séances de l'Academie des Sciences (Paris), D, 284, 2235-2237.

7. Istanbouli, A. and Neville, P. (1977). Etude de la "dormance" des semences d'olivier (Olea europaea L.). Mise en évidence d'une dormance embryonnaire. Comptes Rendus Hepdomadaires des Séances de l'Academie des Sciences (Paris), D, 284, 2503-2506.

8. Istanbouli, A. and Neville, P. (1977). Etude de la "dormance" des semences d'olivier (Olea europaea L.). Influence favorable de la lumière en présence d'obstacles à la germination. Comptes Rendus Hepdomadaires des Séances de l'Académie des Sciences (Paris), D, 285, 41-44.

9. Khattak, G.M. (1962). Effect of locality of collection and seed pre-sowing treatments on the germination of Olea cuspidata. Pakistan Journal of Forestry, 12, 233-235.

10. Kimariyo, P.E. (1973). Handling hardwood seeds in Tanzania. In International Symposium on Seed Processing: Seed Problems, Bergen, Norway. IVFRO, Vol. II, Paper No. 16.

11. Lagarda, A., Martin, G.C. and Polito, V.S. (1983). Anatomical and morphological development of 'Manzanillo' olive seed in relation to germination. Journal of the American Society for Horticultural Science, 108, 741-743.

12. Lalatta, F. (1959). [Horticultural seeds: ripening of seeds of tree fruit species.] Sementi Elette, 5, 65-66. [From Horticultural Abstracts, 1959, 29, 2103.]

13. Macluskie, G. (1898). Effect of different temperatures of water on the germination of olive seeds. Bulletin of the Torrey Botanical Club, 25, 222-225.

14. Milella, A. (1960). [The germinative capacity of wild olive seeds in relation to the ripeness of the fruit.] Studi Sassar., Sez. 111, 8, 85-89. (From Horticultural Abstracts, 1962, 32, 3753.)

15. Rocha, G.G. de la (1957). [Trials with different treatments of olive seeds]. Inf. Mens. Estac. exp. Agric. La Molina, 31, 15-17. (From Horticultural Abstracts, 1958, 28, 1829.)

16. Rocha, G.G. de la (1960). [A trial of different treatments of olive seeds.] Inf. Estac. Mens. exp. Agric. La Molina, 34, 7-10. (From Horticultural Abstracts, 1961, 31, 5227.)

17. Scaramuzzi, F. (1957). [Studies on the germinating power of olive seeds of various ages.]. Agri. Ital., 56. (From Horticultural Abstracts, 1958, 28, 1828.]

18. Lagarda, A. and Martin, G.C. (1983). "Manzallino" olive seed dormancy as influenced by

exogenous hormone application and endogenous abscisic acid concentration. HortScience, 18, 869-871.

19. Lagarda, A., Martin, G.C. and Kester, D.E. (1983). Influence of environment, seed tissue, and seed maturity on "Manzallino" olive seed germination. HortScience, 18, 868-869.

20. Mitrakos, K. and Diamantoglou, S. (1984). Endosperm dormancy breakage in olive seeds. Physiologia Plantarum, 62, 8-10.

CHAPTER 52. OXALIDACEAE

The Oxalidaceae comprise more than 500 species of herbaceous plants, shrubs and trees within about ten genera which provide edible fruits (e.g. Averrhoa carambola L., carambola). The fruits are either dry dehiscent capsules or fleshy and berry-like. Most, if not all, species are thought to show orthodox seed storage behaviour.

SEED DORMANCY AND GERMINATION

No detailed information on seed dormancy and germination is provided in this chapter, but it appears that problems in germination tests are comparatively minor. As a first step with a species of unknown characteristics RBG Kew Wakehurst Place suggests testing the seeds at a constant temperature of 16°C with light applied for 12h/d. If this technique does not result in satisfactory germination clues for alternative techniques could be sought from Table 52.1 which summarises other germination test recommendations.

TABLE 52.1 Summary of germination test recommendations for species within the Oxalidaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Averrhoa bilimbi L.			21d	pre-soak, 24h	Riley
Averrhoa carambola L.	S	25°-30°C	36d	light, continuous	CHML
			21d	pre-soak, 24h	Riley

CHAPTER 53. PALMACEAE

The Palmaceae comprise a very large family of woody trees, erect shrubs and climbers within about 225 genera. Palmae and Arecaceae are alternative names for Palmaceae. The Palmaceae provide very many useful products including edible nuts (e.g. Cocos nucifera L., coconut), edible fruits (e.g. Phoenix dactylifera L., date palm), oils (e.g. Elaeis guineensis Jacq., oilpalm), starch (e.g. Metroxylon sagus Rottb., sago palm), and many other useful products - such as construction materials (e.g. Calamus spp., rattans). The fruits are nuts, berries or drupes and usually indehiscent.

Until recently seed storage behaviour was assumed to be recalcitrant throughout the Palmaceae, but it is now known that this classification was mistaken. Whilst it is possible that some species may ultimately be proven to show recalcitrant seed storage behaviour, for most species seed storage behaviour is expected to be orthodox. For the present seeds of Cocos spp. should be treated as recalcitrant; further investigations are required to clarify seed storage behaviour in these species.

SEED DORMANCY AND GERMINATION

The seeds vary considerably in size and include the largest seed known to man (Lodoicea maldivica (Gmel.) Pers., double coconut). The embryos are comparatively small and are surrounded by substantial endosperm (liquid endosperm in Cocos) and a hard, woody husk; germination is hypogeal.

Dormancy varies considerably between the species. For example, dormancy is substantial in Elaeis spp. but less so in Cocos spp. where seed development and germination may be continuous. It is, however, difficult to germinate seeds of most members of the Palmaceae. The main problem is the time taken by the seeds to germinate: in field or glasshouse sowings the germination of some individuals within an accession takes more than a year. Seedling development also occurs comparatively slowly. Thus embryo culture (for propagation) or the excised embryo test (to estimate viability) - see Chapter 11, Volume I - may be preferable in some cases to attempting to germinate the seeds. Treatments to the seed covering structures, pre-soaking in water (or possibly gibberellins) and constant temperatures of 25°C or 30°C or an alternating temperature of about 20°/30°C (12h/12h) are generally promotory (although some exceptions to the above are noted in this chapter).

Detailed information on seed germination and dormancy is provided in this chapter for the genera Areca (including synonyms within Chrysalidocarpus), Cocos, Elaeis (including synonyms within Corozo), and Phoenix. In addition a summary of information on germination test procedures and/or germination test periods for very many other palms is provided. It will be seen that, unless special treatments are applied, considerable germination test periods are required for many of these species; it is hoped that the provision of this information will help to ensure that germination tests are not concluded too soon.

Seed germination in Palmaceae

Acanthophoenix rubra (Bory) Wendl.

In glasshouse sowings 71d may elapse before the seeds start to germinate (12,13).

Acoelorraphe pimo [Erythea pimo]

In glasshouse sowings 193d may elapse before the seeds start to germinate (12, 13).

Acoelorraphe Wrightii (Gris. & Wendl.) Wendl. ex Becc.

Seeds from which pericarps have been removed begin to germinate after 6m (1), but the delay is only 3m if the seeds are tested in moist sand in an alternating temperature regime of 20°/30°C (night/day) (8). It is suggested that pericarp removal and the latter regime be used as a general procedure for germinating seeds of Acoelorraphe spp.

Acrocomia aculeata

Pre-soaking for 7d followed by warm stratification at 39°C for 80d, with a subsequent germination test at 27°C was not a successful dormancy-breaking treatment (19) - despite the suitability of this procedure for seeds of other palms.

Acrocomia crispa

The seeds are difficult to germinate, but the following is a partly successful dormancy-breaking treatment: remove exocarp and mesocarp, crack endocarp and then pre-soak the seeds for 12 to 24h (7).

Acrocomia mexicana

The seeds are very difficult to germinate. Seeds from which endocarps have been removed start to germinate after 183d whilst for whole seeds the delay is 440d (11).

Acrocomia sclerocarpa Mart.

The seeds are very difficult to germinate. Seeds from which endocarps have been removed take a year before they start to germinate whilst for whole seeds the delay can be 2.5 years (11).

Acrocomia spp.

Filing and scarification are partly successful dormancy-breaking treatments (12, 13), but the following procedure is more successful: pre-dry at 65° to 71°C for 2 to 3w, then germinate in moist sand in a glasshouse with a fluctuating temperature regime where the maximum temperature is 50°C (12, 13).

Actinorhytis calapparia Wendl. & Drude

In glasshouse sowings 2 to 2.5m may elapse before the seeds start to germinate (11, 15).

Aiphanes acanthophylla (Mart.) Burret

There is a delay of 43 to 90d before the seeds start to germinate in moist sand at 20°/30°C (8, 11).

Aiphanes caryotaefolia

In glasshouse sowings 60 to 70d may elapse before the first seeds germinate (11).

Aiphanes erosa [Martinezia erosa Lind.]

Untreated seeds begin to germinate after 58 to 110d (11). Pre-soaking the seeds for 7d followed by warm stratification at 35°C for 80d with subsequent transfer to room temperature

for the germination test is a partly successful dormancy-breaking treatment (19).

Allagoptera campestre

In glasshouse sowings 2m may elapse before the first seeds germinate (11).

Archontophoenix alexandrae (F. Muell.) Wendl. & Drude

The following procedures are partly successful dormancy-breaking treatments for seeds of the Alexandra palm: pre-soak the seeds for 3d, then test for germination in an alternating temperature regime of 20°/26°C for 7w (17); scarify the seeds by hand and then either pre-soak in water or 1000 ppm gibberellic acid for 3d (17); pre-treat the seeds with 1000 ppm gibberellic acid for 3d (18); test for germination at constant temperatures of 25°C, 30°C, or 35°C (21, 24). The following are successful dormancy-breaking procedures: testa removal (17); constant temperatures between 24° and 28°C (3); an alternating temperature regime of 20°/30°C (8); pre-treat with gibberellic acid at 10 or 100 ppm for 3d (18); pre-treat with gibberellic acid at 1000 ppm for 3d (17).

Archontophoenix cunninghamiana (Wendl.) Wendl. & Drude

There is a delay of 90 to 100d before the seeds start to germinate (8, 11), and the optimum constant temperatures for germination are between 24° and 28°C (3).

Archontophoenix spp.

As a general procedure it is suggested that testa be removed from over the embryos, the seeds pre-treated in 100 ppm gibberellic acid for 3d and subsequently tested for germination at 25°C or 30°C.

Areca spp. - see separate section

Arecastrum romanzoffianum (Cham.) Becc.

[Cocos romanzoffianum Cham.; Cocos plumosa Hook.]

The seeds are very difficult to germinate (3, 8, 19). Pre-soaking for 7d followed by warm stratification at 39°C for 80d, with a subsequent germination test at 27°C was not a successful dormancy-breaking treatment (19) - despite the suitability of this procedure for seeds of other palms. Testing for germination in a peat/perlite medium at 24° to 28°C (3) or in moist sand at 20°/30°C (8) have, however, been reported as partly successful dormancy-breaking treatments.

Arenga caudata

Pre-soak the seeds for several days and then test for germination at 27°C - the first seeds begin to germinate after 65d (12, 13).

Arenga engleri Becc.

The seeds are very dormant (6, 7, 8, 11) and between 4 and 21m may elapse before the seeds start to germinate in glasshouse sowings (11). Scarifying the seeds in concentrated sulphuric acid for 5 or 20 min does not promote germination (7), but the following scarification procedures may be promotory: scarifying the mesocarp at the hilum with sandpaper (7); scarifying the mesocarp at the hilum with sandpaper and subsequently pre-soaking the seeds (7); or scarifying the mesocarp at the hilum with sandpaper and then scarifying the seeds in concentrated sulphuric acid for 10 min (7). Alternatively whole seeds can be tested for germination in moist sand in an alternating temperature regime of 20°/30°C for a year (8).

Arenga microcarpa Becc.

In glasshouse sowings 9m may elapse before the seeds start to germinate (11).

Arenga obtusifolia Mart.

In glasshouse sowings between 8 and 12m may elapse before the seeds start to germinate (11).

Arenga pinnata (Wurmb.) Merr. [A. saccharifera Labill.]

The seeds of the sugar palm (or gomuti palm) are difficult to germinate (8, 19) and there can be a 6m delay before the seeds start to germinate in glasshouse sowings (8, 11). Testing the seeds for germination in moist sand at 20°/30°C (8), or at 27°C after first pre-soaking for 7d and then giving a warm stratification treatment at 39°C for 80d (19) promotes the germination of some, but not all, dormant seeds.

Arenga tremula (Blanco) Becc.

There can be a delay of between 103 and 175d before the seeds start to germinate (8, 11). Testing in moist sand at 20°/30°C is only partly-successful in promoting the germination of dormant seeds (8).

Arenga undulatifolia

In glasshouse sowings 9m may elapse before the seeds start to germinate (11).

Arenga Wightii

The seeds are difficult to germinate (11, 19) and 10m may elapse before the seeds start to germinate in glasshouse sowings (11). Pre-soaking the seeds for 7d followed by warm stratification at 39°C for 80d and subsequently testing for germination at 27°C promotes the germination of some, but not all, dormant seeds (19).

Arikuryoba schizophylla

In glasshouse sowings between 51 and 107d may elapse before the seeds start to germinate (11).

Astrocaryum aculeatum G.F.W. Mey

The seeds are very difficult to germinate and may take 3 or more years to germinate in glasshouse sowings (11).

Astrocaryum mexicanum [Hexopetion mexicanum]

The seeds germinate readily in glasshouse sowings, beginning within 38 days (12, 13).

Astrocaryum standleyanum

The seeds take between 50 and 150d before they start to germinate in glasshouse sowings (11, 12, 13). The germination test procedure used is to pre-soak the seeds for several days and then test at a constant temperature of 27°C (12, 13).

Astrocaryum vulgare Mart.

The seeds are difficult to germinate and between 11 and 14m may elapse before they start to germinate in glasshouse sowings (11).

Astrocaryum spp.

Pre-drying the seeds for 2 to 3w at between 65° and 71°C with subsequent germination tests in an alternating temperature environment where the maximum temperature reaches 50°C is reported to promote germination (12, 13).

Attalea cohune [Orbignya cohune Mart.]

The seeds show considerable dormancy (6) and there is a delay of between 2 and 6m before they begin to germinate in glasshouse sowings (11, 12, 13).

Bactris gasipaes HBK [Guilielma gasipaes (HBK) Bailey]

In glasshouse sowings the seeds begin to germinate after 69d (11).

Bactris major Jacq.

In glasshouse sowings the seeds begin to germinate after 6m (11).

Bactris monostachya

The seeds germinate fully during a 3m test at 24° to 28°C (3).

Bactris ottostapfeana

The seeds can be germinated by testing at 27°C after pre-soaking for several days (12, 13).

Bactris rhaphidacantha

In glasshouse sowings there is a delay of 6 to 7m before the seeds start to germinate (11).

Bentinckia condapanna

The seeds can be germinated by testing at 27°C after pre-soaking for several days (12, 13).

Bentinckia nicobarica Becc.

In glasshouse sowings between 74 and 85d may elapse before the seeds start to germinate (11).

Bismarckia nobilis

The seeds can be germinated by testing at 27°C after first pre-soaking the seeds for several days (12, 13).

Borassus flabellifer L.

Seeds of the Palmira palm are difficult to germinate (11, 19) and untreated seeds may require more than 260d before they begin to germinate in glasshouse sowings (11). Moist sand or peat/perlite (1:1) are suitable media for germination (3,26). The germination of some, but not all, dormant seeds can be promoted by pre-soaking for 7d followed by warm stratification at 39°C for 80d and then testing at 27°C (19), but testing whole fruits in a peat/perlite medium (1:1) at 24° to 28°C for 5m is reported to result in full germination (3).

Brahea bella Bailey

The germination of some, but not all, dormant seeds can be promoted by testing in moist sand at 20°/30°C (8).

Brassiophoenix drymophloeoides

In glasshouse sowings 8m may elapse before the seeds start to germinate (11).

Butia bonnetii Becc.

The seeds are very difficult to germinate (8). The germination of some, but not all, can be promoted by testing in moist sand at 20°/30°C for 300d (8).

Butia capitata (Mart.) Becc.

The seeds are very difficult to germinate (8) due to extremely severe dormancy (24) - untreated seeds germinate between 28 and 960d after sowing (8, 11). Gibberellic acid pre-applied for 1h at concentrations between 100 and 2000 ppm can be promotory (24).

Butia eriospatha

The seeds are very difficult to germinate; between 8 and 22m may elapse before they begin to germinate in glasshouse sowings (11).

Butia yatay (Mart.) Becc.

The seeds are very difficult to germinate and, when tested in moist sand at 20°/30°C, take between 2 and 20m to germinate (8).

Calamus spp.

Seeds of the rattans are difficult to germinate and between 107 and 408d may elapse before they begin to germinate in glasshouse sowings (11). The germination of some, but not all, dormant seeds can be promoted by testing whole fruits in a peat/perlite (1:1) medium at 24° to 28°C (3).

Calyptrocalyx spicatus Blume

The seeds are reported to germinate readily in glasshouse sowings (11).

Carpentaria acuminata

In glasshouse sowings the seeds begin to germinate after 78d (11).

Caryota cumingii Lodd.

In glasshouse sowings the seeds begin to germinate after between 114 and 317d (11, 12, 13).

Caryota mitis Lour.

The seeds are difficult to germinate (3,8,11,14,22) and may require 5 to 6m before they begin to germinate (8,11,15,22). The germination of some, but not all, dormant seeds can be promoted by: removing the endocarps and testing in a peat/perlite (1:1) medium at 24° to 28°C (3); testing in moist sand at 20°/30°C (8); testing in vermiculite at 25°C or 30°C (22); or by pre-soaking the seeds for 7d followed by warm stratification at 39°C for 80d with subsequent testing at 27°C (19).

Caryota urens L.

Seeds of the fish-tail, or toddy, palm are difficult to germinate (3,8,11) and may require between 6 and 7m before they begin to germinate either in glasshouse sowings (11) or at 20°/30°C in moist sand (8).

Chamaedorea cataractarum

In glasshouse sowings there can be a delay of 82d before the seeds begin to germinate (11).

Chamaedorea costaricana

In glasshouse sowings 41d may elapse before the seeds begin to germinate (11).

Chamaedorea elatior

In glasshouse sowings 118d may elapse before the seeds begin to germinate (11).

Chamaedorea elegans Mart. [Collinia elegans Liebm.; Neanthe bella O.F. Cook]

The seeds of the parlor palm are difficult to germinate: the first seeds begin to germinate after 4m (with full germination after 10m) in moist sand at 20°/30°C (8). Whole fruits or seeds can be successfully tested for germination: in a peat/perlite medium (1:1) at 24° to 28°C (3); in moist sand or vermiculite at 30°C (24); or in moist sand at 20°/30°C (8).

Chamaedorea erumpens E.H. Moore

The seeds are difficult to germinate and may be delayed for 7m before they begin to germinate (8, 11, 12, 13). Whole fruits or seeds can be successfully tested for germination in a peat/perlite medium (1:1) at 24° to 28°C (3).

Chamaedorea glaucifolia

In glasshouse sowings 8m may elapse before the seeds begin to germinate (11). Pre-soaking the seeds for several days with subsequent testing at 27°C can at least partly promote germination (12, 13).

Chamaedorea humilis

Whole fruits or seeds can be successfully tested for germination in a peat/perlite (1:1) medium at 24° to 28°C (3).

Chamaedorea metallica

In glasshouse sowings there can be a delay of 197d before the seeds begin to germinate (11).

Chamaedorea microspadix Burret

The seeds begin to germinate after between 50 and 100d in test (8, 11). The germination of some, but not all, dormant seeds can be promoted by testing in moist sand at 20°/30°C (8).

Chamaedorea monostachys

In glasshouse sowings the seeds begin to germinate after 5m in test (11).

Chamaedorea oblongata Mart.

The seeds are difficult to germinate (8, 11) and begin to germinate after 40d in glasshouse sowings (11). When tested in moist sand at 20°/30°C the seeds germinate after between 187 and 237d (8).

Chamaedorea oreophila

The seeds are difficult to germinate and begin to germinate after 7m in glasshouse sowings (11).

Chamaedorea seifrizii Burret

The seeds are very difficult to germinate (8, 11) and begin to germinate after 8m in moist sand at 20°/30°C (8).

Chamaedorea tenella Wendl.

The seeds take between 3 and 4m to germinate in moist sand at 20°/30°C (8).

Chamaedorea tepejilote

The seeds are reported to germinate readily (11).

Chamaerops humilis L. var humilis

In glasshouse sowings the seeds begin to germinate after 3m (11). In moist sand at 20°/30°C the seeds take between 4 and 6m to germinate (8).

Chamaerops humilis L. var arborescens

In glasshouse sowings 2m may elapse before the seeds begin to germinate (11).

Chrysalidocarpus lutescens - see Areca section

Clinostigma gronophyllum

In glasshouse sowings 4m may elapse before the seeds begin to germinate (11).

Clinostigma ponapensis H.E. Moore

The seeds begin to germinate after 2.5 to 3.5m in moist sand at 20°/30°C (8). The germination of some, but not all, dormant seeds can be promoted by pre-soaking for several days and then testing at 27°C (12, 13).

Coccothrinax acuminata

In glasshouse sowings there can be a delay of 7w before the seeds begin to germinate (11).

Coccothrinax alta

In glasshouse sowings there can be a delay of 9w before the seeds begin to germinate (11).

Coccothrinax argentata (Jacq.) Bailey [C. argentea Auth.; C. jucunda Sarg.; C. garberi Sarg.; Palma argentata Jacq.]

The seeds are very difficult to germinate and germinate after between 7 and 9m in moist sand at 20°/30°C (8).

Coccothrinax crinita Becc.

The seeds begin to germinate after 3.5 to 6m (8, 11).

Coccothrinax fragrans

The seeds begin to germinate after 45 to 240d (11, 12, 13).

Coccothrinax martii (Gris. & Wendl.) Becc.

The seeds begin to germinate after 47 to 101d (8, 11).

Coccothrinax miraguama (HBK) Becc.

The seeds begin to germinate after 60 to 104d (8, 12, 13).

Coccothrinax pseudorigida

The seeds begin to germinate after 48d (12, 13).

Cocos nucifera - see Cocos section

Cocos plumosa, Cocos romanzoffianum

- see Arecastrum romanzoffianum

Collinia elegans - see Chamaedorea elegans

Copernicia alba Morong

The seeds begin to germinate after 3m in moist sand at 20°/30°C (8).

Copernicia australis Becc.

The germination of some, but not all, dormant seeds can be promoted by testing seeds in aerated water (changed daily) after either no pre-treatment or after scarifying the seeds in 10% sulphuric acid for 15 min (10). Full germination, however, can be achieved by hand scarification near the embryo and then testing in aerated water, or by first pre-soaking for 9m in aerated water and then scarifying the seeds by hand near the embryo (10).

Copernicia burretiana

In glasshouse sowings the seeds begin to germinate after 37d (12, 13).

Copernicia cerifera (Arr.) Mart. [C. prunifera]

In the glasshouse untreated seeds of the Carnauba wax palm begin to germinate 2m after sowing (11). Full germination has been achieved by pre-soaking the seeds for 7d followed by warm stratification at 35°C for 80d and then testing for germination at 27°C (19).

Copernicia cowellii

In glasshouse sowings the seeds begin to germinate after 37d (12, 13).

Copernicia gigas

In glasshouse sowings the seeds begin to germinate after 73d (12, 13).

Copernicia glabrescens Wendl. ex Becc.

The seeds germinate after between 1 and 3m in test (8, 11). Germination can be at least partly promoted by pre-soaking for several days and then testing at 27°C (12, 13).

Copernicia hospita

In glasshouse sowings the seeds begin to germinate after between 1 and 4m (11, 12, 13).

Copernicia macroglossa Wendl. ex Becc.

The seeds germinate after between 70 and 88d in moist sand at 20°/30°C (8).

Copernicia pauciflora

In glasshouse sowings there can be a delay of 33d before the seeds begin to germinate (11).

Copernicia torreana, Copernicia vespertilionum

The seeds are reported to germinate readily (12, 13).

Copernicia yarey

In glasshouse sowings the seeds begin to germinate after 4m (11).

Copernicia spp.

Testing the seeds in aerated water (changed daily) until the first seeds germinate promotes the germination of some dormant seeds - the duration of pre-soaking treatment required varying from 2d for freshly harvested seeds to several weeks for older seeds (10).

Corozo oleifera (HBK) Bailey - see also Elaeis section

The seeds are very difficult to germinate and take a year before they begin to germinate in glasshouse sowings (11).

Corypha elata Roxb.

Seeds of the gebang palm germinate readily - beginning within 20d - when tested in moist sand after pericarp removal (1).

Corypha lecomtei

In glasshouse sowings the seeds begin to germinate after 3m (11).

Corypha umbraculifera L.

Seeds of the talipot palm begin to germinate after 52 to 226d in test (11,12,13,15).

Cryosophila Warscewiczii

In glasshouse sowings the seeds begin to germinate after 68d (11).

Cyrtostachys lakka Becc.

The seeds germinate within 2 to 3m in moist sand at 20°/30°C (8).

Cyrtostachys renda Blume

In glasshouse sowings the seeds begin to germinate after 4m (11).

Deckenia nobilis Wendl.

The seeds are difficult to germinate and only begin to germinate 8m after sowing in the glasshouse (11).

Desmoncus horridus

In glasshouse sowings the seeds begin to germinate after 5m (11).

Dictyosperma album (Bory.) Wendl. & Drude ex Scheff.

The seeds begin to germinate 1 to 3m after sowing (1,3,8,11,12,13). Whole ripe fruits or

seeds can be successfully tested for germination in a peat/perlite (1:1) medium at 24° to 28°C (3).

Dictyosperma aureum (Balf. f.) Nich.

The seeds begin to germinate 54 to 102d after sowing (8,11,12,13).

Dictyosperma furfuraceum - see Syagrus comosa

Diplothemium maritimum

After pre-soaking for several days the seeds begin to germinate 73d after sowing in tests at 27°C (12,13).

Drymophloeus Beguinii

The seeds begin to germinate 26 to 45d after sowing in the glasshouse (11,12,13).

Drymophloeus olivaeformis (Giseke) Miq.

The seeds begin to germinate after 4m in glasshouse sowings (11) and in moist sand at 20°/30°C (8).

Elaeis spp. - see separate section and Coroza oleifera

Erythea armata Wats. [E. Roezlii Lind.]

Seeds of the big blue hesper palm begin to germinate after 5 to 6m in glasshouse sowings (11) and in moist sand at 20°/30°C (8).

Erythea Brandegeeis Purpus

Seeds of the San José hesper palm are difficult to germinate and only begin to germinate 10 to 13m after glasshouse sowings (11). Germination can be at least partly promoted by pre-soaking the seeds for several days and then testing at 27°C (12,13).

Erythea edulis (Wendl.) Wats.

Seeds of the Guadalupe palm begin to germinate after 2.5m in glasshouse sowings (11) and within 6m when tested in moist sand at 20°/30°C (8).

Erythea pimo - see Acoelorraphe pimo

Eugeissona tristis Griff.

Whole fruits begin to germinate 5m after sowing whereas the seeds begin to germinate 7m after sowing (11,15).

Euterpe edulis Mart.

Germination is slow - between 6 and 11w may elapse before the seeds begin to germinate (11) - due to thick, hard mesocarps and endocarps (16). The germination of some, but not all, dormant seeds can be promoted by: mesocarp removal (16); mesocarp removal followed by pre-soaking at 30°C for 3d (16); a 2h ultrasonic treatment at 50 to 60 Hz and 80 W followed by pre-washing for 42h (16); scarification for 10 min in concentrated sulphuric acid followed by pre-soaking at 30°C for 2d (16). But the most successful dormancy-breaking treatment reported is to soak in a 6% hydrogen peroxide solution for 2d after removing the mesocarps from the seeds (16).

Euterpe longibracteata

In glasshouse sowings the seeds begin to germinate after 24d (12,13). Non-dormant seeds can be germinated between moist paper towels at 38°C (16).

Gastrococos crispa [G. armentalis]

In glasshouse sowings between 2 and 4m may elapse before the seeds start to germinate (11).

Gaussia attenuata (O.F. Cook) Becc.

The seeds germinate between 1 and 9m after sowing (8,11,12,13).

Geonoma baculifera

In glasshouse sowings 7m may elapse before the seeds start to germinate (11).

Geonoma congesta

In glasshouse sowings 6m may elapse before the seeds start to germinate (11).

Geonoma longipetiolata

In glasshouse sowings between 2.5 and 4m may elapse before the seeds start to germinate (12,13).

Geonoma longisecta

In glasshouse sowings 9m may elapse before the seeds start to germinate (11).

Geonoma membranacea

In glasshouse sowings fresh and dry seeds begin to germinate after 48d and 141d respectively (11).

Guilielma gasipaes - see Bactris gasipaes

Hedyscepe canterburyana

The seeds are difficult to germinate: whole fruits or seeds begin to germinate after 6 to 7m at 24°/28°C (3).

Heterospathe coriacea

In glasshouse sowings between 2.5 and 7.5m may elapse before the seeds start to germinate (11).

Heterospathe minor

In glasshouse sowings 2m may elapse before the seeds start to germinate (11).

Hexopetion mexicanum - see Astrocaryum mexicanum

Howea Belmoreana Becc. [Kentia Belmoreana F. Muell.]

Whole fruits or seeds can show a delay of between 40 and 223d before they start to germinate (1,3,8).

Howea Forsteriana Becc. [Kentia Forsteriana F. Muell.]

At 24° to 28°C or at 20°/30°C whole fruits or seeds can show a delay of between 2.5 and 8m before they germinate (3,8).

Hyophorbe indica

In glasshouse sowings 75d may elapse before the seeds start to germinate (12,13).

Hyphaene crinita

In glasshouse sowings 72d may elapse before the seeds start to germinate (11).

Hyphaene schatan

In glasshouse sowings 38d may elapse before the seeds start to germinate (11).

Hyphaene thebaica (L.) Mart.

In glasshouse sowings between 2 and 3m may elapse before seeds of the doum, or dum, palm start to germinate (11).

Hyphaene turbinata

In glasshouse sowings 5m may elapse before the seeds start to germinate (11).

Iguanura wallichiana (Mart.) Benth. & HBK.f.ex Becc.

There can be a delay of 11w before the seeds start to germinate (15).

Jessenia bataua

In glasshouse sowings 67d may elapse before the seeds start to germinate (11).

Jubaea chilensis (Molina) Baill.

There can be a delay of 3 to 4m before the seeds start to germinate (8,12,13).

Kentia Belmoreana - see Howea Belmoreana

Kentia Forsteriana - see Howea Forsteriana

Kentiopsis olivaeformis

In glasshouse sowings 317d may elapse before the seeds start to germinate (11).

Latania loddigesii Mart.

There can be a delay of 54 to 70d before the seeds start to germinate (1,8,11).

Latania lontaroides

In glasshouse sowings 100d may elapse before the seeds start to germinate (11).

Latania verschaffeltii Lam.

The seeds should be pre-soaked for several days and then tested for germination at 27°C (12,13).

Licuala amplifrons Miq.

There can be a delay of 70d before the seeds start to germinate in glasshouse sowings (12,13).

Licuala elegans

In glasshouse sowings 74d may elapse before the seeds start to germinate (11).

Licuala glabra Griff.

There can be a delay of 4w before the seeds start to germinate (15).

Licuala gracilis

In glasshouse sowings there can be a one year delay before the seeds start to germinate (11).

Licuala grandis Wendl.

There can be a delay of between 53 and 166d before the seeds start to germinate (1,8,11,12,13).

Licuala lauterbachii

In glasshouse sowings 7m may elapse before the seeds start to germinate (11).

Licuala Muelleri

In glasshouse sowings 4m may elapse before the seeds start to germinate (11).

Licuala Peltata Roxb.

The seeds may take between 3 and 13m to germinate (8,11).

Licuala spinosa Thunb.

Between 2.5 and 16m may be required before untreated seeds germinate (1,8,11), but germination can be promoted by pre-soaking the seeds for several days and then testing at 27°C or 20°/30°C (8,12,13).

Livistona Australis (R. Brown) Mart.

Although there can be a delay of 3 to 4m before the seeds start to germinate (8,11), whole ripe fruits tested in a peat/perlite (1:1) medium at 24° to 28°C are reported to germinate readily (3).

Livistona chinensis (Jacq.) R. Brown & Mart.

The seeds germinate readily, beginning within 1m of sowing (1,8,11,19): full germination has been achieved by testing in moist sand at 25°C, 30°C, 20°/30°C or 25°/30°C (8,20,24,28).

Livistona colchinchinensis (Blume) Mart. [L. hoogendorpii; L. saribus (Lour.) Cheval.]

The seeds begin to germinate within 1m of sowing in the glasshouse (12,13).

Livistona decipiens Becc.

There can be a delay of between 1 and 8m before the seeds germinate (1,8,11).

Livistona humilis

In glasshouse sowings 48d may elapse before the seeds start to germinate (11).

Livistona Jenkinsiana Griff.

In glasshouse sowings 4m may elapse before the seeds start to germinate (11).

Livistona Kingiana Becc.

There can be a delay of 77d before the seeds start to germinate (15).

Livistona Mariae F.W. Muell.

Removal of the exocarps from the seeds with subsequent testing at 27°C can promote full germination (14).

Livistona Muelleri Hort.

In glasshouse sowings 4m may elapse before the seeds start to germinate (11).

Livistona Robinsoniana Becc.

There can be a delay of between 4 and 6m before the seeds start to germinate (8,11).

Livistona rotundifolia (Lam.) Mart. [L. altissima Zoll.]

There can be a delay of between 45 and 199d before the seeds germinate (1,8,11).

Livistona speciosa Kurz

There can be a delay of 9w before the seeds start to germinate (15).

Martinezia erosa - see Aiphanes erosa

Mascarena lagenicaulis Bailey

There can be a delay of between 2 and 8m before the seeds germinate (8,11).

Mascarena verschaffeltii (Wendl.) Bailey

There can be a delay of between 74 and 93d before the seeds germinate (8,11). An optimum temperature for germination of 35°C has been reported (23,24).

Mauritia flexuosa L. f.

There can be a delay of between 5 and 7m before the seeds germinate (8,11).

Microcoelum weddellianum (Wendl.) H.E. Moore

There can be a delay of between 3 and 6m before the seeds start to germinate (8,11), even when tested in an alternating temperature regime of 20°/30°C (8). Pre-soaking the seeds for several days followed by testing at 27°C can at least partly promote germination (12,13).

Nannorhopa ritchiana

The following treatments were not successful in promoting the germination of dormant seeds: pre-soaking for 9 or 16d (9); pre-soaking for 2d and then dipping the seeds in boiling water for 2 min (9); scarification of the seeds with concentrated sulphuric acid for 5 or 10 min (9); scarification of the seeds by hand (9). Testing in moist sand in an alternating temperature regime of 30°/39°C (9h/15h), however, was a partly-successful dormancy-breaking treatment

(9).

Neanthe bella - see Chamaedorea elegans

Nenga pumila (Mart.) Wendl.

The seeds begin to germinate after 70d in test (15).

Neodypsis decaryi Jum.

The seeds begin to germinate after 2m in glasshouse sowings (11) or in moist sand at 20°/30°C (8).

Oenocarpus panamanus Bailey

There can be a delay of between 25 and 70d before the seeds germinate (8,11).

Oncosperma fasciculatum Thwaites

After first pre-soaking for several days, the seeds begin to germinate after 46d in test at 27°C (12,13).

Oncosperma horridum (Griff.) Scheff.

There can be a delay of 200d before the seeds start to germinate (15).

Oncosperma tigillarium Ridley

After first pre-soaking for several days, the seeds begin to germinate after 44d at 27°C (12,13).

Opsiandra maya O.F. Cook

There can be a delay of between 26 and 99d before the seeds germinate (8,11).

Orania appendiculata

In glasshouse sowings 7m may elapse before the seeds start to germinate (11).

Orania sylvicola (Griff.) Moore

There can be a delay of 70d before the seeds start to germinate (15).

Orbignya cohune see Attalea cohune

Orbignya phalerata

There can be a delay of 71d before the seeds start to germinate (12,13).

Orbignya speciosa

Dormant seeds of the babasu palm can be germinated by removing part of the endocarp and then pre-soaking the seeds for 10d before sowing (5).

Orbignya spp.

The seeds can show considerable dormancy (6) and may show a delay of 6m before they start to germinate (11). It is suggested that they be treated as described for O. speciosa (above) and then tested for germination at 30°C.

Oreodoxa oleracea Mart. [Roystonea oleracea O.F. Cook]

Pre-soaking seeds of the cabbage palm, or palmiste, for 7d followed by warm stratification at 35°C for 80d did not promote germination in tests at 27°C (19).

Oreodoxa regia HBK [Roystonea regia O.F. Cook]

Seeds of the royal, or cuban, palm can be dried to 7.9% moisture content and subsequently rehydrated and germinated (25). There can be a delay of between 21 and 142d before fresh seeds germinate (1,3,8,11). The optimum temperature for germination is reported to be 30°C (22,24). Full germination has been achieved using the following (alternative) procedures: mesocarp removal with testing between moist paper towels at 30°C (25); testing in sand at 25°/30°C in light, 24h/d, for 37d (28); testing whole ripe fruits or seeds in a peat/perlite (1:1) medium at between 24° and 28°C (3); or pre-chilling at 10°C for 2m, with subsequent testing for germination at 30°C (4).

Palma argentata - see Coccothrinax argentata

Phoenicophorium Borsigianum (Koch) Wendl.

In glasshouse sowings there can be a delay of between 21 and 124d before the seeds start to germinate (11).

Phoenix spp. - see separate section

Phytelephas macrocarpa Ruiz & Pav.

In glasshouse sowings there can be a delay of between 6 and 12m before seeds of the ivory-nut palm germinate (11).

Pinanga insignis

There can be a delay of 77d before the seeds germinate (15).

Pinanga kuhlii Blume

There can be a delay of between 36 and 79d before the seeds germinate (8,11). The seeds can be germinated at 27°C after pre-soaking for 7d followed by warm stratification at 35°C for 80d (19).

Pinanga malaiana (Mart.) Scheff.

There can be a delay of 4 to 6m before the seeds start to germinate with germination being complete 9m after sowing (15).

Pritchardia Hillebrandii

In glasshouse sowings there can be a delay of 40d before the seeds start to germinate (11).

Pritchardia Kaalae Rock

Embryos can be excised and cultured in a modified Vacin & Went medium (6).

Pritchardia lowreyana

There can be a delay of 45d before the seeds start to germinate (15).

Pritchardia minor

There can be a delay of 2m before the seeds start to germinate (15).

Pritchardia pacifica

In glasshouse sowings there can be a delay of between 44 and 77d before the seeds start to germinate (11).

Pritchardia thurstonii F. Muell. & Drude

The seeds begin to germinate after 4m in moist sand at 20°/30°C (8).

Pseudophoenix Sargentii Wendl. ex Sarg.

The seeds show orthodox seed storage behaviour - germinating after 2 years' dry storage (29) - and can be very dormant, with fresh seeds failing to germinate (29). There can be a delay of 5m before the seeds start to germinate in moist sand at 20°/30°C (8). Endocarp removal with subsequent testing for germination at 29.5°C can promote full germination (29), but testing the seeds in regimes where the temperature for part of the day is below 29.5°C can substantially reduce the proportion of seeds which germinate (29).

Pseudophoenix vinifera (Martens) Becc.

The seeds show othodox seed storage behaviour - germinating after 2 years' dry storage (29) - and can be very dormant, with fresh seeds failing to germinate (29). There can be a delay of between 23 and 178d before the seeds start to germinate in glasshouse sowings (11,12,13). The germination of at least some, but not necessarily all, dormant seeds can be promoted by pre-soaking for several days before testing at 27°C (12,13). Endocarp removal with subsequent testing for germination at 29.5°C can promote full germination (29), but testing the seeds in regimes where the temperature for part of the day is below 29.5°C can substantially reduce the proportion of seeds which germinate (29).

Ptychandra glauca Scheff.

In glasshouse sowings there can be a delay of 49d before the seeds start to germinate (11).

Ptychococcus paradoxus Becc.

In glasshouse sowings there can be a delay of 6m before the seeds start to germinate (11).

Ptychosperma angustifolium

In glasshouse sowings there can be a delay of 5m before the seeds start to germinate (11). The germination of at least some, but not necessarily all, dormant seeds can be promoted by pre-soaking for several days before testing at 27°C (12,13).

Ptychosperma elegans (R. Brown) Blume

The seeds start to germinate about 2m after sowing (1). Full germination has been achieved by testing in moist sand at 20°/30°C (8).

Ptychosperma hosinoi H.E. Moore

There can be a delay of 72d before the seeds start to germinate (8). Pre-soaking for several days and then testing at 27°C can promote germination (12, 13).

Ptychosperma hospitum Bur.

In glasshouse sowings 2m may elapse before the seeds start to germinate (11).

Ptychosperma ledermannianum

If first pre-soaked for several days, the seeds begin to germinate after 2m in test at 27°C (12, 13).

Ptychosperma Macarthurii (Wendl.) Nichols

Seeds of the Macarthur palm begin to germinate 2 to 2.5m after sowing (1,8). Optimum germination test temperatures of 27°C (17), or 25°C, 30°C, and 35°C (21,24) have been reported but germination was not complete in these regimes. Full germination was achieved at 27°C after either pre-soaking the seeds for 3d or pre-treating in 1000 ppm gibberellic acid for 3d (17).

Ptychosperma Nicolai

In glasshouse sowings 3m may elapse before the seeds start to germinate (11).

Ptychosperma propinquum (Becc.) Becc. ex Martelli

When tested in moist sand at 20°/30°C there can be a delay of 5m before the seeds start to germinate (8).

Reinhardtia gracilis (Wendl.) Drude ex Damm.

The seeds begin to germinate after 2.5m in moist sand at 20°/30°C (8).

Rhaphia gracilis Becc. [R. palma-pinus (Gaertn.) Hutch.; R. gaertneri Becc.]

If pre-soaked for several days the seeds start to germinate after 4m in test at 27°C (12, 13).

Rhaphia pedunculata Beauv. [R. farinifera (Gaertn.) Hylander; R. monbuttorum Drude; R. ruffia (Jacq.) Mart.]

There can be a delay of 81d before the seeds start to germinate in glasshouse sowings (12, 13).

Rhapidophyllum hystrix (Pursh.) Wendl. & Drude

The seeds germinate after between 73 and 96d in moist sand at 20°/30°C (8).

Rhapis excelsa (Thunb.) Henry [R. flabelliformis Ait.]

Full germination was achieved within a 5m test in moist sand at 20°/30°C (8).

Rhapis humilis Blume

The seeds germinate after between 3 and 4m in moist sand at 20°/30°C (8).

Rhopalostylis sapida Wendl. & Drude

The seeds start to germinate 2 to 2.5m after sowing (8,12,13).

Rhyticocos amara

The seeds start to germinate 2m after sowing (12,13).

Roystonea oleracea - see Oreodoxa oleracea

Roystonea regia - see Oreodoxa regia

Sabal bermudana Bailey

The seeds germinate between 88 and 137d after sowing (8,11).

Sabal blackburniana

The seeds germinate between 99 and 120d after sowing (1,11).

Sabal causiarum (O.F. Cook) Becc.

The seeds germinate between 43 and 131d after sowing (8,11).

Sabal domingensis

In glasshouse sowings 48d may elapse before the seeds start to germinate (11).

Sabal glaucescens

The seeds start to germinate 2m after sowing in the glasshouse (12,13).

Sabal jamaicensis

In glasshouse sowings 37d may elapse before the seeds start to germinate (11).

Sabal mexicana

There can be a delay of between 48 and 120d before the seeds start to germinate (1,11).

Sabal minor (Jacq.) Pers.

The seeds show considerable dormancy and require 7 or 24m to after-ripen at room temperature or 3° to 5°C respectively (20). There can be a delay of 4m before the seeds start to germinate (8,11). Germination can be promoted partly by 100 ppm gibberellic acid (20). A constant temperature of 25°C has been reported as the optimum germination test temperature (20,24).

Sabal palmetto (Walt.) Lodd.

There can be a delay of 3 or 4m before the seeds start to germinate (8, 11). Optimum germination test temperatures - in moist sand - are 25°C or 30°C (20,24).

Sabal parviflora Becc.

There can be a delay of between 22 and 42d before the seeds start to germinate (8, 11).

Sabal peregrina

In glasshouse sowings 7w may elapse before the seeds start to germinate (11).

Sabal texana (O.F. Cook) Becc.

There can be a delay of between 70 and 169d before the seeds germinate (8, 11).

Sabal yapa C.H. Wright ex Becc.

There can be a delay of between 82 and 220d before the seeds germinate (8, 11).

Salacca conferta Griff.

There can be a delay of between 1 and 6m before the seeds germinate (11, 15).

Salacca edulis Reiw.

There can be a delay of 3m before the seeds start to germinate in moist sand at 20°/30°C (8). Pre-soaking for several days before testing at 27°C can at least partly promote germination (12, 13).

Salacca rumphii Wall.

The seeds are reported to germinate readily (12, 13, 15), and full germination has been achieved in tests at 27°C after first pre-soaking the seeds for several days (12, 13).

Satakentia liukiuensis (Hatusima) H.E. Moore

There can be a delay of between 70 and 112d before the seeds germinate (8, 11).

Scheelea Leandroana

In glasshouse sowings 5m may elapse before the seeds start to germinate (11).

Scheelea phalerata

The seeds are very difficult to germinate and 466d may elapse before the seeds start to germinate (11).

Scheelea preussii

In glasshouse sowings between 3 and 10m may elapse before the seeds start to germinate (11).

Serenoa repens (Bartr.) Small

There can be a delay of 3.5m before seeds tested in moist sand at 20°/30°C begin to germinate (8).

Siphokentia Beguinii

In glasshouse sowings 3.5m may elapse before the seeds start to germinate (11).

Socratea durissima Wendl.

In glasshouse sowings 4.5m may elapse before the seeds start to germinate (11), but pre-soaking the seeds for several days before testing at 27°C can at least partly promote germination (12, 13).

Socratea exorhiza

In glasshouse sowings 4m may elapse before the seeds start to germinate (11).

Syagrus campestris

In glasshouse sowings 4.5m may elapse before the seeds start to germinate (11).

Syagrus campicola

There can be a delay of 10m before the seeds start to germinate (12, 13).

Syagrus comosa [Dictyosperma furfuraceum]

There can be a delay of between 3 and 10m before the seeds start to germinate (12, 13).

Syagrus coronata (Mart.) Becc.

There can be a delay of 3.5m before seeds start to germinate in moist sand at 20°/30°C (8).

Syagrus quinquefaria, Syagrus sancona

In glasshouse sowings between 2 and 2.5m may elapse before the seeds start to germinate (11).

Syagrus weddelliana

Full germination has been achieved by testing whole fruits in a peat/perlite medium (1:1) at 24° to 28°C (3).

Thrinax argentea

The promotion of germination of some, but not all, dormant seeds can be achieved by pre-soaking the seeds for 7d followed by warm stratification at 35°C for 80d and then testing at 27°C (19).

Thrinax barbadensis

It is reported that the seeds germinate readily (1).

Thrinax exmanii

There can be a delay of 99d before the seeds start to germinate in glasshouse sowings (12, 13).

Thrinax microcarpa Sarg.

There can be a delay of 3m before the seeds start to germinate in moist sand at 20°/30°C (8).

Thrinax Morrisii

In glasshouse sowings between 2 and 6m may elapse before the seeds start to germinate (11).

Thrinax parviflora Swartz

There can be a delay of 3 to 4m before the seeds start to germinate (1,8).

Trachycarpus excelsa Wendl.

The seeds germinate readily in moist sand at 25°C (21,24) or 20°/30°C (8).

Trachycarpus fortunei Wendl.

The seeds are more difficult to germinate than T. excelsa (above), and there can be a delay of between 2 and 3m before the seeds start to germinate (8,11,21,24). Optimum germination test temperatures of 25°C or 30°C have been reported (21,24), but do not result in full germination.

Trithrinax acanthocoma

In glasshouse sowings 2.5m may elapse before the seeds start to germinate (11).

Veitchia arecina

In glasshouse sowings 6w may elapse before the seeds start to germinate (11).

Veitchia Joannis Wendl.

There can be a delay of between 1 and 3m before the seeds start to germinate in glasshouse sowings (11,12,13). Embryo excision and culture in a modified Vacin & Went medium is a successful test regime (6).

Veitchia merillii (Becc.) H.E. Moore

There can be a delay of 1 to 2m before the seeds start to germinate (8,11) although when tested in sand at 25°-30°C in light, 24h/d, germination is reported to be completed within 57d (28).

Veitchia montgomeryana H.E. Moore

There can be a delay of 1 to 3m before the seeds start to germinate (8,11).

Veitchia Winin H.E. Moore

There can be a delay of 1 to 2m before the seeds start to germinate (8,11).

Verschaffeltia splendida Wendl.

The seeds germinate readily and completely within 1 to 2m in glasshouse sowings (11) and in moist sand at 20°/30°C (8).

Wallichia caryotoides

There can be a delay of between 3 and 6m before the seeds start to germinate in glasshouse sowings (11,12,13).

Washingtonia filifera (L. Lind.) Wendl.

The seeds begin to germinate after 17d in moist sand at 20°/30°C (8).

Washingtonia robusta Wendl.

The seeds germinate fully within 3m at 24° to 28°C (3) or 20°/30°C (8).

Zombia antillarum (Desc. ex Jacq.) Bailey

There is a delay of between 6 and 21w before the seeds germinate (8,11,12,13).

References

1. Basu, S.K. and Mukherjee, D.P. (1972). Studies on the germination of palm seeds. Principes, 16, 136-137.

2. Bovi, M.L.A. and Cardoso, M. (1978). [A preliminary report on conservation of seeds of hearts of palm.] Bragantia, 37, 65-71.

3. Bunker, E.J. (1975). Germinating palm seeds. Combined Proceedings of the International Plant Propagator's Society, 25, 377-378.

4. Campbell, G.K. (1982). Seed germination following mild chilling in Royal Palm (Roystonea regia). South African Journal of Botany, 1, 79.

5. Gehlsen, C.A. (1937). Observaçoes sobre o babassu (Orbignya speciosa) e sua germinação - a germinação da oiticia. Boletim da secretaria de Agricultura Industria e commercio de Pernambuco, 2, 428-433.

6. Hodel, D. (1977). Notes on embryo culture of palms. Principes, 21, 103-108.

7. Holmquist, J. De D. and Popenoe, J. (1967). Germination experiments. The effect of scarification on the germination of seed of Acrocomia Crispa and Arenga engleri. Principes, 11, 23-25.

8. Ishihata, K. (1974). [Studies on the morphology and cultivation of palms. On the germination of seed in ornamental palms.] Bulletin of the Faculty of Agriculture, Kagoshima University, 24, 11-23.

9. Khattak, G.M. (1962). Seed germination of dwarf palm (Nannorhops ritchiana). Pakistan Journal of Forestry, 12, 202-204.

10. Kitzke, E.D. (1958). A method for germinating Copernicia palm seeds. Principes, 2, 5-8.

11. Koebernik, J. (1971). Germination of palm seed. Principes, 15, 134-137.

12. Loomis, H.F. (1958). The preparation and germination of palm seeds. Principes, 2, 98-102.

13. Loomis, H.F. (1961). Culture of the palms. Preparation and germination of palm seeds. American Horticultural Magazine, 40, 128-130.

14. Lothian, T.R.N. (1959). Further notes concerning the central Australian cabbage palm (Livistona Mariae). Principes, 3, 53-63.

15. Manokaran, N. (1979). Germination of Malaysian palms. Malaysian Forester, 42, 50-52.

16. Mullett, J.H., Beardsell, D.V. and King, H.M. (1981). The effect of seed treatment on the germination and early growth of Euterpe edulis (family Palmae). Scientia Horticulturae, 15, 239-244.

17. Nagao, M.A., Kanegawa, K. and Sakai, W.S. (1980). Accelerating palm seed germination with gibberellic acid, scarification, and bottom heat. HortScience, 15, 200-201.

18. Nagao, M.A. and Sakai, W.S. (1979). Effect of growth regulators on seed germination of Archontophoenix alexandrae. HortScience, 14, 182-183.

19. Rees, W.A. (1963). Germination of palm seeds using a method developed for the oil palm. Principes, 7, 27-30.

20. Sento, T. (1970). [Studies on the germination of seed of the palms. II. Livistona chinensis (R. Brown), Phoenix roebelenii (O'Brien) and Sabal species.] Journal of the Japanese Society for Horticultural Science, 39, 261-268.

21. Sento, T. (1971). [Studies on the germination of seed of the palms. III. Archontophoenix alexandrae (Wendl. & Drude), Ptychosperma macarthurii (Wendl.) and Trachycarpus species.] Journal of the Japanese Society for Horticultural Science, 40, 246-254.

22. Sento, T. (1971). [Studies on the germination of seed of the palms. IV. Areca catechu (Linn.), Caryota mitis (Lour.) and Roystonea regia (O.F. Cook).] Journal of the Japanese Society for Horticultural Science, 40, 255-261.

23. Sento, T. (1972). [Studies on the seed germination of palms. V. On Chrysalidocarpus lutescens, Mascarena verschaffeltii and Phoenix dactylifera.] Journal of the Japanese Society for Horticultural Science, 41, 76-82.

24. Sento, T. (1976). [Studies on the germination of palm seeds.] Memoirs of the College of Agriculture, Echime University, 21, 1-78.

25. Soetisna, U. (1981). Approaches to the conservation of seeds which have previously been difficult to store, with special reference to lime (Citrus aurantifolia (Christm.) Swing.) and royal palm (Oreodoxa regia HBK). Ph.D. thesis, University of Reading.

26. Veerasamy, S. (1982). Polyembryomy and twin seedlings in Borassus flabellifer L. (Palmae). Botanical Journal of the Linnean Society, 85, 147-152.

27. Yocum, H.G. (1964). Factors affecting the germination of palm seeds. American Horticultural Magazine, 43, 104-106.

28. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

29. Read, R.W. (1968). A study of Pseudophoenix (Palmae). Gentes Herbarum, 10, 169-213.

ARECA

A. Aliciae	
A. catechu L. [A. cathecu L.]	areca, betel palm
A. concinna	
A. langloisiana	
A. latiloba	
A. lutescens Boryl [A. madagascariensis; Chrysalidocarpus lutescens (Boryl) Wendl.]	Madagascar palm
A. triandra	

I. Evidence of dormancy

Seeds of Areca spp. may be dormant (4,6), exhibiting poor and delayed germination (1,3,8,10). See the comment for a note on seed storage behaviour.

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

A. catechu

Constant temperatures: 40°C (17)

Pre-dry: 3-12d, in shade (14)

Sodium azide: pre-applied, 24h, 10^{-3}, 10^{-4} M (4)

Sodium ethylenediaminetetraacetate: pre-applied, 24h, 10^{-3}, 10^{-4} M (4)

2-2'-Dipyridyl: pre-applied, 24h, 10^{-3}, 10^{-4} M (4)

8-Hydroxyquinine: pre-applied, 24h, 10^{-3}, 10^{-4} M (4)

8-Hydroxyquinoline: pre-applied, 24h, 10^{-3}, 10^{-4} M (4)

A. lutescens

Constant temperatures: 14°C, 40°C (18)

Removal of seed covering structures: pericarp (3); exocarp, then pre-soak, 24,72h (15)

A. madagascariensis, A. triandra

Pre-soak: 7d, then warm stratification, 35°C, 80d, germinate at 27°C (16)

IV. Partly-successful dormancy-breaking treatments

A. catechu

Constant temperatures: 31°-35°C (6); 25°C, 30°C, 35°C (17)

Pre-soak: 24h (4); then pre-dry, 3-12d (14)

Removal of seed covering structures: pericarp (3); pericarp, germinate at 20°/30°C (8)

2,4-Dinitrophenol: pre-applied, 24h, 10^{-4} M (4) Pectinase: pre-applied, 24h (5)

A. lutescens

Constant temperatures: 25°C, 30°C, 35°C (18)

Pre-soak: 7d, then warm stratification, 39.5°C, 80d, germinate at 27°C (16)

Removal of seed covering structures: exocarp, then GA, pre-applied, 72h, 100-1000 ppm, germinate at 20°-22°C in daylight, 60d (15)

Areca spp.

Pre-soak: 7d, then warm stratification, 39.5°C, 80d, germinate at 27°C (16)

V. Successful dormancy-breaking treatments

A. catechu

Constant temperatures: 24°C (6)

Pre-soak: (11, 12)

Removal of seed covering structures: pericarp, then pre-wash, then pre-dry, 24h (1)

2,4-Dinitrophenol: pre-applied, 24h, 10^{-3} M (4)

A. concinna, A. latiloba

Pre-soak: (11,12)

A. lutescens

Constant temperatures: 30°C (2)

Alternating temperatures: 20°/30°C (8)

Removal of seed covering structures: pericarp, then pre-wash, then pre-dry, 24h (1); pericarp,

then pre-wash, germinate at 20°/30°C (8)

Pre-soak: (11,12)

A. triandra

Removal of seed covering structures: pericarp, then pre-wash, then pre-dry, 24h (1)

VI. Comment

Sand, peat mixed with perlite, and vermiculite are reported to be suitable germination test media (1,3,4,11,12,15,17,18). When sown in moist sand, the calix (top end of the nut) should be pointing up and level with the surface of the sand (9). The germination of seeds of A. catechu is quite sensitive to temperature: at 30°C and above germination is reduced (6,17,18); at 20°C dormancy is reported to be induced (6); the optimum constant temperature for germination is reported to be 25°C (6,17,18). Alternating temperatures may be more suitable than constant temperature germination test regimes since germination is reported to be better in glasshouse sowings than at constant temperatures (12). Despite the reported induction of dormancy at 20°C, a period of warm stratification at this temperature can be promotory (6).

Pre-drying, though widely practised, is an ineffective dormancy-breaking treatment (9,14). We are uncertain, however, whether Areca spp. show orthodox or recalcitrant seed storage behaviour: we are aware that air-dry storage is practised in India and have received assurances that Areca spp. show orthodox storage characteristics, but several publications report damage to the seeds as the result of desiccation (2,7). It remains our suspicion that, despite apparently contradictory evidence, Areca spp. are possibly orthodox.

The most effective dormancy-breaking treatments appear to be removal of the pericarp combined with pre-soaking in water (1,3,8,11,12) or gibberellins (15). Accordingly it is suggested that the pericarps be removed from the seeds and then GA_3 be pre-applied at 1000 ppm for 72 hours and the seeds then tested at 25°C, or possibly 20°/30°C. Germination is slow: allow at least 41 days for A. Aliciae (10); A. catechu may require 55 (10), 71 (11), 90 (1), 103 (6) or 120 days (9) to germinate; A. concinna 43 (11) to 61 days (10); A. langloisiana 114 days (10); A. latiloba 27 (11) to 70 days (13); A. lutescens 31 (11), 120 (16) or 135 days (8); and A. triandra 41 (10,11) to 120 days (16).

VII. References

1. Basu, S.K. and Mukherjee, D.P. (1972). Studies on the germination of palm seeds. Principes, 16, 136-137.

2. Becwar, M.R., Stanwood, P.C. and Roos, E.E. (1982). Dehydration effects on imbibitional leakage from desiccation-sensitive seeds. Plant Physiology, 69, 1132-1135.

3. Bunker, E.J. (1976). Germinating palm seeds. Combined Proceedings of the International Plant Propagators' Society, 25, 377-378.

4. Das, N.K. (1977). Physiology of arecanut (Areca catechu Linn.) germination. V. Studies on the effect of pre-treatment of seednuts with certain respiratory inhibitors on sprouting. Seed Research, 5, 184-186.

5. Das, N.K. and Baruah, H.K. (1974). Physiology of arecanut (Areca catechu L.) germination. III. Effect of pectinase enzyme extract on sprouting of seednuts and growth of seedling. Journal of Plantation Crops, 2, 10-13. (From Horticultural Abstracts, 1975, 45, 7847.)

6. Das, N.K. and Ray, A.K. (1980). Certain dormancy and viability studies in arecanuts (Areca catechu). Preprint 17, 19th International Seed Testing Association Congress 1980, Vienna.

7. Guppy, H.B. (1912). Studies in Seeds and Fruits, Williams and Norgate, London.

8. Ishihata, K. (1974). [Studies on the morphology and cultivation of palms. On the germination of seed in ornamental palms.] Bulletin of the Faculty of Agriculture, Kagoshima University, 24, 11-23.

9. Khandige, S.B. (1956). The influence of drying on the germination of seed arecanuts (Areca catechu L.). Madras Agricultural Journal, 43, 3-6.

10. Koebernik, J. (1971). Germination of palm seed. Principes, 15, 134-137.

11. Loomis, H.F. (1958). The preparation and germination of palm seeds. Principes, 2, 98-102.

12. Loomis, H.F. (1961). Culture of the palms. Preparation and germination of palm seeds. American Horticultural Magazine, 40, 128-130.

13. Manokaran, N. (1979). Germination of Malaysian palms. Malaysian Forester, 42, 50-51.

14. Parameswar, N.S. (1962). Germination of seed arecanuts (Areca catechu L.). Science and Culture, 28, 135-136.

15. Rauch, F.D., Schmidt, L. and Murakami, P.K. (1983). Seed propagation of palms. Combined Proceedings of the International Plant Propagators Society, 32, 341-347.

16. Rees, A.R. (1963). Germination of palm seeds using a method developed for the oil palm. Principes, 7, 27-30.

17. Sento, T. (1971). [Studies on the germination of seed of the palms. IV. On the Areca catechu (Linn.), Caryota mitis (Lour.) and Roystonea regia (O.F. Cook).] Journal of the Japanese Society for Horticultural Science, 40, 255-261.

18. Sento, T. (1972). [Studies on the seed germination of palms. V. On Chrysalidocarpus lutescens, Mascarena verschaffeltii and Phoenix dactylifera.] Journal of the Japanese Society for Horticultural Science, 41, 76-82.

COCOS

C. nucifera L. var aurea Hort.
C. nucifera L. var nana (Griff.) Nar. dwarf coconut
C. nucifera L. var typica Nar. tall coconut

I. Evidence of dormancy

Delayed germination of seeds of C. nucifera var aurea and most C. nucifera var typica is a common problem for growers and breeders (1, 18). Seeds of C. nucifera var nana, and those from C. nucifera var typica grown in Peninsular Malaysia and on the Pacific Coast of Panama, however, germinate more readily (10), and may germinate viviparously (19). But seednuts of Makapuno type fruits, where the endosperm is not liquid but solid, reportedly never germinate (9): germination can only be achieved in this type of fruit by embryo culture (9). Both immature and overmature (little or no liquid endosperm remaining) fruits show delayed germination (2, 10, 15), but storage of mature fruits for 2 to 4 months promotes germination and reduces the subsequent time taken to germinate (16).

II. Germination regimes for non-dormant seeds

C. nucifera

Constant temperatures: 30°-35°C (17)

Alternating temperatures: 20°/30°C (11)

III. Unsuccessful dormancy-breaking treatments

C. nucifera var typica

Removal of seed covering structures: mosecarp (7); part of mesocarp, apical end (7); parts of mesocarp, apical and basal ends (18); part of mesocarp, near base, then 2,4-dichlorophenoxyacetic acid, pre-applied, 24h, 150, 200 ppm (6)

IV. Partly-successful dormancy-breaking treatments

C. nucifera var typica

Constant temperatures: 30°C, 107d (17)

Removal of seed covering structures: part of mesocarp, near base, then 2,4-dichlorophenoxyacetic acid, pre-applied, 24h, 150 ppm, plus 10 ml, 5 ppm, injected into kernel (6)

V. Successful dormancy-breaking treatments

C. nucifera var aurea

Alternating temperatures: 20°/30°C (11)

C. nucifera var typica

Constant temperatures: 35°C (17)

Alternating temperatures: 20°/30°C (11)

Pre-soak: (10); 7d (2); 14d (4, 18)

Removal of seed covering structures: part of mesocarp, near base (6, 13); excise embryo, culture in White's medium (1, 5, 9)

Potassium nitrate: pre-applied, 48h, 10^{-2}, $2x10^{-2}$ M (18)

Sodium carbonate: pre-applied, 48h, 10^{-2}, $2x10^{-2}$ M (18)

Magnesium sulphate: co-applied, 11500, 23000 ppm injected into mesocarp (3)

Copper sulphate: co-applied, 5500, 11000 ppm injected into mesocarp (3)

Manganese sulphate: co-applied, 4250, 8500 ppm injected into mesocarp (3)

Ferric sulphate: co-applied, 3750, 7500 ppm injected into mesocarp (3)

Zinc sulphate: co-applied, 6500, 13000 ppm injected into mesocarp (3)

Ammonium molybdate: co-applied, 50, 100 ppm injected into mesocarp (3)

Sodium borate: co-applied, 5750, 11500 ppm injected into mesocarp (3)

VI. Comment

Until further investigations have clarified seed storage behaviour, coconut must remain classified as probably recalcitrant. Seed dormancy in coconut has been reviewed elsewhere (5, 18). In view of their large size it is unlikely that the fruits will be tested for germination in laboratory tests. The following procedure has been proposed for germinating whole coconut fruits in nursery sowings: place the seednuts close together in a moist sandy soil (6, 11, 17) in full sun, either with the fruits' broadest face down (7, 13) or - in the case of spherical fruits - on their end with the calyx uppermost, and irrigate frequently with an overhead sprinkler (10). The most suitable constant temperatures for germination in nursery sowings are between 30° and 35°C (17), but alternating temperatures, roughly 20°/30°C, are reported to be more effective in promoting germination (11, 14). The duration of the germination test should be at least 100 days for those varieties which germinate more readily, and 150 days for the slower germinating varieties (10). Pre-treatments to the seednuts will probably be required. A 1 to 2 week pre-soak is probably the most effective method of promoting germination (2, 4, 10, 18) - particularly where the fruit has dried (2). The removal of part of the mesocarp at the base of the fruits above the eyes also promotes germination, but if this is done it is essential that the fruits be prevented from drying throughout the subsequent germination test.

Extraction of the embryo from the fruits with subsequent embryo culture is required for laboratory germination tests. Embryo culture has been achieved in a variety of combinations of media (1,5,9), including coconut milk alone (9). The most favoured combination appears to be White's major elements plus vitamins, plus Nitsch's trace elements, plus sucrose, plus coconut milk (1). This has the following composition: 100 ml of White's major elements (50 ppm Ca, 72 ppm Mg, 70 ppm Na, 65 ppm K, 47 ppm N - as nitrate, 4 ppm P - as phosphate, 140 ppm S - as sulphate, 31 ppm Cl, 1 ppm Fe - as ferric citrate, 1.67 ppm Mn, 0.005 ppm Cu, 0.59 ppm Zn, 0.26 ppm B, 0.001 Mo), 1 ml of Nitsch's trace elements (3 ppm managanese sulphate, 0.5 ppm zinc sulphate, 0.025 ppm copper sulphate, 0.5 ppm boric acid, 0.025 ppm sodium molybdate) but also including 25 ppm of cobalt chloride, 4 ml of a 0.25% solution of ferric citrate, 5 ml of White's vitamins (0.57 ppm I, 0.1 ppm thiamin, 0.5 ppm nicotinic acid, 0.1 ppm pyridoxine, 3 ppm glycine, 20000 ppm sucrose) with the addition of 50 ppm calcium pantothenate and 2 ml of a 0.1% solution of indoleacetic acid in alcohol; it is then made up to 1 litre with double distilled water and 0.2g casein hydrolysate, 8g agar, and 20g sucrose added; after autoclaving and subsequent cooling 2 litres of coconut milk are added, the solution mixed, and then left overnight (1). Germination and growth have occurred at temperatures between 15° to 28°C (1) - but it is expected that germination will be most rapid at the higher temperatures. A greater proportion of embryos germinate in light than in dark (9). Germination can be quite rapid - 2 to 4 weeks - but subsequent growth can be very slow (9).

VII. References

1. Abraham, A. and Thomas, K.J. (1962). A note on the in vitro culture of excised coconut embryos. Indian Coconut Journal, 15, 84-88.

2. Aiyadurai, S.G. (1956). Observation on germination of dry seed coconuts. Madras Agricultural Journal, 43, 464-466.

3. Amma, B.S. (1964). Preliminary studies on the effect of micronutrients on the germination of coconut seednuts. Current Science, 33, 49-50.

4. Child, R. (1974). Coconuts. 335 pp. Longmans, London.

5. Cutter, V.M. Jr. and Wilson, K.S. (1954). Effect of coconut endosperm and their growth stimulants upon the development in vitro of embryos of Cocos nucifera. Botanical Gazette, 115, 234-240.

6. Deshpande, B.R. and Kulkarni, V.G. (1962). Studies in germination of coconut. Part I. Coconut Bulletin, 16, 336-338, 343.

7. Espino, R.B. (1923). On the germination of coconuts. Philippine Agriculturist, 11, 191-200.

8. George, M.K. (1964). Off season seed coconuts, will they yield quality seedlings. Coconut Bulletin, 18, 13-15.

9. Guzman, E.V. De and Del Rosario, D.A. (1964). The growth and development of Cocos nucifera L. Makapuno embryo in vitro. Philippine Agriculturist, 48, 82-84.

10. Harries, H.C. (1981). Germination and taxonomy of the coconut. Annals of Botany, 48, 873-883.

11. Ishihata, K. (1974). [Studies on the morphology and cultivation of palms. On the germination of seed in ornamental palms.] Bulletin of the Faculty of Agriculture, Kagoshima University, 24, 11-23.

12. Kartha, S. (1981). Embryo of coconut and its germination. Journal of Plantation Crops, 9, 125-127.

13. Kenman, E.T. (1973). Effect of seednut trimming on the germination and growth of coconuts. Papua New Guinea Agricultural Journal, 24, 26-29.

14. Loomis, H.F. (1961). Culture of the palms. Preparation and germination of palm seeds. American Horticultural Magazine, 40, 128-130.

15. Marar, M.M.K. and Varma, R. (1958). Coconut nursery studies. Effect of maturity of seednuts on germination and vigour of seedlings. Indian Coconut Journal, 11, 81-86.

16. Nampoothiri, K.U.K., Mathew, J. and Sukumaran, C.K. (1974). Variation in germination pattern of coconut cultivars and hybrids. Journal of Plantation Crops, 1, 24-27.

17. Sento, T. (1974). [Studies on the seed germination of palms. VI. On Cocos nucifera L., Phoenix humilis Royle var. hanceana Becc. and Phoenix sylvestris Roxb.] Journal of the Japanese Society for Horticultural Science, 42, 380-388.

18. Thomas, K.M. (1974). Influence of certain physical and chemical treatments on the germination and subsequent growth of coconut Cocos nucifera L. seedlings: A preliminary study. East African Agricultural and Forestry Journal, 40, 152-156.

19. Whitehead, R.A.W. (1965). Speed of germination, a characteristic of possible taxonomic significance in Cocos nucifera L. Tropical Agriculture, Trinidad, 42, 369-372.

ELAEIS

E. guineensis Jacq. [E. madagascariensis Becc.] oil palm

E. guineensis Jacq. x E. oleifera (HBK) Cortés

E. oleifera (HBK) Cortés [E. melanococca Gaertn.; Corozo oleifera (HBK) Bailey] American oil palm

I. Evidence of dormancy

E. guineensis, E. oleifera and the hybrid E. guineensis x E. oleifera show pronounced dormancy which is a substantial problem for planters and breeders (1,2,4,6,7,9-15,19,20,22,24,29,30). Within E. guineensis pisifera oil palms are reported to be more difficult to germinate than dura or tenera oil palms (3,9,19,30). The seed covering structures (pericarp, endocarp and the operculum - testa and endosperm over embryo) are the main cause of

problems when attempting to germinate seeds of oil palm (11, 12). According to some reports excised oil palm embryos are not dormant (11,12), but in other reports embryo dormancy has been detected (22). After-ripening for 2 months at room temperature can result in the loss of embryo dormancy (22), but note that after-ripening of whole seeds is not effective in avoiding the problems caused by the seed covering structures.

In preparing seeds for plantation sowings heat treatments of one sort or another are almost invariably applied. Here such treatments are described as pre-dry where the moisture content of the kernels is less than 16% (fresh-weight basis) for dura, less than 18% for oleifera, or less than 17% for tenera oil palms, but described as warm stratification where kernel moisture content is between 17 to 18% for dura, between 21 to 23% for tenera, or between 27 to 30% for pisifera oil palms. The latter values are the moisture contents of imbibed oil palm kernels. These values appear to be much lower than those for imbibed seeds of other species, but see the comment for information on embryo moisture contents.

II. Germination regimes for non-dornant seeds

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III. Unsuccessful dormancy-breaking treatments

E. guineensis (dura)

Warm stratification: 44.5°C, 50-80d (24); 45°C, 40-50d (13); 50°C, 8-12d (13); 55°C, 4-8d (13); 60°C, 12h (13)

Pre-dry: 60°C, 1-4d (13); 39.5°C, 80d, germinate without additional moisture (23,24)

Pre-soak: 4h, then pre-dry, 20h, 4 cycles (7)

Removal of seed covering structures: pericarp, crack endocarp (26); excise embryo from dry seeds (21,22)

E. guineensis (dura x pisifera)

Pre-soak: (29)

GA_3: pre-applied, 0.25, 0.5 ppm (29); pre-applied, 0.25, 0.5 ppm, then pre-dry, 40°C, 15d, then GA_3, pre-applied, 0.25, 0.5 ppm (29); pre-applied, 0.25, 0.5 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm (29); pre-applied, 0.25, 0.5 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm, then pre-dry, 40°C, 15d, then GA_3, pre-applied, 0.25, 0.5 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm (29)

Kinetin: pre-applied, 0.05, 0.1 ppm (29); pre-applied, 0.05, 0.1 ppm, then pre-dry, 40°C, 15d, then kinetin, pre-applied, 0.05, 0.1 ppm (29)

Ethephon: pre-applied, 1, 2 ppm (29); pre-applied, 1, 2 ppm, then pre-dry, 40°C, 15d, then ethephon, pre-applied, 1, 2 ppm (29); pre-applied, 1, 2 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm (29); pre-applied, 1, 2 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm, then pre-dry, 40°C, 15d, then ethephon, pre-applied, 1, 2 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm (29)

E. guineensis (tenera)

Constant temperatures: 40°C, in air or oxygen, 100% (12)

Pre-soak: 30°C, 5d, germinate at 25°-40°C, in air or oxygen, 100% (12)

Indoleacetic acid: pre-applied, 6h, 10 ppm, plus Vitamin B_1, 100 ppm (10); pre-applied, 12h, 6 ppm, plus Vitamin B_1, 60 ppm (10)

Removal of seed covering structures: endocarp, then pre-soak, 30°C, 5d, germinate at 25°-45°C in air or oxygen, 100% (11,12); endocarp, then pre-soak, 30°C, 5d, germinate at 30°C in oxygen, 20-100% (11,12); endocarp, then pre-soak, 30°C, 5d, germinate at 34°C in oxygen, 20-75% (11); endocarp, then pre-soak, 30°C, 5d, germinate at 34°C in oxygen, 0.2, 2 atmospheres (12); endocarp, then pre-soak, 30°C, 5d, then warm stratification, 28°-30°C, 4w, germinate at 30°C, 40°C (11,12); endocarp, then pre-soak, 30°C, 5d, then warm stratification, 30°C, in oxygen, 100%, 4w, germinate at 30°C in air or oxygen, 100% (12); endocarp, then pre-soak, 30°C, 5d, then warm stratification, 30°C, 42°C, 2m, germinate at 27°C (12); endocarp, then indoleacetic acid, pre-applied, 1h/d, 2w, 1-100 ppm (11); endocarp, then 2,4-dichlorophenoxyacetic acid, pre-applied, 1h/d, 2w, 1-100 ppm (11); endocarp, then ethylene chlorohydrin, pre-applied, 1h/d, 2w, 0.1, 1 ppm (11); operculum, then indoleacetic acid, pre-applied, 24h, 1-100 ppm (11)

E. guineensis

Pre-wash: 24d (14)

GA_3: (4)

Hydrochloric acid: pre-applied, 7d, 5%, then pre-soak (5)

IV. Partly-successful dormancy-breaking treatments

E. guineensis (dura)

Warm stratification: 38°-40°C, 21,28d (27); 40°C, 20,40d (28); 45°C, 35d (13); 50°C, 6d (13); 60°C, 3,6h (13); 35°C, 38d, germinate at 25°/38°C (1d/7d or 1d/14d) (7)

Pre-dry: 40°C, 46-82d (13); 45°C, 22-46d (13); 50°C, 10-22d (13)

Pre-soak: then warm stratification, 39.5°C, 80d (23,24)

Removal of seed covering structures: pericarp (26); pericarp, then hydrochloric acid, pre-applied, 2d, 1% (26); endocarp (7); excise embryo (21)

Gamma irradiation: 1-100 K rad, then pre-soak (32); 1-140 K rad, after pre-soak (32)

E. guineensis (dura x pisifera)

Warm stratification: 38°C, 80, 100d (6)

Pre-dry: 38°C, 80,100d (6); 40°C, 30-60d (29)

GA_3: pre-applied, 0.25, 0.5 ppm, then pre-dry, 40°C, 30-60d, then GA_3, pre-applied, 0.25, 0.5 ppm (29); pre-applied, 0.25, 0.5 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm, then pre-dry, 40°C, 30-60d, then GA_3 pre-applied, 0.25, 0.5 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm (29)

Kinetin: pre-applied, 0.05, 0.1 ppm, then pre-dry, 40°C, 30-60d, then kinetin, pre-applied, 0.05, 0.1 ppm (29)

Ethephon: pre-applied, 1, 2 ppm, then pre-dry, 40°C, 30-60d, then ethephon, pre-applied, 1, 2 ppm (29); pre-applied, 1, 2 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm, then pre-dry, 40°C, 30-60d, then ethephon, pre-applied, 1, 2 ppm, plus kinetin, pre-applied, 0.05, 0.1 ppm (29)

E. guineensis (pisifera)

Removal of seed covering structures: pericarp, then pre-soak, germinate at 39°-40°C (2)

E. guineensis (tenera)

Constant temperatures: 35°-40°C (10)

Alternating temperatures: 35°-40°C/room temperature (15d/11h) (10)

Warm stratification: 38°C, 5w, then 25°C, 2w, germinate at 38°C (12); 38°C, 5w, then 25°/38°C (1-3h/21-23h, 0.5-1.5d/5.5-6.5d) (12) Pre-soak: 25°C, 12h (10); 30°C, 5d, germinate at 40°C in air or oxygen, 100% (12)

Removal of seed covering structures: endocarp, then pre-soak, 30°C, 5d, germinate at 36°-42°C in oxygen, 20-100% (11, 12); endocarp, then pre-soak, 30°C, 5d, germinate at 38°C in oxygen, 1-1.75 atmospheres (11, 12); endocarp, then pre-soak, 30°C, 5d, germinate at 30°C in 100% oxygen/40°C in air (2.4h/21.6h, 6h/18h, 12h/12h, 18h/6h, 21.6h/2.4h) (11, 12); endocarp, then pre-soak, 30°C, 5d, then warm stratification, 30°C in air or oxygen, 100%, 4w, germinate at 28°C in oxygen, 100%, or 40°C in air or oxygen, 100% (11, 12); endocarp, then pre-soak, 30°C, 5d, then warm stratification, 40°C, 4w, germinate at 28°C in air or oxygen, 100%, or 40°C in air (11, 12); endocarp, then pre-soak, 30°C, 5d, then warm stratification, 40°C in oxygen, 100%, 4,8w, germinate at 30°C, 40°C in air or oxygen, 100% (11, 12)

E. guineensis

Warm stratification: (1)

Pre-soak: 4,8d, then remove pericarp (14); 45°C, 7d (5)

Ethephon: pre-applied, 2w, 10^{-2} M (4)

Hydrochloric acid: pre-applied, 7d, 1%, then pre-soak, 3d (5)

Removal of seed covering structures: pericarp, then pre-wash, 3-9d (14)

V. Successful dormancy-breaking treatments

E. guineensis (dura)

Warm stratification: 40°C, 30-80d (20); 40°C, 60,80d (28); 38°-40°C, 35-49d (27); 42°C, 60-80d (24); 38°C, 38d, germinate at 25°/38°C (1d/14d) (7)

Removal of seed covering structures: pericarp, then pre-soak, 25°C, 5-7d, pre-dry, 4-24h, then 39°C, 80d, then pre-soak, 1-3d, pre-dry, germinate at 22°-27°C (3,9,18,23,24); pericarp, then pre-soak, 25°C, 5-7d, then pre-dry, then warm stratification, 39°C, 80d, germinate at 22°-27°C (9,13,23,24,25); excise embryos after rehumidifying previously dried seeds, then culture (21,22)

E. guineensis (dura x pisifera)

Removal of seed covering structures: pericarp, then pre-soak, 25°C, 7d, then warm stratification, 39.5°C, 70d, then pre-soak, 7d (31)

E. guineensis (dura x tenera)

Removal of seed covering structures: pericarp, then pre-soak, 25°C, then pre-dry, 39.5°C, 60d

(17)

E. guineensis (pisifera)

Removal of seed covering structures: epicarp and endocarp, then pre-soak, 24h, then remove operculum, germinate at 35°C (19)

E. guineensis (tenera)

Constant temperatures: 38°C, 9m (10); 40°C, in oxygen, 100%, 3m (11, 12)

Alternating temperatures: 38°C/room temperature (15d/1d) (10)

Warm stratification: 37°C, 2m, germinate at room temperature/37°C (1d/8d or 2d/15d) (10)

Removal of seed covering structures: pericarp, then pre-soak, 25°C, 5-7d, then pre-dry, 2-24h, then 39°C, 80d, then pre-soak, 1-3d, then pre-dry (3,9); pericarp, then pre-soak, 25°C, 5-7d, then pre-dry, then warm stratification, 39°C, 80d (9,25); operculum, germinate at 30°C (11); excise embryo, culture in White's medium (11,12)

E. guineensis

Alternating temperatures: 40°/27°C, 35°/25°C (day/night) (15); 25°/30°C, light, 24h/d, 42d, after heat treatment, 40°C, 60d (33)

Removal of seed covering structures: pericarp, then pre-wash, 11-32d, germinate for 32w (14); excise embryo, culture in Murashige and Skoog medium supplemented with 1 g 1^{-1} casein hydrolysate, 3 g 1^{-1} sucrose, 0.5 mg 1^{-1} indoleacetic acid, 0.1 mg 1^{-1} kinetin and 8 g 1^{-1} agar (8)

E. oleifera

Pre-dry: 39°C, 15d, then pre-soak, 43°C, 15 min, then warm stratification, 39°C, 65d (9)

VI. Comment

Despite widespread suggestions to the contrary seeds of Elaeis spp. show orthodox seed storage behaviour; for example, oil palm embryos which had been dried to 10.4% moisture content (fresh-weight basis) showed no loss in viability during 8 months storage at -196°C (8). There are two problems behind the mistaken classification of Elaeis spp. as recalcitrant. First, the embryos contain substantially more moisture than the average for whole kernels (8,21,22). For example, a typical moisture content of an imbibed kernel is about 21%, but embryos excised from such kernels contain roughly 48% moisture (8). When the kernels are dried to about 7% moisture content, embryo moisture contents are as high as 20-21% (8,22). Moreover equilibrium between kernel and embryo moisture contents is not established within 7 days at room temperature (8). Consequently it is not surprising that such embryos are killed by exposure to sub-zero temperatures (8). The second problem is, we believe, one of imbibition injury. Excised embryos dried to 20% moisture content and then cultured showed no loss in viability, whereas those embryos dried to 10.4% and subsequently cultured showed a 21% loss in viability (8). Similarly cultured embryos extracted from kernels dried below 15.3% moisture content show some development, but fail to produce seedlings whereas those from kernels at higher moisture contents do produce normal seedlings (21). Rehumidification of the dried kernels (15 days in a humid environment) before embryo excision and culture avoids this damage however (21,22), demonstrating that the damage to the dry embryos results from rapid imbibition, not from desiccation per se.

We believe there is a need to distinguish between those practices developed for the germination of seeds destined for large-scale sowings in plantations and those techniques required to promote the germination of oil palm seeds in tests to estimate the viability of accessions maintained in gene banks or to regenerate or multiply accessions. Most of the repeated soaking/drying treatments referred to in the preceding sections are intended to adjust kernel moisture contents to that best suited for germination - often assessed by the colour of the testae. This is necessary because subsequent germination is normally achieved in enclosed conical flasks, jars, polyethylene bags or similar vessels (11-13,17,18,20,23-25,29). Oil palm germination is very sensitive to either excess or inadequate moisture, and such procedures are very difficult to standardise. Consequently it is not recommended that gene banks should apply these techniques.

Whilst non-dormant seeds will germinate rapidly at around 25°C (3,9,10,13,17,20,23-25,27,31), dormant seeds require a higher constant temperature, around 39°C (2,7,9-12), and between 9 (10) and 12 months (7) at this temperature, but alternating temperatures are more effective in promoting germination than are constant temperatures (7,10-12,15). Until more definitive work has been completed a diurnal alternating temperature regime of 25°/35°C (8-12h/12-16h) would seem an appropriate, but temporary, recommendation.

Removal of some or all of the seed covering structures must be considered to be an essential component of oil palm germination tests intended to estimate viability in gene banks. Although embryo excision with subsequent culture for 4 weeks or so is likely to be successful (provided imbibition damage is avoided - see below), it does require both skill and time. We believe that the most appropriate treatment is to remove the operculum from imbided seeds (11,19): with experience it is reported to be possible to de-operculate 200 to 300 seeds per hour (19) and full germination should be achieved within 3 to 4 weeks in the germination test.

Whilst we envisage that the long-term storage of seed of Elaeis spp. under IBPGR preferred conditions (-20°C, with embryos at 5% moistur moisture content) is feasible, further investigations which recognise the potential problems of high embryo moisture contents and imbibition injury in these species would be advisable. The following germination test procedure is suggested. First humidify the dry embryos (or kernels) until embryo moisture content is at least 20% and preferably 40% (fresh weight basis). Then de-operculate the seed and test for germination on top of filter paper or between moist rolled paper towels at 25°/35°C (8-12h/12-16h) for at least 4 weeks. See reference (16) for a description of tetrazolium staining techniques for these species.

VII. References

1. Anonymous (1939). Oil palm seed germination. Bulletin of the Great Britain Imperial Institute, 37, 211-212.

2. Arasu, N.T. (1970). A note on the germination of Pisifera (shell-less) oil palm seeds. Malaysian Agricultural Journal, 47, 524-527

3. Comont, G. and Jacquemard, J.C. (1977). Germination des graines de palmier à huile (E. guineensis) en sacs de polyéthylène. Methodes par "chaleur sèche". Oléagineux, 32, 149-151.

4. Corley, R.H.V. (1976). Germination and seedling growth. In Oil palm Research (eds. R.H.V. Corley, J.J. Hardon and B.J. Wood), pp. 23-36, Elsevier, The Netherlands.

5. Curtler, E.A. (1926). Experiments on the germination of American oil palm seeds. Malayan Agricultural Journal, 14, 84-87.

6. Davidson, L. (1962). Dry heat method of oil palm germination. Planter, Kuala Lumpur, 38, 88-90.

7. Ferwerda, J.D. (1956). Germination of oil palm seeds. Tropical Agriculture, Trinidad, 33, 51-66.

8. Grout, B.W.W., Shelton, K. and Pritchard, H.W. (1983). Orthodox behaviour of oil palm seed and cryopreservation of the excised embryo for genetic conservation. Annals of Botany, 52, 381-384.

9. Hartley, C.W.S. (1977). The Oil Palm. 806 pp., Longman, London.

10. Henry, P. (1951). La germination des graine d'Elaeis. Revue Internationale de Botanique appliqueé et d'Agriculture Tropicale, 31, 565-591.

11. Hussey, G. (1958). An analysis of the factors controlling the germination of the seed of the oil palm Elaeis guineensis (Jacq.). Annals of Botany, 22, 259-284.

12. Hussey, G. (1959). The germination of oil palm seeds: experiments with Tenera nuts and kernels. Journal of the West African Institute for Oil palm Research, 2, 331-354.

13. Labro, M.F., Guénin, G. and Rabéchault, H. (1964). Essai de leveé de dormance des graines de palmier à huile (Elaeis guineensis Jacq.) par des temperatures elevées. Oléagineux, 19, 757-765.

14. Lucy, A.B. (1940). Experiments on the germination of oil palm seeds. Malayan Agricultural Journal, 28, 151-158.

15. Milsum, J.N. (1927). Hastening the germination of oil palm seeds. Malayan Agricultural Journal, 15, 82-84.

16. Mok, C.K. (1972). The tetrazolium test for evaluating the viability of oil palm (Elaeis guineensis Jacq.) seeds. Proceedings of the International Seed Testing Association, 37, 771-778.

17. Mok, C.K. and Hor, Y.L. (1977). The storage of oil palm (Elaeis guineensis) seed after high temperature treatment. Seed Science and Technology, 5, 499-508.

18. Ngui, M. and Ngim, K.S. (1982). An empirical modification to the method of germinating seeds in commercial oil palm seed production. 10 pp. Technical Bulletin No. 6, Department of Agriculture, Sabah, Malaysia.

19. Nwankwo, B.A. (1981). Facilitated germination of Elaeis guineensis var. pisifera seeds. Annals of Botany, 48, 251-254.

20. Odetola, A. (1974). Heat requirement of oil palm seeds for germination. Relation of seed age to heat requirement. Journal of the Nigerian Institute for Oil palm Research, 5, 79-84.

21. Rabéchault, H., Aheé, J. and Guénin, G. (1968). Recherches sur la culture "in vitro" des embryons de palmier à huile (Elaeis guineensis Jacq.). IV. Effets de la teneur en eau des noix et de la dureé de leur stockage. Oléagineux, 23, 233-237.

22. Rabéchault, H., Guénin, G. and Aheé, J. (1969). Recherches sur la culture "in vitro" des embryons de palmier à huile (Elaeis guineensis Jacq. var. dura Becc.) VI. Effets de la déshydratation naturelle et d'une réhydratation de noix dormantes et non dormantes. Oléagineux, 24, 263-268.

23. Rees, A.R. (1961). Effect of high-temperature pre-treatment on the germination of oil palm seed. Nature, 189, 74-75.

24. Rees, A.R. (1962). High-temperature pre-treatment and the germination of seed of the oil palm, Elaeis guineensis (Jacq.). Annals of Botany, 26, 569-581.

25. Rees, A.R. (1965). Some factors affecting the viability of oil palm seed in storage. Journal of the Nigerian Institute for Oil palm Research, 15, 317-324.

26. Savellano, N.S. (1955). Four methods of germinating African oil palm seeds. Philippine Agriculturist, 39, 535-539.

27. Tailliez, B. (1970). Germination accéléreé des graines de palmier à huile. Technique avec substrat. Oléagineux, 25, 335-336.

28. Trouslot, M.F., Guénin, G. and Rabéchault, H. (1967). Conservation et dormance des graines d'Elaeis guineensis Jacq. Oléagineux, Oléagineux, 22, 295-296.

29. Wan, C.K. and Hor, H.L. (1983). A study on the effects of certain growth substances on germination of oil palm (Elaeis guineensis Jacq.) seeds. Pertanika, 6, 45-48.

30. Wonkyi-Appiah, J.B. (1973). Germination of pisifera oil palm seeds under plantation conditions. Ghana Journal of Agricultural Science, 6, 223-226.

31. Wonkyi-Appiah, J.B. (1974). Effect of duration of heat treatment on germination of dura oil palm seed. Ghana Journal of Agricultural Science, 7, 57-59.

32. Wonkyi-Appiah, J.B. and Amuh, I.K.A. (1976). Preliminary investigation into the use of gamma irradiation to induce germination in the seed of the oil palm (Elaeis guineensis Jacq.). Ghana Journal of Agricultural Science, 9, 235-236.

33. Chin, H.F., Hor, Y.L. and Mohd Lassim, M.B. (1984). Identification of recalcitrant seeds. Seed Science and Technology, 12, 429-436.

PHOENIX

P. acaulis	
P. canariensis Chabaud.	
P. dactylifera L.	date palm
P. Loureiri Kunth. [P. roebelenii O'Brien; P. humilis Royle var hanceana Becc.; P. humilis Royle var Loureiri Becc.]	
P. reclinata Jacq. [P. spinosa Thonn.; P. natalensis Hort.]	
P. rupicola T. Anders	
P. sylvestris Roxb.	wild date
P. zeylanica	

I. Evidence of dormancy

The germination of seeds of Phoenix spp. can be slow (1,7,8). After-ripening for 2 months is required to remove dormancy in P. dactylifera (2).

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

P. dactylifera

Constant temperatures: 40°C (14)

Pre-soak: 77°C, then cool, 24h (11); cold, 24h (11)

P. Loureiri

Constant temperatures: 40°C (13,15)

Scarification: concentrated sulphuric acid, 2-16 min (5)

P. sylvestris

Pre-soak: 7d, then warm stratification, 39.5°C, 80d, germinate at 27°C (12)

IV. Partly-successful dormancy-breaking treatments

P. acaulis

Pre-soak: 7d, then warm stratification, 39.5°C, 80d, germinate at 27°C (12)

P. Loureiri

Constant temperatures: 25°C, 35°C (15)

P. sylvestris

Constant temperatures: 25°C, 35°C, 40°C (15)

V. Successful dormancy-breaking treatments

P. canariensis

Pre-wash: then germinate at 20°/30°C (7)

P. dactylifera

Constant temperatures: 25°C, 30°C, 35°C (14)

Warm stratification: 25°C, 12d, germinate at 30°C (6); 30°C, 5d, germinate at 25°C (6)

Pre-soak: 6-8w (1)

Pre-wash: then germinate at 20°/30°C (7).

P. Loureiri

Constant temperatures: 24°-28°C (4); 30°C (15); 25°C, 30°C, 35°C (13)

Pre-wash: then germinate at 20°/30°C (7)

P. reclinata, P. rupicola

Pre-wash: then germinate at 20°/30°C (7)

P. sylvestris

Constant temperatures: 30°C (15)

Pre-wash: then germinate at 20°/30°C (7)

VI. Comment

Despite suggestions to the contrary, P. dactylifera shows orthodox seed storage characteristics (2,6,11) and can be stored successfully under IBPGR preferred conditions (6). Moist sand or paper towels are suitable media for laboratory germination tests (6,13-15). The optimum constant temperature for the germination of seeds of Phoenix spp. is between 25° and 30°C (13-15). Above this range germination is reduced (15), with the exception of P. dactylifera which germinates well at 35°C (14) and P. sylvestris where some seeds can germinate at 40°C (15). Provided the test duration is sufficient, seeds of P. Loureiri will germinate at 15°C (13). Alternating temperature regimes are more likely to be effective germination test regimes than constant temperatures (10), one alternation may be sufficient (6); seeds of 7 Phoenix spp. have been reported to germinate well under alternating temperature regimes between 20° and 30°C in plastic tunnels (7).

It is therefore suggested that seeds be tested for germination in an alternating temperature regime of 20°/30°C (8h/16h?) or, if this is not possible, at a constant temperature of 30°C. The test duration must be sufficient to enable all viable seeds to germinate. The following test periods have been used: 4 months for P. acaulis (12); 39 (8) or 60 days (7) for P. canariensis; 49 (11), 56 (7) or 78 days (8) for P. dactylifera; 39 (8-10), 49 (4), 52 (3) or 65 days (7) for P. Loureiri; 42 (9,10), 67 (8) or 76 days (7) for P. reclinata; 60 (3), 92 (7) or 114 days (8) for P. rupicola; 64 days for P. sylvestris (7); and 25 days for P. zeylanica (8).

VII. References

1. Ammons, N.P. (1926). Date seed germination. Proceedings of the West Virginia Academy of Science, 1, 23.

2. Aroeira, J.S. (1962). [On dormancy and seed storage of some fruit trees.] Experientiae, 2, 541-609.

3. Basu, S.K. and Mukherjee, D.P. (1972). Studies on the germination of palm seeds. Principes, 16, 136-137.

4. Bunker, E.J. (1976). Germinating palm seeds. Combined Proceedings of the International Plant Propagator's Society, 25, 377-378.

5. Dickey, R.D. (1953). Germination of pigmy date palm seed as affected by treatment with sulphuric acid. Proceedings of the Association of Southern Agricultural Workers, 50, 139.

6. Ellis, R.H., Hong, T.D. and Roberts, E.H. (1984). Orthodox seed storage behaviour in date palm (Phoenix dactylifera L.) Plant Genetic Resources Newsletter. (In press).

7. Ishihata, K. (1974). [Studies on the morphology and cultivation of palms. On the germination of seed in ornamental palms.] Bulletin of the Faculty of Agriculture, Kagoshima University, 24, 11-23.

8. Koebernik, J. (1971). Germination of palm seed. Principes, 15, 134-137.

9. Loomis, H.F. (1958). The preparation and germination of palm seeds. Principes, 2, 98-102.

10. Loomis, H.F. (1961). Culture of the palms. Preparation and germination of palm seeds. American Horticultural Magazine, 40, 128-130.

11. Nixon, R.W. (1964). Viability of date seeds in relation to age. Report 41st Annual Date Growers' Institute Coachella, 3-4.

12. Rees, A.R. (1963). Germination of palm seeds using a method developed for the oil palm.

Principes, 7, 27-30.

13. Sento, T. (1970). [Studies on the germination of seed of the palm. II. On the Livistona chinensis (R. Brown), Phoenix roebelenii (O'Brien) and Sabal species.] Journal of the Japanese Society for Horticultural Science, 39, 261-268.

14. Sento, T. (1972). [Studies on the seed germination of palms. V. On Chrysalidocarpus lutescens, Mascarena verschaffeltii and Phoenix dactylifera.] Journal of the Japanese Society for Horticultural Science, 41, 76-82.

15. Sento, T. (1974). [Studies on the seed germination of palms. VI. On Cocos nucifera L., Phoenix humilis Royle var. hanceana Becc. and Phoenix sylvestris Roxb.] Journal of the Japanese Society for Horticultural Science, 42, 380-388.

CHAPTER 54. PAPAVERACEAE

The Papaveraceae comprise about 200 species of herbaceous plants and, rarely, shrubs within about 25 genera. They include species which provide an edible oil (Papaver somniferum L. subsp. hortense) and a narcotic (Papaver somniferum L. subsp. somniferum, opium poppy). The fruits are dehiscent capsules and seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

The seeds are small with a minute embryo surrounded by oily endosperm. Seed dormancy can be considerable, with delayed germination a common problem. B.R. Atwater classifies seed morphology as endospermic seeds with a basal rudimentary embryo (see Table 17.1, Chapter 17). Potassium nitrate, gibberellin and pre-chill treatments generally promote seed germination.

No detailed information on any one genus is provided in this chapter, but Table 54.1 provides a brief summary of recommended germination test procedures and dormancy-breaking treatments. In addition the algorithm below may be helpful in developing suitable germination test procedures for difficult accessions of the species listed in Table 54.1 and for other species.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 11°C, 21°C and 31°C with light applied for 12h/d. If full germination is not achieved in any one regime and the results suggest a trend in the response of germination to constant temperatures then test at a more extreme or an intermediate constant temperature as appropriate. For example, if germination at 11°C is greater than germination at 21°C or 31°C then test a further sample of seeds at a constant temperature of 6°C with light applied for 12h/d. A further example: if germination at 21°C and 31°C is roughly similar but greater than at 11°C then test a further sample of seeds at a constant temperature of 26°C with light applied for 12h/d.

If these constant temperature regimes do not promote full germination then the second step of the algorithm is to test seeds in alternating temperature regimes. If germination at constant temperatures of 21°C and below was greater than at constant temperatures above 21°C in step one then test a further sample of seeds in an alternating temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d. If germination at constant temperatures of 31°C was greater than at all other constant temperatures in step one then test a further sample of seeds in an alternating temperature regime of 33°/19°C (12h/12h) with light applied for 12h/d. If germination at constant temperatures of 21° to 31°C was similar or if germination at a constant temperature of 26°C was greater than at all other constant temperatures in step one then test further samples of seeds in both the alternating temperature regimes described above.

If the second step of the algorithm does not result in full germination then the third step is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test a further sample of seeds in the most successful temperature regime determined from a comparison of the results of steps one and two.

If the third step of the algorithm does not result in full germination then the fourth step is to pre-chill a further sample of seeds at 2° to 6°C for 8w and then test in the most

successful regime determined from a comparison of the results of steps one to three. This may include co-application of GA_3 if the results of step three show a significant increase in germination over the corresponding test in step one or two.

If full germination has not been promoted, the fifth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information summarised in Table 54.1.

TABLE 54.1 Summary of germination test recommendations for species within the Papaveraceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Chelidonium majus L.	TP	20°/30°C	28d	pre-chill	ISTA
Dendromecon rigida Benth.				hot water or alkali soak	Atwater
Eschscholzia california Cham.	TP; BP	10°C; 15°C	14d	potassium nitrate	ISTA
	TP	15°C	10d	potassium nitrate	AOSA
		15°C	14d	potassium nitrate, 0.2%	Atwater
Hunnemannia fumariifolia Sweet	TP	20°/30°C	18d	light, ensure good moisture supply	AOSA
Papaver alpinum L.	TP	10°C; 15°C	14d	potassium nitrate	ISTA
Papaver glaucum Boiss. & Haussk.	TP	10°C; 15°C	14d	light, potassium nitrate	ISTA
	TP	15°C	14d	potassium nitrate	AOSA
Papaver nudicaule L.	TP	10°C; 15°C	14d	light, potassium nitrate	ISTA
	TP	15°C	14d	potassium nitrate	AOSA
		15°C	21d	potassium nitrate, 0.2%	Atwater
Papaver orientale L.	TP	20°/30°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	12d	light, potassium nitrate	AOSA
Papaver rhoeas L.	TP	20°/30°C; 15°C; 20°C	14d	light, potassium nitrate, pre-chill	ISTA
	TP	15°C	8d		AOSA
		15°C	14d		Atwater
Papaver somniferum L.	TP	20°C	10d	pre-chill	ISTA
Romneya coulteri Harvey		20°C	155d	pre-soak, 0.5h, 1N KOH, plus GA, 100ppm	Atwater

CHAPTER 55. PASSIFLORACEAE

The Passifloraceae comprise more than 500 species of herbaceous or woody plants within 12 genera which provide edible fruits (e.g. Passiflora edulis Sims, passion fruit). The fruits are capsules or berries and the seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

The seeds have a fleshy aril (an outer covering of the seed attached to the funiculus, see Chapter 3, Volume I) and may show considerable dormancy. B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos within woody seed coats and an inner semi-permeable layer (see Table 17.2, Chapter 17). Treatments to the seed covering structures and alternating temperatures tend to promote germination.

Detailed information on seed germination procedures and dormancy-breaking treatments are provided for the genus Passiflora in this chapter. In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds in an alternating temperature regime of 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If the above regime does not promote full germination then the second step in the algorithm is to co-apply 7×10^{-4} M GA_3 in the germination test substrate and test a fresh sample of seeds in the alternating temperature regime specified in step one.

PASSIFLORA

P. edulis Sims	passion fruit, granadilla
P. ligularis Juss.	sweet grandilla
P. maliformis	
P. quadrangularis L.	giant granadilla

I. Evidence of dormancy

Difficulties in the germination of seeds of the above orthodox species (1) can occur as a result of seed dormancy (3).

II. Germination regimes for non-dormant seeds

P. edulis

Alternating temperatures: 20°/30°C (16h/8h), 6w (5)

III. Unsuccessful dormancy-breaking treatments

P. edulis

Constant temperatures: 20°C, 30°C (3)

GA_3: co-applied (3)

Pre-soak: 24h (3)

Cytase: (3)

IV. Partly-successful dormancy-breaking treatments

P. edulis

Alternating temperatures: 20°/30°C (12h/12h) (3)

Scarification: sand paper (3); sulphuric acid, 75%, 6h (3)

Removal of seed covering structures: chip (3); crack seed coats (3); crack, seed coats, germinate at 20°/30°C (12h/12h) (3); crack seed coats, then GA_3, co-applied (3)

P. ligularis

Scarification: sandpaper, germinate at 20°/30°C (12h/12h) (3)

P. maliformis

Constant temperatures: 30°C (3)

Alternating temperatures: 20°/30°C (12h/12h) (3)

V. Successful dormancy-breaking treatments

P. edulis

Scarification: file (2); sandpaper (2)

Passiflora spp.

Pre-soak: 24h (4)

VI. Comment

The germination of dormant seeds of Passiflora spp. requires scarification and alternating temperatures (3). It is suggested that the seeds be scarified with sand paper and then tested for germination on top of filter papers at an alternating temperature of 20°/30°C (16h/8h) for 6 weeks.

VII. References

1. Costa, C.F. Da, Oliveira, E.L.P.G. De and Lellis, W.T. (1974). [Persistence of the germinating capacity of passion fruit seeds.] Boletim do Instituto Biológico da Bahia, 13, 76-84. (From Horticultural Abstracts, 1976, 46, 649.)

2. Kuhne, F.A. (1968). Cultivation of granadillas. Farming in South Africa, 43, 29-32.

3. Morley-Bunker, M.J.S. (1980). Seed coat dormancy in Passiflora species. Annual Journal of the Royal New Zealand Institute of Horticulture, 8, 72-84.

4. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

5. Thai, T.Y. (1977). Storage of passion fruit (Passiflora edulis forma flavicarpa) seeds. Malaysian Agricultural Journal, 51, 118-123.

CHAPTER 56. PEDALIACEAE

The Pedaliaceae comprise about 60 species of herbaceous plants within 16 genera and are closely related to Scrophulariaceae and Martyniaceae. Two species are cultivated for their edible (oily) seeds, viz: Sesamum indicum L., sesame; and Ceratotheca sesamoides Endl. The fruits are either capsules or hard indehiscent nuts. Seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

The seeds are non-endospermic, possess linear embryos and flattened cotyledons, and can be dormant. Part of the problems associated with germination tests are caused by the seed coat. Seed coat removal and treatment of the seeds with gibberellins tends to promote germination.

Detailed information is provided for the genus Sesamum in this chapter. For developing suitable techniques for other species, RBG Kew Wakehurst Place suggests, as a first step, testing seeds at a constant temperature of 26°C with light applied for 12h/d (but see comment for Sesamum). If this does not lead to satisfactory germination then experiment with further treatments. Clues to suitable further treatments can be obtained from the information provided for Sesamum in this chapter.

SESAMUM

S. indicum L. [S. orientale L.] sesame, simsim, beniseed, gingelly, till

I. Evidence of dormancy

Sesame seeds may exhibit dormancy (1-4). Six months after-ripening results in loss of dormancy (1). The position of capsules on the plant and the degree of maturity affect dormancy (4). Seeds from wild collections tend to show deeper dormancy (3), apparently failing to germinate due to impermeable seed coats (3).

II. Germination regimes for non-dormant seeds

TP: 20°/30°C (16h/8h): 6d (AOSA,ISTA)

III. Unsuccessful dormancy-breaking treatments

Indolebutyric acid: co-applied, 100 ppm, at 26°C in light, 16h (2); co-applied, 500 ppm, at 26°C in light, continuous or 16h, or dark (2)

Coumarin: co-applied, 500 ppm (2)

IV. Partly-successful dormancy-breaking treatments

Pre-soak: 48h (1)

GA_3: pre-applied, 48h, 1000 ppm (1); co-applied, 0.5-500 ppm, at 26°C in light, 16h (2)

Indolebutyric acid: co-applied, 0.5-50 ppm, at 26°C in light, 16h (2); co-applied, 100 ppm, in light, continuous, or dark (2)

Coumarin: co-applied, 0.5-100 ppm, at 26°C in light, 16h (2) 2,4-Dichlorophenoxyacetic acid: co-applied, 0.5-10, 100, 500 ppm, at 26°C in light, 16h (2)

V. Successful dormancy-breaking treatments

GA_3: pre-applied, 48h, 100-500 ppm (1); co-applied, 0.5-500 ppm, at 26°C in light, continuous, or dark (2)

Indolebutyric acid: co-applied, 0.5-50 ppm, at 26°C in light, continuous, or dark (2)

Coumarin: co-applied, 0.5-100 ppm, at 26°C in light, continuous, or dark (2)

2,4-Dichlorophenoxyacetic acid: co-applied, 0.5-500 ppm, at 26°C in light, continuous, or dark (2)

VI. Comment

The observation that continuous light or continuous dark are both more promotory than a single 16 hour light treatment (2) is surprising. Nevertheless the implication for gene banks is clear: sesame seeds should be tested for germination in the dark. An alternating temperature regime of 20°/30°C (16h/8h) as prescribed by ISTA/AOSA is satisfactory for non-dormant fresh and aged seeds (A), but a further stimulus is required for dormant seeds. Of the four successful dormancy-breaking agents listed above gibberellic acid is the most satisfactory - since it promotes germination over the widest range of conditions (2). Pre-application - 48 hours, 500 ppm is suggested - may be preferable to co-application - 10, or possibly, 50, ppm is suggested - since considerable promotion of germination is provided by pre-soak treatments alone (2).

VII. References

1. Ashri, A. and Palevitch, D. (1979). Seed dormancy in sesame (S. indicum) and the effect of gibberellic acid. Experimental Agriculture, 15, 81-83.

2. Chatterji, U.N., Sankhla, N. and Baxi, D. (1966). Preliminary studies on the effects of certain growth substances on germination of Sesamum indicum Linn. seeds. Indian Agriculturists, 10, 46-56.

3. Richharia, R.H. and Dhodapkar, D.R. (1940). Delayed germination in sesame, Sesamum indicum. Indian Journal of Agricultural Science 10, 93-95.

4. Sheelavantar, M.N., Ramanagouda, P. and Krishnamurthy, K. (1974). Causes for low germination in sesamum variety C-50. Current Research, 3, 89-90.

CHAPTER 57. PIPERACEAE

The Piperaceae comprise over 1000 species of herbaceous plants, shrubs and sometimes climbers and trees some of which provide condiments (e.g. Piper nigrum L., pepper). The fruits are dry or fleshy small indehiscent berries and seed storage behaviour is orthodox (though longevity may be comparatively short).

SEED DORMANCY AND GERMINATION

The seeds are small with a minute embryo, copious perisperm and little endosperm. They may be dormant. Treatments to the seed coat and alternating temperatures may promote germination, but careful regulation of the light environment may be necessary for germination to occur (see Chapter 6, Volume I). Detailed information is provided for the genus Piper in this chapter.

PIPER

P. auritum HBK
P. hispidum Sw.
P. nigrum L. pepper

I. Evidence of dormancy

Evidence of dormancy in seeds of P. nigrum is not great. In nursery cultivation seeds germinate satisfactorily provided they are sown shallow (2), or on top of sand (3), or in the shade (1,3,4). Dormancy may be present in some lots, however, because the germination of over-ripe seeds is reported to be greater than the germination of less mature seeds (3).

Considerable dormancy can be exhibited in seeds of P. auritum and P. hispidum (2,6,7). For example, seeds of P. hispidum maintain imbibed at 25°C in the dark faíled to germinate within a year, but were subsequently capable of germinating if provided with sufficient stimulus (7).

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

P. auritum

Light: far red, 5 lux, at 25°C (6); dark, at 25°C (6)

P. hispidum

Light: dark, at 25°C (2,7); far red, 10 min (2,7); red, less than 20 min (7); red, 10 min/12h (7)

IV. Partly-successful dormancy-breaking treatments

P. hispidum

Light: red, 30-120 min, at 25°C (7); red, 10 min/6h, 10 min/8h (7)

V. Successful dormancy-breaking treatments

P. auritum

Light: red, low (immeasurable), at 25°C (6); white, 12h/d, at 25°C (6)

P. hispidum

Light: white, 12h/d, at 25°C (2,7); red, 6h, at 25°C (7); red, 2h/12h, 2h/8h, at 25°C (7); blue, at 25°C (2)

P. nigrum

Scarification: concentrated sulphuric acid, 2 min, low light (4)

VI. Comment

The above provides ample evidence that the quality and dosage of light received by seeds of Piper spp. markedly influences germination. Incidentally the indirect evidence summarised from observations of nursery bed sowings (1,3-5) emphasises that recommendations on the light environment should accompany samples of accessions destined for field sowings.

On the basis of the limited evidence presently available, it is suggested that seeds of Piper spp. be tested for germination at 25°C with red light applied, either for 2 hours in every 8-12 hours (7), or as recommended in Chapter 6. It is suggested that gene banks might investigate the response of seed germination to alternating temperatures - in a stimulatory light environment - in order to determine whether more suitable germination test regimes can be devised - particularly since alternating temperatures may be beneficial in increasing the permeability of seed coats, which are reported to be impermeable in P. nigrum (4).

VII. References

1. De Waard, P.W.F. and Zeven, A.C. (1969). Pepper. In Outline of perennial crops breeding in the tropics (eds. F.P. Ferwerda and F. Wit), pp. 409-426, Veenman and Zonen, Wageningen.

2. Ludlow Wiechers, B. and Vázquez-Yanes, C. (1976). [Germination of seeds of Piper hispidum under different light conditions.] In Investigaciones sobre la regeneracion de selvas altas en Vera Cruz, Mexico, pp. 263-278, Compania Editorial Continental, S.A.

3. Nuryani, Y. (1978). [Germination of black pepper seeds.] Pemberitaan, 31, 33-40.

4. Purseglove, J.W. (1968). Tropical Crops. Dicotyledons. Longman, London.

5. Singh, H.B. et al (1974). Black pepper (Piper nigrum). In Handbook of Plant Introduction in Tropical Crops, pp. 126-127. Plant Production and Protection Division, FAO, Rome.

6. Vázquez-Yanes, C. (1980). Light quality and seed germination in Cecropia obtusifolia and Piper auritum from a tropical rain forest in Mexico. Phyton, 38, 33-35.

7. Vázquez-Yanes, C. and Orozco-Segovia, A. (1982). Germination of the seeds of a tropical rain forest shrub, Piper hispidum Sw. (Piperaceae), under different light qualities. Phyton, 42, 143-149.

CHAPTER 58. POLYGONACEAE

The Polygonaceae comprise roughly 800 species of herbaceous plants, shrubs and trees within 30 to 40 genera which provide grain (Fagopyrum esculentum Moench, buckwheat), edible stems (in fact the petioles of radicle leaves) (Rheum raponticum L., rhubarb), leaf vegetables (e.g. Rumex acetosa L., garden sorrel), and several medicinal products. The fruits are usually achenes and are sometimes enclosed in perianth, forming a berry-like structure. The seeds show orthodox storage behaviour. For example, Erigonum and Polygonum spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

B.R. Atwater classifies seed morphology as endospermic seeds with peripheral linear embryos (see Table 17.1, Chapter 17). The seeds can exhibit a high degree of dormancy. Light, treatments to the seed coat (particularly removal), pre-chilling and alternating temperatures promote the germination of dormant seeds.

Detailed information on seed dormancy and germination is provided for the genus Fagopyrum in this chapter. Recommendations for germination test procedures and dormancy-breaking treatments for other species are summarised in Table 58.1. In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test the seeds at constant temperatures of 16°C and 26°C, with light applied for 12h/d. If full germination is not achieved but a trend is apparent in the response of germination to constant temperatures then test at more extreme constant temperatures. For example, if a greater proportion of seeds germinate at 16°C than at 26°C then test further samples of seeds at constant temperatures of 6°C and 11°C with light applied for 12h/d. If, however, the proportions of seeds germinating at 16°C and 26°C are similar then test a further sample of seeds at the intermediate constant temperature of 21°C with light applied for 12h/d.

If the above constant temperature regimes do not promote full germination then the second step in the algorithm is to test seeds in an alternating temperature regime of 23°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

TABLE 58.1 Summary of germination test recommendations for species within the Polygonaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Antigonon leptopus Hook. & Arn.		20°C	15d		Atwater
Coccoloba uvifera L.			21d	pre-soak, 24h, then warm stratification	Riley
Eriogonum fasciculatum Benth.		20°C	14d	remove outer coats	Atwater
Polygonum convolvulus	TP	23°C	6d	light, remove fruit coat	R&S
Polygonum lapathifolium	TP	20°/30°C	21d	test at 2°-10°/35°C, 10d, then	Everson

				20°/30°C	
	TP	15°/25°C		light, pre-chill, 2w	M&O
Polygonum pennsylvanicum	TP	10°/35°C	28d	test at 2°/35°C, 21d, then 10°/35°C	Everson
	TP	23°/30°C	21d	light	R&S
Polygonum persicaria	S	20°/30°C	21d	test at 2°-10°/35°C, 14d, then 20°/30°C	Everson
	TP	23°C	6d	light, remove fruit coat	R&S
Polygonum scandens L.		3°-6°C	21d	remove outer coat	Atwater
Rheum palmatum L.	TP; BP	20°/30°C; 20°C	21d		ISTA
Rheum rhabarbarum L.	TP	20°/30°C	21d	light	AOSA
Rheum rhaphonticum L.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	14d	light	Heit
Rumex acetosa L.	TP	20°/30°C	14d	pre-chill	ISTA
	TP; S	20°/30°C	14d	light, test at 15°C	AOSA
	TP	15°C	10d	light, potassium nitrate	Heit
Rumex crispus L.	TP; S	15°/30°C	10d	light	Everson
	TP	20°/30°C		light	M&O
Rumex maritimus	TP	20°/30°C		light	M&O
Rumex obtusifolius L.	TP	20°/30°C			M&O

FAGOPYRUM

F. esculentum Moench [F. sagittatum Gilib.] common buckwheat
F. tataricum Gaertn. India-wheat, tartary buckwheat

I. Evidence of dormancy

Although viviparous germination is sometimes observed in both ripe and unripe seeds of F. esculentum (5), a high degree of dormancy is normally exhibited by seeds of F. esculentum (6) and F. tataricum (1,3) at harvest. At 25°C, 40 (1) or 60-70 days (3) after-ripening are required to remove dormancy from seeds of F. tataricum, but at 2°-3°C as many as 6 months may be necessary (1).

II. Germination regimes for non-dormant seeds

F. esculentum

BP; TP: 20°/30°C (16h/8h); 20°C: 7d (ISTA)

BP: 20°/30°C (16h/8h): 6d (AOSA)

Constant temperatures: 25°C (2)

III. Unsuccessful dormancy-breaking treatments

F. esculentum

Light: blue (6); dark, at 28°C (6)

F. tataricum

Alternating temperatures: 20°/30°C, -20°C/room temperature (1)

Removal of seed covering structures: pericarp only (1,3); prick (1); cut, at base of seed (1)

Scarification: concentrated sulphuric acid, 2 min-24h (1); ethyl alcohol, 95%, 2 min-24h (1)

GA_3: pre-applied, 2 min-24h, 10-1,000 ppm (1); pre-applied, 24h, 1000 ppm, after seedcoat removal (1)

Pre-dry: pre-wet/pre-dry, cycle (1)

IV. Partly-successful dormancy-breaking treatments

F. esculentum

Constant temperatures: 10°-25°C in light, continuous, 200 lux (6); 45°-50°C in light, continuous, 200 lux (6)

Light: sunlight, at 28°C (6); diffuse daylight, at 28°C (6); diffuse daylight plus incandescent, continuous, 400-1200 lux (6); diffuse daylight plus incandescent, 2-12h/d, 200 lux (6); violet (6); green (6); yellow (6); red (6); far red (6)

Kinetin: 10 ppm (4); plus N-chloroacetate-M-iodoaniline (4) N-Chloroacetate-M-iodoaniline: (4)

F. tataricum

Removal of seed covering structures: pericarp and seedcoat (1)

V. Successful dormancy-breaking treatments

F. esculentum

Constant temperatures: 30°C, 35°C, 40°C, light, diffuse daylight plus incandescent, continuous, 200 lux (6); 28°C, light, diffuse daylight plus incandescent, 16-24h/d (6)

Light: diffuse daylight plus incandescent, continuous (6); orange, continuous (6)

F. tataricum

Removal of seed covering structures: pericarp and seedcoat (3)

Pre-dry: 80°C, 2,3d (1); 70°C, 3d (1); 40°C, 2-6w (1)

VI. Comment

Whilst treatment with light promotes the germination of dormant seeds of F. esculentum (6), high doses can inhibit germination (6). It is suggested that seeds of F. esculentum be tested for germination in the alternating temperature regime prescribed by AOSA/ISTA, 20°/30°C (16h/8h), with light applied at 200 lux or as described in Chapter 6. If it is not possible to provide an alternating temperature regime, it is suggested that 30°C would be a suitable constant temperature germination test regime.

It is probable that the germination of seeds of F. tataricum will prove more difficult to achieve. Removal of both the pericarp and seed coat will promote full germination if the seeds have been partly after-ripened (1), but the promotion is meagre for non-after-ripened seeds (1). Similarly treatment with gibberellins may have some promotory effect for partly after-ripened

seeds but fails to promote the germination of non-after-ripened seeds (1). For the present it is suggested that the seeds be tested for germination in the manner described for F. esculentum after the removal of pericarps and seed coats. Although pre-dry treatments have been reported to be successful (1), the treatments themselves are severe and if applied should be used with great caution.

VII. References

1. Born, W.H.V. and Corns, W.G. (1958). Studies on seed dormancy, plant development, and chemical control of tartary buckwheat (Fagopyrum tataricum (L.) Gaertn.) I. Seed dormancy. Canadian Journal of Plant Science, 38, 357-365.

2. Born, W.H.V. and Corns, W.G. (1958). Studies on seed dormancy, plant development, and chemical control of tartary buckwheat (Fagopyrum tataricum (L.) Gaertn.) II. Germination, growth, flowering and seed production. Canadian Journal of Plant Science, 38, 367-373.

3. Cormack, R.G.H. (1952). A note on the dormancy of tartary buckwheat seeds. Scientific Agriculture, 32, 170-172.

4. Ismagilov, F.S. (1981). [On stimulation of buckwheat seed germination by kinetin and N-chloroacetic-m-iodoaniline.] In Rost i Produktivnost' rastenii. Ufa. USSR, pp. 16-22. (From Field Crop Abstracts, 1982, 35, 9219.)

5. Katoch, P.C., Baksh, S., Bhardwaj, S.D. and Kaushal, A.N. (1979). A report of vivipary in buckwheat (Fagopyrum spp.). Current Science, 48, 446-447.

6. Singh, V.P. and Mall, S.L. (1977). Seed germination studies in Fagopyrum esculentum Moench. I. Role of light and temperature. Proceedings of the Indian National Science Academy, B, 43, 37-43.

CHAPTER 59. PORTULACACEAE

The Portulacaceae comprise about 200 species of fleshy herbaceous plants and small shrubs within about 20 genera, a few of which are cultivated as pot-herbs (e.g. Talinum triangulare (Jacq.) Willd., waterleaf). The fruits are usually dehiscent capsules and the seeds show orthodox storage behaviour. For example, Portulaca and Calandrinia spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

The seeds have a curved or ring-like embryo and can exhibit considerable dormancy. B.R. Atwater classifies seed morphology as endospermic seeds with peripheral linear embryos (see Table 17.1, Chapter 17). Treatments to the seed coat, light and alternating temperatures tend to promote seed germination. Detailed information on seed dormancy and germination is provided in this chapter for the genus Talinum only, but recommendations for germination test procedures and dormancy-breaking treatments for other species are summarised in Table 59.1.

TABLE 59.1 Summary of germination test recommendations for species within the Portulacaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Claytonia perfoliata Donn ex Willd.	BP	10°C	21d		ISTA
Portulaca grandiflora Hook.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	7d	light, pre-chill, 5°C, 14-21d	AOSA
		20°/30°C	14d	light, test at 10°C, potassium nitrate	Atwater
Portulaca oleracea L.	TP; BP	20°/30°C	14d	pre-chill	ISTA
	S	20°/30°C	10d	light	Everson

TALINUM

T. triangulare (Jacq.) Willd. waterleaf

I. Evidence of dormancy

At harvest seeds of T. triangulare exhibit considerable dormancy (1-4).

II. Germination regimes for non-dormant seeds

Constant temperatures: 20°C in light (3)

Alternating temperatures: 10°/30°C (12h/12h) in light (1)

III. Unsuccessful dormancy-breaking treatments

Warm stratification: 25°C, dark, 5,10,20d, germinate at 21°C, dark/light (24h/24h) (3)

Pre-soak: (2); 45°C, 75°C, 90°C (4)

Light: dark, at 20°-22°C (1,3); dark, at 25°-30°C, 28°-35°C (1); dark, at 6°-10°C, intact or scarified seeds (1); light, continuous, at 25°-30°C, 28°-35°C (1); light, 1-5d, 700 lux, 21°C, then dark, 21°C (3)

Scarification: concentrated sulphuric acid (4); sulphuric acid, 0.1, 2 N, 10 min (2)

Hydrogen peroxide: pre-applied, 10 min, 6% (2)

Acetone: (4)

Sodium hypochlorite: (4)

Thiourea: (4)

Potassium nitrate: (4)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 6°-10°/28°-35°C (12h/12h), dark (1); 28°-35°/6°-10°C, light/dark (12h/12h) (1)

Pre-chill: 4°C, dark, 5,10,20,30d, germinate at 21°C in light, continuous, 700 lux (3); 4°-5°C, 30d, in activated carbon-paste (2); 4°C, dark, 5d, then warm stratification, 25°C, dark, 15d, germinate at 21°C in light, continuous (3); 4°C, dark, 10d, then warm stratification, 25°C, dark, 10d, germinate at 21°C in light, continuous (3)

Warm stratification: 25°C, dark, 5,10,20d, germinate at 21°C in light, 5-25d, 700 lux, then 21°C in dark (3); 25°C, dark, 5,10,20d, germinate at 21°C in light, continuous, 700 lux (3); 25°C, dark, 5d, then pre-chill, 4°C, dark, 15d, germinate at 21°C in light, continuous (3)

Pre-soak: 60°C (4); 60°C, 2 min (2)

Light: continuous, at 20°-22°C (1,3); white, 0.25-8h/d, 700 lux, at 21°C (3); 10-25d, 700 lux, at 21°C, then dark, at 21°C (3) Scarification: sand paper, then pre-soak, 3h (2)

Removal of seed covering structures: chip, then pre-soak, 20 min (2); chip, then thiourea, pre-applied, 20 min, 5% (2)

Thiourea: pre-applied, 20 min, 5% (2)

V. Successful dormancy-breaking treatments

Warm stratification: 25°C, dark, 30d, germinate at 21°C in light, continuous (3); 25°C, dark, 10d, then pre-chill, 4°C, dark, 10d, germinate at 21°C in light, continuous (3)

Removal of seed covering structures: prick, germinate at 20°-22°C in light, continuous (1)

VI. Comment

Light appears to be an essential requirement for the germination of seeds of T. triangulare (1,3); 8 hours light per day is sufficient to promote the maximum response (3). Alternating temperatures (1), pre-chill (2,3), warm stratification (3), and pricking the seed coat (1) can all be promotory and it is suggested that these be incorporated in dormancy-breaking and germination test routines as follows: prick the seed coat with a needle then imbibe the seeds at 25°C in the dark for 10 days, transfer to 4°C in the dark for a further 10 days and then test for germination at 10°/30°C (12h/12h) with light applied for 8 hours per day during part of the

period spent at the higher temperature. For some (less dormant) accessions the germination test regime alone may be sufficiently promotory. Incidentally, pre-chilling after a warm stratification treatment is more promotory than pre-chilling first (3).

VII. References

1. Agble, F. (1970). Germination of seeds of Talinum triangulare, Ghana Journal of Science, 10, 29-32.

2. Fawusi, M.O.A. (1979). Germination of Talinum triangulare L. seeds as affected by various chemical and physical treatments. Annals of Botany, 44, 617-622.

3. Nwoke, F.I.O. (1982). Effects of photoperiod on germination of seeds of Talinum triangulare (Jacq.) Willd. Annals of Botany, 49, 23-29.

4. Stephens, C.E. (1967). The genetical basis of flower colour variation in Talinum triangulare (Jacq.) Willd. and cytological studies of Hydrocleis nyphoides (Willd.) Buchenau. M.Sc. Thesis, University of Ghana. [Cited by Agble, F. (1970).]

CHAPTER 60. PROTEACEAE

The Proteaceae comprise about 1000 species of trees and shrubs within more than 50 genera. The most useful species is Macadamia ternifolia F. Muell., Macadamia or Queensland nut, which provides an edible nut. The fruits are nuts, drupes, capsules or follicles. Seed storage behaviour is uncertain. Although many species show orthodox seed storage behaviour - for example, Embothrium coccineum is maintained in the long-term seed store at the Wakehurst Place Gene Bank - recalcitrant seed storage behaviour has been suggested, though not confirmed, in the Macadamia nut.

SEED DORMANCY AND GERMINATION

Advice on suitable germination test procedures and dormancy-breaking treatments is limited (Table 60.1). In developing appropriate techniques, RBG Kew Wakehurst Place suggests a useful first step is to test a sample of the seeds in an alternating temperature regime of 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

TABLE 60.1 Summary of germination test recommendations for species within the Proteaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Gevuina avellana			21d	pre-soak, 24h, then warm stratification	Riley
Grevillea robusta Cunn. ex R. Br.	TP	20°/30°C	28d	potassium nitrate, pre-chill	ISTA
	TP; BP	20°/30°C	21d	light	AOSA
Macadamia spp.			30d	pre-soak, 24h	Riley

CHAPTER 61. PUNICACEAE

The Punicaceae comprise several species of trees and shrubs within the genus Punica. Punica granatum L., pomegranate, provides an edible fruit, and the roots, fruit rind and seeds have medicinal uses. The fruit is a berry containing numerous seeds surrounded by a juicy pulp. Seed storage behaviour is orthodox (see below).

SEED DORMANCY, GERMINATION AND STORAGE

The only reference we have found to the germination and storage behaviour of seeds within the Punicaceae is Riley (1981) for Punica granatum L. There it is suggested that the seeds should be dried to 70% of their harvest weight and stored at 4° to 5°C. Under these storage conditions it is suggested that the seeds will have a storage life of 3 years and germinate within 14 to 30 days of sowing if they are pre-chilled at 1° to 5°C for between 30 and 60 days (Riley, 1981). Since no recommended germination test procedures are available for pomegranate we investigated the germination response of a single seed lot to a limited number of constant and alternating temperature germination test regimes. The results are described and discussed below.

Seeds were extracted by hand from fruits purchased locally, rinsed in water several times, blotted surface dry and then dried over silica gel (changed daily) at 20°C for 10 days. Seed moisture contents before and after drying were 76.5 and 4.8% (fresh weight basis) respectively. Initial germination (normal) of the fresh seeds when extracted and tested between moist rolled paper towels at 20°/30°C (16h/8h) for 42 days was 87%. A further test after drying (test details as above) recorded 88% normal germination.

The dried seeds were hermetically stored in a deep freeze maintained at -20°C. After 3 weeks in storage 2000 seeds were removed. Ten groups of 200 seeds each were tested for germination in one of each of the following regimes: constant temperatures of 10°C, 15°C, 20°C, 25°C, 30°C, or 35°C; alternating temperatures (all 16h/8h) of 15°/30°C, 20°/30°C, or 20°/35°C; or 3° to 5°C for 7 days (that is pre-chilling) then 20°/30°C (16h/8h). In all cases the seeds received a brief daily exposure to diffuse indoor light. The tests were concluded after 21 days. Since the highest germination was observed in the 20°/35°C alternating temperature regime all the seeds which had failed to germinate within 21 days in the original test environment were transferred to this alternating temperature regime for a further 14 days. Cumulative normal germination after various periods in test are shown in Table 61.1.

The pomegranate seeds germinated most rapidly at constant temperatures of 30° and 35°C (Table 61.1); at 35°C initial germination was slightly more rapid, but the seedlings were not vigorous and fungi developed on several seeds tested in this regime (whereas in other regimes no such problems occurred). Pre-chilling for 7 days was not advantageous (compared to 20°/35°C throughout), but the seeds were not killed by exposure to the lower temperatures. For example, no seeds germinated when tested at 10°C for 21 days, but 93% germinated when subsequently transferred to 20°/35°C (Table 61.1). Of the regimes investigated, it is clear that an alternating temperature regime of 20°/35°C (16h/8h) is the most suitable (at least for this lot) for germination tests of Punica granatum. In this regime no more seeds germinated after 28 days in test.

Clearly the seeds show orthodox seed storage behaviour since they were neither killed by desiccation to 5% moisture content nor by exposure to sub-zero temperatures (-20°C) (once

dried). On the basis of these results, it is suggested that seeds of Punica granatum be tested for germination between moist paper in an alternating temperature regime of 20°/35°C (16h/8h) for a minimum of 28 days.

Reference

Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

Table 61.1 Germination (normal) or seeds (200 per test) of Punica granatum L. in various constant and alternating temperature test regimes.

Initial Test	Cumulative normal germination, %			
	Days in initial test environment			After a further
Environment				14 days at
	7	14	21	20°/35°C
10°C	0	0	0	93
15°C	0	0	0	96
20°C	0	2	39	91
25°C	0	23	53	88
30°C	20	83	84	84
35°C	25	81	83	84
15°/30°C	0	10	46	95
20°/30°C	0	63	85	90
20°/30°C*	0	75		91
20°/35°C	0	73	94	95

* After pre-chilling for 7 days at 3°-5°C; subsequently moved to 20°/35°C after 14d at 20°/30°C

CHAPTER 62. ROSACEAE

The Rosaceae comprise more than 3000 species of trees, shrubs and herbaceous plants within about 115 genera. The most important genera are those which provide edible fruits (e.g. Eriobotrya japonica Lindl., loquat). Fruit structure is diverse, viz: achenes, follicles, hips, pomes or drupes. Seed storage behaviour is orthodox, although the storage behaviour of loquat has not been clarified.

SEED DORMANCY AND GERMINATION

The seeds are usually non-endospermic and dormancy can be a considerable problem. B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos within a woody seed coat and an inner semi-permeable layer (see Table 17.2, Chapter 17). Although the several layers of seed covering structures can prevent or delay germination, embryo dormancy can also be a considerable problem. Typical methods of promoting germination include scarification, chipping or removing the seed covering structures and pre-chilling: considerable pre-chill durations may be necessary to promote full germination of the more dormant seed populations.

Detailed information on seed dormancy and germination is provided in this chapter for the genera Fragaria, Prunus (including synonyms within Amygdalus, Armeniaca, Cerasus, Laurocerasus, Padus and Persica), Pyrus (including synonyms within Aronia, Malus and Mespilus) and Rubus. Further recommendations for suitable germination test procedures and dormancy-breaking treatments are summarised in Table 62.1. In addition the two algorithms below (for herbaceous and woody species respectively) may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm for herbaceous rosaceous species

The first step in the algorithm for seeds of herbaceous species is to test at constant temperatures of 16°C, 21°C and 26°C with light applied for 12h/d. If full germination has not been achieved and the results suggest a trend of germination response to constant temperatures then further samples of seeds are tested at more extreme constant temperatures. For example, if a greater proportion of seeds germinate at 16°C than at the two higher constant temperatures, test two further samples of seeds at constant temperatures of 6°C and 11°C with light applied for 12h/d.

If full germination has not been achieved in any of the above constant temperature regimes then the second step of the algorithm is to test a further sample of seeds in an alternating temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d during the phase of each cycle spent at the upper temperature.

If full germination has not been promoted, the third step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to

the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided for four genera in this chapter and from Table 62.1.

RBG Kew Wakehurst Place algorithm for woody rosaceous species

The first step in the algorithm is to pre-chill samples of seeds for 8, 12 and 24w at 2° to 6°C and then test the pre-chilled seeds at constant temperatures of 16°C and 21°C with light applied for 12h/d.

If the first step in the algorithm does not result in full germination then the second step is to take two further samples of seeds. Remove the seed coats from one sample of seeds, but only chip the seed coats of the second sample and then subject both samples to the most successful pre-chill and constant temperature germination test regime determined from a comparison of the results of step one.

If the second step in the algorithm does not result in full germination then the third step is to estimate viability using a tetrazolium test (as described for the third step of the algorithm for herbaceous rosaceous species).

TABLE 62.1 Summary of germination test recommendations for species within the Rosaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Agrimonia eupatoria L.	TP	20°/30°C	60d	pre-soak, 24h, chip or file off fragment of testa	ISTA
Amelanchier laevis wiegand				warm stratification, 25°C, 4w, then pre-chill, 1°-5°C, 16w	G&R
Amelanchier spp.			21d	scarify, abrade with sharp sand, or file or nick seed coat, pre-chill, 1°-5°C, 30-60d	Riley
Chaenomeles japonica Lindl.				warm stratification, 25°C, 2w, then pre-chill, 1°-5°C, 8-16w	G&R
Cotoneaster spp.		20°/30°C; 10°/25°C		light, 8h/d, warm stratification, 25°C, 12w, then pre-chill, 1°-5°C, 12w	G&R
Crataegus mollis Scheele	TP; BP	20°/30°C	14d	scarify, sulphuric acid, 2h, then warm stratification, 20°C, 90d, then pre-chill, 3°-5°C, 120d	AOSA
Crataegus monogyna Jacq.	S	20°/30°C	28d	warm stratification, 25°C, 3m, then pre-chill, 3°-5°C, 9m	ISTA
Crataegus spp.				warm stratification, 25°C, 4-16w, then pre-chill, 1°-5°C, 12-16w	G&R
			40d	scarify, abrade with sharp sand, or file or nick seed coat, pre-chill, 1°-5°C, 30-60d	Riley
Cydonia oblonga Mill.				warm stratification, 25°C, 2-4w, then pre-chill, 1°-5°C, 16w	G&R
			21d	pre-chill, 1°-5°C, 90d	Riley
Eriobotrya japonica Lindl.			21d	pre-chill, 1°-5°C, 30-60d	Riley
Geum x borisii Hort.	TP; BP	20°/30°C; 20°C	21d	light	ISTA
Geum chiloense Balbis	TP; BP	20°/30°C; 20°C	21d	light	ISTA
Geum quellyon		20°/30°C	21d	keep wet	Atwater

Sweet					
Geum spp.	TP	20°/30°C	21d	seeds sensitive to drying out in test	AOSA
			28d	dry storage (to after-ripen seeds), test at alternating temperatures	Atwater
Potentilla anserina L.		20°/30°C	14d	light, potassium nitrate, 0.2%	Atwater
Potentilla flabelliformis	TP	20°/30°C; 20°C		light, pre-chill, 3°-5°C, 4w	M&O
Potentilla glandulosa Lindl.	soil		9d		Atwater
Potentilla tridentata Ait.		20°/30°C	45d	light, potassium nitrate, 0.2%	Atwater
Rosa multiflora Thunb.	TP	10°/30°C	28d	pre-chill, 3°-5°C, 28d	ISTA
	TP	10°/30°C	28d	light, pre-chill, 3°-5°C, 28d	AOSA
Rosa rugosa Thunb.			30d	pre-chill, 1°-5°C, 30-60d	Riley
Rosa spp. (except R. multiflora)	S	20°C	70d	pre-chill, 12m	ISTA
Rosa spp.				warm stratification, 25°C, 0-8w, then pre-chill, 1°-5°C, 8-16w	G&R
Sanguisorba minor Scop.	TP; BP	20°/30°C; 20°C	28d		ISTA
	BP	15°C	14d		AOSA
Sorbus spp.	S	20°/30°C	28d	pre-chill, 3°-5°C, 4m	ISTA
				warm stratification, 25°C, 2w, then pre-chill, 1°-5°C, 14-16w	G&R
			30d	pre-chill, 1°-5°C, 60d	Riley

FRAGARIA

Fragaria spp. strawberry

I. Evidence of dormancy

Strawberry seed germination is generally slow and erratic (5). This is one manifestation of dormancy, germination continuing to occur, for example, between 5 and 10 weeks in germination tests at 24°C (1). After-ripening treatments of 6 months duration result in partial, but not complete, loss in dormancy (1).

Dormancy varies considerably between cultivars (1). Seeds produced by self-pollination can be much more dormant than seeds produced from cross-pollination (1). Dormancy may be substantially less in seeds extracted from rotted fruits (3), but drying seeds at room temperature (18°-20°C) may induce dormancy (3). Since much of the work on dormancy in strawberry seeds does not specify the species, the information provided here is not divided into the separate species.

II. Germination regimes for non-dormant seeds

Constant temperatures: 24°C, 36d (4); 24°C, 70d (1); 25°C, 60d (5)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 19°-20°C, 60d (3); 31°-33°C, 22d (9)

Pre-chill: 0°-1°C, 10d (2); 0°-1°C, 2-4w (2); 0°-1°C, 6w (2); 2°C, 4w (15); 3°-5°C, 16d (7); 5°C, 10d (8); 5°C, 3w (4)

Thiourea: 0.1, 0.2% (8)

Scarification: concentrated sulphuric acid (13); concentrated sulphuric acid, 15 min (10)

Pre-soak: 8,24h (11)

Light: dark, at 25°C (12)

Coumarin: co-applied, 1-50 mg/1, at 25°C in dark (12)

2-4, Dichlorophenoxyacetic acid: co-applied, 1-10 mg/l, at 25°C in dark (12)

GA_1: co-applied, 1 mg/l, at 25°C in dark (12)

GA_3: co-applied, 1, 10 mg/l, at 25°C in dark (12)

$GA_{3/4}$: co-applied, 500 ppm, in red light (13)

GA_5: co-applied, 1-50 mg/l, at 25°C in dark (12)

GA_7: co-applied, 1-50 mg/l, at 25°C in dark (12)

GA_9: co-applied, 1-50 mg/l, at 25°C in dark (12)

Indoleacetic acid: pre-applied, 24h, 100, 200 ppm (9)

Colchicine: pre-applied, 24h, 400 ppm (9)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 24°C, 60d (4); 25°C in light (8)

Alternating temperatures: 15°/30°C (16h/8h) in light (8)

Pre-chill: 0°-1°C, 1-5w (2); 0°-1°C, 1-5m (2); 0°-1°C, 2-8m (2); 4°C, 2-16w, germinate at 24°C, 10w (1); 4°C, 1m (3); 5°C, 6w (4); 5°C, 30-90d (8); 2°C, 18d, plus $GA_{3/4}$, co-applied, 100 ppm, in red light (13); 2°C, 18d, plus thiourea, co-applied, 25 ppm, in red light (13); 2°C, 8w (15)

Thiourea: pre-applied, 24h, 500 ppm (9); pre-applied, 24h, 0.1, 0.2%, germinate at 20°-22°C (6); 0.01, 0.05% (8); co-applied, 100, 250 mg/l, at 25°C in dark (12); co-applied, 5-250 ppm, in red light (13)

GA_1: co-applied, 10, 50 mg/l, at 25°C in dark (12)

GA_3: pre-applied, 24h, 25-75 ppm, germinate at 20°-22°C (6); pre-applied, 24h, 100, 200 ppm (9); 100-500 ppm (8); co-applied, 50 mg/l, at 25°C in dark (12)

$GA_{3/4}$: co-applied, 1-100 ppm, in red light (13)

GA_4: co-applied, 1-50 mg/l, at 25°C in dark (12)

GA_5: co-applied, 10 mg/l, at 25°C in dark (12)

2-Chloroethane phosphonic acid: pre-applied, 24h, 1000, 2500 ppm, germinate at 20°-22°C (6); 50-200 ppm (8); 500-5000 ppm (8)

Scarification: sulphuric acid, 96%, 8 min, with or without pre-chill, 3°-5°C, 16d (7); concentrated sulphuric acid, 2,3 min (8)

Ammonium nitrate: pre-applied, 24h, 0.2, 0.5% (9)

Potassium nitrate: 0.1, 0.2% (8); pre-applied, 24h, 0.2% (9)

Sodium hypochlorite: pre-applied, 8,24h, 1% (11)

Light: red, 5 min-24h, at 25°C (12); red, continuous (13); green, continuous, at 25°C (12)

Nitric acid: pre-applied, 24h, 0.15, 0.25% (9)

Malic hydrazide: pre-applied, 24h, 200-500 ppm (9)

Colchicine: pre-applied, 24h, 250 ppm (9)

Hydrogen peroxide: pre-applied, 4,14,24h (9)

V. Successful dormancy-breaking treatments

Pre-chill: 2°C, 44d, with or without GA_3, co-applied, 10, 100 ppm, or with or without $GA_{3/4}$, 1, 10 ppm, at 20°-25°C in red light (13)

2-Chloroethane phosphonic acid: pre-applied, 24h, 5000 ppm, germinate at 20°-22°C (6); pre-applied, 24h, 5000, 10000 ppm (15)

Potassium nitrate: 0.2%, at 15°/30°C (16h/8h) in light (8)

Light: red, continuous, at 25°C (12)

VI. Comment

Light is essential for promoting the germination of dormant strawberry seeds (12) - red light being promotory and far red light being inhibitory (8,14). For practical treatments white light is sufficient for the promotion of germination (8). 25°C is the most suitable constant temperature germination test regime (5). For seed lots which are only slightly dormant, testing in continuous light at 25°C is sufficient for full germination (12), but for slightly more dormant seeds an alternating temperature regime of 15°/30°C (16h/8h) gives substantially greater germination than a constant 25°C (8).

We can confirm that the germination of dormant strawberry seeds is promoted by alternating temperature regimes: within the range 11°-38°C constant temperatures between 23°-27°C are the most suitable, but alternating temperatures with similar mean temperatures give more rapid and greater germination provided the maximum temperature of the alternation is below about 34°C (A). The maximum benefit from alternating temperatures only requires a small amplitude of alternation, 3°-7°C, and there is some benefit in providing the lower temperature of the alternation for the greater part of the cycle; 23°/30°C (16h/8h) is the most suitable regime (A).

The more dormant strawberry seed lots require further dormancy-breaking treatments in addition to alternating temperatures and light (A). Pre-chill treatments have been applied

widely. Optimum treatment periods are reported to vary from 4 to 12 weeks between lots (1), but 4 months' pre-chilling is reported to be a suitable compromise between conflicting optimum periods, at least in one investigation with 28 seed lots (2). Very long pre-chill treatments may be counter-productive, for example 6 months (2), and there is some suggestion that very short-duration treatments may also reduce germination, for example 16 days (7). These points minimise the usefulness of pre-chill treatments.

Of the gibberellins, GA_4 is the most successful in promoting germination (12), but the effect of gibberellins is often marginal (6) and in some cases may cause a reduction in germination (13). Ethrel (2-chloroethanephosphonic acid) can be very successful in promoting germination (6), but treatment with potassium nitrate is reported to be a more effective dormancy-breaking agent than either ethrel or gibberellins (8). The response to pre-treatment with sodium hypochlorite is variable between lots and in some cases may be injurious (11). Consequently it is not advisable to use a standard sodium hypochlorite disinfection treatment.

Scarification of strawberry seeds with concentrated sulphuric acid can be promotory and far more effective than pre-chill treatments (7). However, the treatment period is a critical factor, 8 minutes' treatment being promotory (7) whilst 15-minute treatments may reduce germination in some seed lots (10).

We found that no single dormancy-breaking agent could be applied which would promote full germination in all lots (A). Consequently we devised a germination test regime which combined a number of stimulatory factors. On the basis of this work the following regime is recommended for germinating strawberry seeds: first scarify the seeds in concentrated sulphuric acid for 10 minutes, then pre-wash for 30 minutes, then treat in 1 M hydrogen peroxide for 24 hours, and finally test for 49 days in an alternating temperature regime of 23°/30°C (16h/8h) with light during the 8h cycle and 0.2% potassium nitrate co-applied (A). The combined treatment has been found to be non-injurious to seeds (A), but the reader is reminded that the provision of an alternating temperature regime with light and potassium nitrate alone is likely to be sufficient for the less dormant seed lots (8).

For large scale sowings of seeds (regeneration or multiplication) it is important to apply light whilst preventing the seeds from drying out. This can be achieved by sowing the seeds on top of compost (that is, exposed to light) and using a mist-propagation unit to maintain a high humidity above the seeds (15).

VII. References

1. Adam, J. and Wilson, D. (1967). Factors affecting the germination of strawberry seeds. Report of the Long Ashton Research Station for 1966, 90-95.

2. Bringhurst, R.S. and Voth, V. (1957). Effect of stratification on strawberry seed germination. Proceedings of the American Society for Horticultural Science, 70, 144-149.

3. Brown, A.E. and Musa, M.J. (1980). The beneficial effect of rotting of strawberry fruit by Botrytis cinerea on subsequent germination. Seed Science and Technology, 8, 269-275.

4. Guttridge, C.G. and Bright, S. (1978). Accelerating and synchronizing germination of strawberry seeds by osmotic pre-treatments. Euphytica, 27, 843-848.

5. Henry, E.M. (1934). The germination of strawberry seeds and the technic of handling the seedlings. Proceedings of the American Society for Horticultural Science, 31, 431-433.

6. Iyer, C.P.A., Chacko, E.K. and Subramanium, M.D. (1970). Ethrel for breaking dormancy of strawberry seeds. Current Science, 39, 271-272.

7. Jonkers, H. (1958). Accelerated flowering of strawberry seedlings. Euphytica, 7, 41-46.

8. Nakamura, S. (1972). [Germination of strawberry seeds.] Journal of the Japanese Society for Horticultural Science, 41, 367-375.

9. Negi, S.P. and Singh, R. (1972). Effect of different chemicals on germination of strawberry seeds. Indian Journal of Horticulture, 29, 265-268.

10. Scott, D.H. and Ink, D.P. (1948). Germination of strawberry seed as affected by scarification treatment with sulfuric acid. Proceedings of the American Society for Horticultural Science, 51, 299-300.

11. Scott, D.H. and Ink, D.P. (1955). Treatments to hasten the emergence of seedlings of blueberry and strawberry. Proceedings of the American Society for Horticultural Science, 66, 237-242.

12. Thompson, P.A. (1968). The effect of some promoters and inhibitors on the light controlled germination of strawberry seeds; Fragaria vesca semperflorens Ehr. Physiologia Plantarum, 21, 833-841.

13. Thompson, P.A. (1969). The use of chilling and chemical treatments to promote rapid germination of strawberry achenes. Journal of Horticultural Science, 44, 201-210.

14. Toole, E.H. (1961). The effect of light and other variables on the control of seed germination. Proceedings of the International Seed Testing Association, 26, 659-673.

15. Wilson, D., Goodall, A. and Reeves, J. (1973). An improved technique for the germination of strawberry seeds. Euphytica, 22, 362-366.

PRUNUS

P. americana Marsh.	wild cherry, wild yellow plum
P. amygdalus Batsch. [P. dulcis D.A. Webb]	almond
P. armeniaca L. [Armeniaca vulgaris Lam.]	apricot
P. avium L. [P. cerasus avium L.; Cerasus avium Moench.]	sweet cherry, mazzard cherry, gean, bird cherry
P. besseyi Bailey [P. prunella Daniels; P. pumila besseyi Waugh]	Bessey cherry, western sand cherry
P. cerasia Bl.	kerassi
P. cerasifera Ehrh. [P. domestica var myrobalan L.; P. myrobalana Loisel.; P. korolkowi Vilm.]	myrobalan plum, cherry plum, mariana plum
P. cerasus L. [Cerasus vulgaris Mill.]	sour cherry, pie cherry
P. domestica L. [P. damascena Dierb.; P. communis Huds.]	plum
P. fruticosa	ground cherry
P. laurocerasus L. [Laurocerasus officinalis Roem.]	common laurel, cherry laurel
P. lusitanica L. [Laurocerasus lusitanica Roem.]	Portugal laurel
P. padus L. [P. racemosa Lam.; Padus racemosa Schneid.; Cerasus padus DC.]	European bird cherry
P. pensylvanica L. [P. persicifolia Desf.; P. montana Marsh.; P. lanceolata Willd.]	pin cherry, wild red cherry, fire cherry
P. persica Batsch. [Amygdalus persica L.; Persica vulgaris Mill.]	peach
P. salicina Lindl. [P. triflora Roxb.]	Japanese plum
P. sargentii Rehd.	Sargents cherry
P. serotina Ehrh. [Padus serotina Borkh.]	black cherry, rum cherry

P. spinosa L.	sloe, blackthorn
P. virginiana L. [P. nana DuRoi; P. demissa (Nutt.) D. Dietr.; Padus nana (Du Roi) Borkh.]	choke cherry

I. Evidence of dormancy

Seed dormancy in Prunus spp. is pronounced and dormancy-breaking treatments are required as a matter of routine. For general reviews of seed drying, storage, germination and dormancy in Prunus spp. see (10,20). Because of the stony endocarp seed dormancy is often thought to be the sole property of the seed coat, but this is not so since extracted embryos are dormant (e.g. 20,32). For example, in P. domestica dormancy is associated with the entire seed, viz. testa, cotyledons and embryo (30). Secondary dormancy can be induced if the seeds are set to germinate at high temperatures (19,20). For example, in P. avium 2 weeks at 25°C in darkness induces dormancy (32).

II. Germination regimes for non-dormant seeds

Prunus spp.

S: 20°/30°C (16h/8h); 20°C: 28d (ISTA)

TP; S: 18°-22°C: 10-14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

P. americana

Pre-chill: 1°-10°C, 4m (17)

P. armeniaca

Warm stratification: 22°C, 1-4w (5)

Malonic acid: pre-applied, 1h, 100-500 ppm (5)

P. avium

Pre-chill: 1°C, 3w (36); 1°C, 1m, with or without GA_3, pre-applied, 24h, 100-400 ppm (16); 3°C, 30w (42)

Warm stratification: 20°C, 3-16w (36); 22°C, 5m (15)

Pre-soak: 19°C, 96h, then pre-dry, 30 min (49)

GA_3: pre-applied, 24h, 100-400 ppm (16)

Removal of seed covering structures: stones cracked (23); stones cracked and seed coats removed (23)

P. cerasia

Warm stratification: 25°C, 2-4m (12)

Pre-soak: 24h, then sun dry (12)

Scarification: sulphuric acid, 15,30 min (12)

P. cerasus

Pre-chill: 3°C, 27w (42)

P. domestica

GA_3: 16 ppm, plus N-6-benzyladenine, 8 ppm (30)

Removal of seed covering structures: testa (30); excise embryo (30)

P. laurocerasus

Pre-chill: 6°C, 1,2m, with or without GA_3, pre-applied, 24h, 100 ppm (39)

Warm stratification: 18°-21°C, 1-12m (39)

GA_3: pre-applied, 24h, 100 ppm, with or without warm stratification, 18°-21°C, 1-12m (39)

P. pensylvanica

Pre-chill:.5°C, 150d (29)

Warm stratification: 20°C, 30d, then pre-chill, 5°C, 120d (29)

Potassium nitrate: pre-applied, 48h, 0.05 M, 20°C (29)

P. persica

Pre-chill: 4.4°C, 1-4w, germinate at 20°C (46); 5°C, 2w (7); 7°C, 15d, with or without seed coat (38); 10°C, 15d (38)

Warm stratification: 24°C, 15-60d (38); 24°C, 15,30d, after seed coat removal (38); 31°C (7)

Pre-wash: 5d, germinate at 20°C (46)

Removal of seed covering structures: excise embryo (46); endocarp (46)

GA_3: pre-applied, 0.3-3g/1 (7); pre-applied, 24h, 500, 1000 ppm, to pre-chilled seeds (9); co-applied, 0.02 ppm, plus benzyladenine, 1 ppm (8); co-applied, 2 ppm, plus benzyladenine, 100 ppm (8); pre-applied, 24h, 50, 100 ppm (37)

$GA_{4/7}$: pre-applied, 24h, 50, 100 ppm (37)

GA_7: (7)

Malonic acid: pre-applied, 1h, 100-5000 ppm (5)

Urea: pre-applied, 6h, 10^{-3}-$3x10^{-1}$ M, after 2d at 20°C (35)

Mercaptoethanol: pre-applied, 6h, 10^{-4}-10^{-1} M, after 2d at 20°C (35)

Mercaptoethylamine: pre-applied, 6h, 10^{-4}-10^{-1} M, after 2d at 20°C (35)

6-Benzylaminopurine: (7)

2-Chloroethylphosphonic acid: (7)

P. spinosa

Pre-chill: 3°C, 32w (34)

IV. Partly-successful dormancy-breaking treatments

P. americana

Pre-chill: 1°-10°C, 5-7m (17)

P. amygdalus

Constant temperatures: 2°C, 10°C, 15°C, 40d (45); 10°C, 19-27w (28) Removal of seed covering structures: endocarp, germinate at 10°C, 15°C, 30d (45)

P. amygdalus x P. persica

Constant temperatures: 10°C, 19-27w (28)

P. armeniaca

Pre-chill: 0°C, 10°C, 1-4w (5); 3°C, 1-3w (5); 4.5°C, 1w (5); 3°C, 27w (42)

Removal of seed covering structures: seedcoats (5)

GA_3: pre-applied, 30 min, 20-20000 ppm (5)

P. avium

Pre-chill: 1°C, 8w (36); 1°C, 2-6m, with or without GA_3, pre-applied, 24h, 100-400 ppm (16); 1°-2°C, 20-80d (22); 2°-3°C,' 5-8m (23); 2°-5°C, 120d (49); 2°-7°C, 3-6m (18); 3°C, 2-8m (15); 3°-5°C, 4m (24)

Warm stratification: 20°C, 2w, then pre-chill, 3°-5°C, 3.5m (24); 20°C, 2w, then 3°C, 27-33w (33,40,41,42,43); 20°C, 2w, then 1-3 cycles of 3°/25°C (2w/2w or 4w/2w), then 3°C, 32w (33)

GA_3: pre-applied, 24h, 100 ppm (15)

Removal of seed covering structures: crack stones (16); crack stones, then GA_3, pre-applied, 24h, 400 ppm (16)

Scarification: notch stone with emery wheel, then with or without hydrogen peroxide, pre-applied, 24h, 0.5%, then pre-chill, 2°-5°C, 120d (49)

P. besseyi

Pre-chill: 7m (1)

P. cerasia

Pre-chill: 5°C, 2-4m (12)

P. cerasifera

Pre-chill: 3°C, 27-32w (34,42)

Warm stratification: 20°C, 2w, then 3°C, 27-32w (34,42)

P. cerasus

Pre-chill: 2°-7°C, 3-7m (18)

Warm stratification: 20°C, 3w, then pre-chill, 2°-7°C, 7m (18); 20°C, 2w, then 3°C, 27w (42)

P. domestica

Pre-chill: 3°C, 27-35w (34,42)

Warm stratification: 20°C, 2w, then 3°C, 27-35w (34,42) Removal of seed covering structures: testa (30); crack stones (3); crack stones, then pre-chill, 3°-6°C, 35d (3); crack stones, then pre-chill, 3°-6°C, 28d, then GA_3, co-applied, 20-100 ppm (3); crack stones, then pre-chill, 3°-6°C, 28d, then thiourea, co-applied, 2500-10000 ppm (3); crack stones, then pre-chill, 3°-6°C, 28d, then GA_3, co-applied, 50 ppm plus thiourea, co-applied, 5000 ppm (3)

P. fruticosa

Pre-chill: 3°C, 27w (42)

Warm stratification: 20°C, 2w, then 3°C, 27w (42)

P. laurocerasus

Pre-chill: 6°C, 4-12m (39)

Warm stratification: 18°-21°C, 1,2m, then pre-chill, 6°C, 3-4m (39)

GA_3: pre-applied, 24h, 100 ppm, then pre-chill, 6°C, 4-6m (39)

P. mahaleb

Pre-chill: 3°C, 27w (42)

Warm stratification: 20°C, 2w, then 3°C, 27w (42)

P. padus

Pre-chill: 3°C, 30w (42)

Warm stratification: 20°C, 2w, then 3°C, 30w (42)

P. pensylvanica

Alternating temperatures: 5°/20°C, 5°/30°C (1d/1d, 5d/5d), 30d, then pre-chill, 5°C, 120d (29)

Warm stratification: 30°C, 30d, then pre-chill, 5°C, 120d (29)

Calcium nitrate: (2); pre-applied, 24h, 20°C, 0.02 M (29)

Ammonium sulphate: (2)

Urea: (2)

P. persica

Constant temperatures: 1°-10°C, 3.5m (6); 10°C, 19-27w (28)

Pre-chill: 35d, then GA_3, pre-applied, 24h, 20-200 ppm (9); 1°-2°C, 20-80d (22); 3°C, 2-10w (8); 3°C, 27w (42); 3°C, 2-6w, plus GA_3, co-applied, 2 ppm, plus benzyladenine, 100 ppm (8); 4.4°C, 8w, germinate at 20°C (46); 4.4°C, 1,2,4w, excise embryos or remove endocarps, germinate at 20°C (46); 5°C, 6w (7); 5°C, 34w (42); 7°C, 30-75d, with or without seed coat

(38); 10°C, 30-75d (38); 10°C, 15-75d, after seed coat removal (38); 5°C, 5-20d (37)

Warm stratification: 24°C, 75d (38); 24°C, 45-75d, after seed coat removal (38); 20°C, 2w, then 3°C, 27w (42); 20°C, 2w, then 5°C, 34w (42)

Pre-wash: 5d, then excise embryos, germinate at 20°C (46)

Removal of seed covering structures: pericarp, germinate at 1°C, 10°C, 3.5m (6); endocarp, then pre-chill, 6°C, 16-83d (4); endocarp, with or without GA_3, pre-applied, 24h, 0.3, 1 g/l (7); endocarp, then pre-chill, 5°C, 2w (7); seed coats (5); endocarp, then pre-chill, 20d (11); endocarp, then GA_3, pre-applied, 1000 ppm, then pre-chill, 20d (11)

GA_3: pre-applied, 30 min, 100-20000 ppm (5); pre-applied, 6h, 10^{-3} -$3x10^{-1}$ M, after 2d at 20°C (35); pre-applied, 24h, 100-200 ppm, germinate at 4°-6°C, 8w (26)

Thiourea: pre-applied, 6h, 10^{-3} -$3x10^{-2}$, $3x10^{-1}$ M, after 2d at 20°C (35); pre-applied, 24h, 2500-7500 ppm, germinate at 4°-6°C, 8w (26)

6-Benzyl-amino-purine: pre-applied, 24h, 60-100 ppm (37)

P. persica x P. amygdalus

Constant temperatures: 10°C, 19-27w (28)

P. serotina

Pre-chill: 3°C, 27w (42)

Storage: room temperature (dry), 37d, then pre-chill, 0°-3°C, 120d (21)

P. spinosa

Warm stratification: 20°-25°C, 2w, then pre-chill, 1°-5°C, 18w (19); 20°C, 2w, then 3°C, 32w (34)

P. virginiana

Pre-chill: 3°C, 10,16,24w, germinate at 10°/16°C, 16°/21°C, 21°/27°C, dark/light (10h/14h) (31)

V. Successful dormancy-breaking treatments

P. amygdalus

Pre-soak: 16h, then pre-chill, 0°-10°C, 3-4w (27)

Removal of seed covering structures: endocarps, germinate at 2°C, 40d (45)

P. armeniaca

Pre-chill: 3°C, 4w (5); 4°-5°C, 2-4w (5)

Warm stratification: 20°C, 2w, then 3°C, 27w (42)

Removal of seed covering structures: seed coat, then GA_3, pre-applied, 30 min, 4000, 12000 ppm (5)

P. avium

Pre-chill: 1°C, 16w (36)

Warm stratification: 20°C, 3w, then pre-chill, 2°-7°C, 6m (18); 20°C, 2w, then 3°C, 2,4,6w, then 25°C, 2w, then 3°C, 30w (42); 20°C, 2w, then 4-10 cycles of 3°/25°C (2w/2w), then 3°C, 32w (33); 20°C, 2w, then 4-8 cycles of 3°/25°C (4w/2w), then 3°C, 32w (33); 20°C, 2w, then 2 cycles of 3°/25°C (8w/2w) or (14w/2w), then 3°C, 12-16w (33)

P. domestica

Removal of seed covering structures: testa, plus GA_3, 4 ppm and N-6-benzyladenine, 2 ppm (30); testa, plus GA_3, 16 ppm and N-6-benzyladenine, 8 ppm (30); excise embryo, plus GA_3, 16 ppm and N-6-benzyladenine, 8 ppm (30)

P. persica

Pre-chill: 4.5°C, 8w (5); 5°C, 10w (7); 5°C, 30-70d, germinate at 25°C, dark (37)

Removal of seed covering structures: pericarp, then pre-soak, 16h, then remove inner seed coat, germinate at 25°C (13); pericarp, germinate at 5°C, 3.5m (6); endocarp, then warm stratification, 20°C, 2d, then pre-chill, 6°C, 25d, germinate at 20°C in light, 800 fc, 12h/d (4); endocarp, plus GA_3, pre-applied, 24h, 3 g/1 (7); endocarp, then pre-chill, 5°C, 6, 10w (7); endocarp (37); endocarp, then pre-chill, 5°C, 10-30d (37)

Thiourea: pre-applied, 6h, 10^{-1} M, after 2d at 20°C (35)

6-Benzyl-amino-purine: pre-applied, 24h, 150-250 ppm (37); pre-applied, 24h, 200 ppm, plus GA_3, 100 ppm (37); pre-applied, 24h, 200 ppm plus $GA_{4/7}$, 100 ppm (37)

P. serotina

Warm stratification: 20°C, 2w, then 3°C, 27w (42)

Prunus spp.

Excise embryo, or Pre-chill (ISTA)

Excise embryo (AOSA)

VI. Comment

An indication of the degree of dormancy within seeds of Prunus spp. is provided by the fact that the preferred method of determining viability in ISTA rules is the tetrazolium test and the second preference is the excised embryo test; germination tests following a 3 to 4 month pre-chill at 3°-5°C is the least preferred ISTA procedure. Similarly AOSA rules suggest the use of either the excised embryo test or the tetrazolium test. Details of tetrazolium and excised embryo test procedures are provided in Chapter 11. In addition, references (47) and (25) provide details of embryo culture procedures for P. americana, P. avium, P. cerasus, P. persica, and P. amygdalus, P. avium, P. domestica, P. persica, P. salicina respectively. If sufficient expertise is available (and this is essential) then gene banks may decide to follow AOSA/ISTA rules and use either tetrazolium or excised embryo tests to monitor the viability of Prunus accessions in long-term storage. Even so, it is essential that the bank is able to promote the germination of dormant seeds when this is required. There are problems with embryo culture: seedlings obtained from excised embryo culture have a very low survival percentage in field sowings (49).

Before considering germination it is necessary to point out a further problem for gene banks.

In many of the references cited here the seeds were not dried: they were extracted from the fruits and then immediately placed under conditions designed to remove dormancy. Dry intact seeds, however, may take between 40 and 60 days to become fully imbibed (46); removing the endocarp halves this time (46); soaking the seeds in water further reduces this period (46). When removing the endocarp it is possible to damage the seed mechanically which results in microbial damage in subsequent germination tests (23). However, such injury can be avoided if the seeds are dried before endocarp removal (23). In most reports endocarp removal and pre-soaking or pre-washing (to increase moisture content and/or to remove possible inhibitors to germination) were used as routine preliminary seed treatments, e.g. (8), and are suggested for gene bank use. Incidentally, it is desirable to clean seeds of all pulp and juice - by washing - as soon as possible at seed extraction (19).

Pre-chill treatments have been widely used to break dormancy, but treatment periods of six months may be necessary to promote germination. Endocarp removal can substantially reduce the pre-chill periods required for full germination, but without a long pre-chill treatment dwarf seedlings may result (14,48). A short exposure of such seedlings to low temperatures, however, overcomes this problem (14). Although pre-chill treatments between 1° and 10°C have been effective, e.g. (6,17), 3° to 5°C appear to be the most suitable constant pre-chill temperatures (5,17). A fluctuation of the pre-chill temperature between 2° and 5°C may be more promotory than a constant temperature of 3°C (49). Seeds will in fact germinate under the pre-chill treatment conditions, for example, at 2°C (45) and 10°C (28) for P. amygdalus, at 3°C for P. virginiana (31), between 1° and 10°C for P. americana (17), and at 3°C for P. armeniaca, P. avium, P. cerasifera, P. cerasus, P. domestica, P. fruticosa, P. mahaleb, P. padus, P. persica, and P. serotina (42). For this reason it is suggested that seeds undergoing pre-chill treatments be checked and seedlings removed regularly - just as in germination tests. Subsequent germination tests should not be at too high a temperature, 20°C is suggested, otherwise secondary dormancy may be induced. However, after very long pre-chill treatments the risk of secondary dormancy is reduced, in which case higher temperatures, such as an alternating temperature regime of 21°/27°C (10h/14h) (31), appear to result in greater germination than lower temperatures - 10°/16°C, 16°/21°C (10h/14h) (31), and wide amplitude alternating temperatures are also promotory - for example, 5°/25°C (16h/8h) (42). Nevertheless, since it cannot be guaranteed in advance that a pre-chill treatment has been sufficient to remove the risk of secondary dormancy being induced, germination test temperatures of 20°C or below are recommended. Of course, one alternative is to use an extended pre-chilling treatment, 3°-5°C, throughout and treat it as a very long germination test.

Although there is seldom any benefit from warm stratification treatments alone, a short treatment prior to a pre-chill treatment can be of benefit (4,19,29,32-34,39-44). The temperature recommended for the warm stratification is usually 20° to 25°C, but for P. pensylvanica 30°C has been suggested (29). The following pre-treatments have been recommended for breaking dormancy: 2 weeks' warm stratification then 11 to 27 weeks' pre-chill for P. armeniaca, P. cerasifera, P. mahaleb, and P. serotina, (42); 2 weeks' warm stratification then 12 to 34 weeks' pre-chill for P. persica (42); 2 weeks' warm stratification then 13 to 30 weeks' pre-chill for P. domestica (42); 2 weeks' warm stratification then 15 to 27 weeks' pre-chill for P. cerasus (42); 2 weeks' warm stratification then 15 to 33 weeks' pre-chill for P. avium (42); 2 weeks' warm stratification then 27 weeks' pre-chill for P. fruticosa (42); 2 weeks' warm stratification then 8 to 12 weeks' pre-chill for P. avium (44); 2 weeks' warm stratification then 11 to 18 weeks' pre-chill for P. armeniaca (19); 2 weeks' warm stratification then 18 weeks' pre-chill for P. avium, P. cerasifera, P. persica, P. spinosa and P. virginiana (19); 2 to 4 weeks' warm stratification then 18 weeks' pre-chill for P. padus, P. sargentii and P. serotina (19); 9 weeks' pre-chill for P. amygdalus, P. lusitanica (19); a 2 day pre-soak in 0.05 M calcium nitrate, then alternate between 30°C and 5°C for 30 days with 3 cycles of 5 days at each temperature, then pre-chill for 60 days at 5°C with a further 30 days at 1°-2°C, then pre-

soak in 0.05% GA_3 for 1 day, then pre-chill for a further 5 days at 5°C, and then move to 30°C for germination for 10 days, cycling between these two later regimes for as long as necessary for P. pensylvanica (29); pre-soak in 400 ppm GA_3 for 1 day, then pre-chill for 5 to 6 months for P. avium (16). If treatment with gibberellic acid is contemplated then it is worth considering treatment with thiourea as an alternative, since thiourea is reported to be a more successful dormancy-breaking agent than gibberellic acid (35). It is worth pointing out that many of the above treatments were devised for nursery sowings where uniform, rapid, germination is desired after, but not during, the pre-chill treatment. In one case (42), however, the range of pre-chill periods given above indicate the variation in time, taken to germinate at 3°C after a warm stratification treatment for the first and last seeds to germinate. A more detailed summary of these procedures has been provided elsewhere (10).

In addition to the promotion to germination which results from warm stratification prior to pre-chilling, further promotion can occur in P. avium when the pre-chilling treatment is interrupted by one or more warm stratification treatments (33,42). For the second (and any subsequent) warm stratification treatment a temperature of 25°C is more promotory than 20°C (42). The most promotory alternating warm stratification/pre-chill treatments reported are 2 weeks at 20°C, then 2 weeks at 3°C, then 2 weeks at 25°C, then 3°C until germination was complete (42), and 2 weeks at 20°C, then 4 cycles of 2 weeks at 3°C and 2 weeks at 25°C, then 3°C until germination was complete (33). In the latter case full germination was achieved after 9 months in all (33), but it is worth noting that although the intermediate treatments at 25°C increased the total proporation of seeds germinating (that is they further promoted the germination of dormant seeds) the germination of the least dormant seeds in the population was delayed (33). Similar treatments with P. cerasifera, P. domestica, and P. spinosa, however, failed to promote germination (34), although the treatments increased the proportions of viable (but ungerminated) seeds of P. cerasifera and P. spinosa at the end of the tests (34).

Although the two preceding paragraphs provide some help in suggesting suitable germination test regimes, differences between seed lots within species (42) will make it difficult for gene banks to choose an appropriate germination test regime for each Prunus accession. The following preliminary investigation at accession receipt has been suggested where sufficient seeds (and staff to carry out the work) are available (10). When the accession has been dried and placed under long-term storage conditions, randomly sample 350 seeds. Randomly divide the sub-sample into 7 groups of 50 seeds and test as follows.

1. Estimate viability using the excised embryo test or a staining test.

2. Test for germination at 3° to 5°C for up to 6 months.

3. Treat the imbibed seeds at 20°C for 2 weeks, and then test for germination at 3° to 5°C for up to 6 months.

4. Treat the imbibed seeds at 20°C for 2 weeks, then subject to 4 cycles of 2 weeks at 3° to 5°C and 2 weeks at 25°C, and then test for germination at 3° to 5°C for up to 6 months.

5,6,7. As for 2,3,4 respectively but first remove the endocarps from the dry seeds.

VII. References

1. Adams, J. (1927). The germination of the seeds of some plants with fleshy fruits. American Journal of Botany, 14, 415-428.

2. Auchmoody, L.R. (1979). Nitrogen fertilization stimulates germination of dormant pin cherry seed. Canadian Journal of Forest Research, 9, 514-516.

3. Bajwa, G.S., Sandhu, A.S. and Khajuria, H.N. (1980). Seed germination studies in plum. Research Bulletin of Marathwada Agricultural University, 4, 6-7. (From Seed Abstracts, 1981, 4, 3132.)

4. Biggs, R.H. (1966). Germination of "Okinawa" peach seeds under conditions of Florida. Proceedings of the Florida State Horticultural Society, 79, 370-373.

5. Chao, L. and Walker, D.R. (1966). Effects of temperature, chemicals, and seed coat on apricot and peach seed germination and growth. Proceedings of the American Society for Horticultural Science, 88, 232-238.

6. Crocker, W. and Barton, L.V. (1931). After-ripening, germination, and storage of certain rosaceous seeds. Contributions from the Boyce Thompson Institute, 3, 385-404.

7. Davies, F.T. (1983). Breaking seed dormancy of "Nemaguard" peach. HortScience, 18, 959.

8. Diaz, D.H. and Martin, G.C. (1972). Peach seed dormancy in relation to endogenous inhibitors and applied growth substances. Journal of the American Society for Horticultural Science, 97, 651-654.

9. Donoho, C.W. and Walker, D.R. (1957). Effect of gibberellic acid on breaking of rest period in Elberta peach. Science, 126, 1178-1179.

10. Ellis, R.H. and Hong, T.D. (1984). Prunus seed germination and storage. In Maintenance of temperate fruit collections by long-term seed storage, IBPGR, Rome (in press).

11. El-Tomi, A.L., Shawky, I., Rawash, M.A. and Makrem, M. (1978). Effect of cold stratification and gibberellic acid on seed germination of Mit Ghamr peach. Research Bulletin of the Faculty of Agriculture, Ain Shams University, 834, 1-13. (From Seed Abstracts, 1981, 4, 569.)

12. Evenari, M., Konis, E. and Zirkin, D. (1948). On the germination of some rosaceous seeds. II. The germination of Kerassi seeds. Palestine Journal of Botany, 4, 166-170.

13. Flemion, F. (1934). Dwarf seedlings from non-after-ripened embryos of peach, apple, and hawthorn. Contributions from the Boyce Thompson Institute, 6, 205-209.

14. Flemion, F. and Waterbury, E. (1945). Further studies with dwarf seedlings of non-after-ripened peach seeds. Contributions from the Boyce Thompson Institute, 13, 415-422.

15. Fogle, H.W. (1958). Effects of duration of after-ripening, gibberellin and other pretreatments on sweet cherry germination and seedling growth. Proceedings of the American Society for Horticultural Science, 72, 129-133.

16. Fogle, H.W. and McCrory, C.S. (1960). Effect of cracking, after-ripening and gibberellin on germination of Lambert cherry seeds. Proceedings of the American Society for Horticultural Science, 76, 134-138.

17. Giersbach, J. and Crocker, W. (1932). Germination and storage of wild plum seeds. Contributions from the Boyce Thompson Institute, 4, 39-52.

18. Gil, S., Guerra, D.R. and Lavandero, R.R. (1979). [Germination of cherry seeds in relation to stratification conditions.] Ciencia e Investigación Agraria, 6, 95-98. (From Seed Abstracts, 1980, 3, 2342.)

19. Gordon, A.G. and Rowe, D.C.F. (1982). Seed Manual for Ornamental Trees and Shrubs.

Forestry Commission Bulletin 59, 132 pp., HMSO, London.

20. Grisez, T.J. (1974). Prunus L. Cherry, peach, and plum. In Seeds of Woody Plants in the United States, pp. 658-673. Agricultural Handbook 450, Forest Service, U.S.D.A., Washington DC.

21. Grisez, T.J. (1976). Black cherry seeds stored 8 years. USDA Forest Service Tree Planters Notes, 27, 20-21, 24.

22. Haut, I.C. (1933). The influence of drying on the after-ripening and germination of fruit tree seeds. Proceedings of the American Society for Horticultural Science, 29, 371-374.

23. Havis, L. and Gilkeson, A.L. (1949). Starting seedlings of Montmorency cherry. Proceedings of the American Society for Horticultural Science, 53, 216-218.

24. Herrero, J. (1980). [Stratification of cherry stones.] Anales de la Estación Experimental de Aula Dei, 15, 46-53. (From Seed Abstracts, 1982, 5, 2217.)

25. Hesse, C.O. and Kester, D.E. (1955). Germination of embryos of Prunus related to degree of embryo development and method of handling. Proceedings of the American Society for Horticultural Science, 65, 251-264.

26. Hundal, P.S. and Khajuria, H.N. (1979). Effect of GA_3 and thiourea on seed germination of different varieties of peach. Indian Journal of Agricultural Sciences, 49, 417-419.

27. Kester, D.E. (1969). Almonds. In Handbook of North American Nut Trees (ed. R.A. Jaynes), pp. 309, Northern Nut Growers Association.

28. Kester, D.E. (1969). Pollen effects on chilling requirements of almond and almond-peach hybrid seeds. Journal of the American Society for Horticultural Science, 94, 318-321.

29. Laidlaw, T.F. (1983). Studies on pin cherry germination. II. The impact of temperature and temperature fluctuation in a 30 day initial treatment period preceding continuous cold stratification. Internal NOVA Report, pp. 1-61, Laidlaw Vegetation Consulting Ltd., Tofield, Alberta. (In preparation.)

30. Lin, C.F. and Boe, A.A. (1972). Effects of some endogenous and exogenous growth regulators on plum seed dormancy. Journal of the American Society for Horticultural Science, 97, 41-44.

31. Lockley, G.C. (1980). Germination of chokecherry (Prunus virginiana) seeds. Seed Science and Technology, 8, 237-244.

32. Michalska, S. (1982). Embryonal dormancy and induction of secondary dormancy in seeds of Mazzard cherry (Prunus avium L.). Arboretum Kórnickie, 27, 311-332.

33. Michalska, S. and Suszka, B. (1980). The effect of multiple induction of dormancy in Prunus avium L. seed. In Secondary dormancy of seeds of Prunus species, pp. 13-24, Polish Academy of Sciences, Institute of Dendrology, Kórnik near Poznañ, Poland.

34. Michalska, S. and Suszka, B. (1980). Effects of multiple induction of dormancy on germination of seeds of various Prunus L. species. In Secondary dormancy of seeds of Prunus species, pp. 27-40, Polish Academy of Sciences, Institute of Dendrology, Kórnik near Poznañ

35. Paul, J.R. and Biggs, R.H. (1963). Influence of gibberellic acid, mercaptoethanol, mercaptoethylamine, thiourea, and urea on the germination of 'Okinawa' peach seeds.

Proceedings of the Florida State Horticultural Society, 76, 393-397.

36. Proctor, J.T.A. and Dennis, F.G. (1968). Gibberellin-like substances in after-ripening seeds of Prunus avium L. and their possible role in dormancy. Proceedings of the American Society for Horticultural Science, 93, 110-114.

37. Rouskas, D. and Hugard, J. (1982). Possibilité d'utilisation d'une cytokinine seule ou associeé à d'autres regulateurs de croissance pour lever la dormance des graines de rosaceés fruitierès du genre Prunus. Fruits, 37, 195-202.

38. Sharma, H.C. and Singh, R.N. (1978). Effect of stratification temperature, stratification period and seed coat on seed germination of peach cultivar 'Sharbati'. Scientia Horticulturae, 9, 47-53.

39. Simancik, F. (1970). Germination of seeds of Prunus laurocerasus L. after gibberellic acid treatment at warm, cold and warm-followed-by-cold stratifications. Proceedings of the International Seed Testing Association, 35, 393-403.

40. Suszka, B. (1962). [Influence of the temperature factors on the breaking of dormancy in mazzard seeds (Prunus avium L.).] Arboretum Kórnickie, 7, 189-275.

41. Suszka, B. (1964). [The influence of method and duration of stone storage on the germination capacity of mazzard cherry (Prunus avium L.).] Arboretum Kórnickie, 9, 223-235.

42. Suszka, B. (1967). [Studies on dormancy and germination of seeds from various species of the genus Prunus L.] Arboretum Kórnickie, 12, 221-282.

43. Suszka, B. (1970). [Storage of mazzard cherry (Prunus avium L.) seeds over many years.] Arboretum Kórnickie, 15, 129-137.

44. Suszka, B. (1978). Germination of tree seed stored in a partially afterripened condition. Acta Horticulturae, 83, 181-187.

45. Therios, I.N. (1982). Effects of temperature, moisture stress and pH on the germination of seeds of almond (Prunus amygdalus 'Truoito'). Seed Science and Technology, 10, 585-594.

46. Toit, H.J.du, Jacobs, G. and Strydom, D.K. (1979). Role of the various seed parts in peach seed dormancy and initial seedling growth. Journal of the American Society for Horticultural Science, 104, 490-492.

47. Tukey, H.B. (1934). Artificial culture methods for isolated embryos of deciduous fruits. Proceedings of the American Society for Horticultural Science, 32, 313-322.

48. Tukey, H.B. and Carlson, R.F. (1945). Morphological changes in peach seedlings following after-ripening treatments of the seeds. Botanical Gazette, 106, 431-440.

49. Zielinski, Q.B. (1958). Some factors affecting seed germination in sweet cherries. Proceedings of the American Society for Horticultural Science, 72, 123-128.

PYRUS

P. amygdaliformis Vill.	wild pear
P. arbutifolia L. [Aronia arbutifolia Ell.; Mespilus arbutifolia L.]	red chokeberry
P. betulaefolia Bnge.	wild pear
P. Calleryana Decne.	wild pear
P. communis L. [P. pyraster Borkh.; P. caucasica]	cultivated pear
P. dimorphophylla Makino	wild pear

P. elaeagrifolia Pall.	wild pear
P. P. Fauriei Scheidweiler	wild pear
P. gharbiana Trabut.	wild pear
P. hondoensis Nakai & Kikuchi	wild pear
P. malus L. [Malus domestica Borkh.; Malus communis DC.; Malus sylvestris Mill.]	apple
P. mamorensis Trabut.	wild pear
P. pashia Hamet	wild pear
P. pyrifolia (Burm.) Nakai [P. serotina Rehd.; P. sinensis Hort.]	Japanese pear, Chinese pear, sand pear
P. syriaca Boiss.	wild pear
P. ussuriensis Maxim. [P. sinensis Lindl.; P. Lindleyi; P. amurensis; P. ovoidea]	Harbin pear

I. Evidence of dormancy

Seeds of Pyrus spp. extracted from fresh, mature fruits are, almost without exception, dormant and fail to germinate unless specific treatments to remove dormancy are applied (2,32). If partly dormant seeds of Pyrus spp. are tested for germination or dried at temperatures of about 20°C or above secondary dormancy is likely to be induced and prevent germination (1,11-13,16,30). This secondary dormancy may be more difficult to remove than the innate dormancy of freshly extracted seeds (13).

II. Germination regimes for non-dormant seeds

P. communis

TP; S: 18°-22°C: 10-14d (AOSA)

P. malus

TP; S: 18°-22°C: 7-10d (AOSA)

Constant temperatures: 15°C (20,25)

Potassium cyanide: co-applied, 10^{-5}-10^{-2} M, 20°C (18)

Pyrus spp.

S: 20°/30°C (16h/8h): 28d (ISTA)

III. Unsuccessful dormancy-breaking treatments

P. arbutifolia

Constant temperatures: 15°-30°C, 150d (5)

Alternating temperatures: 10°/30°C, 20°/30°C (5)

Pre-chill: 10°C, 60-120d (5)

P. betulaefolia

Pre-chill: -1°C (32); 5°C, 32d (32); -15°C, 10d (32)

P. Calleryana

Pre-chill: -6°C, 22d (32); 4°C, 4-44d, then GA_3, pre-applied, 24h, 250-1000 ppm (34)

GA_3: pre-applied, 24h, 250-1000 ppm, then pre-chill, 4°C, 4-44d (34)

P. communis

Pre-chill: 5°C, 32d (32)

P. elaeagrifolia

Pre-chill: -1°C (32); 5°C, 32d (32)

P. Fauriei

Pre-chill: -1°C (32)

P. malus

Alternating temperatures: 10°/25°C, with or without pre-soak, 20h (2)

GA_3: pre-applied, 3d, 5-200 ppm, germinate at 15°C (20); co-applied, 5-200 ppm, germinate at 15°C (20)

Removal of seed covering structures: outer coat (11); embryo, germinate at 20°/24°C in light, 10000 lux, 12h/d (35)

Kinetin: pre-applied, 3d, 1-100 ppm, germinate at 15°C (20); co-applied, 1-100 ppm, germinate at 15°C (20)

Hydrogen peroxide: pre-applied, 3d, 1-10%, germinate at 15°C (20); co-applied, 1-10%, germinate at 15°C (20)

Thiourea: pre-applied, 3d, 0.05-1%, germinate at 15°C (20); co-applied, 0.05-1%, germinate at 15°C (20)

Potassium nitrate: pre-applied, 3d, 0.05-1%, germinate at 15°C (20); co-applied, 0.05-1%, germinate at 15°C (20)

Ethephon: pre-applied, 100-1000 ppm (31); pre-applied, 3d, 0.1-1%, germinate at 15°C (20); co-applied, 0.1-1%, germinate at 15°C (20)

8-Hydroxyquinoline sulphate: pre-applied, 4-9w, 200 ppm (31)

Silver nitrate: pre-applied, 4-6w, 50-100 ppm (31)

Storage: room temperature, with or without pre-soak, 20h (2)

P. pashia

Pre-chill: -1°C (32)

P. pyrifolia

Pre-chill: 5°C, 32d (32)

P. ussuriensis

Pre-chill: -1°C, 2°C (32)

IV. Partly-successful dormancy-breaking treatments

P. amygdaliformis

Pre-chill: 2°C, 5°C, 10°C (32)

P. arbutifolia

Pre-chill: 1°C, 5°C, 60-120d (5)

P. betulaefolia

Pre-chill: 2°-10°C (32); 5°C, 32d (32)

P. Calleryana

Pre-chill: -1° to 10°C (32); -6°C, 22d, then 7°C, 10d (32); 7°C, 10d (32); 4°C, 4-24d, germinate at 20°C in light, 0.2 W m^{-2}, or dark (34); 4°C, 28-44d, germinate at 20°C, dark (34)

P. communis

Pre-chill: -1° to 7°C (32); 5°C, 32d (32)

Pre-soak: 24h, after pre-chill (32)

GA_3: pre-applied, 24h, 500 ppm, then pre-chill, 5°C, 69d (32); pre-applied, 24h, 500 ppm, then pre-chill, 5°C, 90d (23)

Dimethylsulphoxide: pre-applied, 24h, 10-100 ppm (32)

P. elaeagrifolia

Pre-chill: 2°-7°C (32)

GA_3: pre-applied, 24h, 500 ppm, then pre-chill, 5°C, 30-40d (32)

P. Fauriei

Pre-chill: 2°-10°C (32); 5°C, 32d (32)

P. hondoensis

Pre-chill: -1°C, 7°C (32)

P. malus

Constant temperatures: 1°-5°C, stored seeds (5); 5°-10°C, 10w (11)

Pre-chill: 1°-5°C, 4,10w (5); 0°C, 6w (3); 3°C, 80-120d, germinate at 20°C, 25°C, 20d (26); 5°C, 6d, germinate at 5°-28°C, 46d (1); 5°-10°C, 10w, germinate at 20°C (11); -2° to 10°C (2); in fruit, 10°-20°C, 21-112d, remove seed coats, germinate at 20°C (25); in fruit, 0°-5°C, 21,35,56d, remove seed coats, germinate at 20°C (25); in fruit, 0°C, 120d, remove seed coats, germinate at 20°C, 25°C (25); in fruit, 0°C, 8w, germinate at 15°C (19)

Warm stratification: 30°-35°C, 5d or more, germinate at 20°C (24)

Pre-soak: 48h, then pre-chill, 2°-5°C, 14-60d, germinate at 25°C (13)

Ethephon: 250-1000 ppm, after pre-chill (22)

Hydrogen cyanide: 10^{-3} -10^{-5} M (8)

GA_3: 125-500 ppm, after pre-chill (22)

Removal of seed covering structures: inner and outer coats (10); inner and outer coats, germinate at 15°C (19,20);

Scarification: concentrated sulphuric acid, 30 min, 30°C, germinate at 15°C (20); concentrated sulphuric acid, 30 min, 30°C, germinate at 15°C with GA_3, co-applied, 5-200 ppm (20); sulphuric acid, 0.8-100% (2)

P. pashia

Pre-chill: 5°-10°C (32); 4.4°C, 7-28d (7)

GA_3: pre-applied, 36h, 50, 100 mg/l, then pre-chill, 4°C, 7d (7)

Thiourea: pre-applied, 36h, 1, 2.5 g/l, then pre-chill, 4°C, 7d (7)

P. pyrifolia

Pre-chill: 2°-7°C (32); 5°C, 5m, germinate at 13°-18°C (15)

P. syriaca

Pre-chill: 5°C, 32d (32)

P. ussuriensis

Pre-chill: 5°C (32)

V. Successful dormancy-breaking teatments

P. amygdaliformis

Pre-chill: 5°C, 25d (32); 7°C (32)

P. arbutifolia

Pre-chill: 1°C, 90d, germinate at 20°C (5)

P. betulaefolia

Pre-chill: 5°C, 85d (32)

P. Calleryana

Pre-chill: 5°C, 80d (32); 5°C, 32d (32); 4°C, 28-44d, germinate at 20°C, in light, continuous, 0.2 W m^{-2} (34)

P. communis

Embryo excision (AOSA)

Pre-chill: 5°C, 130d (32); 60-90d (27)

Removal of seed covering structures: inner and outer coats, after pre-chill (32)

GA_3: pre-applied, 24h, 500 ppm, then pre-chill, 5°C, 95d (32)

P. dimorphophylla

Pre-chill: 5°C, 90d (32)

P. elaeagrifolia

Pre-chill: 5°C, 130d (32)

P. Fauriei

Pre-chill: 5°C, 80d (32)

P. gharbiana

Pre-chill: 5°C, 80d (32)

P. hondoensis

Pre-chill: 5°C, 170d (32); 2°C, 5°C (32)

P. malus

Embryo excision (AOSA, ISTA)

Constant temperatures: 5°C, 52d (1)

Pre-chill: 75-100d (27); 0°-10°C, 8-10w (4); 3°C, 80d, germinate at 15°C, 20d (26); 5°-10°C, 180d (6); 5°C, 75d, germinate at 15°C (20); 5°C, 100d, germinate at 25°C (1); 5°C, 45d, then remove seed coats, germinate at 25°C (1); 4°C, 68d, germinate at 25°C (14); 5°C, 21d, germinate at 5°C, 28d (1); 0°C, 127-190d, germinate at 5°-10°C, 24d (11); 0°C, 160-190d, germinate at 20°C, 13d (11); 1°-2°C, 56d (12); 5°C, 21d, then remove seed coats, germinate at 15°-17°C (9); in fruit, 0°C, 5°C, 112d, then remove seed coats, germinate at 20°C (25); in fruit, 0°C, 120d, then remove seed coats, germinate at 5°C, 10°C, 15°C (25); in fruit, 0°C, 11w, germinate at 15°C (19); in fruit, 0°C, 8-40w, then remove seed coats, germinate at 15°C (19)

Removal of seed covering structures: inner and outer coats, germinate at 15°C with GA_3, co-applied, 5-200 ppm (20) Storage: 20°C, 50d, then remove seed coats, pre-chill, 5°-10°C, 68d, germinate at 19°C, 4d (11)

Ethephon: co-applied, 100 mg/l, pre-chill, 40d, then excise embryo, germinate at 20°/24°C (night/day) in light, 10000 lux, 12h/d (35)

P. mamorensis

Pre-chill: 5°C, 60d (32)

P. pashia

Pre-chill: 5°C, 40d (32)

GA_3: pre-applied, 36h, 150 mg/l, then pre-chill, 4°C, 7-28d (7); pre-applied, 36h, 50, 100 mg/l, then pre-chill, 4°C, 14-28d (7)

Thiourea: pre-applied, 36h, 5 g/l, then pre-chill, 4°C, 7-28d (7); pre-applied, 36h, 1-2.5 g/l, then pre-chill, 4°C, 14-28d (7)

P. pyrifolia

Pre-chill: 5°C, 160d (32)

P. syriaca

Pre-chill: 5°C, 80d (32); 5°C, 9d (32)

P. ussuriensis

Pre-chill: 5°C, 100d (32); 7°C (32)

Pyrus spp.

Excise embryo, Pre-chill (ISTA)

VI. Comment

Seed storage and germination of apple and pear for genetic resources conservation has recently been reviewed elsewhere (9). The preferred ISTA and AOSA methods for testing viability are the tetrazolium or excised embryo tests. Chapter 11 provides details of these procedures. From the above it is apparent that pre-chill treatments have been widely applied to promote the germination of dormant seeds of Pyrus spp. In addition to conventional pre-chill treatments to the seeds, Pyrus seed dormancy can be removed by pre-chill treatments whilst the seeds remain within the fruits (19,21). However, the longer that seeds remain within fruits under such conditions the longer they take to germinate (33). There is also some evidence that pre-chilled seeds subsequently dried and stored require additional pre-chill treatments after storage before they will germinate (12). In fact this is because drying the seeds at warm temperatures induces secondary dormancy (1,11-13,16,30). It is recommended that the seeds be extracted from the fruits as soon as possible after harvest and dried at around 15°C with a high airflow rate and low relative humidity (about 10%) (9). Some intermediate storage of fruits is probably unavoidable. During this period the fruits should be stored at 5°C (9).

Although optimum temperatures for pre-chilling may vary between species (32), a common pre-chill temperature of about 5°C can be used for all species provided the treatment period is allowed to vary (32). Unfortunately the pre-chill treatment periods required to promote germination of the most dormant seed are substantial, for example 170-180 days (6,32). In general seeds of pear species require shorter pre-chill treatments than those of apple (27).

Seeds will eventually germinate during a pre-chill treatment at 5°C, for example, after 15 weeks (1) or 17-19 weeks (5). In fact the germination of dormant seeds is higher the lower the temperature, at least down to about 5°-10°C (1,11,25,26). The range of 15°-17°C has been described as the compensation temperature (1). If seeds are tested for germination at temperatures below this range germination may be reduced because of secondary dormancy. If seeds are tested for germination at temperatures below this range dormancy is likely to continue to be broken during the germination tests (1). However, the mean time to germinate will also increase (25). Thus 15°C is a sensible germination test temperature for Pyrus spp. provided seed dormancy is removed by another treatment.

Seed coats of Pyrus spp. remain permeable to moisture after drying (28). Seed coat removal aids germination of dormant seeds and is preferable to 15 or 30 minutes concentrated sulphuric acid scarification (20). However, if seed coats are removed from fresh seeds and these seeds tested for germination at 25°C then the resulting seedlings are dwarf (10). Thus a germination test temperature of 15°C should be used even if seedcoats are removed. Seed coat removal is rarely completely effective on its own, but pre-chill treatment periods can be

reduced if seed coats are removed (28). There is no effect of the seed coat during the pre-chill treatment (29), and it is both easier and preferable (to avoid fungal decay during the pre-chill) to remove seed coats from the moist seeds after the pre-chill treatment but before the germination test (29).

The following general procedure has been recommended and found to be satisfactory. Pre-chill the seeds on top of moist filter paper at 5°C for 21 days; then remove all three seed coats from each seed and place the seeds on clean moist filter paper and test for germination at 15°-17°C for 21 days; return non-deteriorated seeds which fail to germinate within this period to 5°C for a further (21 day) pre-chill treatment and then return to 15°-17°C (9).

At 15°C radicle growth may be substantially greater than hypocotyl growth (9). The optimum temperature for the former is 15°C whereas that for the latter is 25°C (17). Within the range 5°-25°C, the temperature at which embryo germination occurs does not affect subsequent radicle or hypocotyl growth rates in other environments (17). Thus to aid normal seedling development it is advisable to transfer germinating seedlings from 15°C to 20°C to enable more balanced growth of both radicle and hypocotyl (9).

Gibberellins could be provided as an additional stimulus to promoting the germination of the more dormant seeds. Pre-applied GA_3 - 24h, 500 ppm (23,32) - is suggested. This is more promotory if applied prior to the pre-chill treatment (32).

VII. References

1. Abbott, D.L. (1955). Temperature and the dormancy of apple seeds. Proceedings of the XIVth International Congress, Scheveningen, 1, 746-753.

2. Bakke, A.L., Richey, H.W. and Reeves, K. (1926). Germination and storage of apple seeds. Iowa Agricultural Experimental Station Research Bulletin, 97, 241-255.

3. Connor, H.C. (1947). The storage and germination of apple seed. Agricultural Gazette of New South Wales, 58, 414-416.

4. Crocker, W. (1928). Storage, after-ripening, and germination of apple seeds. American Journal of Botany, 15, 625-626.

5. Crocker, W. and Barton, L.V. (1931). After-ripening, germination and storage of certain rosaceous seeds. Contributions from the Boyce Thompson Institute, 3, 385-404.

6. Dall'Orto, F.A.C., Ojima, M., Rigitano, O., Scaranari, H.J. and Martins, F.P. (1978). [Germination of apple seeds.] Bragantia, 37, 83-91. (From Seed Abstracts, 1979, 2, 2645, 2885.)

7. Dhillon, B.S. and Sharma, M.R. (1978). Note on the effect of growth-regulators on the germination of wild pear seeds. Indian Journal of Agricultural Sciences, 48, 370-372.

8. Dziewanowska, K., NiedŸwiedŸI., Chodelska, I. and Lewak, S. (1979). Hydrogen cyanide and cyanogenic compounds in seeds. I. Influence of hydrogen cyanide on germination of apple embryos. Physiologie Végétale, 17, 297-303.

9. Ellis, R.H. (1982). Seed storage and germination of apple and pear. Plant Genetic Resources Newsletter, 50, 53-61.

10. Flemion, F. (1934). Dwarf seedlings from non-after-ripened embryos of peach, apple and hawthorn. Contributions from the Boyce Thompson Institute, 6, 205-209.

11. Harrington, G.T. (1923). After-ripening and germination of apple seeds. Journal of

Agricultural Research, 23, 153-161.

12. Haut, I.C. (1932). The influence of drying on the after-ripening and germination of fruit tree seeds. Proceedings of the American Society for Horticultural Science, 29, 371-374.

13. Kamiñski, W. and Zagaja, S.W. (1974). [Secondary dormancy of apple seeds. Part I. The effect of raised temperature.] Prace Instytutu Sadownictwa w Skierniewicach, A, 18, 3-8.

14. Luckwill, L.C. (1952). Growth-inhibiting and growth-promoting substances in relation to the dormancy and after-ripening of apple seeds. Journal of Horticultural Science, 27, 53-67.

15. Omura, M., Sato, Y. and Seike, K. (1978). Long term preservation of Japanese pear seeds under extra-low temperatures. In Long Term Preservation of Favourable Germ Plasm in Arboreal Crops (eds. T. Akihama and K. Nakajima), pp. 26-30, Fruit Tree Research Station, M.A.F., Fujimoto, Japan.

16. Perino, C. and Côme, D. (1977). Influence de la température sur les phases de la germination de l'embryon de pommier (Pirus malus L.). Physiologie Végétale, 15, 469-474.

17. Perino, C. and Côme, D. (1979). Conditions de germination de l'embryon de pommier et croissance de la racine et de l'hypocotyle de la plantule. Physiologie Végétale, 17, 829-838.

18. Perino, C. and Côme, D. (1981). Influence du cyanure de potassium sur la germination de l'embryon de pommier (Pirus malus L.) non dormant. Physiologie Végétale, 19, 219-227.

19. Sanada, T., Yoshida, Y. and Haniuda, T. (1980). [Studies on the method of seed storage in apple breeding. I. Suitable method for short-term storage.] Bulletin of the Fruit Tree Research Station, Series C, Morioka, 7, 1-14.

20. Sanada, T., Yoshida, Y. and Haniuda, T. (1980). [Studies on the method of seed storage in apple breeding. II. Effective method for breaking dormancy of dry stored seed.] Bulletin of the Fruit Tree Research Station, Series C, Morioka, 7, 15-31.

21. Sanada, T., Yoshida, Y. and Haniuda, T. (1981). [Studies on the method of seed storage in apple breeding. III. Differences in storage using early to late maturing cultivars and wild species.] Bulletin of the Fruit Tree Research Station, Series C, Morioka, 8, 15-29.

22. Sinha, M.M., Pal, R.S. and Awasthi, D.N. (1977). Effect of stratification and plant growth regulating substances on seed germination and seedling growth in apples. Progressive Horticulture, 9 (2), 27-30.

23. Shawky, I., Tomi, A. El., Rawash, M.A. and Makanem, M. (1978). Preliminary studies on the germination of Pyrus communis seeds. Research Bulletin, Ain Shams University, Faculty of Agriculture, 826, 12 pp. (From Seed Abstracts, 1980, 3, 1030.)

24. Thévenot, C. and Côme, D. (1978). Levée de dormance des embryons de pommier (Pirus malus L.) par traitement des graines à des températures élevées. Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences, D, 287, 1127-1129.

25. Thévenot, C., Perino, C. and Côme, D. (1983). Influence of temperature on breaking of dormancy, germination sensu stricto and growth of apple embryo: thermal optimum of these phenomena. Israel Journal of Botany, 32, 139-145.

26. Tylkowski, T. (1978). [New method for evaluating germinability of common antonovka apple seeds in a cold-warm thermal regime.] Arboretum Kórnickie, 23, 153-159.

27. United States Department of Agriculture. Some characteristics of seeds of species used as

rootstocks for tree fruits and nuts. In Seeds: The Yearbook of Agriculture 1961 (ed. A. Stefferud), pp. 550-551, USDA, Washington D.C.

28. Visser, T., (1954). After-ripening and germination of apple seeds in relation to the seed coats. Proceedings Koninklijke Nederlandse Akademie van Wetenschappen, 57, 175-185.

29. Visser, T. (1956). The role of seed coats and temperature in after-ripening, germination and respiration of apple seeds. Proceedings Koninklijke Nederlandse Akademie van Wetenschappen, 59, 211-222.

30. Visser, T. (1956). Some observations on respiration and secondary dormancy in apple seeds. Proceedings Koninklijke Nederlandse Akademie van Wetenschappen, 59, 314-324.

31. Wan, C.K. (1980). The role of ethylene in seed dormancy with particular reference to apple (Malus domestica Bork H.) seeds. Pertanika, 3, 78-81. (From Seed Abstracts, 1981, 4, 3721.)

32. Westwood, M.N. and Bjornstad, H.O. (1968). Chilling requirements of dormant seeds of 14 pear species as related to their climatic adaptation. Proceedings of the American Society for Horticultural Science, 92, 141-149.

33. Wills, R.B.H. and Scriven, F.M. (1983). Relation between germination of apple seeds and susceptibility of fruit to storage breakdown. Journal of Horticultural Science, 58, 191-195.

34. Shen, X.-S. and Mullins, M.G. (1983). Seed germination in pear rootstock. Australian Horticulture, 81, 50-51.

35. Sinska, I. and Gladon, R.J. (1984). Ethylene and the removal of embryonal apple seed dormancy. HortScience, 19, 73-75.

RUBUS

R. allegheniensis Porter	blackberry, mountain blackberry
R. axillaris Lej.	blackberry
R. bellardii Weihe & Nees [R. glandulosus Bellardi]	blackberry
R. caesius L.	dewberry
R. chamaemorus L.	bakeapple, cloudberry
R. corylifolius (Sm.)	blackberry
R. fuscus Weihe & Nees	blackberry
R. harmannii Sudre	blackberry
R. idaeus L.	European raspberry, red and yellow garden raspberry
R. insularis F. Aresch.	blackberry
R. laciniatus Willd.	cut-leaved blackberry, evergreen blackberry
R. lindebergii P.J. Muell.	blackberry
R. neglectus Peck	purple raspberry
R. nessensis W. Hall	blackberry
R. nitidus Weihe & Nees [R. divaricatus P.J. Muell.]	blackberry
R. occidentalis L.	black raspberry, black cap raspberry
R. odoratus L.	flowering raspberry, thimbleberry
R. phoenicolasius Maxim.	wineberry
R. plicatus Weihe & Nees	blackberry
R. radula Weihe ex.Boenn.	blackberry
R. scheutzii Lindeb.	
R. scissus W. Wats.	blackberry

R. sprengelii Weihe	
R. sulcatus Tratt.	
R. taeniarum Lindeb.	blackberry
R. thyrsanthus Focke	blackberry
R. vestitus Weihe & Nees	blackberry

I. Evidence of dormancy

Seeds of Rubus spp. show delayed and poor germination thereby causing substantial problems for breeders (5,7,13-15,18). Dormancy is not limited to that imposed by the seed coat alone (7,8,10,11,14). Many authors have failed to indicate the species. Where the species has been identified it is given here; the remaining information is classified as blackberry, dewberry or raspberry.

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

R. allegheniensis

Pre-chill: 0°-3°C, 5°-8°C, 10°C, 1-8m (7); plus potassium nitrate, co-applied, 0.2% (7)

Vitamin B_1: pre-applied (7)

Acetic acid: pre-applied, 6, 12h (7)

R. chamaemorus

Pre-chill: 1°C, 3-5m (15); 4°C, 7m (22); 4°C, 7m, then pre-soak, 8m (22); 4°C, 7m, then remove endocarp (22); 4°C, 7m, then kinetin, co-applied, 4.6×10^{-7} M (22)

Scarification: concentrated sulphuric acid, 0.5-2h (15)

R. corylifolius, R. fuscus

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d, 1% in saturated calcium hydroxide (14)

R. idaeus

Pre-chill: 4-5m (1); 5°C, 3m (10)

Pre-soak: (16)

Oxygen: (16)

Ether: (16)

Scarification: acid (16)

R. insularis, R. lindebergii

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d, 1% in saturated calcium hydroxide (14)

R. neglectus

Pre-chill: 2°-4°C, 5m (21)

Scarification: concentrated sulphuric acid, 4h (21)

R. phoenicolasius

Pre-chill: 2°-4°C, 5m (21)

Scarification: concentrated sulphuric acid, 1,4,5.5h (21)

R. vestitus

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d, 1% in saturated calcium hydroxide (14)

Rubus spp. - blackberry

Pre-chill: 5°C, 3m (10); 2°-4°C, 5m (21); 5°-7°C, 3m, germinate in dark (17)

Pre-soak: 1,2,3w (18)

Removal of seed covering structures: excise embryo (11)

Sodium hypochlorite: pre-applied, 1,2,3w, 1% (18)

Scarification: concentrated sulphuric acid, 30 min (18,23); concentrated sulphuric acid, 1,2,5.5h (21); concentrated sulphuric acid, 30 min, then pre-chill, 2°C, 4m (13)

Thiourea: pre-applied, 6d, 1% (23)

Rubus spp. - dewberry

Pre-chill: 2°-4°C, 5m (21)

Scarification: concentrated sulphuric acid, 1,5h (21)

Rubus spp. - raspberry

Pre-chill: 2°-4°C, 5m (21); 5°-7°C, 3m, germinate in dark (17)

Calcium chloride: (12)

IV. Partly-successful dormancy-breaking treatments

R. allegheniensis

Warm stratification: 3.5m, then pre-chill, 3°-5°C, 4m (7)

Scarification: concentrated sulphuric acid, 0.5,1,1.5h (7); concentrated sulphuric acid, 10-60 min, then pre-chill, 3°-5°C, 3m (7); concentrated sulphuric acid, 50,60 min, then pre-chill, 1°-5°C, 1-3m (6)

R. axillaris, R. bellardii, R. caesius

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d, 1% in saturated calcium hydroxide (14)

R. chamaemorus

Pre-chill: 1°C, 6-13m (15); 4°C, 7m, then remove endocarp and nick seed coat (22); 4°C, 7m, then GA_3, co-applied, $5.7x10^{-7}$-$5.7x10^{-5}$ M (22); 4°C, 7m, then kinetin, co-applied, $4.6x10^{-6}$, $4.6x10^{-5}$ M (22); 4°C, 7m, then pre-soak, 6h, 23°C, then remove endocarp and nick seed coat (22)

Light: 665 lux, 12h/d, at 18°C (22)

R. hartmannii

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d, 1% in saturated calcium hydroxide (14)

R. idaeus

Warm stratification: 25°C, 4-6w, then pre-chill, 0°C, 7-8w (4); 15°-20°C, 140d (16)

Calcium hypochlorite: pre-applied, 4d, 1% (4)

Removal of seed covering structures: endocarp, then scarify, concentrated sulphuric acid, 2h, germinate at 18°-23°C in dark (16)

Scarification: concentrated sulphuric acid, 15-30 min, then pre-chill, 1°-4°C, 1-3m (6); concentrated sulphuric acid, 20 min, then calcium hypochlorite, pre-applied, 7d, 3% (20)

R. laciniatus

Pre-chill: 4-5m (1)

R. neglectus

Scarification: concentrated sulphuric acid, 1,2h (21)

R. nessensis, R. nitidus

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d, 1% in saturated calcium hydroxide (14)

R. occidentalis

Warm stratification: 20°/30°C (night/day), 3m, then pre-chill, 5°C, 3m (10)

Sodium hypochlorite: pre-applied, 6d, 1%, then pre-chill, 2°-3°C, 5m (18)

Scarification: concentrated sulphuric acid, 15,20 min, then pre-chill, 1°-4°C, 1-3m (6); concentrated sulphuric acid, 20 min, then pre-chill, 2°-3°C, 5m (18)

R. odoratus

Pre-chill: 4-5m (1)

R. phoenicolasius

Scarification: concentrated sulphuric acid, 2h (21)

R. plicatus, R. radula, R. scheutzii, R. scissus, R. sprengelii, R. sulcatus, R. taeniarum, R. thyrsanthus

Scarification: concentrated sulphuric acid, 60 min, then calcium hypochlorite, pre-applied, 5d,

1% in saturated calcium hydroxide (14)

Rubus spp. - blackberry

Pre-chill: 0°-2°C, 5-6m (2); 3°C, 4-5m (11); 4°-7°C, 3m, light, germinate in light (17)

Warm stratification: 20°/30°C (16h/8h), 3m, then pre-chill, 5°C, 3m (10)

Potassium hydroxide: pre-applied, 30-60 min, 2 M (14)

Sodium hypochlorite: pre-applied, 1,2w, 1%, then warm stratification, 21°-24°C, 7w, then pre-chill, 2°-3°C, 3m (18) Calcium hypochlorite: pre-applied, 6d, 1% (23)

Scarification: concentrated sulphuric acid, 30 min (14); concentrated sulphuric acid, 2-4h (2); concentrated sulphuric acid, 4h (21); concentrated sulphuric acid, 1,3h, at 0°C, then pre-chill, 2°C, 4m (13); concentrated sulphuric acid, 0.5h, then warm stratification, 21°-24°C, 7w, then pre-chill, 2°-3°C, 3m (18); concentrated sulphuric acid, 0.5-2h, then calcium hypochlorite, pre-applied, 5d, 0.5, 1% in saturated calcium hydroxide (14); concentrated sulphuric acid, 30 min, then calcium hypochlorite, pre-applied, 6d, 1%, then pre-chill, 2°-4°C, 6w (23); concentrated sulphuric acid, 3h, then pre-soak, 30 min, oxygenated water, germinate at 20°/10°C in light, 14h/d (25); concentrated sulphuric acid, 3h, then pre-soak, 30 min, oxygenated 10^{-5} M GA, germinate at 20°/10°C in light, 14h/d (25); concentrated sulphuric acid, 3h, then pre-soak, 30 min, oxygenated 10^{-7} M benzyladenine, germinate at 20°/10°C in light, 14h/d (25)

Rubus spp. - dewberry

Scarification: concentrated sulphuric acid, 2,4h (21)

Rubus spp. - dewberry

Rubus spp. - raspberry

Pre-chill: -2°C, 6m (5); 5°-7°C, 3m, light, germinate in light (17); 3°-4°C, 8w (8); 6m, then calcium hypochlorite, pre-applied, 4d, 1% in saturated calcium hydroxide (19)

Warm stratification: 15°C, 8w, light, 16h/d (8); 15°C, 6w, light, 16h/d, then pre-chill, 3°-4°C, 2w (8); 15°C, 4w, light, 16h/d, then pre-chill, 3°-4°C, 4w (8); 15°C, 2w, light, 16h/d, then pre-chill, 3°-4°C, 6w (8); 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18)

Pre-soak: 1w, then pre-chill, 2°-3°C, 3m (18); 1w, then warm stratification, 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18)

Light: daylight supplemented by mercury vapour lamp, 16h/d (8)

Sodium hypochlorite: pre-applied, 6,9d, 0.5, 1% (8); pre-applied, 1w, then pre-chill, 2°-3°C, 3m (18); pre-applied, 1w, then warm stratification, 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18)

Potassium hydroxide: (12)

GA_3: (12)

Scarification: notch (3); sandpaper (5); sulphuric acid (12); concentrated sulphuric acid, 20-50 min (5); concentrated sulphuric acid, 10-30 min (8); concentrated sulphuric acid, 50 min (24); concentrated sulphuric acid, 1-4h (21); concentrated sulphuric acid, 20 min, then pre-chill, 2°-3°C, 3m (18); concentrated sulphuric acid, 20 min, then warm stratification, 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18); concentrated sulphuric acid, 10,20 min, then sodium

hypochlorite, pre-applied, 6,9d, 0.5, 1% (8); concentrated sulphuric acid, 20 min, then sodium hypochlorite, pre-applied, 6d, 0.5%, then pre-chill, 3°-4°C, 4-10w (8); concentrated sulphuric acid, 20 min, then sodium hypochlorite, pre-applied, 6d, 1%, then GA_3, co-applied, 100-1000 ppm (8); concentrated sulphuric acid, 20 min, then sodium hypochlorite, pre-applied, 6d, 1%, then pre-chill, 3°-4°C, 4,6w, then GA_3, co-applied, 100-1000 ppm (8); concentrated sulphuric acid, 20 min, then calcium hypochlorite, pre-applied, 6d, 1, 2% in saturated calcium hydroxide (8); concentrated sulphuric acid, 20 min, then calcium hypochlorite, pre-applied, 6d, 1, 2% in saturated calcium hydroxide, then pre-chill, 3°-4°C, 4,6w (8); concentrated sulphuric acid, 20 min, then thiourea, pre-applied, 6d, 0.5-2% (8); concentrated sulphuric acid, 20 min, then thiourea, pre-applied, 6d, 0.5-2% in saturated calcium hydroxide (8); concentrated sulphuric acid, 20 min, then thiourea, pre-applied, 6d, 1% in saturated calcium hydroxide, then GA_3, co-applied, 500 ppm (8)

V. Successful dormancy-breaking treatments

R. idaeus

Warm stratification: 20°/30°C (night/day), 3m, then pre-chill, 5°C, 3m, germinate at 20°/30°C (night/day) (10)

R. occidentalis

Warm stratification: 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18)

Sodium hypochlorite: pre-applied, 6d, 1%, then warm stratification, 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18)

Scarification: concentrated sulphuric acid, 20 min, then warm stratification, 21°-24°C, 2m, then pre-chill, 2°-3°C, 3m (18)

Rubus spp. - blackberry

Removal of seed covering structures: endocarp, then pre-chill, 2°-3°C, 5m (9)

VI. Comment

It should be clear from the long list of only partly successful dormancy-breaking treatments which incorporate several stimulatory treatments that the promotion of germination of dormant seeds of Rubus spp. is difficult and rarely sufficient to promote full germination. For this reason the topographical tetrazolium test has been recommended as essential for assessing seed viability in Rubus spp. (19): no combined dormancy-breaking and germination test procedure has yet been devised which will promote the germination of all seeds of all Rubus spp., or which will promote the germination of all seeds of all cultivars within a single species.

Single application of many dormancy-breaking agents such as pre-chilling, alternating temperatures, light, potassium nitrate, thiourea and kinetin are generally ineffective (7,8,10,17,21,22), but have some effect when applied to seeds previously scarified (4,6-9,13,18,20,22,23). Gibberellins, sodium hypochlorite, calcium hypochlorite or prolonged warm stratification applied singly can promote the germination of intact seeds of Rubus spp. (4,7,8,22), but their effectiveness is greatly increased when applied to seeds previously scarified (8,14,18,20,23). However, scarification alone is either unsuccessful (11,13,15,16,22,23) or has only limited effect (2,5-8,14,16,18,20,21,24). Sulphuric acid (concentrated) scarification gives variable results depending upon treatment duration, seed lots, and species. For the majority of raspberry species a 20-30 minute treatment is safe and partly effective (5,6,8,18,20), but some seed lots have a requirement for 1-4 hours treatment for maximum promotion (21). For the majority of blackberry species 30 minute to 2 hour

treatments are optimal (6,7,14), although some require 2-4 hours (2,13,21) whilst 3 hour duration treatments may kill seeds in other blackberry seed lots (13). Consequently, to avoid damage to the seeds, it is suggested that the duration of the concentrated sulphuric acid scarification should not exceed 20 minutes.

It is quite clear that gene banks will have to use multifactor dormancy-breaking treatments to promote the germination of seeds of Robus spp. The following multifactor treatment has been recommended and, though not completely successful, is suggested as the most satisfactory treatment currently available. Scarify the seeds in concentrated sulphuric acid for 20 minutes, then soak for 6 days in a 1% solution of calcium hypochlorite dissolved in saturated calcium hydroxide, then pre-chill the seeds at 3°-5°C for 6 weeks, and finally test for germination at 20°/30°C (16h/8h) in the light on the top of filter papers moistened with 500 ppm GA_3 (8).

The following investigations are suggested to those attempting to improve this procedure: the effect of replacing the calcium hypochlorite treatment with a shorter duration hydrogen peroxide treatment; the effect of an additional warm stratification treatment prior to pre-chilling; the effect of alternating warm stratification/pre-chilling treatments - see section on Prunus; and the effect of co-application of gibberellins during pre-chilling as well as during the germination test.

VII. References

1. Adams, J. (1927). The germination of the seeds of some plants with fleshy fruits. American Journal of Botany, 14, 415-428.

2. Afanasiev, M. (1942). Propagation of trees and shrubs by seeds. Oklahoma Agricultural Experiment Station, Circular 106, 43 pp.

3. Baumeister, G. (1959). [A method for accelerating germination in Rubus seed. Short communication.] Zuchter, 29, 185-187. (From Horticultural Abstracts, 1959, 29, 3324.)

4. Cadman, C.H. and Anderson, K.S. (1954). Report of the Scottish Horticulture Research Institute for 1953-1954, pp. 17-19.

5. Fejer, S.O. and Spangelo, L.P.S. (1971). Seed germination in the red raspberry. Fruit Varieties and Horticultural Digest, 25, 75-76.

6. Heit, C.E. (1966). Propagation from seed. VII. Germinating six hardseeded groups. American Nurseryman, 125, 10-12, 37, 39-41, 44-45.

7. Heit, C.E. and Slate, G.L. (1950). Treatment of blackberry seed to secure first year germination. Proceedings of the American Society for Horticultural Science, 55, 297-301.

8. Jennings, D.L. and Tulloch, B.M.M. (1965). Studies on factors which promote germination of raspberry seeds. Journal of Experimental Botany, 16, 329-340.

9. Kerr, E.A. (1954). Seed development in blackberries. Canadian Journal of Botany, 32, 654-672.

10. Krepting, L.W. and Roe, E.I. (1949). The role of some birds and mammals in seed germination. Ecological Monographs, 19, 269-286.

11. Lasheen, A.M. and Blackhurst, H.T. (1956). Biochemical changes associated with dormancy and after-ripening of blackberry seed. Proceedings of the American Society for Horticultural Science, 67, 331-340.

12. Misic, P.D. and Belic, M.V. (1973). [Methods for improving the germination of red

raspberry seeds.] Jugoslovensko Vocarstvo, 7, 153-156. (From Horticultural Abstracts, 1975, 45, 1562.)

13. Moore, J.N., Brown, G.R. and Lundergan, C. (1974). Effect of duration of acid scarification on endocarp thickness and seedling emergence of blackberries. HortScience, 9, 204-205.

14. Nybom, H. (1980). Germination in swedish blackberries (Rubus L. subgen. Rubus). Botaniska Notiser, 133, 619-631.

15. Rantala, E.-M. (1976). Sexual reproduction in the cloudberry. Annales Agriculturae Fenniae, 15, 295-303.

16. Rose, R.C. (1919). After-ripening and germination of seeds of Tilia, Sambucus, and Rubus. Botanical Gazette, 67, 281-308.

17. Scott, D.H. and Draper, A.D. (1967). Light in relation to seed germination of blueberry, strawberries and Rubus. HortScience, 2, 107-108.

18. Scott, D.H. and Ink, D.P. (1957). Treatment of Rubus seeds prior to after-ripening to improve germination. Proceedings of the American Society for Horticultural Science, 69, 261-267.

19. Sokolova, V.A. and Kichina, V.V. (1971). [Increasing the germination rate of raspberry seeds.] Vestnik Sel'skokhozyaistvennoi Nauki, 16, 87-90. (From Horticultural Abstracts, 1972, 42, 3289.)

20. Topham, P.B. and Carmichael, E. (1972). The improvement of seedling production in two subfertile raspberry crosses following the application of growth substances. Journal of Horticultural Science, 47, 5-9.

21. Tukey, H.B. (1924). Studies of fruit seed storage and germination. New York State Agricultural Experiment Station Bulletin, 509, 3-19.

22. Warr, H.J., Savory, D.R. and Bal. A.K. (1979). Germination studies of bakeapple (cloudberry) seeds. Canadian Journal of Plant Science, 59, 69-74.

23. Wenzel, W.G. and Smith, C.W.J. (1975). Germination tests with blackberry seeds. Angewandte Botanik, 49, 11-14.

24. Williams, D.D. (1956). Sulphuric acid treatment of raspberry seed. Canadian Horticulture Council Report 1955, 60 pp.

25. Lundergan, C.A. and Carlisi, J.A. (1984). Acceleration of the reproductive cycle of the cultivated blackberry. HortScience, 19, 102-103.

CHAPTER 63. RUBIACEAE

The Rubiaceae comprise about 5000 species of mainly trees and shrubs within about 400 genera. The two most important genera are Coffea which provides beverages and Cinchona which provides medicinal products. The fruits are capsules, berries or drupes. Seed storage behaviour in the Rubiaceae is now believed to be orthodox. For example, Crucianella, Hymenopogon, and Phyllis spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank. Information on seed storage behaviour in Cinchona and Coffea spp. is discussed in subsequent sections of this chapter.

SEED DORMANCY AND GERMINATION

The seeds are usually non-endospermic; seed size varies considerably from very small in the Cinchonoideae tribe to the very much larger "bean" of the Coffeoideae tribe; dormancy is a common problem. Detailed information on seed dormancy and germination is provided in this chapter for the genera Cinchona and Coffea, and a brief summary of further information on dormancy and germination in the Rubiaceae is provided in Table 63.1. In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 16°C and 26°C with light applied for 12h/d. If full germination does not occur and a trend in germination response to constant temperatures is apparent then test further samples of seeds at more extreme constant temperatures. For example, if a greater proportion of seeds germinates at 16°C than at 26°C then test further samples of seeds at constant temperatures of 6°C and 11°C with light applied for 12h/d. If full germination does not occur and there is no significant difference between the proportions of seeds germinating at 16°C and 26°C then test a further sample of seeds at a constant temperature of 21°C with light applied for 12h/d.

If the above constant temperature regimes do not result in full germination then the second step of the algorithm is to test a further sample of seeds in an alternating temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature of each cycle.

TABLE 63.1 Summary of germination test recommendations for species within the Rubiaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Galium boreale L.	TP	20°/30°C		light, pre-chill, 4w	M&O
Ixora javanica L.	S	25°-30°C	42d	light, continuous	CHML

CINCHONA

C. josephiana Wedd. quinine
C. ledgeriana Moens ex. Tremen quinine

I. Evidence of dormancy

Although seeds of Cinchona spp. are reported to germinate readily in nursery or glasshouse sowings (1,3-6), in some cases seeds continue to germinate and emerge 2 years after sowing

(5) suggesting that the seeds are dormant. Moreover in laboratory tests it is reported that the seeds only germinate in particular environments (3,6). Attempts cannot be made to remove dormancy by after-ripening since the seeds are reported to lose viability rapidly at room temperature (2,3,5,6), though at 5-8% moisture content and -4°C no loss in viability was observed over a 4 year storage period (3).

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

C. josephiana

Light: dark (6)

C. ledgeriana

Constant temperatures: 15°C (3)

Light: sunlight (4)

IV. Partly-successful dormancy-breaking treatments

C. ledgeriana

Constant temperatures: 30°C (3)

V. Successful dormancy-breaking treatments

C. josephiana

Light: diffuse light (6)

C. ledgeriana

Constant temperatures: 20°C, 25°C (3); 22°C (4)

Alternating temperatures: 10°/30°C, 15°/30°C, 20°/30°C (16h/8h) (3)

VI. Comment

Germination of seeds of Cinchona spp. requires light (6), but at low illuminance (4). It is suggested that the seeds be tested for germination on top of filter papers in petri dishes at 25°C (3) in diffuse light - see Chapter 6. An alternating temperature regime of 20°/30°C (16h/8h) can be used as an alternative to a constant 25°C: both regimes were equally successful in promoting germination (3) with no advantage of the alternating temperature regime (3). Germination tests should be continued for at least 42 days (6).

VII. References

1. Anonymous (1939). Quinine seed was germinated readily at the experiment station. Puerto Rico Agricultural Experiment Station, Report 1938, 27-29.

2. Anonymous (1940). Cinchona seeds lose viability rapidly. Puerto Rico Agricultural Experiment Station, Report 1940, 18-19.

3. Barton, L.V. (1947). Effect of different storage conditions on the germination of seeds of Cinchona ledgeriana Moens. Contributions from the Boyce Thompson Institute, 15, 1-10.

4. Morrison, B.Y. (1943). Quinine from seed. Agriculture in the Americas, 3, 131-133. (From Horticultural Abstracts, 1943, 13, 1533.)

5. Portères, R. (1948). Competition ou entr'aide au sein de l'espèce et de la race. Le cas des germinations de Cinchona. Comptes Rendus de l'Académie des Sciences, 227, 1114-1115.

6. Thomas, A.S. (1946). Cinchona in Uganda. Empire Journal of Experimental Agriculture, 14, 75-84.

COFFEA

C. arabica L. arabica	coffee
C. canephora Pierre ex Froehner [C. robusta Linden; C. laurentii De Wild.; C. maclaudii A.Chev.;	robusta coffee
C. arabica L. var. stuhlmannii Warb.; C. bukobensis Zimm.; C. welwitschii Pierre ex De Wild.;	
C. ugandae Cramer; [C. kouilouensis Pierre ex De Wild.; C. quillou Wester]	
C. excelsa A.Chev. [C. dewevrei De Wild. & Th. Dur. var. excelsa A. Chev.]	
C. liberica Bull ex Hiern [C. abeokutae Cramer; C. klainei Pierre ex De Wild.]	liberica coffee
C. racemosa Lour	racemosa coffee
C. stenophylla G. Don	

I. Evidence of dormancy

A discussion of the seed storage characteristics (orthodox) of Coffee spp. is provided in the comment since these have provide substantial problem in the past. Delayed and/or low germination of under-ripe or freshly harvested seeds (3,9,30) or intact seeds (1-3,14,16-19,22,33,34) is reported frequently. A short period of after-ripening at room temperature (8-32 days) can increase the proportion of seeds germinating and reduce the time taken to germinate (18,19). Dried seeds can show particularly delayed and erratic germination (10,15,29,31). The delay to germination caused by drying has been described as secondary dormancy in Coffea spp. (29). An inhibitor to germination is reported to be present in the endocarps of the seeds (29), but others disagree (19).

II. Germination regimes for non-dormant seeds

Coffea spp.

Constant temperatures: 25°C (14,18,19,32); 30°C (6,8,20,22,26,28,33,34)

Alternating temperatures: 18°/30°C (20)

III. Unsuccessful dormancy-breaking treatments

C. arabica

Removal of seed covering structures: exocarp, mesocarp, endocarp and testa (12)

Pre-soak: 40°-45°C, 5h (16)

GA_3: pre-applied, 48h, 10-1000 ppm (24); pre-applied, 48h, 0.5×10^{-3}, 10^{-3} M, germinate at 30°C in light, 5400 lux (26); pre-applied, 48h, 10^{-4} M (28)

Light: white, continuous (28)

Biuret: co-applied, 2.5% (25); pre-applied, 0.5-2.5% (25)

Abscisic acid: pre-applied, 48h, 10^{-4} M (28)

IV. Partly-successful dormancy-breaking treatments

C. arabica

Pre-soak: 48h (16)

Pre-wash: (29)

Hydrochloric acid: pre-applied, 48h, 1 N (16)

Sulphuric acid: pre-applied, 48h, 1 N (16)

Boric acid: pre-applied, 48h, B at 10 ppm (16)

Pentothenic acid: pre-applied, 48h, 0.1% (16)

Ascorbic acid: pre-applied, 48h, 0.1% (16)

Nicotinic acid: pre-applied, 48h, 0.1% (16)

Riboflavin: pre-applied, 48h, 0.1% (16)

Inositol: pre-applied, 48h, 0.1% (16)

Thiourea: pre-applied, 48h, 1% (16)

Indoleacetic acid: pre-applied, 48h, 100 ppm (16)

Indolepropionic acid: pre-applied, 48h, 100 ppm (16)

Naphthaleneacetic acid: pre-applied, 48h, 100 ppm (16)

GA_3: pre-applied, 48h, 100 ppm (16)

Copper sulphate: pre-applied, 48h, Cu at 10 ppm (16)

Manganese chloride: pre-applied, 48h, Mn at 10 ppm (16)

Zinc sulphate: pre-applied, 48h, Zn at 10 ppm (16)

Pyridoxine: pre-applied, 48h, 0.1% (16)

Removal of seed covering structures: endocarp, test for 18d (29); endocarp, test for 28d (1)

C. canephora pH: 4-6 (18,20)

Removal of seed covering structures: part of endocarp over embryo (19); part of endocarp from distal half of seed (19); part of endocarp from flat side of seed (19)

V. Successful dormancy-breaking treatments

C. arabica

Constant temperatures: 28°-30°C (33); 30°C (22,34); 30°C in dark (28)

Pre-soak: 2,4d, at 24°C (18); 24h, then warm stratification (35)

Pre-wash: 6h (16)

Light: dark, continuous (28)

Removal of seed covering structures: endocarp (2,3,5,9,17,18, 19,22,24,28,29,31,33,34); endocarp, then pre-soak, 24h (32)

Kinetin: pre-applied, 48h, 10^{-4}, 10^{-5} M (28)

Thiamine: pre-applied, 48h, 0.1% (16)

Folic acid: pre-applied, 48h, 0.1% (16)

Ferrous sulphate: pre-applied, 48h, Fe at 10 ppm (16)

C. canephora

Constant temperatures: 24°-34°C in dark (20); 28°-33°C (33); 30°C (22)

Alternating temperatures: 18°/30°C (20)

Oxygen: above 21% (19)

Removal of seed covering structures: endocarp (10,18,19,21,22,23,33); endocarp, then pre-soak, 24h (32)

Pre-soak: 2,4d, at 24°C, germinate at 30°C (18)

C. excelsa

Removal of seed covering structures: endocarp, germinate at 28°-33°C (33)

C. liberica

Pre-soak: 24h, then warm stratification (35)

Removal of seed covering structures: endocarp, germinate at 28°-33°C (33)

C. stenophylla

Removal of seed covering structures: endocarp, germinate at 28°-33°C (33)

VI. Comment

Sand, paper towels (test between papers) and filter papers (test on top in petri dishes) are all suitable substrata for germination tests of Coffea spp. (4,5,8,10,14,17,19,21,22,29,31,33). A high level of moisture in the germination test substratum can delay germination (22), although coffee seeds will germinate satisfactorily in aerated water provided their endocarps have been removed (18,19). This suggests that oxygen can be a limiting factor in germination tests. If sand is used for germination tests a suitable moisture content for the sand is 10% by volume (22).

Fresh, intact, coffee seeds require between 60 and 110 days to germinate (14,18,19). The removal of the endocarps increases the proportion of seeds which will germinate and reduces the time taken to germinate by between 14 to 21 days (2,24,31) and 28 to 42 days (18,19,21). The endocarp is reported to be impermeable to water (9), but it seems more likely that the endocarp delays the uptake of moisture rather than preventing it completely. Minimum germination test periods for fresh seeds from which the endocarps have been removed is 21

days for C. arabica, 43 days for C. canephora, 46 days for C. excelsa and C. Stenophylla, and 53 days for C. liberica (33). Endocarps should be removed by hand: mechanical removal is damaging (12).

Drying the seeds results in erratic germination in subsequent tests (10,15,29,31). Even with endocarp removal dried seeds take longer to germinate than fresh seeds (15,31): the cause of this appears to be a delay to imbibition in the dried seeds (14). Dried seeds from which endocarps have been removed require 90 days for germination (5,7). Even so, the total proportions of seeds germinating may be low. The previously dried seeds which remain ungerminated at the end of germination tests are reported to be dormant (29). Treatment with kinetin can be promotory in such cases (28), but gibberellin and light treatments are reported to inhibit coffee seed germination (24,26,28). 29°C is reported to be the most suitable constant temperature for seed germination (20).

Consequently it is suggested here that coffee seeds be tested for germination, after the endocarps have been removed, at 30°C in the dark for approximately 100 days, or more. Where dormancy is a problem it is suggested that a 48 hour pre-treatment in 10^{-4} or 10^{-5} M kinetin be provided.

It seems necessary to add some notes at this point concerning the seed storage behaviour of Coffea spp. Despite a number of reports to the contrary, Coffea spp. show orthodox seed storage behaviour. That is, for air-dry seeds longevity is increased by reducing seed moisture content (3-8,11,18,20,21,31,33) - although of course, as with seeds of other orthodox species, in the presence of sufficient oxygen coffee seed survival periods at moisture contents close to fully imbibed can be substantial and greater than those at intermediate moisture contents (31) - see Chapter 1. One way in which we are able to demonstrate orthodox seed storage behaviour in Coffea spp. is to calculate the value of the constant C_W of the improved viability equation - see the 1982 Report - which describes the relative improvement to longevity obtained by reducing seed moisture content. The value obtained (3.5, calculated from reference 7) is similar to that for onion (Allium cepa L.).

Nevertheless there are a number of problems. Although one report has shown that seed moisture content can be reduced to 5% without damage to the seeds (8), certain other reports suggest damage to seeds dried below 8% moisture content (5,6,21,27). It is possible that many of these reports are due to failure of the very dry seeds to imbibe and germinate within the duration of the germination test; that is germination test periods may be adequate for fresh and partly-dried seeds but inadequate for the very dry seeds. For example, within the range of 5 to 10% seed moisture content storage at the highest moisture content was reported to be preferable to storage at lower moisture contents in one investigation, but this conclusion was based on germination tests which were concluded after only 8 days (8).

Problems, however, have also been reported at low storage temperatures. For example, for coffee seeds at 13 to 15% moisture content a storage temperature of 2° to 5°C has been reported to result in poorer germination than storage at 10°C (8,31). Moreover, dry seeds stored at -18°C for 2 months or -10° to -16°C for 10 days showed reduced germination (33), whilst seeds dried to 5 to 7% moisture content and stored at -19° to -15°C for 5 months failed to germinate at all in a subsequent germination test (21).

Thus whilst we are confident that Coffea spp. show orthodox seed storage behaviour, storage under IBPGR preferred conditions cannot be recommended until the above problems have been satisfactorily resolved. We suggest that the following factors should be taken into account when attempting to resolve these problems. First, germination test environment and duration must be sufficient to enable the very dry seeds to germinate. This means that endocarp removal and a very long test duration are essential. Secondly, when seeds are dried and moisture content determined the experimeter must ensure that embryo moisture content

(that is, not just moisture content of the whole seed) is below the levels at which freezing damage would be expected. Either allow seed moisture content to equilibrate throughout the seeds after drying by maintaining at around 15°C for some time before storing at sub-zero temperatures, or remove the seed covering structures before drying and dry and store the embryos only. Finally, it may be advisable to humidify the very dry seeds prior to germination tests.

VII. References

1. Anonymous (1951). Studies in the germination of coffee seeds. Fourth Annual Report of the Research Department of the Indian Coffee Board (1950-1951), Bulletin No. 4, 30-32.

2. Anonymous (1952). Studies in the germination of coffee seeds. Fifth Annual Report of the Research Department of the Indian Coffee Board (1951-1952), Bulletin No. 5, 46-49.

3. Anonymous (1953). A semente de café. Bol. Super. Serv Café Sao Paulo, 28, 27-28. (From Horticultural Abstracts, 1953, 23, 4603.)

4. Arcila-Pulgarin, J. (1977). Influence of drying temperature on the germination of coffee seeds. Indian Coffee, 41, 261,264.

5. Bacchi, O. (1955). [Sun-drying of coffee seeds.] Bragantia, 14, 225-236.

6. Bacchi, O. (1956). [Further experiments on sun-drying coffee seed.]

Bragantia, 15, 83-91.

7. Bacchi, O. (1958). [Seed storage study. IV. Coffee.] Bragantia, 17, 261-270.

8. Bendana, F.E. (1962). The physiology of coffee seeds. I. Problems related to storage. Coffee, Turrialba, 4, 73-75.

9. Bendana, F.E. (1962). The physiology of coffee seeds. II. Factors retarding germination, parchment. Coffee, Turrialba, 4, 76-79.

10. Bouharmont, P. (1971). La conservation des graines de caféiers destineés à la multiplication au Cameroun. Café Cacao Thé, 15, 202-210.

11. Carelli, M.L.C. and Monaco, L.C. (1977). [Racemosa coffee seed conservation.] Bragantia, 36, 31-34.

12. Coste, R. (1955). Les caféiers et les cafés dans le monde. In Les Caféiers, pp. 66. Larose, Paris.

13. Couturon, E. (1980). Le maintein de la viabilité des graines de caféiers par le controle de leur teneur en eau et de la temperature de stockage. Café Cacao Thé, 24, 27-32.

14. Goldbach, H. and Vizcarra, A.H. (1980). Some observations on tetrazolium-testing of coffee seed (Coffea arabica and C. canephora). Turrialba, 30, 223-226.

15. Gonzalez, J.A. (1973). Germinacion de la semilla de Coffea arabica variedades Bourbon y pacas almacenada en polietileno a distintas humedades. Instituto Salvadoreno de Investigaciones del Cafe. Boletin Informativo Suplemento No. 28, 24 pp.

16. Gopal, N.H. and Ramaiah, P.K. (1971). Studies on hastening of germination of arabica coffee seed and further growth of the seedlings. I. Hastening of germination. Indian Coffee, 35, 459-464.

17. Gopal, N.H. and Ramaiah, P.K. (1972). Studies on the physiology of germination of coffee seed. I. Observations on sprouting. Journal of Coffee Research, 2, 14-19.

18. Huxley, A. (1962). Physiological and ecological investigation with coffee seeds and seedlings in Uganda. Ph.D. Thesis, University of Reading.

19. Huxley, P.A. (1964). Some factors which can regulate germination and influence viability of coffee seeds. Proceedings of the International Seed Testing Association, 29, 33-60.

20. Huxley, P.A. (1964). The effect of hydrogen-ion concentration, temperature and seed-drying method on the germination of coffee seeds. Proceedings of the International Seed Testing Association, 29, 61-70.

21. Huxley, P.A. (1964). Investigations on the maintenance of viability of Robusta coffee seed in storage. Proceedings of the International Seed Testing Association, 29, 423-444.

22. Huxley, P.A. (1965). Coffee germination test recommendations and defective seed types. Proceedings of the International Seed Testing Association, 30, 705-714.

23. Kamau, I.N. (1975). Coffee seeds and their care. Kenya Coffee, Research Notes, 306 pp. Coffee Research Station, Ruiru, Kenya.

24. Maestri, M. and Vieira, C. (1961). [A note on the reduction of the percentage of coffee seed (Coffea arabica L. var. bourbon) by the action of gibberellic acid.] Rev. Ceres, 11, 247-249. (From Horticultural Abstracts, 1963, 33, 3995.)

25. Naik, C.S.K., Raju, T. and Rao, W.K. (1980). Effect of biuret on seed germination and growth of coffee seedlings. Journal of Coffee Research, 10, 47-52. (From Horticultural Abstracts, 1981, 51, 3107.)

26. Takaki, M. and Dietrich, S.M.C. (1980). Effects of GA_3 and light on polysaccharide levels and metabolism in germinating coffee seeds. Journal of Experimental Botany, 31, 1643-1649.

27. Ultee, A.J. (1933). Storage of coffee seed. Archiv v Koffiecult Nederland Indié, 7, 75-83. (From Biological Abstracts, 10, 4111.)

28. Valio, I.F.M. (1976). Germination of coffee seeds (Coffea arabica L. cv. mundonovo). Journal of Experimental Botany, 27, 983-991.

29. Velasco, J.R. and Gutierrez, J. (1974). Germination and its inhibition in coffee. Philippine Journal of Science, 103, 1-11.

30. Visweshwara, S. and Raju, K.S.K. (1972). Seed germination in coffee. Indian Coffee, 36, 278-285, 290.

31. Vossen, H.A.M. van der (1979). Methods of preserving the viability of coffee seed in storage. Seed Science and Technology, 7, 65-74.

32. Wellman, F.L. (1961). Coffee, botany, cultivation and utilisation, pp. 122-128. Leonard Hill, London.

33. Wellman, F.L. and Toole, V.K. (1960). Coffee seed germination as affected by species, diseases and temperature. Proceedings of the Caribbean Section, American Society of Horticultural Sciences, 4, 1-6.

34. Went, F.W. (1957). The experimental control of plant growth. Chronica Botanica, 17, 164-168.

35. Riley, J.M. (1981). Growing rare fruit from seed. California Rare Fruit Growers Yearbook, 13, 1-47.

CHAPTER 64. RUTACEAE

The Rutaceae comprise about 1500 species of trees and shrubs within about 130 genera which provide edible fruits (e.g. Casimiroa edulis Llave & Lex., white sapote), flavourings (e.g. Murraya koenigii (L.) Spreng., curry-leaf tree) and medicinal products (e.g. Ruta graveolens L., rue). The fruits may be dehiscent capsules, samara-like, or fleshy and berry-like. Seed storage behaviour is now thought to be orthodox. For example, Dictamnus albus L. is maintained in the long-term seed store at the Wakehurst Place Gene Bank, and Murraya exotica L. is known to show orthodox seed storage behaviour. Information on Citrus seed storage behaviour is provided in a subsequent section of this chapter.

SEED DORMANCY AND GERMINATION

Germination of the seeds can be slow and a part of the cause may be dormancy. Treatments to the seed covering structures and gibberellins can promote germination. Detailed information on seed dormancy and germination is provided in this chapter for the genus Citrus (including synonyms within Limonia and Poncirus). Information on other species is summarised in Table 64.1 and in addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step of the algorithm is to test seeds in an alternating temperature regime of 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature in each cycle.

If this does not result in full germination then the second step in the algorithm is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test a fresh sample of seeds in the above alternating temperature regime.

If this does not result in full germination then the third step in the algorithm is to chip the seed covering structures of a fresh sample of seeds and then test in the alternating temperature regime described in step one, with 7×10^{-4} M GA_3 co-applied if the proportion of seeds which germinated in step two was significantly greater than the proportion which germinated in step one.

TABLE 64.1 Summary of germination test recommendations for species within the Rutaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Aegle marmelos (L.) Correa			21d	pre-soak, 24h, then warm stratification	Riley
Casimiroa spp.			21d	complete removal of seed covering structures,	Riley
				then pre-soak, 24h	
Clausena spp.			21d	pre-soak, 24h	Riley
Dictamnus albus L.	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 45d	AOSA
Feronia limonia			21d	pre-soak, 24h	Riley
Fortunella spp.			21d	pre-soak, 24h	Riley

Murraya exotica L.	S	25°-30°C	18d	light, continuous	CHML
Ruta graveolens L.	TP; BP	20°/30°C; 15°C; 20°C	28d	pre-chill	ISTA

CITRUS

C. aurantifolia Swingle [C. lima Lunan; C. limetta Auth.; Limonia aurantifolia Christm.]	lime
C. aurantium L. [C. Bigardia Risso]	sour orange, seville orange
C. grandis Osbeck [C. aurantium var grandis L.; C. decumana L.; C. maxima Merr.]	akune burntan, shaddock, pummel, pompelmous
C. jambhiri Lush	rough lemon, jamberi
C. karna Raf.	karna khatta
C. limettoides Tan.	sweet lime
C. limon Burm. f. [C. medica var Limon L.; C. Limonum Risso]	lemon
C. limonia Osbeck [C. reticulata Blanco x C. sinensis Osbeck]	Rangpur lime
C. natsudaidai Hayata	natsudaidai
C. paradisi Macf. [C. maxima var uvacarpa Merr. & Lee]	grapefruit, pomelo
C. reticulata Blanco [C. nobilis Andr.; C. deliciosa Ten.; C. nobilis var deliciosa Swingle]	mandarin, tangerine, satsuma
C. sinensis Osbeck	sweet orange
C. trifoliata L. [Poncirus trifoliata Raf.]	trifoliate-orange
C. trifoliata L. x C. sinensis Osbeck	troyer citrange

I. Evidence of dormancy

In all Citrus spp. seed germination is generally slow and often erratic. For example, moist seeds of C. sinensis tested for germination at 23°C showed no germination in the first 15 days in test, and only thereafter was germination observed, with individual seeds continuing to germinate up to at least 31 days in test (17).

Moreover, drying Citrus seeds results in a considerable further delay to radicle emergence (18). There is a linear relationship between the mean rate of seed germination and initial seed moisture content, such that drying moist seeds extracted from fruits at 56% moisture content to 5% moisture content doubles the mean germination time of intact seeds at 20°C from 14 to 28 days, and 42 days are required for full germination (18). It has been suggested that this substantial delay to germination resulting from desiccation has been confused with loss in viability (germination test periods being too short to record the germination of dried seeds) and accounts for conflicts in the literature as to whether or not Citrus seeds can be dried safely (18). The delay to the germination of dried seeds results entirely from the considerable periods taken by the seeds to imbibe sufficiently to reach the fully imbibed state (33).

There is some doubt in the literature as to whether or not seeds of Citrus spp. exhibit dormancy. Despite emphatic reports that there is no dormancy in Citrus seeds (31), seed dormancy can be discerned in some lots (4,5). The major problem in testing seeds of Citrus spp. for germination, however, is the delay to germination. For Citrus seeds, treatments which do or do not reduce the delays to germination, or which do or do not increase the proportion of seeds germinating during tests of limited duration are included here as dormancy-breaking treatments according to the layout used for all other genera. This is partly for convenience and partly because there is a view that slow germination in seeds of Citrus spp. may result, in part, from dormancy (33). It should be noted that the majority of citations concern seeds that have not been dried.

II. Germination regimes for non-dormant seeds

C. aurantifolia

Constant temperatures: 25°C (28)

C. aurantium

Constant temperatures: 15°-38°C, 66d (7); 25°C (23,28); 26°C (24,25); 29°C (11)

Alternating temperatures: 20°/30°C (16h/8h) (3)

C. limon

Constant temperatures: 23°C (27)

Alternating temperatures: 20°/30°C (16h/8h) (3)

C. limonia

Constant temperatures: 21°-38°C, 61d (7)

C. paradisi

Constant temperatures: 15°-38°C, 45d (7)

Alternating temperatures: 20°/30°C (16h/8h) (3)

C. reticulata

Constant temperatures: 15°-35°C (22); 25°C (21,23)

C. sinensis

Constant temperatures: 18°-37°C, 66d (7); 23°-33°C (13); 23°C in light, 100 fc (17)

Alternating temperatures: 20°/30°C (16h/8h) (3)

C. trifoliata

Constant temperatures: 12°-35°C (22); 26°C (6)

C. trifoliata x C. sinensis

Constant temperatures: 26°C (6)

III. Unsuccessful dormancy-breaking treatments

C. aurantifolia

Pre-chill: 3°C, 14d, germinate at 25°C (33)

Pre-soak: 15 min, 50°C, germinate at 30°C, 20d (33)

Citric acid: pre-applied, 15 min, 50°C, 1%, with or without GA_3, pre-applied, 24h, 500 ppm, germinate at 30°C, 20d (33)

Ethylenediaminetetraacetic acid: pre-applied, 15 min, 50°C, 0.001 M, with or without GA_3, pre-applied, 24h, 500 ppm, germinate at 30°C, 20d (33)

C. aurantium

Pre-chill: 2-6w (12)

Pre-soak: 24h (10)

Pre-wash: 50°C (10)

GA_3: pre-applied, 24h, 100, 1000 ppm (29)

Benzyladenine: pre-applied, 24h, 5-25 ppm (29)

Scarification: concentrated sulphuric acid, 20-60s (10)

Sodium hydroxide: pre-applied, 0.1 N, 100%, 20s-20 min (10)

2,4-Dichlorophenoxyacetic acid: pre-applied, 24h, 10-50 ppm (29)

C. limon

Constant temperatures: 20°C, 21d (18)

Pre-chill: 3°C, 7-21d, germinate at 20°C, 42d (33); 2-6w (12)

GA_3: co-applied, 50, 150 ppm, germinate at 30°C (33)

C. reticulata

2,4-Dichlorophenoxyacetic acid: pre-applied, 24h, 10-50 ppm (29)

Benzyladenine: pre-applied, 24h, 5-25 ppm (29)

GA_3: pre-applied, 24h, 100, 500 ppm (29)

C. sinensis

Constant temperatures: 21°C, 35d (4)

C. trifoliata, C. trifoliata x C. sinensis

GA_3: pre-applied, 10 mg/l (6); co-applied, 10 mg/l (6)

IV. Partly-successful dormancy-breaking treatments

C. aurantifolia

Constant temperatures: 20°C, 70d (19); 20°C, 25°C, 42d (33)

GA_3: pre-applied, 6,12h, 10-40 ppm (8); co-applied, 34.6, 3460 ppm, at 20°C, 42d (33)

1-Napthaleneacetic acid: pre-applied, 6, 12h, 10-40 ppm (8)

Thiourea: pre-applied, 6, 12h, 1-2% (8)

Potassium nitrate: pre-applied, 6, 12h, 1-2% (8)

C. aurantium

Constant temperatures: 20°C, 70d (18)

Pre-chill: 0°-5°C, 45d (30)

GA_3: pre-applied, 24h, 500 ppm (29)

Removal of seed covering structures: testa, germinate at 25°C (10,23)

C. jambhiri

Pre-chill: 0°-5°C, 45d (30)

C. limettoides

Ethylenediaminetetraacetic acid: pre-applied, 15 min, 10^{-3} M, 50°C, then GA_3, pre-applied, 24h, 200-500 ppm (1)

C. limon

Constant temperatures: 20°C, 42d (18); 20°C, 70d (19); 20°C, 25-56d (33)

Removal of seed covering structures: testa, germinate at 20°C, 42d (18)

Scarification: emery paper, germinate at 20°C, 42d (18)

C. limonia

Potassium nitrate: pre-applied 6, 12h, 1-2% (9)

Thiourea: pre-applied, 6, 12h, 1-2% (9)

1-Napthaleneacetic acid: pre-applied, 6, 12h, 10, 20 ppm (9)

C. paradisi

Removal of seed covering structures: slit or remove testa (34)

C. reticulata

Pre-chill: 0°-5°C, 45d (30)

GA_3: pre-applied, 24h, 1000 ppm (29)

C. sinensis

Pre-chill: 3°-4°C, 7-21d, germinate at 21°C, 35d (4); 3°-4°C, 56d, germinate at 21°-32°C (4); 3°-4°C, 56d, then GA_3, pre-applied, 24h, 1000 ppm, germinate at 21°C, 27°C, 32°C (4)

Pre-soak: 24h (5)

GA_3: pre-applied, 24h, 1-10,000 ppm (5); pre-applied, 24h, 1000 ppm, germinate at 21°C (4)

Removal of seed covering structures: remove outer seed coat (34)

C. trifoliata

Pre-chill: 4°C, 28-84d, germinate at 26°C (6); 2-6w (12); 4.5°C, 2,4w, germinate at 25°C (21)

GA_3: pre-applied, 24h, 1000 ppm, germinate at 18°C (26)

C. trifoliata x C. sinensis

Pre-chill: 4°C, 28-84d, germinate at 26°C (6)

V. Successful dormancy-breaking treatments

C. aurantifolia

Constant temperatures: 30°C, 35°C, 42d (33)

Alternating temperatures: 25°/35°C (12h/12h), 42d (33)

Pre-chill: 3°C, 14d, germinate at 25°C, 42d (33)

GA_3: pre-applied, 12h, 40 ppm (8); pre-applied, 24h, 500 ppm, germinate at 30°C, 20d (33); co-applied, 346 ppm, germinate at 20°C, 42d (33)

1-Napthaleneacetic acid: pre-applied, 12h, 40 ppm (8)

Removal of seed covering structures: testa, germinate at 25°C (28)

C. aurantium

Removal of seed covering structures: seed coat, germinate at 25°C (28)

C. jambhiri

GA_3: pre-applied, 24h, 500 ppm (32)

C. karna

Potassium nitrate: pre-applied, 24h, 750 ppm (32)

C. limon

Constant temperatures: 30°C, 28d (33)

Removal of seed covering structures: testa, germinate at 23°C (27); testa, germinate at 25°C (28)

Alcohol: pre-applied, 30,40 min, 80% (28)

Sodium hydroxide: pre-applied, 30 min, 5% (2)

C. limonia

GA_3: pre-applied, 6, 12h, 10-40 ppm (9)

1-Napthaleneacetic acid: pre-applied, 6, 12h, 40 ppm (9)

C. sinensis

Ascorbic acid: pre-applied, 12h, 100 ppm (20)

C. trifoliata

Pre-chill: 4.5°C, 5-12w, germinate at 25°C (21); 5°C, 30-120d, germinate at 30°C (14)

VI. Comment

Although Citrus seeds will germinate over a wide range of constant temperatures, roughly 15°-38°C (7), seed germination is most rapid and complete within the range 30°-35°C (4,7,22,33). In dry Citrus seeds the time taken to germinate is affected by the rate of imbibition and the rate of the subsequent growth processes. Temperature affects both; because of the substantial delays to the germination of dried Citrus seeds it is important to optimise the germination test temperature with regard to these rates; at 30°C the rates are not at a maximum (22,33), but higher temperatures during the growth phase can cause seedling abnormalities and may reduce percentage germination in some seed lots (22,33). Consequently a germination test temperature of 30°C is recommended. Germination tests at this temperature should be continued until a full seven days have passed in which no seeds have begun to germinate. It is expected that this will require about 28-42 days.

Treatment with gibberellins can reduce the time taken to germinate (1,5,33), but the effect is marginal (33) and unreliable (5). Indeed in many cases control treatments where the seeds are pre-soaked in water with no gibberellins present account for most of the apparent effect of gibberellins compared to untreated seeds (5). Treatment with gibberellins after treatment with chelating agents (e.g. ethylenediaminetetraacetic acid) has been reported to reduce further the germination time due to increased permeability of the seed coat (1). Again, however, the effect appears unreliable since other workers report no effect of such combined treatments (33). If dormancy is present then pre-chill treatments are more effective than treatment with gibberellins and also reduce the time taken to germinate in the subsequent germination test regime (6) - although if the pre-chill period is included in the calculation of the time taken to germinate then there is no overall reduction (33).

It is not possible to give precise recommendations for pre-chill treatment periods where these are required to remove dormancy. Nevertheless, it is suggested that these be carried out at 3°-5°C, and that it is unlikely that treatment periods greater then 28 days are necessary.

Removing seedcoats can also reduce the time taken to germinate by both moist (11) and dry (18) seeds. In both cases the effect can be substantial (in contrast to the marginal effect of gibberellins). For example, removing seedcoats from moist seeds of C. aurantium reduced the mean germination time from about 35 to 5 days at 29°C (11). Removing seed coats as a regular procedure is not recommended, however, since it is time consuming and - provided sufficient time is allowed in the germination test - rarely results in greater cumulative percentage germination (18). Moreover, embryos can be damaged where the seed coats are removed from dried Citrus seeds (18).

It is worth noting that the extreme period taken by dry Citrus seeds to imbibe can also affect the results of rapid viability tests. Tetrazolium staining studies with seeds of C. trifoliata (21) and C. natsudaidai (16) show that such tests are unreliable for dried seeds. A further important point to note concerns the availability of moisture during the germination test. Slight water stress (-2.3 bars) substantially reduced the percentage of seeds - moist, C. sinensis - germinating - at least within 31 days - and dramatically increased the time taken to germinate (17), whereas in sunflower and lettuce, the same degree of moisture stress caused only a minor delay to germination and had no significant effect on the percentage of seeds which had germinated by the end of the test (17). It is thus vital, and much more important than in most other species, to ensure that sufficient moisture is available to Citrus seeds throughout germination tests. Testing between paper and regularly re-moistening the paper should be sufficient to prevent problems arising from this source.

VII. References

1. Achituv, M. and Mendel, K. (1973). Effect of certain treatments on the germination of sweet lime (Citrus limettoides Tan.) seed. The Plant Propagator, 19 (4), 15-20.

2. Anonymous, (1980). Methods of hastening the germination of citrus seed. Information Bulletin, Citrus and Sub-Tropical Fruit Research Institute, 91, 3-4. (From Seed Abstracts, 1981, 4, 2820.)

3. Barton, L.V. (1943). The storage of citrus seed. Contributions from the Boyce Thompson Institute, 13, 47-55.

4. Burger, D.W. and Hackett, W.P. (1982). Influence of low temperature and gibberellic acid treatment on the germination of 'Valencia' orange seed. HortScience, 17, 801-803.

5. Burns, R.M. and Coggins, C.W. (1969). Sweet orange germination and growth aided by water and gibberellin seed soak. California Agriculture, 23, 18-19.

6. Button, J., Bornman, C.H. and Hackland, B.A. (1971). Effect of some pre-sowing treatments on the germination of Poncirus trifoliata and troyer citrange seeds. The Citrus and Sub-Tropical Fruit Journal, 45, 9-11.

7. Camp, A.F., Mowry, H. and Loucks, K.W. (1933). The effect of soil temperature on the germination of citrus seeds. American Journal of Botany, 20, 348-357.

8. Choudhari, B.K. and Chakrawar, V.R. (1980). Effect of some chemicals on the germination of kagzi lime (Citrus aurantifolia Swingle) seeds. Journal of Maharashtra Agricultural Universities, 5, 173-174. (From Seed Abstracts, 1982, 5, 308.)

9. Choudhari, B.K. and Chakrawar, V.R. (1981). Note on the effect of some chemicals on the germination of Rangpur lime seeds. Indian Journal of Agricultural Sciences, 51, 201-203.

10. Cohen, A. (1956). Studies on the viability of citrus seeds and certain properties of their coats. Bulletin of the Research Council of Israel, Section D, 5, 200-209.

11. Demni, S. and Bouzid, S. (1979). Premières informations sur la germination des graines de bigaradier (Citrus aurantium L.). Fruits, 34, 283-287.

12. Elze, D.L. (1949). Germination of citrus seeds in relation to certain nursery practices. Palestine Journal of Botany, 7, 69-80.

13. Fawcett, H.S. (1929). Temperature experiments in germinating orange seeds. California Citrograph, 14, 515. (Cited by Edwards, T.I. (1932). Temperature relations of seed germination. Quarterly Review of Biology, 7, 428-444.)

14. Fu, W.H. (1951). Germination and storage of trifoliata orange seeds. California Citrograph, 37, 38-39.

15. Honjo, H. and Nakagawa, Y. (1978). Suitable temperature and seed moisture content for maintaining the germinability of citrus seed for long-term storage. In Long-term Preservation of Favourable Germplasm in Arboreal Crops (eds. T. Akihama and K. Nakajima), pp. 31-35, Fruit Tree Research Station, Fujimoto, Japan.

16. Honjo, H. and Nakagawa, Y. (1979). [Tetrazolium test for evaluating the germination capacity of citrus seed.] Bulletin of the Fruit Tree Research Station, Series A, 6, 37-42.

17. Kaufmann, M.R. (1969). Effect of water potential on germination of lettuce, sunflower and Citrus seeds. Canadian Journal of Botany, 47, 1761-1764.

18. King, M.W. and Roberts, E.H. (1980). The desiccation response of seeds of Citrus limon L. Annals of Botany, 45, 489-492.

19. King, M.W., Soetisna, U. and Roberts, E.H. (1981). The dry storage of Citrus seeds. Annals of Botany, 48, 865-872.

20. Misra, R.S. and Verma, V.K. (1980). Studies on the seed germination of Kinnow orange in the Central Himalayas. Progressive Horticulture, 12, 79-84. (From Seed Abstracts, 1981, 4, 3153.)

21. Mobayen, R.G. (1980). Germination of trifoliate orange seed in relation to fruit development, storage and drying. Journal of Horticultural Science, 55, 285-289.

22. Mobayen, R.G. (1980). Germination and emergence of citrus and tomato seeds in relation to temperature. Journal of Horticultural Science, 55, 291-297.

23. Monselise, S.P. (1953). Viability tests with citrus seeds. Palestine Journal of Botany, 8, 152-157.

24. Monselise, S.P. (1959). Citrus germination and emergence as influenced by temperature and seed treatments. Bulletin of the Research Council of Israel, Section D, 7, 29-34.

25. Monselise, S.P. (1962). Citrus seed biology. XVIth International Horticultural Congress, Brussels, 559-565.

26. Moss, G.I. (1980). Propagation of citrus for future planting. Proceedings of the International Society of Citriculture, 1978, Griffith, NSW, Australia, 132-135.

27. Mumford, P.M. and Grout, B.W.W. (1979). Desiccation and low temperature (-196°C) tolerance of Citrus limon seed. Seed Science and Technology, 7, 407-410.

28. Panggabean, G. (1981). Dry storage of citrus seeds and factors affecting their germination. M.Sc. Thesis, University of Birmingham.

29. Rawash, M.A., Montaser, A., Habib, S.S., Nabawy, S.E. and Mahmoud, N. (1980). Germination of some citrus seeds as affected by soaking in growth regulators, water washing and sowing date. Research Bulletin, Faculty of Agriculture, Ain Shams University, 1299, 1-10.

30. Rawash, M.A. and Mougheith, M.G. (1978). Effect of some storage treatments on seed germination of some citrus rootstocks. Research Bulletin, Faculty of Agriculture, Ain Shams University, 835, 1-11.

31. Schneider, H. (1968). The anatomy of citrus. In The Citrus Industry (eds. W.L. Rather, L. Batchelor and H. Webber), Volume II, pp. 1-85, University of California, Berkeley, USA.

32. Singh, H.K., Shankar, G. and Makhija, M. (1979). A study on citrus seed germination as affected by some chemicals. Haryana Journal of Horticultural Science, 8, 194-195. (From Seed Abstracts, 1981, 4, 143.)

33. Soetisna, U., King, M.W. and Roberts, E.H. (1985). Germination test recommendations for estimating the viability of moist or dry seeds of lemon (Citrus limon L. Burm.) and lime (C. aurantifolia (Christm.) Swing.). Seed Science and Technology, 13, 87-110.

34. Tager, J.M. and Cameron, S.H. (1957). The role of the seed coat in chlorophyll deficiency (albinism) of citrus seedlings. Physiologia Plantarum, 10, 302-305.

CHAPTER 65. SAPINDACEAE

The Sapindaceae comprise more than 1000 species of trees, shrubs and, rarely, herbaceous plants within about 125 genera which provide edible fruits (e.g. Blighia sapida Koenig, akee), beverages (e.g. Paullinia cupana HBK, guarana) and oils (Schleichera oleosa (Lour.) Merr., lac tree). The fruits are diverse: the edible portion of fruits such as akee and litchi (Litchi chinensis Sonn.) is the aril which surrounds the seed. Seed storage behaviour may be variable; further investigations are required. Some species are known to show orthodox seed storage behaviour - for example, Koelreuteria paniculata Laxm. is maintained in the long-term seed store at the Wakehurst Place Gene Bank. But the species with edible fruits such as Euphoria longan Steud., Litchi chinensis Sonn., and Nephelium spp. are thought to show recalcitrant seed storage behaviour.

SEED DORMANCY AND GERMINATION

Germination and seedling development can be comparatively slow, and the seed coats may delay germination. B.R. Atwater classifies seed morphology as non-endospermic seeds with axile foliar embryos within hard seed coats (see Table 17.2, Chapter 17). Table 65.1 provides a brief summary of information on suitable germination test procedures and dormancy-breaking treatments. In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

It is obligatory to chip the seed coats of all seeds prior to testing for germination in this algorithm.

The first step in the algorithm is to test samples of the chipped seeds at constant temperatures between 6°C and 36°C with light applied for 12h/d. Where sufficient seeds are available it is suggested that seven constant temperature regimes (6° to 36°C in 5°C steps) be used in this first step. If this is not possible then test in four constant temperature regimes (6° to 36°C in 10°C steps). In the latter case if full germination is not achieved but the results suggest a trend in germination response to constant temperatures then test a further sample of chipped seeds at the most appropriate intermediate constant temperature. For example, if the proportions of seeds germinating at 26°C and 36°C are similar but greater than for the lower constant temperatures then test a further sample of chipped seeds at a constant temperature of 31°C with light applied for 12h/d.

If full germination does not occur in the above constant temperature regimes then the second step in the algorithm is to test two further samples of chipped seeds in alternating temperature regimes of 23°/9°C (12h/12h) and 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If full germination does not occur in the second step of the algorithm then the third step is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test a further sample of chipped seeds in the most appropriate temperature regime determined from a comparison of the results of steps one and two.

TABLE 65.1 Summary of germination test recommendations for species within the Sapindaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Blighia sapida Koenig			21d	warm stratification	Riley
Cardiospermum halicacabum L.	BP	20°/30°C	10d	clip seed coat	AOSA
		20°/30°C	28d		Atwater
Euphoria longan Steud.	S	25°-30°C	17d	light, continuous	CHML
			30d	warm stratification	Riley
Litchi chinensis Sonn.	S	25°-30°C	16d	light, continuous	CHML
			30d	warm stratification	Riley
	BP	25°C; 30°C; 35°/20°C;	63d	scarify	A
		20°/30°-35°C			
Melicoccus bijugatus L.			21d	pre-soak, 24h	Riley
Nephelium lappaceum L.	S	25°-30°C	14d	light, continuous	CHML
Nephelium malaiense	S	25°-30°C	16d	light, continuous	CHML
Pometia pinnata Forst. & G. Forst.			21d	warm stratification	Riley

CHAPTER 66. SAXIFRAGACEAE

The Saxifragaceae comprise more than 1000 species of herbaceous plants and shrubs within about 70 to 100 genera. The most important genus is Ribes which provides edible fruits (currants and gooseberries); some authorities classify the genus Ribes in the Grossulariaceae. The fruits are capsules or many-seeded berries. Seed storage behaviour is orthodox. For example, Ribes spp. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

The seeds contain abundant endosperm and dormancy can be a considerable problem. B.R. Atwater classifies seed morphology as endospermic seeds with axillary miniature embryos (see Table 17.1, Chapter 17). Pre-chill treatments and alternating temperature test regimes (particularly when combined) tend to promote seed germination provided the test duration is sufficient.

Detailed information on seed dormancy and germination is provided in this chapter for the genus Ribes (including synonyms within Chrysobotrya and Grossularia). A brief summary of suggested germination test procedures and dormancy-breaking treatments for other species is provided in Table 66.1. In addition the algorithm below for the Grossulariaceae may be helpful in developing suitable germination test procedures for species which can be so classified.

RBG Kew Wakehurst Place algorithm (Grossulariaceae)

The first step in the algorithm is to test seeds at constant temperatures of 11°C and 16°C with light applied for 12h/d. If neither constant temperature regime promotes full germination and there is a trend in germination response to constant temperatures then test further samples of seeds at more extreme constant temperatures. For example, if the proportion of seeds germinating at 11°C is greater than that at 16°C then test a further sample of seeds at a constant temperature of 6°C with light applied for 12h/d.

If the above constant temperature regimes do not result in full germination then the second step in the algorithm is to test a further sample of seeds in an alternating temperature regime of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If the second step of the algorithm does not result in full germination then the third step is to pre-chill a further sample of seeds at 2° to 6°C for 8w and then test in the most appropriate temperature regime determined from a comparison of the results of steps one and two.

TABLE 66.1 Summary of germination test recommendations for species within the Saxifragaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Heuchera sanguinea Engelm.	TP	20°/30°C; 20°C	21d	potassium nitrate, pre-chill	ISTA
	TP	20°/30°C	18d	light, potassium nitrate	AOSA
		20°C	21d	light, potassium nitrate, 0.2%	Atwater

RIBES

R. americanum Mill. [R. floridum L'Her.]	American blackcurrant
R. aureum Pursh [R. tenuiflorum Lindl.; Chrysobotrya aurea Rydb.]	golden currant
R. cynosbati L. [R. gracile Michx.; Grossularia cynosbati (L.) Mill.]	pasture gooseberry, prickly gooseberry
R. Grossularia L. [R. reclinatum L.; Grossularia reclinata Mill.]	English gooseberry
R. missouriense Nutt. [R. gracile Pursh not Michx.; Grossularia missouriensis (Nutt.) Cov. & Britt.]	Missouri gooseberry
R. multiflorum Kid.	white currant
R. nigrum L.	European blackcurrant
R. odoratum Wendl. [R. fragrans Lodd.; Chrysobotrya odorata Rydb.]	Missouri currant, buffalo currant, golden currant, flowering currant
R. Roezli Regel	
R. rotundifolium Michx. [Grossularia rotundifolia (Michx.) Cov. & Britt.]	round-leaf gooseberry
R. sativum Syme [R. vulgare Jancz. not Lam.; R. rubrum Auth. not L.; R. rubrum var sativum Reichb.]	common currant, garden currant

I. Evidence of dormancy

The germination of seeds of Ribes spp. is often irregular, unpredictable, and substantially delayed as a result of dormancy (1,2,5-7,11). Consequently seed dormancy is a major problem for breeders (1). Dormancy in R. aureum has been described as extreme (6). In R. missouriense seed germination problems are reported to result from both a seed coat effect and from dormancy within the extracted seeds (9).

II. Germination regimes for non-dormant seeds

R. americanum

Alternating temperatures: 20°/30°C (night/day) (3)

R. aureum

Alternating temperatures: 20°/30°C (night/day) (3,6)

R. cynosbati

Alternating temperatures: 20°/30°C (night/day) (3)

R. missouriense

Alternating temperatures: 20°/30°C (night/day) (3,9)

R. odoratum

Alternating temperatures: 20°/30°C (night/day) (3)

R. rotundifolium

Alternating temperatures: 10°/25°C (night/day) (3,5)

III. Unsuccessful dormancy-breaking treatments

R. americanum

Constant temperatures: 15°C (5)

R. aureum

Constant temperatures: 20°C (6)

Alternating temperatures: 20°/30°C (night/day) (6)

R. cynosbati

Constant temperatures: 20°C (5)

Alternating temperatures: 15°/32°C, 20°/32°C (night/day) (5)

R. multiflorum

Scarification: concentrated sulphuric acid, 1,2h (12)

R. nigrum

Constant temperatures: 24°C, dark (1)

Alternating temperatures: 10°/4°C (12h/12h) (1)

Scarification: concentrated sulphuric acid, 1,2h (12)

R. rotundifolium

Constant temperatures: 20°C (5)

Alternating temperatures: 20°/32°C (night/day) (5)

R. sativum

Scarification: concentrated sulphuric acid, 1,2h (12)

Ribes spp.

Scarification: concentrated sulphuric acid, 15 min-2h (12)

IV. Partly-successful dormancy-breaking treatments

R. americanum

Pre-chill: 5m (2); 5°-7°C, 200d, germinate at 20°/30°C (night/day) (3)

Warm stratification: 20°/30°C (night/day), 60d, then pre-chill, 5°C, 90-120d, germinate at 20°/30°C (night/day) (3)

R. aureum

Constant temperatures: 25°C (6)

Pre-chill: 5°C, 90d, germinate at 20°/30°C (night/day) (3); 2°-4°C, 2m, germinate at 20°/30°C (night/day) (6)

R. cynosbati

Constant temperatures: 5°C, 10°C, 15°C (5)

Alternating temperatures: 10°/25°C (night/day) (5)

Pre-chill: 5°C, 90d, germinate at 20°/30°C (night/day) (3)

Warm stratification: 25°C, 32°C, 2m, germinate at 10°/25°C (5)

R. missouriense

Constant temperatures: 15°C (5)

Pre-chill: 5°C, 90d, germinate at 20°/30°C (night/day) (9)

Warm stratification: 20°/30°C (night/day), 90d, then pre-chill, 5°C, 90d, germinate at 20°/30°C (night/day) (9)

R. nigrum

Alternating temperatures: 24°/4°C (12h/12h, 16h/8h, 8h/16h) (1); 18°/4°C, 30°/4°C, 24°/15°C, 24°/18°C (12h/12h) (1); 24°/4°C (12h/12h, 24h/24h, 48h/48h, 72h/72h, 48h/24h, 24h/48h, 72h/24h, 24h/72h), 12w, then 24°/4°C (12h/12h) (1)

Pre-chill: 4°C, 2-28w, germinate at 24°/4°C (12h/12h) (1); 4°C, 2-28w, then scarify, notch, germinate at 24°/4°C (12h/12h) (1); 4°C, 12w, then scarify, 50% sulphuric acid, 5 min, germinate at 24°/4°C (12h/12h) (1)

Warm stratification: 24°C, 12w, germinate at 24°/4°C (12h/12h) (1)

GA_3: pre-applied, 0.02-0.1%, then pre-chill 2°-3°C, 140d (8) Removal of seed covering structures: notch seed coat with razor (1)

R. odoratum

Warm stratification: 20°/30°C (night/day), 60d, then pre-chill, 5°C, 60-90d, germinate at 20°/30°C (night/day) (3)

R. rotundifolium

Constant temperatures: 5°C, 10°C, 15°C (5)

Alternating temperatures: 10°/25°C, 15°/32°C (night/day) (5)

Warm stratification: 25°C, 32°C, 2m, germinate at 10°/25°C (night/day) (5)

Scarification: concentrated sulphuric acid, 35 min (5)

V. Successful dormancy-breaking treatments

R. aureum

Warm stratification: c. 2w, then pre-chill, 2°-4°C, 2m, germinate at 20°/30°C (night/day) (6)

R. cynosbati

Pre-chill: 5m (2)

R. Grossularia

Pre-chill: 0°-10°C, 90-120d (4); 3°C, 3-4m (7)

R. missouriense

Pre-chill: 5°C, 90d, germinate at 20°/30°C (night/day) (3)

R. Roezli

Pre-chill: 2.5°C, 3.5m (11)

R. sativum

Pre-chill: (10); 3°C, 3-4m (7)

VI. Comment

Seed dormancy in Ribes spp. can vary considerably between accessions produced in different years (1). Although a number of treatments have been reported as successful (above), the reports derive mainly from glasshouse sowings and we suspect that the most dormant seeds failed to germinate. Prolonged pre-chilling and alternating temperature germination test regimes are the most effective dormancy-breaking treatments (1-7,9,10,11). Alternating temperatures of 24°-25°/4°-10°C are the most effective in promoting germination (1,3,5); the higher temperature should be applied for the greater part - 16 hours - of the diurnal cycle (1). Although prolonged pre-chilling - 3 to 5 months at between 2° and 4°C - may be sufficient for some seed lots of Ribes spp. (2,7,10,11), it fails to promote complete germination in accessions of R. americanum, R. aureum, R. cynosbati, R. nigrum and R. odoratum (1,3,6,9).

There appears to be no satisfactory procedure at present for promoting the germination of all dormant seeds within Ribes spp., and it has been suggested that viability can only be determined by using a tetrazolium test (6), but the authors provided no details of the procedures to be followed. More work is required before a completely satisfactory procedure can be advised. We suggest that investigations should concentrate on alternating temperature regimes. Three different types of treatment may be useful when combined; warm stratification, then pre-chill, then an alternating temperature for germination. Alternatively a single alternating temperature regime may be sufficient.

In the meantime the following general procedure is suggested. First notch the seed coat using a razor, then pre-chill at 3°-5°C for 2-4 months, and finally transfer to an alternating temperature regime of 24°/4°C (16h/8h) - for at least a further 6 to 8 weeks. For the least dormant accessions, or where some germination is required in a short period of time, the above alternating temperature regime alone can be provided.

VII. References

1. Adam, J. and Wilson, D. (1967). Factors affecting the germination of black currant seed. Report of the Long Ashton Research Station for 1966, pp. 96-103.

2. Adams, J. (1927). The germination of the seeds of some plants with fleshy fruits. American Journal of Botany, 14, 415-428.

3. Anonymous (1948). Ribes L. Currant, gooseberry. In Woody Plant Seed Manual, pp. 317-320. USDA Forest Service, Miscellaneous Publication No. 654.

4. Barton, L.V. (1939). Experiments at Boyce Thompson Institute on germination and dormancy in seeds. Scientific Horticulture, 7, 186-193.

5. Fivaz, A.E. (1931). Longevity and germination of seeds of Ribes, particularly R. rotundifolium, under laboratory and natural conditions. USDA, Technical Bulletin No. 261, 40 pp.

6. Heit, C.E. (1971). Propagation from seed. Part 22: Testing and growing western desert and mountain shrub species. American Nurseryman, 133, 10-12, 76-89.

7. Keep, E. (1975). Currants and gooseberries. In Advances in fruit breeding (eds. J. Janick and J.N. Moore), pp. 197-268, Purdue University Press, Indiana.

8. Khokhlova, V.V. (1979). [Effect of gibberellin on black currant seed germination.] Fiziologiya i Biokhimiya Kul'turnykh Rastenii, 11, 605-610. (From Seed Abstracts, 1980, 3, 3114.)

9. Krepting, L.W. and Roe, E.I. (1949). The role of some birds and mammals in seed germination. Ecological Monographs, 19, 269-286.

10. Pammel, L.H. and King, C.M. (1929). Germination of trees and shrubs. Proceedings of the Iowa Academy of Science, 36, 201-211.

11. Quick, C.R. (1936). Chemical control of harmful fungi during stratification and germination of seeds of Ribes roezli. Phytopathology, 26, 694-697.

12. Tukey, H.B. (1924). Studies of fruit seed storage and germination. New York State Agricultural Experiment Station Bulletin 509, 19 pp.

CHAPTER 67. SOLANACEAE

The Solanaceae comprise more than 2000 species of herbaceous plants - including climbers, shrubs and small trees within about 75 genera which provide edible fruits (e.g. Cyphomandra betacea (Cav.) Sendt., tree tomato), edible tubers (e.g. Solanum tuberosum L., potato), and drugs and narcotics (e.g. Datura spp.). The fruits are berries or capsules and the seeds show orthodox storage behaviour. For example, Atropa belladonna L. and Physalis peruviana L. are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

The seeds have a copious endosperm, a curved or annular embryo, and can show considerable dormancy. B.R. Atwater classified seed morphology as endospermic seeds with either axillary linear embryos or axillary miniature embryos (see Table 17.1, Chapter 17). Alternating temperatures, light, gibberellins and potassium nitrate tend to promote seed germination.

Detailed information on seed dormancy and germination is provided in this chapter for the genera Capsicum, Datura, Lycopersicon (including synonyms within Solanum), Nicotiana and Solanum. Recommended germination test procedures and dormancy-breaking treatments for other species are summarised in Table 67.1. In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 21°C, 26°C, and 31°C with light applied for 12h/d. If full germination does not occur and a trend in germination response to constant temperatures is observed then test further samples of seeds at more extreme constant temperatures. For example, if a greater proportion of seeds germinate at 21°C than at higher temperatures then test further samples of seeds at constant temperatures of 6°C, 11°C and 16°C with light applied for 12h/d.

If the above constant temperature regimes do not promote full germination then the second step of the algorithm is to test a further sample of seeds in the alternating temperature regime 33°/19°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If full germination does not occur in the second step of the algorithm then the third step is to test three further samples of seeds at the most appropriate temperature regime determined from a comparison of the results of steps one and two, with GA_3 co-applied to the germination test substrates at 3×10^{-4} M, 7×10^{-4} M, and 2.6×10^{-3} M.

If full germination does not occur in the third step of the algorithm then the fourth step is to attempt other GA_3 concentrations (e.g. if a trend is apparent in the results of step three then test at more extreme GA_3 concentrations) or after-ripen (e.g. expose a sample of the air-dry seeds to the ambient laboratory environment for several weeks).

If full germination has not been promoted, the fifth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environment can be obtained from the information provided for five genera in this chapter and from Table 67.1.

TABLE 67.1 Summary of germination test recommendations for species within the Solanaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Atropa belladonna L.	TP; BP	20°/30°C	28d	pre-chill	ISTA
	TP	20°/30°C	28d	light, potassium nitrate	AOSA/Heit
Browallia viscosa HBK	TP; BP	20°/30°C; 20°C	21d		ISTA
Browallia spp.	TP	20°/30°C	14d	light	AOSA
Cyphomandra betacea (Cav.) Sendt.	TP	25°-30°C	20d	light, continuous, pre-chill	CHML
			21d	pre-soak, 24h	Riley
Hyoscyamus niger L.	TP	20°/30°C	28d	light, potassium nitrate	Heit
Nierembergia hippomanica Miers	TP	20°/30°C; 20°C	21d		ISTA
		20°/30°C	14d	light, potassium nitrate, 0.2%	Atwater
Nierembergia spp.	TP	20°/30°C	14d		AOSA
Petunia x hybrida Vilm.	TP	20°/30°C; 20°C	14d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	10d	light	AOSA
		20°/30°C	14d	light, potassium nitrate, 0.2%	Atwater
Petunia spp.		20°/30°C	14d	fluorescent light, potassium nitrate, 0.2%, or GA, 400ppm	Atwater
	TP	20°/30°C	10d	potassium nitrate, pre-chill	AOSA
Physalis alkekengi L.	TP	20°/30°C	28d	light, potassium nitrate, pre-chill	ISTA
		20°/30°C	28d	light, potassium nitrate, 0.2%	Atwater
Physalis pubescens L.	TP	20°/30°C	28d	potassium nitrate	ISTA
	TP	20°/30°C	28d	light, potassium nitrate	AOSA
	TP	20°/30°C	12d	potassium nitrate	SGCF
Physalis virginianum	TP	20°/30C	12d	potassium nitrate	SGCF
Physalis spp.	TP	20°/30°C	24d	light, potassium nitrate	AOSA
Salpiglossis sinuata Ruiz & Pav.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	12d	potassium nitrate	AOSA
		20°/30°C	14d	light, potassium nitrate, 0.2%	Atwater
Schizanthus pinnatus Ruiz & Pav.	TP; BP	10°C; 15°C	14d	pre-chill	ISTA
		15°C	14d		Atwater

Schizanthus spp.	TP	15°C	8d	sensitive to warm temperatures	AOSA

CAPSICUM

C. annuum L. var abbreviatum Fingerh	wrinkled peppers
C. annuum L. var acuminatum Fingerh	chillies
C. annuum L. var cerasiforme (Mill.) Irish	cherry peppers
C. annuum L. var conoides (Mill.) Irish	cone peppers, tabasco
C. annuum L. var fasciculatum (Sturt.) Irish	cluster peppers
C. annuum L. var grossum (L.) Sendt.	sweet peppers, paprika
C. annuum L. var longum (DC.) Sendt.	long pepper
C. annuum L. var minimum	
C. baccatum (L.) Irish	cherry capsicum
C. chacoense Hunz.	
C. chinense Jacq.	
C. frutescens L. [C. minimum Roxb.]	bird chillies
C. microcarpum DC.	
C. pubescens Rucz & Pav.	

I. Evidence of dormancy

Freshly harvested seeds of C. annuum, C. frutescens, C. chacoense, C. chinense, C. baccatum and C. pubescens can show dormancy (12,16). An after-ripening period of about 6 weeks is required at room temperature to remove dormancy (12).

II. Germination regimes for non-dormant seeds

Capsicum spp.

BP; TP: 20°/30°C (16h/8h): 14d (ISTA,AOSA)

C. annuum

Constant temperatures: 15.5°-37.5°C (1); 21°-26.5°C (2); 15°-25°C (3); 14°-34°C (4); 20°C, light, $5x10^{-5}$ mol m^{-2} s^{-1}, 12h (5); 18°-30°C (7); 25°C, dark (10,14,15,17)

III. Unsuccessful dormancy-breaking treatments

C. annuum

Pre-soak: 5h, 21°C (1); 2-8d (19)

Pre-dry: 22°C, 32°C, 37°C, 1-7d (2)

Light: incandescent (9); infra red (10)

Potassium nitrate: co-applied, 0.2% (8)

Indoleacetic acid: co-applied, 1000 ppm (19)

$GA_{4/7}$: co-applied, 10-100 ppm (19,20,21)

Kinetin: co-applied, 10-100 ppm (19)

Oxygen: 10, 100%, at 25°C, 15°C (21)

Acetone: pre-applied, 8h, germinate at 15°C, dark (15)

Chloroform: pre-applied, 8h, germinate at 15°C, dark (15)

Dichloromethane: pre-applied, 8h, germinate at 15°C, dark (15)

Dimethylsulphoxide: pre-applied, 8h, germinate at 15°C, dark (15)

Sodium hypochlorite: pre-applied, 5 min, 1%, rinse, then hydrochloric acid, pre-applied, 10 min, 10^{-2} N (5)

Removal of seed covering structures: germinate at 25°C (20)

C. annuum var minimum

Constant temperatures: 15°-35°C (16)

C. baccatum

Constant temperatures: 15°C, 20°C, 25°C, 35°C (16)

C. chinense

Constant temperatures: 15°-35°C (16)

C. pubescens

Constant temperatures: 15°C (16)

IV. Partly-successful dormancy-breaking treatments

C. annuum

Constant temperatures: 15°C, 35°C (16); 22.5°C, light (12)

Warm stratification: 30°C, 12,24,48h, germinate at 15°C, dark (15)

Pre-soak: 24h (13)

Potassium cyanide: pre-applied, 24h, 10^{-3} M (13)

Potassium nitrate: pre-applied, 3,6,9d, 3%, at 20°C, germinate at 15°C, dark (15)

Sodium azide: pre-applied, 24h, 10^{-3} M (13)

Sodium hypochlorite: pre-applied, 5 min, 1% (5)

Acetone: pre-applied, 8h, vacuum dry, 1h, imbibe, 30°C, 48h, germinate at 15°C, dark (15)

Palmitic acid: pre-applied, 8h, 10^{-4} M, dissolved in acetone, vacuum dry, 1h, imbibe, 30°C, 48h, germinate at 15°C, dark (15)

Stearic acid: pre-applied, 8h, 10^{-4} M dissolved in acetone, vacuum dry, 1h, imbibe, 30°C, 48h, germinate at 15°C, dark (15)

Oleic acid: pre-applied, 8h, 10^{-4} M dissolved in acetone, vacuum dry, 1h, imbibe, 30°C, 48h, germinate at 15°C, dark (15)

Linoleic acid: pre-applied, 8h, 10 M dissolved in acetone, vacuum dry, 1h, imbibe, 30°C, 48h, germinate at 15°C, dark (15)

Linolenic acid: pre-applied, 8h, 10^{-4} M dissolved in acetone, vacuum dry, 1h, imbibe, 30°C, 48h, germinate at 15°C, dark (15)

Polyethylene glycol 6000: pre-applied, 5d, -8 bar at 15°C, germinate at 25°C (22); pre-applied, 5d, -8 bar, plus potassium chloride, 10^{-1}, 10^{-2} M, 15°C, germinate at 25°C (22); pre-applied, 5d, -8 bar, plus potassium nitrate, 10^{-1}, 10^{-2} M, 15°C, germinate at 25°C (22); pre-applied, 5d, -8 bar, plus GA_3, 2.5, 25, 100 ppm, 15°C, germinate at 25°C (22)

Hydroxylamine hydrochloride: pre-applied, 24h, 10^{-3} M (13)

Oxygen: (14, 18)

GA_3: co-applied, 200-800 ppm (18)

C. baccatum

Constant temperatures: 30°C (16)

Warm stratification: 30°C, 35°C, 45d, germinate at 30°/15°C (16h/8h) (16)

C. chacoense

Constant temperatures: 22.5°C, light (12)

C. pubescens

Constant temperatures: 20°C, 30°C, 35°C (16)

Warm stratification: 30°C, 35°C, 45d, germinate at 30°/15°C (16h/8h) (16)

C. frutescens

Constant temperatures: 15°C, 20°C, 25°C, 35°C (16); 22.5°C, light (12)

V. Successful dormancy-breaking treatments

Capsicum spp.

Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

C. annuum

Warm stratification: 20°C, 25°C, 30°C, 35°C, 45d, then 30°/15°C (16h/8h) (16); 15°C, 65d, then 30°/15°C (16h/8h) (16)

GA_3: co-applied, 100 ppm, 25°C, any light regime (10); co-applied, 1000 ppm (18)

Removal of seed covering structures: germinate at 15°C (20)

Oxygen: 40, 60%, at 15°C, 25°C (21)

$GA_{4/7}$: co-applied, 500, 1000 ppm (19)

C. baccatum

Warm stratification: 20°C, 25°C, 45d, then 30°/15°C (16h/8h) (16)

C. chinense

Warm stratification: 20°C, 25°C, 30°C, 35°C, 45d, then 30°/15°C (16h/8h) (16); 15°C, 54d, then 30°/15°C (16h/8h) (16)

C. frutescens

Constant temperatures: 30°C (16)

Warm stratification: 15°C, 65d, then 30°/15°C (16h/8h) (16)

C. pubescens

Constant temperatures: 25°C (16)

Warm stratification: 20°C, 45d, then 30°/15°C (16h/8h) (16); 15°C, 65d, then 30°/15°C (16h/8h) (16)

VI. Comment

It would appear that no special precautions are necessary for the light environment because although incandescent light is inhibitory the fluorescent light sources likely to be used in germination cabinets do not inhibit Capsicum seed germination - but neither are they reported to promote germination (9). Nevertheless if at all possible the light regime given in Chapter 6 should be provided.

Non-dormant seeds of all Capsicum spp. germinate well when tested over the constant temperature range 15°-30°C (1,3,4,6,7,15,16) and non-dormant seeds of C. baccatum also germinate fully at 10°C and 13°C (6,11). The alternating temperature regimes 15°/30°C, 15°/27°C or 20°/30°C promote the germination of dormant seeds of C. annuum, C. baccatum, C. chinense, C. frutescens and C. pubescens quite substantially (6,16). Dormant seeds of C. annuum var minimum, C. baccatum and C. chinense fail to germinate when tested at constant temperatures of 15° to 30°C for up to 60 days, but germinate promptly when transferred to the alternating temperature regime 30°/15°C (16h/8h) (16). Consequently it is suggested that the AOSA/ISTA prescribed alternating temperature regime of 20°/30°C (16h/8h) is likely to be satisfactory for most gene bank purposes, but that the regime 30°/15°C (16h/8h) provided for more than 14 days may be preferable for the most dormant seeds.

VII. References

1. Cochran, H.L. (1935). Some factors which influence the germination of pepper seeds. Proceedings of the American Society for Horticultural Science, 33, 477-480.

2. Cochran, H.L. (1943). Effect of stage of fruit maturity at time of harvest and method of drying on the germination of pimento seed. Proceedings of the American Society for Horticultural Science, 43, 229-234.

3. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

4. Bierhuizen, J.F., Wagenvoort, W.A. and Nilwik, H. (1978). Analysis of the relationship between temperature and germination of sweet pepper. Acta Horticulturae, 83, 195-199.

5. Fieldhouse, D.J. and Sasser, M. (1975). Stimulation of pepper seed germination by sodium hypochlorite treatment. HortScience, 10, 622.

6. Gerson, R. and Honma, S. (1978). Emergence response of the pepper at low soil temperature. Euphytica, 27, 151-156.

7. Kotowski, F. (1926). Temperature relation to germination of vegetable seed. Proceedings of the American Society for Horticultural Science, 24, 176-184.

8. Miguel, M.C. (1975). Report of the working group on the germination of Solanaceae. Seed Science and Technology, 3, 110-115.

9. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

10. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

11. Randle, W.M. and Honma, S. (1980). Inheritance of low temperature emergence in Capsicum baccatum var. pendulum. Euphytica, 29, 331-335.

12. Randle, W.M. and Honma, S. (1981). Dormancy in peppers. Scientia Horticulturae, 14, 19-25.

13. Roberts, E.H. (1964). The distribution of oxidation-reduction enzymes and the effects of respiratory inhibitors and oxidising agents on dormancy in rice seeds. Physiologia Plantarum, 17, 14-29.

14. Sachs, M., Cantliffe, D.J. and Nell, T.A. (1981). Germination studies of clay-coated sweet pepper seeds. Journal of the American Society for Horticultural Science, 106, 385-389.

15. Sachs, M., Cantliffe, D.J. and Watkins, J.T. (1980). Germination of pepper seed at low temperatures after various pretreatments. Proceedings of the Florida State Horticultural Society, 93, 258-260.

16. Sato, T., Yazawa, S. and Namiki, T. (1982). [Requirement of alternating temperature for germination of pepper seeds.] Scientific Reports of the Kyoto Prefectural University, Agriculture, 34, 21-27.

17. Singh, R.D., Tiwari, S.N. and Lal, S.D. (1975). Studies on the temperature and media relations to germination of vegetable seeds. I. Knol Kahl (Brassica oleracea L. var. caulorapa) and Capsicum (Capsicum annuum L.). Progressive Horticulture, 7, 47-50.

18. Sosa-Coronel, J. and Motes, J.E. (1982). Effect of gibberellic acid and seed rates on pepper seed germination in aerated water columns. Journal of the American Society for Horticultural Science, 107, 290-295.

19. Watkins, J.T. and Cantliffe, D.J. (1983). Hormonal control of pepper seed germination. HortScience, 18, 342-343.

20. Watkins, J.T. and Cantliffe, D.J. (1983). Mechanical resistance of the seed coat and endosperm during germination of Capsicum annuum at low temperature. Plant Physiology, 72, 146-150.

21. Watkins, J.T., Cantliffe, D.J. and Sachs, M. (1983). Temperature and gibberellin-induced respiratory changes in Capsicum annuum during germination at varying oxygen

concentrations. Journal of the American Society for Horticultural Science, 108, 356-359.

22. Yaklich, R.W. and Orzolek, M.D. (1977). Effect of polyethylene glycol-6000 on pepper seed. HortScience, 12, 263-264.

DATURA

D. ferox L.
D. innoxia Mill.
D. metel L. [D. fastuosa L.; D. cornucopia Hort.]
D. stramonium L. jimson-weed, jametown-weed, thorn-apple

I. Evidence of dormancy

Freshly harvested seeds of all the above species are likely to be extremely dormant (1-9, 11-14). In seeds of D. ferox after-ripening treatments of 3 years at room temperature have not been sufficient to remove dormancy (11).

II. Germination regimes for non dormant seeds

D. ferox

Alternating temperatures: 20°/30°C (15h/9h) (1-4,6,7,11)

D. innoxia

Constant temperatures: 20°C (10)

D. metel

TP; BP; S: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

Constant temperatures: 30°C (10)

D. stramonium

TP; BP; S: 20°/30°C (16h/8h); 20°C: 21d (ISTA)

Constant temperatures: 25°C (10)

Alternating temperatures: 20°/30°C (16h/8h) (12)

III. Unsuccessful dormancy-breaking treatments

D. ferox

Constant temperatures: 10°C, 20°C, 30°C (11)

Alternating temperatures: 10°/20°C, 20°/10°C, 10°/30°C, 30°/10°C, 20°/30°C, 30°/20°C (9h/15h) (11)

Warm stratification: 20°C, 3-4w, germinate at 20°/30°C (15h/9h), dark (3)

Pre-soak: 3d (11)

Thiourea: co-applied, 0.1, 0.25, 0.5, 1%, decoated seeds (11)

Light: continuous dark (2,6); far red, 9500 erg cm^{-2} sec^{-1}, 3 min (11)

Abscisic acid: co-applied, 10^{-4} M (2)

GA_3: co-applied, 50-200 ppm (7)

D. innoxia

Thiourea: pre-applied, 16h, 1% (9)

Ascorbic acid: pre-applied, 18h, 2% (8)

X-rays: 2000-8000 R, 770 R/min (9)

Pre-dry: 40°C, 48,96h (9); 60°C, 96h (9)

Scarification: hand (8); sulphuric acid (8)

D. metel

Removal of seed covering structures: testa (14)

Scarification: concentrated sulphuric acid (14)

D. stramonium

Ethylene: co-applied, 1-100 ppm (13)

Light: red, 1.9×10^{-4} W cm^{-2}, 5 min, after 24h (13)

IV. Partly-successful dormancy-breaking treatments

D. ferox

Alternating temperatures: 20°/30°C (15h/9h) (2,3,4); 20°/30°C (15h/9h) in light (1)

Humidification: 25°C, 100% rh, 7d, germinate at 20°/30°C (15h/9h), dark, 2d, then red light, 9×10^{-4} W cm^{-2}, 0.5-10 min (6)

Removal of seed covering structures: decoated (4,7,11); decoated, germinate at 20°/30°C (15h/9h), dark, 1-3d, then red light, 20 min (4)

Light: 400 lux, 9h/d (11); red, 900 erg cm^{-2} s^{-1}, 20 min, after 48h imbibition (1); red, 1-100 min (2,4); red, 0.5-10 min (6); red, 10 min, after 16h imbibition (11); blue, 320-480nm, 1500 erg cm^{-2} s^{-1} (11)

GA_3: co-applied, 500 ppm, intact seeds (7); co-applied, 50 ppm, decoated seeds (7); co-applied, 100, 200 ppm, in dark, decoated seeds (11); pre-applied, 200 ppm, 2,3d, then decoated (7)

D. innoxia

Thiourea: pre-applied, 18h, 0.2-4% (8); pre-applied, 16h, 0.25-0.75% (9); pre-applied, 18h, 0.02%, plus ascorbic acid, 0.02% (8); pre-applied, 18h, 0.2%, plus ascorbic acid, 0.3%, 0.4% (8); pre-applied, 18h, 0.3%, plus ascorbic acid, 0.2, 0.3% (8)

Ascorbic acid: pre-applied, 18h, 0.2-1% (8); pre-applied, 16h, 0.25-1% (9)

Electric shock: in acidified water, 220V, 15-60s (9)

X-rays: 500-1000 R, 770 R/min (9)

Pre-dry: 60°C, 48h (9)

Storage: 4°C, -6°C, 48,96h (9); 20°C, 100% rh, 3-4w (3)

D. metel

Pre-soak: 10-12h (14)

Ethanol: pre-applied, 3-4h, 90% (14)

V. Successful dormancy-breaking treatments

D. ferox

Alternating temperatures: 20°/30°C (15h/9h), 1-3d, then seeds decoated, plus GA_3, co-applied, 200 ppm (7)

Warm stratification: 35°C, 2d, decoated seeds, germinate at 20°/30°C (15h/9h) in light, 400 lux, 9h/d (11)

Sodium azide: co-applied, $5x10^{-3}$ M, isolated embryos (5)

Removal of seed covering structures: plus GA_3, co-applied, 100-500 ppm, at 20°/30°C (15h/9h) in light, white or red, 900 erg cm^{-2} s^{-1}, 20 min, after 2d imbibition (7); decoated, germinate at 20°/30°C (15h/9h), 1-3d, then plus GA_3, co-applied, 200 ppm (7); decoated, then GA_3, pre-applied, 24h, 200 ppm, germinate at 20°/30°C (15h/9h) (7)

D. metel, D. stramonium

Pre-chill, Scratch hard seeds (ISTA)

VI. Comment

To germinate seeds of Datura spp. it is necessary to provide both alternating temperatures and light. In addition gibberellic acid is very effective in promoting germination and may also be required. It is suggested that successful germination test regimes for seeds of Datura spp. are likely to include more than one of the following; an alternating temperature regime of 20°/30°C (15-16h/8-9h); a short duration light treatment similar to those given in Chapter 6 or those provided for D. ferox above; seed coat removal; GA_3, either co-applied at about 50-300 ppm, or pre-applied for 24 hours at about 2000 ppm.

VII. References

1. Burkart, S. and Sánchez, R.A. (1969). Interaction between an inhibitor present in the seeds of Datura ferox and light in the control of germination. Botanical Gazette, 130, 42-47.

2. De Miguel, L.C. (1980). Changes in levels of endogenous inhibitors during dormancy breakage in Datura ferox L. seeds. Zeitschrift für Pflanzenphysiologie, 96, 415-421.

3. De Miguel, L.C. and Soriano, A. (1974). The breakage of dormancy in Datura ferox seeds as an effect of water absorption. Weed Research, 14, 265-270.

4. Gugliada, M.L., Soriano, A. and Burkart, S. (1967). The seed coat effect in relation to the photoinduction of germination of Datura ferox L. Canadian Journal of Botany, 45, 377-381.

5. Sánchez, R.A. and De Miguel, L.C. (1983). Ageing of Datura ferox seed embryos during dry storage and its reversal during imbibition. Zeitschrift für Pflanzenphysiologie, 110, 319-329.

6. Sánchez, R.A., Eyherabide, G. and De Miguel, L.C. (1981). The influence of irradiance and water deficit during fruit development on seed dormancy in Datura ferox L. Weed Research, 21, 127-132.

7. Sánchez, R.A., Soriano, A. and Slabnik, E. (1967). The interaction of the seed coat and gibberellic acid in the germination of Datura ferox L. Canadian Journal of Botany, 45, 371-376.

8. Singh, C. (1974). Seed germination in Datura innoxia Mill. Indian Journal of Experimental Biology, 12, 291.

9. Singh, C., Bhan, A.K. and Kaul, B.L. (1974). The role of some physical and chemical agents in the improvement of seed germination in Datura innoxia. Seed Science and Technology, 2, 421-425.

10. Singh, C. and Kaul, B.L. (1976). Note on the effect of temperature on seed germination in Datura species. Seed Research, 4, 134-135.

11. Soriano, A., Sánchez, R.A. and De Eilberg, B.A. (1964). Factors and processes in the germination of Datura ferox L. Canadian Journal of Botany, 42, 1189-1203.

12. Steinbauer, G.P., Grigsby, B., Correa, L. and Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-51.

13. Taylorson, R.B. (1979). Response of weed seeds to ethylene and related hydrocarbons. Weed Science, 27, 7-10.

14. Zutsi, U. and Atal, C.K. (1970). Scopoletin induced inhibition of germination in Datura species. Herba Hungarica, 9, 51-54.

LYCOPERSICON

L. esculentum Mill. [L. lycopersicon Karst.; L. lycopersicum (L.) Farwell; Solanum lycopersicum] tomato

I. Evidence of dormancy

Seeds of L. esculentum can show considerable dormancy (28). In addition secondary dormancy can be induced by chilling (28,32), warm stratification (19) or from prolonged exposure to far red light (15,24). Finally it should be noted that the pattern of germination of non-dormant seeds can be erratic (33).

II. Germination regimes for non-dormant seeds

BP; TP: 20°/30°C (16h/8h): 14d (ISTA, AOSA)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 25°C, 30°C, dark (28)

Alternating temperatures: 5°/15°C (12h/12h) (25)

Pre-chill: 0°-14°C, 3d (32); 6°C, 20d (28); 8°C, 8-24h (5)

Warm stratification: 35°C, 1-5w, germinate at 25°C (19)

Light: incandescent (6,20,28,36); far red (24,35); far red, 0.132×10^{-6} mol cm^{-2} s^{-1} (6); far red, continuous, 5 W m^{-2} (9); far red, intermittent, 2 min/h (9); far red, 30 min (9); far red, 14×10^{-6} W cm^{-2}, 1,16 min, prolonged irradiation (15); far red, 185×10^{-6} W cm^{-2}, 15s-10 min (16, 36); far red, intermittent, 1-4 min/30-120 min (light/dark) (37); far red, 500 ergs cm^{-2} s^{-1} (20); infra red, at 25°C (22); diffuse daylight, 12-24h/d, at 20°/30°C (16h/8h) (18); white, continuous, at 15°C (28); white, continuous, at 17.5°C (35)

Kinetin: co-applied, 10, 20 ppm (4)

GA_3: co-applied, 10-500 ppm (18); co-applied, 100, 200 ppm (26)

Potassium nitrate: co-applied, 10^{-2} M (26); co-applied, 0.2% (17); pre-applied, 2%, dark imbibition, 6d, 20°C, then pre-dry, 2d, 20°C (hardening) (34)

Wetting/Drying: 3 cycles (24h/48h), 20°C (hardening) (34); 1 cycle (1d, 2d/1d), 20°C (hardening) (5)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: above 35°C (2,19)

Alternating temperatures: 20°/30°C (16h/8h), dark or light (13,18,28)

Light: continuous, 50-1000 ergs cm^{-2} s^{-1}, at 27°C (20); white, 4-12h/d, at 20°/30°C (16h/8h) (18); white, 8h/d, at 20°/30°C (16h/8h) (13); red, 295×10^{-6} W cm^{-2}, 15s-1 min, at 20°C, alone or after far red (16,35,37)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h) in light or dark (7); co-applied, 10^{-1} M (26); co-applied, 10^{-2} M, plus kinetin, co-applied, 1-50 ppm (26); co-applied, 10^{-2} M, plus kinetin, co-applied, 10 ppm, plus GA_3, co-applied, 10 ppm (26); plus tripotassium phosphate, pre-applied, 5,10,20d, 10°C, 24°C, 1-2%, germinate at 15°C (hardening) (5,10); plus tripotassium phosphate, pre-applied, 1-8d, 0.2-1.8% (hardening) (14)

Polyethylene glycol: pre-applied, 5-20d, 10°C, 15°C, -5 to -15 bars, germinate at 15°C (hardening) (5,10)

Mannitol: pre-applied, 4h-2d, 0.6M (hardening) (9)

GA_3: pre-applied, 12h, 10-500 ppm, germinate at 20°/30°C (16h/8h), continuous dark (18); pre-applied, 1-48h, 200 ppm, germinate at 20°/30°C (16h/8h), continuous light or dark, or 6 cycles light/dark (12h/12h), or 1 cycle 3d/3d dark/light or light/dark (18); co-applied, 100 ppm, infra red (22); co-applied, 10, 50, 500 ppm (26)

V. Successful dormancy-breaking treatments

Potassium nitrate (ISTA)

Light, Potassium nitrate (AOSA)

Constant temperatures: 10°C, dark (23); 16°-22°C, dark (1); 20°C, dark (15,16,35,36); 25°C, dark (4,5,9,22,37); 27°C, dark (20); 10°-30°C (12); 15°-30°C (19); 14°-24°C (27); 15°C, 20°C (29); 20°-26°C (30,32); 20°-26°C, light, 12h/d (31); 25°-30°C under many different light regimes (15); 13°-25°C, fluorescent light, 8h/d (3); 15°-29°C, white light, 8h/d (11); 26°-32°C, low light intensity, 12h/d (30); 20°C, red light, 1 min, 0.3×10^{-6} W cm^{-2} (15,16); 27°C, white light

or 40 min or continuous red light, 60 ergs cm s (20); 20°C, first 24h in dark (35); 20°C, light, Pfr/P=0.4 (6,16)

Alternating temperatures: 17°/27°C (16h/8h), light, 4000 fc, 8h/d (8); 20°/30°C (16h/8h), dark (24); 20°/30°C (16h/8h), fluorescent light, 175-200 fc, 8h/d (24)

Pre-chill: 10°C, 4m, germinate at 27°C (8)

Potassium nitrate: co-applied, 0.2%, at 20°/30°C (16h/8h), light (13); co-applied, 10^{-2} M, at 30°C or 20°/30°C (16h/8h), daylight (28)

Mannitol: pre-applied, 3-7d, 0.6M, in dark, germinate at 25°C in any light condition (9)

Scarification: cut endosperm over radicle region, germinate at 22°C, light, 16h/d (33)

VI. Comment

The germination of tomato seeds is reported to be dependent on the phytochrome ratio resulting from the light regime in which they are tested (6,9,15,16,18,20-22,24,28,35,36,37). Several authors have reported apparently contradictory effects of light on tomato seed dormancy and germination (7,28). The reader is referred to Chapter 6 for clarification of the effect of phytochrome on germination and the high irradiance reaction - which explain the apparently contradictory results. In particular the light treatment given in Chapter 6 is recommended for this genus. The first 8 to 16 hours after the onset of imbibition are the most critical with regard to the light environment (9,16). After 24 hours of imbibition the effect of light is minimal (35). In passing it should be noted that coloured filter papers - particularly if seeds are germinated between papers - such as blue grey, brown or dark green can inhibit the germination of tomato seeds (24).

Optimum temperatures for germination appear to be constant temperatures between 25° and 30°C (15) or an alternating temperature of 20°/30°C (16h/8h) (24). The range 25° to 30°C appears to be an optimum temperature range for germination since seeds within this range are less dependent upon the light regime for germination, but the germination of the most dormant seeds is not promoted at either these constant temperatures or the alternating temperature regime 20°/30°C (28), but co-applied potassium nitrate may further promote germination in these regimes (13,28).

As a practical regime for seed banks it is suggested that seeds be tested for germination at an alternating temperature of 20°/30°C (16h/8h) with potassium nitrate, co-applied, 0.2% with the light regime given in Chapter 6. Incidentally co-applied potassium nitrate at low concentrations (10^{-1} M) is not deleterious to aged seeds and may enhance the rate of germination (26). (In commerce imbibition in potassium nitrate or water followed by drying back is known as hardening and is often used with tomato seeds.)

VII. References

1. Abdul-Baki, A.A. and Stoner, A. (1978). Germination promoter and inhibitor in leachates from tomato seeds. Journal of the American Society for Horticultural Science, 103, 684-686.

2. Berry, S.Z. (1969). Germinating response of the tomato at high temperature. HortScience, 4, 218-219.

3. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

4. Boscut, S. (1981). Effects of kinetin and salinity on germination of tomato, barley and cotton seeds. Annals of Botany, 48, 81-84.

5. Bussell, W.T. and Gray, D. (1976). Effects of pre-sowing seed treatments and temperatures on tomato seed germination and seedling emergence. Scientia Horticulturae, 5, 101-109.

6. Egles, D. and Rollin, P. (1968). La photosensibilité des graines de tomate var. St. Pierre. Comptes Rendus de l'Académie de Science, Paris, 266D, 1017-1020.

7. Eifrig, H. (1962). Zur Methodik der Keimprüfung einiger Germiisesämereien. Proceedings of the International Seed Testing Association, 27, 649-656.

8. El-Sayed, M.N. and John, C.A. (1973). Heritability studies of tomato emergence at different temperatures. Journal of the American Society for Horticultural Science, 98, 440-443.

9. Georghiou, K., Thanos, C.A., Tafax, T.P. and Mitrakos, K. (1982). Tomato seed germination, osmotic pretreatment and far red inhibition. Journal of Experimental Botany, 33, 1068-1075.

10. Gray, D. and Bussell, W.T. (1974). Effects of temperature on tomato seed germination. National Vegetable Research Station, Annual Report 1974, 79-80.

11. Guy, R. (1981). Influence de la temperature sur la dureé de germination des semences de dix espéces potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 13, 219-225.

12. Harrington, J.F. (1963). The effect of temperature on the germination of several kinds of vegetable seeds. 16th International Horticultural Congress, 2, 435-441.

13. Kelk, O.M. (1953). Some studies on the germination of tomato seed. Proceedings of the Association of Official Seed Analysts, 43, 89.

14. Maluf, W.R. and Tigchelaar, E.C. (1980). Responses associated with low temperature seed germinating ability in tomato. Journal of the American Society for Horticultural Science, 105, 280-283.

15. Mancinelli, A.L., Borthwick, H.A. and Hendricks, S.B. (1966). Phytochrome action in tomato seed germination. Botanical Gázette, 127, 1-5.

16. Mancinelli, A.L., Yaniv, Z. and Smith, P. (1967). Phytochrome and seed germination. I. Temperature dependence and relative Pfr levels in the germination of dark-germinating tomato seeds. Plant Physiology, 42, 333-337.

17. Miguel, M.C. (1975). Report of the working group on the germination of Solanaceae. Seed Science and Technology, 3, 110-115.

18. Mittal, S.P. and Mathur, S.N. (1965). Effect of white light and gibberellin on tomato seed germination. Physiologia Plantarum, 18, 798-804.

19. Mobayen, R.G. (1980). Germination and emergence of citrus and tomato seeds in relation to temperature. Journal of Horticultural Science, 55, 291-297.

20. Mondain-Monval, O.D. (1963). Etude de l'action de la lumière sur la germination des graines de tomate (Lycopersicum esculentum Miller) variété Marmande. Comptes Rendus des Séances de l'Académie de Science, 257, 3646-3648.

21. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). [Effect of light on the germination of

vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

22. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

23. Ng, T.J. and Tigchelaar, E.C. (1973). Inheritance of low temperature seed sprouting in tomato. Journal of the American Society for Horticultural Science, 98, 314-316.

24. Nutile, G.E. and Hackett, T.E. (1959). Light filtering effect of blotters on the germination of seed of tomato (Lycopersicon esculentum). Proceedings of the Association of Official Seed Analysts, 49, 93-97.

25. Patterson, B.D., Paull, R. and Smillie, R.M. (1978). Chilling resistance in Lycopersicon hirsutum Humb. & Bonpl., a wild tomato with a wide altitudinal distribution. Australian Journal of Plant Physiology, 5, 609-617.

26. Puls, E.E. Jr. and Lambeth, V.N. (1974). Chemical stimulation of germination rate in aged tomato seeds. Journal of the American Society for Horticultural Science, 99, 9-12.

27. Scott, S.J. and Jones, R.A. (1982). Characterization of seed germination responses of Lycopersicon species over a wide temperature range. HortScience, 17, 512.

28. Shuck, A.L. (1936). The germination of secondary dormant tomato seeds and their formation. Proceedings of the International Seed Testing Association, 8, 136-158.

29. Smith, P.G. and Millett, A.E. (1964). Germination and sprouting responses of the tomato at low temperatures. Proceedings of the American Society for Horticultural Science, 84, 480-484.

30. Thompson, P.A. (1974). Characterisation of the germination responses to temperature of vegetable seeds. I. Tomatoes. Scientia Horticulturae, 2, 35-54.

31. Thompson, P.A. and Fox, D.J.C. (1976). The germination responses of vegetable seed in relation to their history of cultivation by man. Scientia Horticulturae, 4, 1-14.

32. Went, F.W. (1961). Problems in seed viability and germination. Proceedings of the International Seed Testing Association, 26, 674-685.

33. Whittington, W.J. and Fierlinger, P. (1972). The genetic control of time to germination in tomato. Annals of Botany, 36, 873-880.

34. Wickham, B.D. and Nichols, M.A. (1976). Germination studies with "hardened" vegetable seed. New Zealand Journal of Experimental Agriculture, 4, 457-461.

35. Yaniv, Z. and Mancinelli, A.L. (1967). Phytochrome and seed germination. II. Changes of Pfr requirement for germination in tomato seed. Plant Physiology, 42, 1147-1148.

36. Yaniv, Z. and Mancinelli, A.L. (1968). Phytochrome and seed germination. IV. Action of light sources with different spectral energy distribution on the germination of tomato seeds. Plant Physiology, 43, 117-120.

37. Yaniv, Z., Mancinelli, A.L. and Smith, P. (1967). Phytochrome and seed germination. III. Action of prolonged far red irradiation on the germination of tomato and cucumber seeds. Plant Physiology, 42, 1479-1482.

NICOTIANA

N. alata Link & Otto	
N. acuminata	
N. benthamiana	
N. bigelovii (Torr.) Wats.	
N. corymbosa	
N. eastii	
N. glutinosa L. x N. tabacum L.	
N. goodspeedii	
N. gossei Domin	
N. maritima	
N. megalosiphon	
N. miersii	
N. nudicaulis	
N. rustica L.	nicotine tobacco
N. x sanderae Wats.	
N. suaveolens Lehm.	
N. suaveolens Lehm. x N. langsdorffii Weinmann	
N. tabacum L.	tobacco
N. trigonophylla	

I. Evidence of dormancy

Seeds of the cultivated and wild tobacco species and the hybrids cited above can show considerable dormancy (1-4,9,12,13,17,20,27,29). Seed dormancy is said to persist for 1-3 weeks after harvesting (2). However, if light is not applied to promote germination in the test procedure, tobacco seeds may not germinate at all after 6 months or even many years dry storage at room temperature (10,23).

II. Germination regimes for non-dormant seeds

N. alata, N. x sanderae

TP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

TP: 20°/30°C (16h/8h): 12d (AOSA)

N. suaveolens

TP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

N. tabacum

TP: 20°/30°C (16h/8h): 16d (ISTA)

TP: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

N. tabacum

Constant temperatures: 20°C, 25°C, dark, continuous (3,4,8,9,16,23,27)

Pre-chill: 10°C, dark, 8d, germinate at 25°C, dark or light (3); 5°-17°C, dark, 2w, germinate in dark (9)

Pre-soak: 60°C, 75°C, 90°C, 0.25,0.5 min (3); 60h (12)

Oxygen: 40-80%, germinate in dark (3)

Acetic acid: pre-applied, 24h, 10^{-1}, 1 M, germinate in dark (3)

Butyric acid: pre-applied, 24h, 10^{-2}, 10^{-1} M, germinate in dark (3)

Hydrogen peroxide: pre-applied, 24h, 5-50%, germinate in light (3)

Ether: pre-applied, 15,30,60 min, germinate in dark (3)

Potassium phosphate: co-applied, 10^{-3} M, plus ammonium citrate, $5x10^{-3}$, 10^{-2} M, co-applied, dark (7)

Glucose: co-applied, $5x10^{-3}$ M, at 25°C, light, 50 lux, 10 min (15)

Kinetin: co-applied, 0.01-50 ppm, dark (16)

Ammonium nitrate: co-applied, $5x10^{-3}$ -10^{-1} M, dark (25)

Ammonium sulphate: co-applied, $5x10^{-3}$ -10^{-1} M, dark (5,25)

Ammonium chloride: co-applied, $5x10^{-3}$ -10^{-1} M, dark (5,25)

Potassium sulphate: co-applied, $5x10^{-3}$ -10^{-1} M, dark (5,25)

Potassium chloride: co-applied, $5x10^{-3}$ -10^{-1} M, dark (5,25)

Potassium phosphate: co-applied, $5x10^{-3}$ -10^{-1} M, dark (5,25)

Ammonium phosphate: co-applied, $0.6x10^{-3}$ -$0.2x10^{-1}$ M, dark (25)

Glycine: co-applied, 10^{-2} M, dark (30)

A-Alanine: co-applied, 10^{-2} M, dark (30)

L-Aspartic acid: co-applied, 10^{-2} M, dark (30)

Glutamic acid: co-applied, 10^{-2} M, dark (30)

A-Ketoglutaric acid: co-applied, 10^{-2} M, dark (30)

Scarification: concentrated sulphuric acid, 0.5,1 min (3)

IV. Partly-successful dormancy-breaking treatments

N. corymbosa, N. maritima, N. megalosiphon, N. miersii, N. nudicaulis

Sodium hypochlorite: pre-applied, 15-30 min, 2%, rinse in acetone (2)

N. tabacum

Pre-chill: 10°C, 8d, in light, germinate at 25°C, dark (3); 10°C, 2d, germinate at 25°C, dark (9)

Pre-soak: 60h, in non-dormant tobacco seed filtrate (1g ground seed/10ml water), germinate at 25°C, dark (12,13)

Pre-dry: 85°-90°C, 1h, germinate at 25°C, dark (18)

Potassium nitrate: co-applied, 10^{-2} M, at 25°C, dark (16); co-applied, $2x10^{-2}$ M, at 25°C, dark (4,15); co-applied, $2x10^{-2}$-$8x10^{-2}$ M, at 25°C, dark (5); co-applied, 10^{-3}-10^{-2} M, at 25°C, dark (15); pre-applied, 8h, 100-1000 ppm, germinate at 25°C, dark (20); pre-applied, 10^{-4}-10^{-2} M, germinate at 25°C, dark (3)

Potassium nitrite: co-applied, 10^{-3}-10^{-2} M, at 25°C, dark (15)

Ammonium nitrate: co-applied, 10^{-2} M, at 25°C, dark (15); co-applied, $2x10^{-2}$ M, at 25°C, dark (4); co-applied, $2x10^{-2}$-$8x10^{-2}$ M, at 25°C, dark (5); pre-applied, 24h, 10^{-1}-10^{-4} M, germinate at 25°C, dark (3)

Ammonium sulphate: pre-applied, 24h, 10^{-1}-10^{-4} M, germinate at 25°C, dark (3)

Ammonium hydroxide: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Potassium sulphocyanate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Potassium sulphate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Potassium hydroxide: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Sodium sulphocyanate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Sodium iodide: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Sodium sulphate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Sodium nitrate: pre-applied, 24h, 10^{-1}-10^{-4} M, germinate at 25°C, dark (3); co-applied, 10^{-2} M, at 25°C, dark (15)

Sodium hydroxide: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Lithium sulphate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Lithium nitrate: co-applied, 10^{-2} M, at 25°C, dark (15)

Nickel sulphate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Zinc sulphate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Aluminium nitrate: pre-applied, 24h, 10^{-3}, 10^{-4} M, germinate at 25°C, dark (3)

Cobalt nitrate: pre-applied, 24h, 10^{-2}-10^{-4} M, germinate at 25°C, dark (3)

Hydrogen peroxide: 0.5%, at 25°C, dark (19); pre-applied, 27h, 5-50%, germinate at 25°C, dark (3)

Ether: pre-applied, 15,30,60 min, germinate at 25°C, light (3)

Acetic acid: pre-applied, 24h, 10^{-2}-10^{-4} N, germinate at 25°C, dark (3); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

-3 -4

Butyric acid: pre-applied, 24h, 10 , 10 N, germinate at 25°C, dark (3)

Citric acid: pre-applied, 24h, 10^{-1}-10^{-4} N, germinate at 25°C, dark (3); co-applied $5x10^{-3}$ M, at 25°C, dark (15); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

Tartaric acid: pre-applied, 24h, 10^{-1}-10^{-4} N, germinate at 25°C, dark (3); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

Malic acid: pre-applied, 24h, 10^{-1}-10^{-4} N, germinate at 25°C, dark (3); co-applied $5x10^{-3}$ M, at 25°C, dark (15); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

Sulphuric acid: pre-applied, 24h, 10^{-2}-10^{-5} N, germinate at 25°C, dark (3)

Hydrochloric acid: pre-applied, 24h, 10^{-3}-10^{-5} N, germinate at 25°C, dark (3)

Phosphoric acid: pre-applied, 12h, 0.5%, germinate at 25°C, dark (13)

Boric acid: pre-applied, 12h, 0.5%, germinate at 25°C, dark (13)

Formalin: pre-applied, 12h, 0.5%, germinate at 25°C, dark (13)

Calcium nitrate: co-applied, 10^{-2} M, at 25°C, dark (15)

Magnesium nitrate: co-applied, 10^{-2} M, at 25°C, dark (15)

Barium nitrate: co-applied, 10^{-2} M, at 25°C, dark (15)

Bismuth nitrate: co-applied, 10^{-2} M, at 25°C, dark (15)

Hydroxylamine: co-applied, 10^{-3} M, at 25°C, dark (15)

Glycine: co-applied, $5x10^{-3}$, 10^{-2} M, light, 50 lux, 10 min (15)

Alanine: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Valine: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Leucine: co-applied, $5x10^{-3}$, 10^{-2} M, light, 50 lux, 10 min (15)

Arginine: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Aspartic acid: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Glutamic acid: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Tryptophane: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Asparagine: co-applied, 10^{-3}-10^{-2} M, light, 50 lux, 10 min (15)

Glycerine: co-applied, $5x10^{-3}$ M, light, 50 lux, 10 min (15)

Pyruvic acid: co-applied, $5x10^{-3}$ M, light, 50 lux, 10 min (15); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

-3 -2

A-Ketoglutaric acid: co-applied, 5x10 M, light, 50 lux, 10 min (15); co-applied, 10 M, plus GA_3, co-applied, 10 ppm (24)

Succinic acid: co-applied, $5x10^{-3}$ M, light, 50 lux, 10 min (15); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

Fumaric acid: co-applied, $5x10^{-3}$ M, light, 50 lux, 10 min (15); co-applied, 10^{-2} M, plus GA_3, co-applied, 10 ppm (24)

Indoleacetic acid: co-applied, 10^{-7} M, at 25°C, dark (23)

Kinetin: co-applied, 10 ppm, at 25°C, dark (5); co-applied, 10, 20 ppm, plus potassium nitrate, or ammonium chloride, or potassium chloride, co-applied, $2x10^{-2}$, $5x10^{-2}$ M (5)

Benzyladenine: co-applied, 10^{-7} M, at 25°C, dark (23)

GA_1: co-applied, $5x10^{-6}$-$5x10^{-4}$ M, plus potassium nitrate, co-applied, 10^{-2} M, at 25°C, dark (6)

GA_2: co-applied, $5x10^{-6}$-$5x10^{-4}$ M, plus potassium nitrate, co-applied, 10^{-2} M, at 25°C, dark (6)

GA_3: pre-applied, 24h, 100, 500 ppm, germinate at 25°C, dark (17); pre-applied, 8h, 1-100 ppm, plus potassium nitrate, pre-applied, 8h, 100 ppm (20); co-applied, 30 ppm, at 25°C, dark (4); co-applied, 0.3-30 ppm, at 25°C, dark (5); co-applied, 1-100 ppm, at 25°C, dark (16,20); co-applied, 10^{-4} M, at 25°C, dark (23); co-applied, 5-20 ppm, at 25°C, dark (26); co-applied, 100 ppm at

25°C, dark (19); co-applied, 0.3-30 ppm, plus potassium nitrate or ammonium nitrate, co-applied, $4x10^{-2}$, $8x10^{-2}$ M, at 25°C, dark (4,5); co-applied, 10 ppm, plus ammonium chloride or ammonium sulphate or potassium chloride or potassium sulphate, co-applied, $5x10^{-2}$, 10^{-1} M, at 25°C, dark (5); co-applied, 10 ppm, plus potassium nitrate, co-applied, $4x10^{-2}$ M, plus potassium phosphate, co-applied, 10^{-2} -$4x10^{-2}$ M, at 25°C, dark (7); co-applied, 10 ppm, plus ammonium nitrate or ammonium sulphate or ammonium chloride, co-applied, $5x10^{-3}$ -10^{-1} M, at 25°C, dark (25); co-applied, $5x10^{-6}$ -$5x10^{-4}$ M, plus potassium nitrate, co-applied, 10^{-2} M, at 25°C, dark (6)

GA_4: co-applied, 10^{-7} -$5x10^{-6}$ M, plus potassium nitrate, co-applied, 10^{-2} M, at 25°C, dark (6)

V. Successful dormancy-breaking treatments

N. alata

Potassium nitrate (ISTA)

Light (AOSA)

N. acuminata, N. benthamiana, N. bigelovii, N. eastii

Sodium hypochlorite: pre-applied, 15-30 min, 2%, rinse in acetone (2)

N. glutinosa x N. tabacum

Light: 200-400 fc, 8h/d, at 25°C (23)

N. goodspeedii, N. gossei

Sodium hypochlorite: pre-applied, 15-30 min, 2%, rinse in acetone (2)

N. rustica

GA_3: pre-applied, 8h, 10-100 ppm, plus potassium nitrate, 250-1000 ppm, germinate at 25°C, diffuse light, 4h/d (20)

N. x sanderae

Potassium nitrate (ISTA)

Light (AOSA)

N. suaveolens

Potassium nitrate (ISTA)

N. tabacum

Potassium nitrate (ISTA)

Light (AOSA)

Alternating temperatures: 20°/30°C (16h/8h), light or dark (14); 20°/30°C (16h/8h), light (21,22,23,27)

Light: diffuse, at 25°C (9); diffuse, at 20°C (10,11); fluorescent, 200-400 fc, 8h/d, at 25°C (23); red, 16-32 min, after 24h dark (8); red, 8-32 min, after 48h dark (8); red, 1-2 min, after 72h dark (8); red, 0.5 min, after 96h dark (8); red, continuous, at 15°-25°C or 20°/30°C (16h/8h) (14,27)

Potassium nitrate: co-applied, 0.2%, at 10°/30°C (16h/8h), diffuse light (22); co-applied, 0.2%, at 20°/30°C (16h/8h), diffuse light (21,22); co-applied, 0.2%, at 20°/30°C (16h/8h), continuous red light, 0.3×10^{-3} W cm^{-2} (27); co-applied, 10^{-2} M, plus kinetin, co-applied, 10 ppm, at 25°C, light, 3h (16)

GA_3: (18); pre-applied, 1.5h, 12×10^{-5} M (1); pre-applied, 24h, 500 ppm (17); co-applied, 10^{-4} M, with or without indoleacetic acid, 10^{-7} M, or benzyladenine, 10^{-7} N, at 20°/30°C (16h/8h), fluorescent light, 200-400 fc, 8h/d (23); co-applied, 50 ppm, plus potassium nitrate, 10^{-2} M, co-applied, at 25°C, in light, 1h (16,20) Sodium hypochlorite: pre-applied, 15-30 min, 2%, rinse in acetone (2)

N. trigonophylla

Sodium hypochlorite: pre-applied, 15-30 min, 2%, rinse in acetone (2)

VI. Comment

The pre-applied sodium hypochlorite treatment has been used frequently and regularly to remove dormancy in seeds of many species and interspecific hybrids within the genus Nicotiana and is reported to be very useful in breeding programmes and when regenerating collections of diverse germplasm (2).

When germinating seeds of Nicotiana spp. it is essential to provide light (3,8-11,14,20,23,27,28). The light regime provided in Chapter 6 is recommended. Whether the germination test is conducted in the light or dark, the germination of dormant seeds will be

promoted more by the use of alternating temperature regimes than it will be at constant temperatures (14,21-23,27): 20°/30°C (16h/8h) appears to be a satisfactory regime (14,21-23,27). Thus the AOSA/ISTA prescriptions are generally satisfactory. If it is not possible to provide an alternating temperature regime and a constant temperature is provided then higher temperatures (30°C) should be avoided because germination may be inhibited: use 20°C (10,14,16).

If further dormancy breaking treatments are required then treatment with gibberellins is likely to be among the more effective (4,5). For successful treatment concentrations see above. Other useful dormancy-breaking agents, in declining order of reported effectiveness are ammonium nitrate, potassium nitrite, potassium nitrate (15). In the case of accessions with considerable dormancy, combinations of gibberellins and potassium nitrate are suggested, co-applied at the concentrations given above, since there can be powerful positive interactions in the effect of these two agents (16,20). Finally if these are insufficient try combining the preceding with the sodium hypochlorite pre-treatment (2).

VII. References

1. Andersen, R.A. (1975). Effects of gibberellic and pretreatments on the germination of hybrid tobacco seeds. Kentucky Agricultural Experiment Station, Lexington, Annual Report, 88, 28.

2. Burk, L. (1957). Overcoming of seed dormancy in Nicotiana. Agronomy Journal, 49, 461.

3. Gardner, W.A. (1921). Effect of light on germination of light sensitive seeds. Botanical Gazette, 71, 249-288.

4. Hashimoto, T. (1958). Increase in percentage of gibberellin-induced dark germination of tobacco seeds by N-compounds. The Botanical Magazine, Tokyo, 71, 845-846.

5. Hashimoto, T. (1961). Influence of inorganic nitrogenous compounds on tobacco seed germination induced by gibberellin A_3, kinetin and ammonium salts of organic acids. Plant and Cell Physiology, 2, 463-469.

6. Hashimoto, T. and Yamaki, T. (1960). Comparative effectiveness of gibberellins A_1, A_2, A_3 and A_4, with special reference to that of A_4. The Botanical Magazine, Tokyo, 73, 64-68.

7. Hashimoto, T. and Yamaki, T. (1962). Interaction of GA and inorganic phosphate in tobacco seed germination. Plant and Cell Physiology, 3, 175-187.

8. Holdsworth, M. (1972). Phytochrome and seed germination. New Phytologist, 71, 105-110.

9. Honing, J.A. (1930). Nucleus and plasma in the heredity of the need of light for germination in Nicotiana seeds. Genetica, 12, 441-468.

10. Kasperbauer, M.J. (1968). Dark germination of receiprocal hybrid seed from light-requiring and -indifferent Nicotiana tabacum. Physiologia Plantarum, 21, 1308-1311.

11. Kasperbauer, M.J. (1968). Germination of tobacco seed. I. Inconsistency of light sensitivity. Tobacco, 166, 24-26. (From Field Crop Abstracts, 1969, 22, 1436.)

12. Krishnamoorthi, T. and Moses, J.S.L. (1969). Breaking of seed dormancy in tobacco (Nicotiana tabacum L.). Indian Journal of Agricultural Science, 39, 1098-1101.

13. Manolov, A.J. (1957). Breaking dormancy of tobacco seeds. Izv. Inst. Biol. Met. Popov, Ban. 8, 83-98. (From Horticultural Abstracts, 1959, 29, 2610.)

14. Mayer, A.M. and Poljakoff-Mayber, A. (1963). The germination of seeds. Pergamon Press.

15. Ogawara, K. and Ono, K. (1955). Effects of various nitrogen compounds and respiratory intermediates on the germination of the light-favored tobacco seeds. Bulletin of School of Education, Okayama University, 1, 97-104.

16. Ogawara, K. and Ono, K. (1961). Interaction of gibberellin, kinetin and potassium nitrate in the germination of light-sensitive tobacco seeds. Plant and Cell Physiology, 2, 87-98.

17. Popov, M. (1962). Breaking post-harvest physiological dormancy in tobacco seeds. Bâlg. Tjutjun, 7, 52-54. (From Horticultural Abstracts, 1963, 33, 7695.)

18. Rajarao, D.C. (1970). Recent trends of the research on the factors influencing the germination of tobacco seed. Rajahmundri (India): Central Tobacco Research Institute, 15pp. (From Field Crop Abstracts, 1970, 23, 3963.)

19. Roman, T. and Michlewska, C. (1964). [Further studies on the influence of some chemical compounds on the germination of tobacco seeds.] Biul. Centr. Lab. Przem. Tyton., Krakow, 3, 13-19. (From Field Crop Abstracts, 1969, 20, 577.)

20. Sarma, C.M. and Phukan, J.D. (1981). Synergism between gibberellic acid and potassium nitrate on the germination of positively photoblastic seeds of tobacco. Indian Agriculturist, 25, 221-226.

21. Schmidt, B. (1963). [Physiology of germination and methods of assessing the germinative power of tobacco seeds.] Dtsch. Tabakbau, 43, 9-10. (From Horticultural Abstracts, 1964, 34, 1195.)

22. Schmidt, B. (1964). [Investigation on the germination capacity of tobacco seed.] Landw. Forsch., 17, 17-22. (From Horticultural Abstracts, 1964, 34, 7245.)

23. Spaulding, D.W. and Steffens, G.L. (1969). Elimination of light requirements for tobacco seed germination with gibberellic acid, indole-3-acetic acid and N6-benzyladenine. Tobacco Science, 13, 156-159.

24. Takahashi, N., Moroo, T., Hashimoto, T. and Yamaki, T. (1962). Effects of some organic acids on the dark germination of tobacco seed. The Botanical Magazine, Tokyo, 75, 163-169.

25. Takahashi, N., Yamada, T., Hashimoto, T. and Yamaki, T. (1962). Effect of inorganic compounds on the dark germination of tobacco seeds induced by gibberellin. The Botanical Magazine, Tokyo, 75, 49-55.

26. Takahashi, N., Yamada, T., Moroo, T. and Yamaki, T. (1962). Further studies upon the effect of inorganic compounds on the dark germination of tobacco seeds induced by gibberellin. The Botanical Magazine, Tokyo, 75, 83-91.

27. Toole, E.H., Toole, V.K., Borthwick, H.A. and Hendricks, S.B. (1955). Interaction of temperature and light in germination of seeds. Plant Physiology, 30, 473-478.

28. Tramvalidis, C. and Sideris, E.G. (1978). The effect of red light illumination on the germination of seeds from four oriental varieties of Nicotiana tabacum L. Bulletin d'Information Coresta, 50.

29. Watanabe, N. (1980). [Genetical studies on the photoblastism of tobacco seed.] Research Bulletin of the Faculty of Agriculture, Gifu University, 44, 1-34. (From Seed Abstracts, 1981, 4, 2676.)

30. Yamaki, T. and Takahashi, N. (1962). Some considerations upon the dark germination of

tobacco seed. The Botanical Magazine, Tokyo 75, 245-254.

SOLANUM

S. acaule Bitt. [S. depexum Juz. & Buk.]	
S. aviculare Forst.	
S. caldasii	
S. canasense Hawk.	
S. capsicastrum Link	
S. carolinense L.	horsenettle
S. chacoense Bitt. [S. schickii Juz. & Buk.]	
S. chacoense Bitt. x S. emmeae Juz. & Buk.	
S. chancayense	
S. chomatophilum	
S. demissum Lindl.	bittersweet
S. dulcamara L.	
S. garciae	
S. giganteum Jacq.	
S. guerreroense x S. isopetalum	igbagba
S. incanum L.	
S. jamesii Torr.	
S. khasianum Clarke	
S. laciniatum Ait.	
S. marginatum L.	
S. medians	
S. melongena L.	aubergine, brinjal, eggplant, melongene
S. multidissectum	
S. nigrum L.	common nightshade
S. papita Rydb.	
S. parodii	
S. phureja Juz. & Buk.	
S. pinnatisectum Dunal x S. jamesii Torr.	
S. rostratum	buffalo bur
S. sarrachoides Sendt.	
S. schickii	
S. stenotomum Juz. & Buk.	
S. stoloniferum Schlecht.	
S. tarijense	
S. tlaxcalense	
S. trifidum Correll. x S. jamesii Torr.	
S. tuberosum L.	potato
S. verrucosum Schlecht.	
S. viarum Dunal	
S. xanthocarpum Schrad. & Wendl.	
S. yabari	

I. Evidence of dormancy

Seeds extracted from freshly harvested berries of S. tuberosum may show deep dormancy (5,6,9,13,16,18,19,21,34,35,36,38,40-42,44-46) which results in serious problems for breeders

(18,19,42,45). Moreover, seeds of tetraploids can be more dormant than seeds of diploids (36). Claims of immediate germination of freshly harvested seeds (28) are somewhat exaggerated. Although many seeds germinate relatively quickly, other seeds continue to germinate after 90 days in test (28).

At room temperature after-ripening periods of several weeks (9), 2-3 months (13,40), 3-5 months (45), 6 months to 2 years (36) or more than a year (44) have been reported to be necessary before dormancy is lost. At lower temperatures (0°-5°C) dormancy may be maintained for between 5 (39) and 13 years (5).

Seeds of other tuber-bearing Solanum spp. - and their hybrids - may show considerably more dormancy (2,16,36,37,40). Thus, for example, seeds of S. chancayense, S. medians, S. multidissectum and S. pinnatisectum stored at 1°-3°C with 5% moisture content continued to lose dormancy after more than 10 years in storage (56). In addition it should be noted that secondary dormancy has been reported in S. chacoense, S. demissum, S. tarijense, S. tuberosum and S. verrucosum (37,39).

Dormancy has also been reported in seeds of the cultivated S. melongena (24,26,27,54,60), other non-tuber bearing Solanum spp. which provide vegetables or pharmaceuticals, viz. S. acaule (20), S. dulcamara (32), S. incanum (15), S. khasianum (4,17,23), S. laciniatum (11,30,49), S. nigrum (33,58,59), and S. xanthocarpum (29,59), and the weed species S. carolinense (55) and S. sarrachoides (31).

II. Germination regimes for non-dormant seeds

S. capsicastrum

TP; BP: 20°/30°C (16h/8h); 20°C: 28d (ISTA)

S. carolinense, S. dulcamara

Constant temperatures: 30°C (43)

Alternating temperatures: 20°/30°C (16h/8h) (43)

S. giganteum

TP; BP: 20°/30°C (16h/8h); 20°C: 28d (ISTA)

S. laciniatum

TP: 20°/30°C (16h/8h); 20°C: 28d (ISTA)

S. marginatum

TP; BP: 20°/30°C (16h/8h); 20°C: 28d (ISTA)

S. melongena

TP; BP: 20°/30°C (16h/8h): 14d (AOSA,ISTA)

Constant temperatures: 15°-25°C (3)

S. nigrum, S. rostratum

Constant temperatures: 30°C (43)

Alternating temperatures: 20°/30°C (16h/8h) (43)

Solanum spp.

TP: 20°/30°C (16h/8h): 14d (AOSA)

III. Unsuccessful dormancy-breaking treatments

S. aviculare

Constant temperatures: 15°-25°C, dark (62)

Pre-chill: 4°C, 1-10w (62)

GA_3: pre-applied, 24h, 10^{-2}, 10^{-5} M (30); pre-applied, 72h, 10^{-2} M (30); pre-applied, 72h, 10^{-2} -10^{-5} M, dissolved in acetone (30)

Scarification: concentrated sulphuric acid, 5-60 min (30); mechanical, air turbine scarifier, 1h (30) Acetone: pre-applied, 24h (30)

S. carolinense

Light: 1500 lux, 8h/d, at 20°/30°C (16h/8h) (55)

Ethylene: co-applied, 1, 10, 100 ppm, at 20°/30°C (16h/8h) (55)

S. dulcamara

Constant temperatures: 15°C, 20°C, 25°C (32)

S. khasianum

Light: continuous (23); dark (17,23)

Ammonium nitrate: pre-applied, 24h, 0.1, 0.5, 1% (23)

Scarification: sulphuric acid, 80%, 5 min, then pre-soak, 16h, germinate at 25°C in dark, with or without either potassium nitrate, pre-applied, 16h, 1%, or thiourea, pre-applied, 16h, 1% (17)

S. laciniatum

Constant temperatures: 10°C, 40°C (11); 15°-30°C, dark (62)

Pre-chill: 4°C, 1-10w (62)

Potassium nitrate: pre-applied, 24,48h, 0.1-0.3% (49); pre-applied, 3,6d, 1, 3, 55% (49)

Thiourea: co-applied, 1% (30)

GA_3: pre-applied, 24h, 10^{-4}, 10^{-5} M, dissolved in acetone (30); pre-applied, 72h, 10^{-2} M (30); pre-applied, 24,48,72h, 0.01, 0.1, 1 ppm (49); pre-applied, 9d, 500-1500 ppm (49)

Cytokinin: co-applied, $5x10^{-7}$ -$5x10^{-5}$ M (30)

Indoleacetic acid: pre-applied, 24-72h, 0.001-0.1 ppm (49)

Pre-wash: 1-5d (49)

Storage: 1,2,3d, -5°-35°C (49)

Scarification: concentrated sulphuric acid, 5-60 min (30); mechanical, air turbine scarifier, 1h (30)

S. melongena

Constant temperatures: 9°-16°C (60); 20°C, 25°C (54); 25°C (24,27); 15°C, 20°C, 25°C, light or dark (52)

Light: (25); continuous (52); infra red, 25°C (27); far red (52); blue (52)

Oxygen: 10-21% (52)

Carbon dioxide: (52)

S. nigrum

Constant temperatures: 4°-30°C (33); 21°C, light or dark (58); 10°C, 15°C, 40°C, 45°C in light, 10^{-4} mol m^{-2} s^{-1}, 16h/d, or dark (61); 10°-45°C, dark (61)

Pre-soak: 12h (58)

Potassium nitrate: co-applied, 0.2% (33)

Light: green (33); dark (33); far red, 42 W m^{-2}, 5 min (33); sunlight, 8h/d (59); red (59)

S. stenotomum

Alternating temperatures: 20°/30°C (18h/6h) (16)

GA_3: co-applied, 1000, 2000 ppm (16)

S. tuberosum

Constant temperatures: 0°-10°C (46,47); 25°C, 30°C (42); 30°C, diffuse light (6); 30°C, 35°C (46,47)

Alternating temperatures: 20°/30°C (18h/6h) (16)

Pre-chill: 0°-5°C, 3d (46); 5°C, 7d, with or without potassium nitrate, co-applied, 0.2% (42); 3°-5°C, 7-21d, germinate at 20°/30°C (16h/8h) (6)

Pre-soak: 24h (19); 48h (36,46)

Pre-dry: 72°C, to constant weight (46)

Storage: -5°C, 2d (36); berries, 0°-5°C, 20°-23°C, 35d (46)

Light: continuous (1); 600-2500 fc, 16h/d (18); daylight, 4h/w (36); dark (36)

Potassium nitrate: co-applied, 0.2% (36); co-applied, 1% (42)

Thiourea: co-applied, 1% (42)

Coumarin: co-applied, 200 ppm (36)

Hydrogen peroxide: co-applied, 3% (46)

Scarification: concentrated sulphuric acid, 1 min (46); concentrated sulphuric acid, 1-5 min (42); sulphuric acid, 2, 5, 10, 25%, 45 min (45,46); sulphuric acid, 75%, 15-45 min (6)

Ethyl alcohol: pre-applied, 1h, 5-50% (45,46)

Ethylene chlorohydrin: pre-applied, 12h, 6% (45,46)

Thiram: dust, 75% (19)

S. xanthocarpum

Constant temperatures: 20°C, 25°C, 35°C, light, 5-6h/d (59)

Light: daylight, 8-24h/d (59); dark, continuous (59); red (59)

IV. Partly-successful dormancy-breaking treatments

S. acaule

GA_3: co-applied, 500 ppm (20)

S. aviculare

Constant temperatures: 25°C in light (62)

Alternating temperatures: 20°/30°C (16h/8h) (62)

GA_3: pre-applied, 24h, 10^{-3}, 10^{-4} M (30); pre-applied, 24h, 10^{-2}-10^{-5} M, dissolved in acetone (30); pre-applied, 72h, 10^{-3}-10^{-5} M (30)

Pre-soak: 1,3d (30)

S. caldasii

Potassium nitrate: co-applied, 0.2-1% (41)

Scarification: sulphuric acid, 30%, 6-14 min (41)

S. canasense

GA_3: co-applied, 500 ppm (16)

S. chomatophilum

GA_3: pre-applied, 16h, 1500 ppm (2)

Pre-soak: 16h (2)

Pellet: in charcoal with or without GA_3, 1500 ppm (2)

S. dulcamara

Constant temperatures: 30°C, daylight, short period (32)

$GA_{4/7}$: co-applied, 300 ppm, at alternating temperatures (32)

S. guerreroense x S. isopetalum

Pre-soak: 16h (2)

Pellet: in charcoal (2)

GA_3: pre-applied, 16h, 1500 ppm (2)

S. incanum

Alternating temperatures: 10°/25°C (8h/16h) (15)

Removal of seed covering structures: (15)

GA_3: pre-applied, 1,6d, 10°C, 25°C, 500 ppm, then pre-dry (15)

Pre-dry: after imbibition, 1,6d, 10°C, 25°C (15)

S. jamesii

GA_3: pre-applied, 24h, 2000 ppm (40)

S. khasianum

Pre-soak: 4h (4); 16h, germinate at 25°C in light (17)

Light: (17); diffuse (23)

Potassium nitrate: pre-applied, 16h, 1%, to scarified seeds, sulphuric acid, 80%, 5 min, germinate at 25°C in light (17)

Ammonium nitrate: pre-applied, 24h, 0.125%, diffuse light (23)

Thiourea: pre-applied, 16h, 1%, to scarified seeds, sulphuric acid, 80%, 5 min, germinate at 25°C in light (17)

Ethrel: pre-applied, 4h, 500-1250 ppm (4)

S. laciniatum

Alternating temperatures: 15°/25°C, 20°/30°C (16h/8h), dark (62)

Pre-soak: 1,3d (30)

GA_3: pre-applied, 24h, 10^{-2}, 10^{-5} M (30); pre-applied, 72h, 10^{-3}-10^{-5} M (30); pre-applied, 3,6d, 500-1500 ppm (49); co-applied, 1000 ppm (11)

Potassium nitrate: pre-applied, 3d, 0.1-0.3% (49); pre-applied, 9d, 1, 3, 55% (49)

Acetone: pre-applied, 1d (30)

S. melongena

Constant temperatures: 23°-26°C (60)

Alternating temperatures: 30°/20°C (16h/8h) (52,54); 30°/15°C (16h/8h) (24,27)

Warm stratification: 20°C, 1-5d, then 10°C, 15°C, 25°C, 30°C, 2h, germinate at 30°/20°C (16h/8h) (54); 25°C, 1-6d, then 5°C, dark, 2-8h, germinate at 25°C, dark (53); 25°C, 1-6d, then 35°C, dark, 4h, germinate at 25°C, dark (53); 40°C, 45°C, 7d, plus GA_3, co-applied, 100 ppm, germinate at 25°C, dark (51)

Light: short exposure (51,52); red, low temperatures (52); dark, alternating temperatures (52)

Potassium nitrate: co-applied, 0.2%, germinate at 25°C or 30°/15°C (16h/8h) (24,27)

GA_3: co-applied, 25, 50 ppm, at 30°/20°C (16h/8h) (54); co-applied, 50, 100 ppm, at 25°C, 30°/15°C (16h/8h) (24,27); co-applied, 100 ppm, at 20°C, 25°C, 30°C, 35°C, dark or light (51)

S. nigrum

Constant temperatures: 15°C, light (59); 20°C, light, 10^{-4} mol m^{-2} s^{-1}, 16h/d (61)

Alternating temperatures: 10°-15°/25°C (16h/8h) in light (33); 25°/9°C (16h/8h) (58); 20°/30°C, 15°/30°C (16h/8h) (59)

Pre-chill: 3°-5°C, 1-6w (58)

Warm stratification: 30°C, 1-10w (33)

Light: diffuse daylight, 4-8h/d (59); direct sunlight, 2-6h/d (59); plus aerated water (59)

S. parodii

Potassium nitrate: co-applied, 0.2-1% (41)

Scarification: sulphuric acid, 30%, 6-14 min (41)

S. pinnatisectum x S. jamesii

GA_3: pre-applied, 24h, 2000 ppm (40)

S. sarrachoides

Alternating temperatures: 10°/25°C, 10°/30°C, 20°/30°C (16h/8h) (31)

S. stenotomum

Constant temperatures: 10°C, 20°C (16)

Alternating temperatures: 10°/30°C (18h/6h) (16)

Pre-chill: 5°-10°C, 7d (16)

GA_3: co-applied, 500 ppm (16)

Potassium nitrate: co-applied, 0.2% (16)

Light: (16)

S. tuberosum

Constant temperatures: 7°C, 10°C, 20°C, continuous light (1); 10°C in light (16); 15°C, 20°C (42); 12°C, 20°C, 25°C, diffuse light (6)

Alternating temperatures: 10°/30°C, 12°/20°C, 20°/12°C (18h/6h) (16); 20°/30°C (16h/8h) (42); 12°/20°C, 20°/30°C (17h/7h) (6)

Pre-chill: 5°-10°C, 7d (16); 0°C, 5°C, 55d (46)

Warm stratification: 30°C, 45d, germinate at 20°C (47); 30°C, 3w, diffuse light, germinate at 20°/30°C (17h/7h) (6)

Light: (16); 1200 fc, 4,8h/d (18); 600 fc, 16h/d (18); diffuse daylight (36)

Potassium nitrate: co-applied, 0.2% (16,42); co-applied, 0.2-1% (41); pre-applied, 24h, 0.2-2% (6)

GA_3: co-applied, 500, 1000, 2000 ppm (16); co-applied, 0.5, 5 ppm, at 20°C in light, 1200 fc, 16h/d (18); co-applied, up to 200 ppm, plus cysteine, co-applied, 1780 ppm (36); pre-applied, 16h, 1500 ppm (2)

Pre-soak: 24h (6)

Removal of seed covering structures: (36,45,46)

Scarification: concentrated sulphuric acid, 1 min (45); sulphuric acid, 30% 6-14 min (41); sulphuric acid, 20, 25, 30%, 5, 10 min (41); concentrated sulphuric acid, drip (41); sand paper (45)

S. verrucosum

GA_3: pre-applied, 24h, 2000 ppm (40)

S. viarum

Constant temperatures: 30°C (57)

Acetic acid: pre-applied, 2%, germinate at 30°C (57)

S. xanthocarpum

Alternating temperatures: 20°/25°C, 25°/30°C, 30°/35°C, 35°/40°C (16h/8h), daylight, 5-6h/d (59)

Light: daylight, 2-3h/d (59); plus aerated water (59)

S. yabari

Scarification: concentrated sulphuric acid, drip (41); sulphuric acid, 20, 25, 30%, 5, 10 min (41)

V. Successful dormancy-breaking treatments

S. acaule

GA_3: co-applied, 500 ppm (16)

S. aviculare

Alternating temperatures: 15°/25°C (16h/8h), light (62)

Acetone: pre-applied, 72h (30)

S. capsicastrum

Light, Potassium nitrate (ISTA)

S. carolinense

Potassium nitrate: co-applied, 0.2%, at 30°C or 20°/30°C (16h/8h) (43)

S. chacoense

GA_3: co-applied, 500 ppm (16); pre-applied, 24h, 2000, 4000 ppm (40)

Removal of seed covering structures: (41)

S. chacoense x S. emmeae

GA_3: pre-applied, 24h, 2000, 4000 ppm (40)

S. demissum

GA_3: co-applied, 250 ppm, plus cysteine, 900 ppm, co-applied (36); pre-applied, 24h, 1000, 2000, 4000 ppm (40)

S. dulcamara

Alternating temperatures: 10°/25°C, 10°/30°C, 20°/30°C (16h/8h) (32)

Pre-chill: 4°C, 1m (32)

Potassium nitrate: co-applied, 0.2%, at 30°C or 20°/30°C (16h/8h) (43)

$GA_{4/7}$: co-applied, 300 ppm, at 20°C, 25°C or 30°C (32)

S. garciae

Removal of seed covering structures: (41)

S. giganteum

Light, Potassium nitrate (ISTA)

S. guerreroense x S. isopetalum

Pellet: in charcoal with GA_3, 1500 ppm (2)

S. khasianum

GA_3: pre-applied, 16h, 1%, to scarified seeds, sulphuric acid, 80%, 5 min, germinate at 25°C in light (17)

S. laciniatum

Potassium nitrate (ISTA)

Constant temperatures: 22°C, 30°C (11); 28°C (14)

Alternating temperatures: 15°/25°C (16h/8h), light, 8h (62)

Pre-chill: 4°C, 3w, germinate at 26°C (30)

GA_3: pre-applied, 24h, 10^{-3}, 10^{-4} M, germinate at 26°C (30); pre-applied, 24h, 10^{-2}, 10^{-3} M, dissolved in acetone, germinate at 26°C (30)

Thiourea: co-applied, 0.01-0.75%, at 26°C (30)

Acetone: pre-applied, 72h, germinate at 26°C (30)

S. marginatum

Light, Potassium nitrate (ISTA)

S. melongena

Potassium nitrate, Light (AOSA)

Alternating temperatures: 20°-23°/30°C, 28°-30°/20°±3°C (16h/8h) (60)

GA_3: co-applied, 50, 100, 200 ppm, at 30°/20°C (16h/8h) (50,54); pre-applied, 24h, 10-40 ppm (12)

Indoleacetic acid: pre-applied, 24h, 10, 20 ppm (12)

1-Naphthaleneacetic acid: pre-applied, 24h, 10-40 ppm (12)

Polyethylene glycol: pre-applied, 14d, at 15°C (25)

S. nigrum

Constant temperatures: 25°C, 30°C, 35°C in light, 10^{-4} mol m^{-2} s^{-1} (61)

Alternating temperatures: 10°/30°C, 15°/30°C (16h/8h) in light (33); 15°-20°/25°C (16h/8h) in dark or light, 8h/d (59); 20°/30°C (16h/8h) (43)

Pre-chill: 4°C, 1-10w (33)

Warm stratification: 15°C, 3-12d, daylight or red light, 5 min, 11.7 W m^{-2} (33)

Light: diffuse daylight, 8-14h/d, at 15°/25°C (16h/8h) (59); dark, continuous, at 15°/25°C (16h/8h) (59); green (59)

Potassium nitrate: co-applied, 0.2%, at 30°C or 20°/30°C (16h/8h) (43)

GA_3: co-applied, 500 ppm (33); co-applied, $5x10^{-3}$ M, at 25°C, 35°C, light or dark (61)

$GA_{4/7}$: co-applied, 10^{-4} M, at 25°C, 35°C, light or dark (61)

S. papita

GA_3: co-applied, 500 ppm (16)

S. phureja

GA_3: pre-applied, 24h, 2000 ppm (40)

S. rostratum

Potassium nitrate: co-applied, 0.2%, at 30°C or 20°/30°C (16h/8h) (43)

S. sarrachoides

Alternating temperatures: 4°/25°C (16h/8h) (31) Pre-chill: 4°C, 6m (31)

S. schickii

Removal of seed covering structures: (41)

S. stoloniferum

GA_3: pre-applied, 24h, 1000 ppm (40)

S. trifidum x S. jamesii

GA_3: pre-applied, 24h, 2000 ppm (40)

S. tlaxcalense

Removal of seed covering structures: (41)

S. tuberosum

Constant temperatures: 10°C (7); 10°C, discontinuous light (1); 20°C (46)

Warm stratification: 16°-18°C, 12d (22,48); 30°C, 55d (46)

GA_3: pre-applied, 24h, 2000 ppm (8,9,19,21); pre-applied, 24h, 2000, 4000 ppm (40); co-applied, 50, 500 ppm, at 20°C in light, 1200 fc, 8h/d (18); co-applied, 300, 1000 ppm, plus cysteine, co-applied, 1780 ppm (36); co-applied, 250 ppm, plus cysteine, co-applied, 900 ppm (36)

Pellet: in charcoal with GA_3, 1500 ppm (2)

Removal of seed covering structures: (9,10,41)

S. viarum

GA_3: pre-applied, 12-18h, 1000 ppm (29)

S. xanthocarpum

Alternating temperatures: 25°/35°C (16h/8h) in light, 5-6h/d (59)

GA_3: pre-applied, 12-18h, 1000 ppm (29)

S. yabari

Removal of seed covering structures: (41)

Solanum spp.

Light, Potassium nitrate (AOSA)

VI. Comment

The widely recognised ability of gibberellic acid to promote the germination of dormant seeds of Solanum spp. is apparent from this list of successful dormancy breaking agents - though it should also be noted that on occasion treatment with gibberellic acid may have no effect at all (16,30,49) - particularly when applied at low concentrations - or be only partly successful (15,16,18,20,27,30,36,40,54). In general pre-application is preferable to co-application. In the latter case high concentrations can result in abnormal seedling morphology.

The following general procedure is recommended for S. tuberosum: 2000 ppm GA_3, pre-applied for 24 hours, with subsequent testing for germination at 20°C for 28 days in diffuse daylight or the light regime provided in Chapter 6. This procedure is sufficiently promotory for

the majority of seed lots and does not result in the production of abnormal seedlings (21,A). Moreover, treatment with GA_3 at this concentration does not appear to damage aged seeds (A). Extremely dormant seeds may require treatment with 4000 ppm GA_3 (40).

Solanum collections are unlikely to be limited to S. tuberosum alone; rather they will contain very many Solanum spp. (e.g. see (56)). In general tuber-bearing Solanum spp. give higher germination at constant temperatures than at alternating temperatures (16,42). 20°C is suitable although sometimes 10°C may be preferable (1,7). Whichever constant temperature is used diffuse light is essential and treatment with GA_3 recommended (as given for S. tuberosum).

In contrast non-tuber-bearing Solanum spp. tend to require alternating temperatures for full germination (15,24,27,31-33,43,54,58-61). For example, in S. melongena an alternating temperature regime of 29°-30°/23°C (8h/16h) was sufficient alone to provide suitable conditions for rapid (within 5 days) and almost complete germination of both fresh and 1 year old dormant seeds (60). Note that this alternating temperature regime is similar to that prescribed by AOSA and ISTA.

The following general procedure is suggested for non-tuber-bearing Solanum spp., but the GA_3 treatment may not always be essential: 500-2000 ppm GA_3 pre-applied for 24 hours or 10^{-3} -10^{-4} M GA_3 co-applied at alternating temperature regimes of 20°/30°C, 30°/20°C, or 30°/15°C (16h/8h) either in diffuse light or the light regime given in Chapter 6.

VII. References

1. Anonymous (1980). True potato seed investigations. Crop Research News, 22, 41-49.

2. Bamberg, J.B. and Hanneman, R.E. Jr. (1983). Promotion of potato seed germination with activated charcoal and gibberellic acid. American Potato Journal, 60, 801.

3. Bierhuzen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

4. Chauhan, Y.S. (1978). Effect of 'ethrel' on the germination of S. khasianum Cl. seeds. Indian Journal of Pharmaceutical Sciences, 40, 61-63.

5. Clark, C.F. (1940). Longevity of potato seed. American Potato Journal, 17, 147-152.

6. Clarke, A.E. and Stevenson, F.J. (1943). Factors influencing the germination of seeds of the potato. American Potato Journal, 20, 247-258.

7. Firsova, M.K. (1937). Special characteristics of the germination of potato seed. Bull. Applied Bot. Gen. and Plant Breeding, Leni. Acad. Agr. Sci. Series IV, 2, 56-64.

8. Fischnich, O. and Grimm, H. (1958). Aufhebung der Keimruhe von Kartoffelsamen durch Gibberellin (Vorl. mitt). Landbforsch. Völkenrode, 8, 95-96.

9. Fischnich, O. and Krug, H. (1959). Gibberellin in der Hand des Kartoffelziichters. Kartoffelbau., 10, 189-191

10. Fischnich, O. and Lübbert, G. (1955). Fruchtbidung bei Kartoffeln und Förderung der Keimschnelligkeit ihrer Samen. Beitr. Biol. Pfl., 31, 179-206.

11. Foldesi, D., Svab, J. and Vagujfalvi, D. (1963). [Biological research into the germination of Solanum laciniatum.] Herba Hungarica, 2, 201-215.

12. Gupta, S.C. (1971). Effect of NAA, IAA and GA on germination of brinjal (Solanum melongena L.) seeds. Indian Journal of Agricultural Research, 5, 215-216.

13. Haigh, J.C. (1952). A note on the viability of potato seeds. Annals of Botany, 16, 317-319.

14. Jatisatienr, A. (1982). Biology of germination of Solanum laciniatum Aiton seeds. XXIst International Horticultural Congress Hamburg, International Society for Horticultural Science, 2, Abstract 1846. (From Seed Abstracts, 1983, 6, 540.)

15. Joshua, A. (1978). Seed germination of Solanum incanum: An example of germination problems of tropical vegetable crops. Acta Horticulturae, 83, 155-161.

16. Junges, W., Ludwig, H., Rothacker, and Engel, K.-H. (1967). Keimfähigkeit und Keimruhe der Samen von Knollentragenden Solanum species und S. tuberosum - Sorten. Proceedings of the International Seed Testing Association, 32, 71-99.

17. Laha, M.K. and Basu, P.K. (1980). Positively photoblastic nature of seed germination in Solanum khasianum Clarke. Geobios, 7, 262-263.

18. Lam, S.L. and Erickson, H.T. (1966). Interaction of light and gibberellin on potato seed germination. American Potato Journal, 43, 443-449.

19. Lauer, F.I., Mullin, R. and Blomquist, A.W. (1965). Potato seed germination as influenced by food blender injury, gibberellic acid, thiram and fermentation. American Potato Journal, 42, 71-75.

20. Ludwig, H., Hinze, E. and Junges, W. (1982). Endogene Rhythmen des Keimverhaltens der Samen von Kartoffeln, insbesondere von Solanum acaule. Seed Science and Technology, 10, 77-86.

21. Martin, M.W. (1983). Techniques for successful field seeding of true potato seed. American Potato Journal, 60, 245-259.

22. Mehra, K.L., Subramanyam, K.N. and Gajaraja, C.P. (1965). Raising potato seedlings under Bihar conditions. Indian Potato Journal, 7, 106.

23. Mitra, S. and Kushari, D.P. (1982). Effect of ammonium nitrate on germination of seed of Solanum khasianum Clarke. Geobios, 9, 47-48.

24. Nakamura, S. (1959). [Germination-promoting effects of gibberellin on seeds of eggplant, Perilla, and other crops.] Agriculture and Horticulture, 34, 1277-1278.

25. Nakamura, S. and Enohara, N. (1980). [Improvement of the germination of vegetable seeds using polyethylene glycol. I. Eggplant, Cryptotaenia japonica and carrot.] Journal of the Japanese Society for Horticultural Science, 48, 443-452.

26. Nakamura, S., Okasako, Y. and Yamada, Y. (1955). [Effect of light on the germination of vegetable seeds.] Journal of the Horticultural Association of Japan, 24, 17-28.

27. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

28. Odland, M.C. (1938). Immediate germination of certain selfed and hybrid potato seed. American Potato Journal, 15, 67-71.

29. Pingle, A.R. and Dnyansagar, V.R. (1979). Induction of germination in Solanum. Current

Science, 48, 449-450.

30. Porter, N.G. and Gilmore, H.M. (1976). Germination studies of the seed of Solanum laciniatum Ait. and S. aviculare Forst. New Zealand Journal of Experimental Agriculture, 4, 343-345.

31. Roberts, H.A. and Boddrell, J.E. (1983). Field emergence and temperature requirements for germination in Solanum sarrachoides Sendt. Weed Research, 23, 247-252.

32. Roberts, H.A. and Lockett, P.M. (1977). Temperature requirements for germination of dry-stored, cold-stored and buried seeds of Solanum dulcamara L. New Phytologist, 79, 505-510.

33. Roberts, H.A. and Lockett, P.M. (1978). Seed dormancy and field emergence in Solanum nigrum L. Weed Research, 18, 231-241.

34. Ross, R.W. (1969). Seed dormancy and longevity in Solanum species. American Potato Journal, 46, 438.

35. Simmonds, N.W. (1963). Correlated seed and tuber dormancy in potatoes. Nature, 197, 720-721.

36. Simmonds, N.W. (1963). Experiments on the germination of potato seeds. I. European Potato Journal, 6, 45-60.

37. Simmonds, N.W. (1963). Experiments on the germination of potato seeds. II. European Potato Journal, 6, 69-76.

38. Simmonds, N.W. (1964). The genetics of seed and tuber dormancy in the cultivated potatoes. Heredity, 19, 489-504.

39. Simmonds, N.W. (1968). Prolonged storage of potato seeds. European Potato Journal, 11, 150-156.

40. Spicer, P.B. and Dianne, L.A. (1961). Use of gibberellin to hasten germination of Solanum seed. Nature, 189, 327-328.

41. Srinivasachar, D. and Dwivedi, R.S. (1959). Breaking dormancy of true seeds of tuber-bearing Solanum species. Indian Potato Journal, 1, 10-13.

42. Steinbauer, G.P. (1957). Interaction of temperature and moistening agents in the germination and early development of potato seedlings. American Potato Journal, 34, 89-93.

43. Steinbauer, G.P., Grigsby, B., Correa, L. and Frank, P. (1955). A study of methods for obtaining laboratory germination of certain weed seeds. Proceedings of the Association of Official Seed Analysts, 45, 48-51.

44. Stevenson, F.J. and Milstead, E.H. (1932). Potato breeding technique. American Potato Journal, 9, 111.

45. Stier, H.L. (1937). Delayed germination in seeds of the potato. Proceedings of the American Society for Horticultural Science, 34, 433-435.

46. Stier, H.L. (1937). The effect of certain seed treatments on the germination of recently harvested potato seeds. Proceedings of the American Society for Horticultural Science, 35, 601-605.

47. Stier, H.L. and Cordner, H.B. (1936). Germination of seeds of the potato as affected by temperature. Proceedings of the American Society for Horticultural Science, 34, 430-432.

48. Subramanyam, K.N. (1971). The germination of true seeds of potato under long storage conditions. Current Science, 40, 379-380.

49. Sudiatso, I.S. and Wilson, D.R. (1974). Seed germination of Solanum laciniatum Ait. New Zealand Journal of Agricultural Research, 17, 455-458.

50. Suzuki, Y. (1963). [The effect of gibberellin on germination in eggplant seed.] Agriculture and Horticulture, 38, 1889-1890.

51. Suzuki, Y. (1964). [A study on the effect of gibberellin upon the germination of eggplant seeds.] Science Report of the Faculty of Education, Fukushima University, 14, 48-54.

52. Suzuki, Y. and Kimoto, U. (1965). [Studies on the germination of eggplant seeds.] Science Report of the Faculty of Education, Fukushima University, 15, 42-55.

53. Suzuki, Y. and Kimoto, U. (1966). Requirement of insertion of low or high temperature treatment on the germination of eggplant seeds. Science Report of the Faculty of Education, Fukushima University, 16, 55-58.

54. Suzuki, Y. and Takahashi, N. (1968). Effects of after-ripening and gibberellic acid on the thermoinduction of seed germination in Solanum melongena. Plant and Cell Physiology, 9, 653-660.

55. Taylorson, R.B. (1979). Response of weed seeds to ethylene and related hydrocarbons. Weed Science, 27, 7-10.

56. Towill, L.E. (1983). Longevity of true seed from tuber-bearing and closely related non-tuber-bearing Solanum species. American Potato Journal, 60, 75-83.

57. Tyagi, M.C. and Sharma, B. (1982). Studies on the effect of temperature and glyco-alkaloid containing mucilage covering on seed germination in Solanum viarum Dun. In Proceedings of National Seminar on Medicinal and Aromatic Plants, pp. 62-64. Coimbatore, India. (From Seed Abstracts, 1983, 6, 1605.)

58. Wagenvoort, W.A. and Van Opstal, N.A. (1979). The effect of constant and alternating temperatures, rinsing, stratification and fertilizer on germination of some weed seed. Scientia Horticulturae, 10, 15-20.

59. Wakhloo, J.L. (1964). Ecological and physiological studies on two species of Solanum. I. Germination and development of S. xanthocarpum Schrad. & Wendl. and S. nigrum L. Flora, Jena, 155, 237-249.

60. Winden, C.M.M. Van and Bekendam, J. (1975). [Germination of eggplant seed.] Groenten en Fruit, 31, 729.

61. Poljakoff-Mayber, A. (1984). Germination behaviour of Solanum nigrum seeds. Journal of Experimental Botany, 35, 588-598.

62. Porter, N.G. and Clark, S.M. (1979). Effect of temperature and light on the germination of seed of S. aviculare and S. laciniatum. New Zealand Journal of Experimental Botany, 7, 307-310.

CHAPTER 68. STERCULIACEAE

The Sterculiaceae comprise about 750 species of trees, shrubs, and - rarely - herbaceous plants within about 50 genera which provide beverages (e.g. Theobroma cacao L., cocoa), masticatories (e.g. Cola spp.) and gums (e.g. Sterculia urens Roxb.). The fruits are pods. (woody drupes), capsules, and follicles. Seed storage behaviour is variable. Rulingia pannosa is orthodox and maintained in the long-term seed store at the Wakehurst Place Gene Bank, but Theobroma cacao L. is widely reported as recalcitrant. Seed storage behaviour in Cola spp. is not entirely clear: the seeds are treated as recalcitrant (that is they are not dried) but, if they are recalcitrant, then they are some of the longest-lived recalcitrant species so far reported.

SEED DORMANCY AND GERMINATION

The main food storage organ of the seeds is the cotyledons (two or more), but a residual endosperm may also be present as a thin membrane. The testa is thin, but can be quite tough and delay or prevent germination. Detailed information on seed dormancy and germination is provided in this chapter for the genus Cola. A brief summary of recommended germination test procedures and dormancy-breaking treatments for Theobroma cacao L. is provided in Table 68.1.

TABLE 68.1 Summary of germination test recommendations for species within the Sterculiaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Theobroma cacao L.	S	25°-30°C	21d	light, continuous	CHML
		27°C	14d	pre-soak, 24h	Riley

COLA

C. acuminata (P. Beauv.) Schott & Endl. abata kola, cola nut, goora nut
C. nitida (Vent.) Schott & Endl. gbanja kola

I. Evidence of dormancy

Seeds of Cola spp. can show considerable dormancy (1,5-7,12-14). Freshly harvested seeds of C. nitida take between 3 and 9 months to germinate whereas completely after-ripened seeds are reported to germinate immediately (6,9,13,14). After-ripening periods of between 3 months and 1 year are reported to be required to remove dormancy (1,6,7,13,14). The after-ripening treatments were carried out in moist environments (e.g. undried nuts in a polyethylene bag). Therefore the success of after-ripening treatments does not provide evidence of orthodox seed storage behaviour.

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

C. nitida

Constant temperatures: 37°C, 45°C, 55°C (7)

Thiourea: pre-applied, 24,48h, 5000 ppm (1)

Removal of seed covering structures: part of hull (6)

IV. Partly-successful dormancy-breaking treatments

C. acuminata

Removal of seed covering structures: testa and tip of cotyledon (11); testa, then tease apart cotyledons (11)

C. nitida

Constant temperatures: 20°C, 30°C (7)

Alternating temperatures: 24°/30°C (7)

Warm stratification: 37°C, 2,3w, germinate at 25°C, 30°C (7)

Pre-soak: 24h (12)

Light: shade (7,8,9); fluorescent, continuous (7); 1000 fc (1)

Kinetin: pre-applied, 24,48h, 25-100 ppm, germinate at 37°-39°C in light, 1000 fc (1)

Thiourea: pre-applied, 24h, 2000 ppm (12); pre-applied, 24,48h, 1000, 2000 ppm, germinate at 37°-39°C in light, 1000 fc (1)

Removal of seed covering structures: testa and upper half of cotyledons (3,4,10); testa and tip of cotyledons (7,8,12); split nut (7,9); testa, then tease apart cotyledons, germinate at 20°C, 25°C, 35°C (12)

V. Successful dormancy-breaking treatments

C. nitida

Removal of seed covering structures: testa (5); testa, then tease apart cotyledons, germinate at 30°C (12); testa, then tease apart cotyledons, then pre-soak; 24h (12)

VI. Comment

In freshly harvested seeds of Cola spp. the embryo is 1-1.5 mm long and lies at the deepest point of the basal furrows in the cotyledons which are firmly held together (2,7,12). When placed in contact with a moist medium the nut imbibes moisture but germination may not occur for some weeks or months: only after considerable delays do the embryos begin to develop (7). If the cotyledons are gently teased apart without damaging their contact with the embryo or the seeds are pre-soaked or the cotyledon tip removed then the embryo imbibes more rapidly and the delay to germination is reduced (7,9,12). Consequently for dormant seeds it is suggested that testa removal and cotyledon parting be practised.

Quite high temperatures are required for germination. A constant temperature of 30°C has been reported as optimal (7,12). Although continuous exposure to 37°C will eventually kill the seeds, warm stratification at 37°C for 2 to 3 weeks with subsequent removal to a lower temperature can reduce the time taken by the seeds to germinate (7) - possibly by increasing

the embryo's imbibition rate? Diffuse sunlight or fluorescent light are promotory (1,5,7), but direct sunlight (in nursery sowings) can reduce germination (5,8). It is suggested that the seeds be tested for germination in moist sand or between moist paper towels at 30°C, and recommended that attention be paid to keeping the germination test medium moist throughout the test.

VII. References

1. Ashiru, G.A. (1969). Effect of kinetin, thiourea, thiourea dioxide, light and heat on seed germination and seedling growth of kola (Cola nitida (Ventenant) Schott and Endlicher). Journal of the American Society for Horticultural Science, 94, 429-432.

2. Brown, D.A.L. (1970). A review of germination of kola seed (Cola nitida (Vent.) Schott & Endl.). Ghana Journal of Agricultural Science, 3, 179-186.

3. Brown, D.A.L. and Afrifa, M.K. (1971). Effect of cutting cola nut on the germination rate and subsequent seedling characters. Ghana Journal of Agricultural Science, 4, 117-120.

4. Brown, D.A.L. and Afrifa, M.K. (1972). Cola, germination investigations. Ghana, Cocoa Research Institute Tafo, Annual Report for 1970/1971, 38-39.

5. Clay, D.W.T. (1964). Germination of the kola nut (Cola nitida (Vent.) Schott and Endl.). Tropical Agriculture, Trinidad, 41 41, 55-60.

6. Dublin, P. (1965). Le colatier (C. nitida) en République Centrafricaine. Café-Cacao-Thé, 9, 97-115.

7. Eijnatten, C.L.M. van (1968). The germination of kola nuts, Cola nitida (Ventenant) Schott and Endlicher. Nigerian Agricultural Journal, 5, 72-82.

8. Eijnatten, C.L.M. van and Odegbaro, O.A. (1966). Kola, germination trials. Annual Report, Cocoa Research Institute of Nigeria 1964/1965, 4, 93-94.

9. Eijnatten, C.L.M. van and Quarcoo, T. (1968). Studies on kola, germination studies. Annual Report, Cocoa Research Institute of Nigeria 1966/1967, 46-50.

10. Godfrey-Sam-Aggrey, W. (1969). Cola production in Ghana. World Crops, 21, 196-199.

11. Ibikunle, B.O. (1975). The germination of Cola acuminata (P. Beauv.) Schott and Endl. Acta Horticulturae, 49, 75-83.

12. Ibikunle, B.O. and MacKenzie, J.A. (1974). Germination of kola (Cola nitida (Vent.) Schott and Endl.). Turrialba, 24, 187-192.

13. Karikari, S.K. (1973). The effect of maturity and storage on the germination of cola nut (Cola nitida (Ventenant) Schott and Endlicher). Ghana Journal of Agricultural Science, 6, 87-91.

14. Odegbaro, O.A. and Ogutuga, D.B.A. (1967). The influence of the time of storage on the germination of kola nuts. Annual Report, Cocoa Research Institute of Nigeria 1965/1966, 112-114.

CHAPTER 69. THEACEAE

The Theaceae are often known as the Ternstroemiaceae (an older name) and are sometimes described also as the Camelliaceae. The Theaceae comprise about 200 species of trees and shrubs within 18 to 20 genera, but the only important species is tea, Camellia sinensis Kuntze (Thea sinensis L.). The fruits are capsules (e.g. Camellia) or berries (e.g. Cleyera). Seed storage behaviour in Camellia spp. was thought to be recalcitrant, but we now question this assumption - see the Comment on Camellia in this chapter.

SEED DORMANCY AND GERMINATION

The seeds are non-endospermic with a linear embryo, thick cotyledons and a thin testa. Tea seed germination is epigeal, but the testa can delay germination. Detailed information on seed dormancy and germination is provided in this chapter for the genus Camellia (including synonyms within Thea). In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to pre-chill two samples of seeds at 2° to 6°C for 8w and then test for germination in alternating-temperature regimes of 26°/16°C (12h/12h) and 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature. If the supply of seeds is limited then pre-chill one sample only and then test at 26°/16°C.

If the first step in the algorithm does not result in full germination then the second step is to pre-treat imbibing seeds at 26°C for 4w (i.e. a warm stratification treatment), then pre-chill at 2° to 6°C for 8w and, finally, test for germination in the alternating-temperature regime described in step one which gave the greater germination. If no difference in germination was observed during step one between the two alternating temperature regimes then test at 26°/16°C.

If the second step of the algorithm does not result in full germination then the third step is to experiment with further dormancy-breaking agents (see the information on Camellia for examples of likely suitable treatments) in addition to the warm stratification/pre-chill/alternating temperature regime described in step two.

CAMELLIA

C. sinensis (L.) Kuntze [C. thea Link; C. theifera Griff.; Thea bohea L.; Thea sinensis L.; Thea viridis L.; Thea viridis L.] tea

I. Evidence of dormancy

The germination of untreated seeds of C. sinensis can be slow (4,7,8,11,12), particularly if the seeds are light or not ripe, but full and rapid germination can be achieved by various pre-treatments (4,6-8, 10-15). Seed dormancy is manifested by a delay to germination rather than by preventing germination: in 9-week germination tests no difference is seen in the cumulative germination of treated and untreated seeds, but the germination progress curves differ considerably (11). See the Comment for a discussion of seed storage characteristics.

II. Germination regimes for non-dormant seeds

Constant temperatures: 16°-18°C (12); 20°-25°C (4,8); 25°C (1,13,16)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 5°C, 35°C (8); 27°C+ (4,12)

Pre-soak: 7d (11); 9d (15)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 14°-17°C (4)

Pre-soak: (10); 1-8d, then crack shells (15)

Removal of seed covering structures: shells, then pre-soak, 1d (8); crack shells (8,10); crack shells, then pre-soak (8)

V. Successful dormancy-breaking treatments

Constant temperatures: 16°-18°C (12); 20°-25°C (4,8); 25°C, (1,13)

Pre-chill: 5°-10°C, 3w (7)

Pre-soak: (6); 1-4d (11); 5d (4); 1-7d, then remove shells (15); 1d, then pre-dry, sunlight (4)

Removal of seed covering structures: shells (4,8,10,12-14); shells, then pre-soak, 1-5d (15); crack shells at micropylar end (11); crack shells, then pre-soak, 2-5d, then remove shells (15)

VI.. Comment

The delay to seed germination in C. sinensis is caused by the seed covering structures (14). They act as a mechanical barrier to germination (11), and their removal promotes rapid, full germination (4,8,10-14). Pre-soaking, though widely applied, is not necessary if the shells are removed prior to testing for germination (15).

Germination test temperatures above 27°C are reported to be deleterious (4,8,12), resulting in the production of abnormal seedlings (12,13). However, this problem is reduced if the seed covering structures are first removed before testing for germination (12,13) - presumably because the period of exposure to the high temperature before germination occurs is reduced.

It is suggested that the seeds be tested for germination in moist sand at 20°C or 25°C (1,4,8,12,13). If the shells are removed prior to the test then a 50-day test period should be sufficient for most accessions (7), but intact seeds may require 4 to 5 months in test (4). It is reported that an easy method of cracking the shells is to place wet seeds in hot sunshine for 15 minutes (15). This technique might be useful for field sowings of large numbers of seeds, but is not suggested for use in laboratory germination tests.

C. sinensis has been reported to exhibit recalcitrant seed storage behaviour (5), since desiccation is reported to result in loss in viability (1,3,11). The viability period of seeds stored moist (but not fully imbibed) is short (2 to 4 weeks) at room temperature, but viability remains high at 5°-7°C after 9 months (11) or 2 years storage (7), or after six years' storage at 1°C (16). The critical moisture content - below which loss in seed viability occurs rapidly - is reported to be at about 23% fresh weight (11), although even in that report some seeds germinated after drying to 17% fresh weight (11).

However, we suggest that the evidence is not yet conclusive that C. sinensis shows

recalcitrant seed storage behaviour. Indeed there are some grounds to suspect that the seeds may be orthodox. First the dried seeds' failure to germinate may result from delayed imbition. For example, in one investigation the dried seeds failed to re-imbibe to the moisture content reached by moist seeds when they were set to germinate (11). Second, and more striking, is the evidence that the majority of seeds of C. sinensis dried to equilibrium at either 0, 10, 25, 40, or 55% relative humidity remained viable for 20 weeks at 0°C (15). Moreover in this investigation the seeds were soaked for 2 days prior to the germination test and the shells cracked, a treatment which the authors acknowledged may have resulted in the seed rotting which they observed (15). As discussed elsewhere (Volume I), such treatments are known to damage very dry seeds of orthodox species - the damage to orthodox seeds being described as imbibition injury. Consequently we recommend that further investigations are required to clarify the seed storage behaviour of C. sinensis.

VII. References

1. Amma, S. (1978). [Rapid germinability test with sugars exuded from tea seed.] Study of Tea, 55, 1-6.

2. Andrews, D.N. (1966). The cold storage of tea seed. Revue Agricole et Sucrière de l'Ile Maurice, 45, 303-304.

3. Anonymous (1955). Effect of desiccation and seed dressings on germination of tea seeds and the resulting plants. Annual Report, Indian Tea Association Scientific Department, Tocklai, 1954, 1955, pp. 116-120.

4. Bonheure, D. (1962). La semence de théier d'Assam et le jardin semencier. Bulletin Information de L'institut National pour l'étude Agronomique du Congo Belge, 11, 119-140.

5. Chin, H.F. and Roberts, E.H. (1980). Recalcitrant Crop Seeds. Tropical Press, Kuala Lumpur, Malaysia.

6. Hume, P.F. (1955). Storage of tea seed. Tea Quarterly, 26, 93-95.

7. Katsuo, K., Toyao, T. and Kayumi, S. (1970). [The germination of tea seed. Part 1. Relation of the picking period and conditions for storage to the seed germination.] Study of Tea, 39, 14-19.

8. Katsuo, K., Toyao, T. and Kayumi, S. (1970). [The germination of tea seed. Part 2. Accelerating effect of pre-treatment on the seed germination.] Study of Tea, 39, 20-25.

9. Nakayama, A. and Harada, S. (1962). [Studies on the effect of temperature on the growth of the tea plant. Part 1. The effect of temperature on seed germination.] Bulletin Tea Research Station, Japan, 1, 1. (From Horticultural Abstracts, 1963, 33, 6380.)

10. Sanikidze, Z.G. (1975). [Measures for hastening and stimulating tea seed germination in Adygeya conditions.] Subtropicheskie Kul'tury, 5, 24-26. (From Horticultural Abstracts, 1977, 47, 2102.)

11. Sebastiampillai, A.R. and Anandappa, T.I. (1979). The influence of moisture and temperature of the germinability and longevity of tea (Camellia sinensis L.) seeds. Tea Quarterly, 48, 8-20.

12. Shaw, D.E. and Burnett, W.M. (1968). Investigation into the cause of leaf tumours of tea seedlings. Papua and New Guinea Agricultural Journal, 19, 167-192.

13. Toyao, T. and Kayumi, S. (1970). [Germination of tea seeds. Part 3. Abnormal growth of plumule caused by high temperature during germination.] Study of Tea, 40, 7-12.

14. Tubbs, F.R. (1932). The germination of tea seed. Tea Quarterly, 5, 66-69.

15. Visser, T. and de Waas Tillekeratne, L.M. (1958). Observations on the germination and storage of tea pollen and seed. Tea Quarterly, 29, 30-35.

16. Amma, S. and Watanabe, A. (1983). [Long-term storage of germ plasm in tea (Camellia sinensis (L.) O. Kuntze).] Bulletin of National Research Institute of Tea, 19, 29-57.

CHAPTER 70. TILIACEAE

The Tiliaceae comprise about 400 species of trees, shrubs and, rarely, herbaceous plants within more than 35 genera, some of which provide fibres (e.g. Cephalonema polyandrum K. Schum.). The fruits are capsules, berries or drupes and the seeds show orthodox storage behaviour. For example, Corchorus fructicosus is maintained in the long-term seed store at the Wakehurst Place Gene Bank. Incidentally, comments that seeds of certain Corchorus spp. should not be stored at moisture contents below 10% are erroneous and result from researchers confounding hardseededness (see below) with loss in viability.

SEED DORMANCY AND GERMINATION

Hardseededness is likely to be the most prevalent problem in germination tests, but can be avoided by suitable treatments to the seed covering structures (e.g. chipping off a part of the seed coat). Comparatively high temperatures are required for germination tests. Detailed information on seed dormancy and germination is provided in this chapter for the genus Corchorus. A summary of recommended germination test procedures and dormancy-breaking treatments for other species is provided in Table 70.1. In addition the algorithm below may be helpful in developing suitable germination test procedures.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 31°C and 36°C with light applied for 12h/d.

If the first step of the algorithm does not result in full germination then the second step is to chip the seed coats of a further sample of seeds and then test for germination at the constant temperature regime which resulted in the greater proportion of seeds germinating in step one. If there was no significant difference between the results at the two temperatures then test the chipped seeds at 31°C.

If the second step of the algorithm does not result in full germination then the third step is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test a further sample of seeds at the most appropriate regime determined from a comparison of the results of steps one and two. This will include a requirement to chip the seeds if hard seeds are present in the accession.

TABLE 70.1 Summary of germination test recommendations for species within the Tiliaceae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Muntingia calabura L.			21d	pre-soak, 24h, then warm stratification	Riley
Tilia cordata Mill.	S	20°/30°C	28d	pre-chill, 3°-5°C, 6-9m	ISTA
Tilia platyphyllos Scop.	S	20°/30°C	28d	pre-chill, 3°-5°C, 6-9m	ISTA
Tilia spp.				scarify, concentrated sulphuric acid, or soak in	

				hot water, 70°C, 5 times G&R	

CORCHORUS

C. aestuans L. [C. acutangulus Lam.]	
C. capsularis L.	white jute, jute
C. depressus C. Chr. [C. antichorus Raeusch.]	
C. mello	
C. olitorius L.	tossa jute, nalta jute, jews-mallow
C. trilocularis L.	

I. Evidence of dormancy

With the exception of a requirement for light (see Comment) there is no direct evidence of dormancy being a problem when germinating seeds of Corchorus spp., but seeds of the wild Corchorus spp. C. aestuans, C. depressus, and C. trilocularis can be hardseeded (4,10).

II. Germination regimes for non-dormant seeds

C. capsularis, C. olitorius

TP; S: 30°C: 5d (ISTA)

Constant temperatures: 30°C, light (3,8,9)

III. Unsuccessful dormancy-breaking treatments

C. aestuans

Constant temperatures: 30°C, light, continuous, 1000 lux (10)

Scarification: sulphuric acid (4); alcohol (4)

Pre-soak: 24h (4)

C. capsularis

GA_3: pre-applied, 0.01, 0.1% (1)

Indoleacetic acid: pre-applied, 0.01, 0.1% (1)

C. depressus

Scarification: sulphuric acid (4); alcohol (4)

Pre-soak: 24h (4)

C. mello

2,4-Dichlorophenoxyacetic acid: pre-applied, 3,6h, 10, 20, 40 ppm (2)

C. olitorius

GA_3: pre-applied, 0.01, 0.1% (1); co-applied, 50, 100 ppm (7)

Indoleacetic acid: pre-applied, 0.01, 0.1% (1)

C. trilocularis

Scarification: sulphuric acid (4); alcohol (4)

Pre-soak: 24h (4)

IV. Partly-successful dormancy-breaking treatments

C. aestuans

Scarification: sand paper, germinate in direct sunlight or shade (4)

Pre-dry: 70°C, 3-5d (10); 80°C, 2-5d (10); 90°C, 1-5d (10); 100°C, 2-4d (10); 110°C, 1-3d (10)

C. capsularis

Constant temperatures: 25°C, light (8); 25°C (9); 20°C, 25°C, light or dark (3)

Alternating temperatures: 20°/30°C (16h/8h) (9); 20°/30°C, 20°/35°C (16h/8h), light or dark (3)

GA_3: co-applied, 200 ppm (6)

Potassium nitrate: pre-applied, 0.01, 0.1% (1)

Thiourea: pre-applied, 0.01, 0.1% (1)

C. depressus

Scarification: sandpaper, germinate in direct sunlight or shade (4)

C. mello

Colchicine: pre-applied, 3,6h, 20 ppm (2)

C. olitorius

Constant temperatures: 15°-41°C, light, 12h/d (5); 25°C in light, 8h/d (8); 25°C (9)

Alternating temperatures: 21°/31°C, 21°/41°C, 15°/41°C, 31°/41°C (12h/12h), light, 12h/d (5); 20°/30°C (16h/8h) (9)

GA_3: co-applied, 200 ppm (6)

Indoleacetic acid: co-applied, 50, 100 ppm (7)

Kinetin: co-applied, 50 ppm (7)

Potassium nitrate: pre-applied, 0.01, 0.1% (1)

Thiourea: pre-applied, 0.01, 0.1% (1)

C. trilocularis

Scarification: sand paper, germinate in direct sunlight or shade (4)

V. Successful dormancy-breaking treatments

C. capsularis

Constant temperatures: 30°C, light (3,8,9); 35°C (9)

Alternating temperatures: 25°

C. mello

GA_3: pre-applied, 3,6h, 50-200 ppm, at 30°C (2)

Colchicine: pre-applied, 3,6h, 5-10 ppm, at 30°C (2)

C. olitorius

Constant temperatures: 30°C, light (3,8,9); 35°C (9)

Alternating temperatures: 25°/35°C (16h/8h) (9)

VI. Comment

The most suitable seed germination test regime for Corchorus spp. appears to be a constant temperature of 30°C (2,3,5,8,9), as prescribed by ISTA. Alternating temperature regimes are, apparently, not superior to constant temperature germination test regimes (3,9), and may indeed be inferior in 40 day tests (5). Light is required for germination (3-5), although the effect may be only marginal. Consequently it is suggested that gene banks test seeds of Corchorus spp. for germination at 30°C with light applied for 8 hours per day. Hardseededness is likely to be a problem for some accessions, particularly those of the wild Corchorus spp. (4,10). It is suggested that the seed coats of non-imbibed seeds be scarified or pricked with a needle after 4 or 5 days in test, and the test continued for at least a further 5 days.

VII. References

1. Chakraverty, R.K. (1975). Germination, viability and seedling growth in two species of Corchorus. Science and Culture, 41, 393-395.

2. Fahmy, R. (1974). Soaking jute seeds in different concentrations of gibberellic acid, 2,4-D and colchicine and its effect on germination and organic compounds formed in the seedlings. Biochemie and Physiologie der Pflanzen, 165, 141-148.

3. Figueirêdo, F.J.C., Carvalho, J.E.U. De., Oliveira, R.P. De. and Frazâo, D.A.C. (1980). [Temperature and light in the germination of jute seeds.] Boletim de Pesquisa, Centro de Pesquisa Agropecuaria do Trópico Umido, 4, 1-16.

4. Islam, A.S. and Khan, M.I. (1957). Studies on the seed germination of Corchorus spp. Biologia, 3, 165-167.

5. Okusanya, O.T. (1979). Quantitative analysis of the effects of photoperiod, temperature, salinity and soil types on the germination and growth of Corchorus olitorius. Oikos, 33, 444-450.

6. Rahman, A. (1978). Effects of gibberellic acid on the germination of Corchorus capsularis and Corchorus olitorius. Bangladesh Journal of Scientific and Industrial Research, 13, 243-246.

7. Rizk, T.K., Fayed, M.T. and El-Deepah, H.R. (1978). Effect of some promoters on weed seed germination. Research Bulletin of the Faculty of Agriculture, Ain Shams University, 818, 1-30.

8. Singh, A., Karna, I. and Verma, K. (1972). Germination methods for jute seed. Proceedings of the International Seed Testing Association, 37, 793-796.

9. Verma, M.M. and Arora, N. (1978). Further studies on seed testing procedures for jute (Corchorus capsularis and C. olitorius seeds. Seed Research, 6, 151-157.

10. Chawan, D.D. and Sen, D.N. (1973). Diversity in germination behaviour and high temperature tolerance in the seeds of Corchorus aestuans Linn. Annals of Arid Zone, 12, 23-32.

CHAPTER 71. TYPHACEAE

The Typhaceae comprise about 18 species of herbaceous plants within the single genus Typha which provide fibrous leaves used for matting and construction. The fruit is a dehiscent nutlet and the seeds show orthodox storage behaviour. Information on seed dormancy and germination is provided below.

TYPHA

T. angustata Bory & Chaub.	
T. angustifolia L.	
T. domingensis (Pers.) Steud.	
T. latifolia L.	common cat-tail

I. Evidence of dormancy

Seeds of Typha spp. can be very dormant. For example, seeds of T. latifolia remained dormant after between 2 and 3 years storage (5) and seed germination is reported to be low without specific treatments to remove dormancy (12).

II. Germination regimes for non-dormant seeds

T. angustifolia, T. domingensis

Constant temperatures: 24°C, 30°C, light, 100 fc (4)

T. latifolia

Constant temperatures: 21°C, 3w (12); 24°C, 30°C, light, 100 fc (4); 25°-30°C in light (9)

Alternating temperatures: 10°/32°C, 15°/32°C (18h/6h) (5); 15°/30°C, 15°/35°C, 20°/30°C, 20°/35°C (16h/8h) (9)

III. Unsuccessful dormancy-breaking treatments

T. angustata

Light: white, less than 100 lux (8); blue (8)

T. domingensis

Constant temperatures: 15°C, 20°C, 30°C (11)

T. latifolia

Constant temperatures: -11°C, 5°C, 21°C, 32°C (12); 10°C (1); 10°-38°C in dark (5); 15°C, 20°C, 30°C (11)

Alternating temperatures: 15°/27°C, 22°/32°C, 22°/38°C (18h/6h), dark (5)

Warm stratification: 21°C, 7d, then -11°C, 5°C, 7d, germinate at 21°C (12)

Light: far red, 5 min (1); dark (5,9); blue (9)

Oxygen: 21, 37% (6)

Storage: -11°C, 5°C, 7d (12)

Scarification: concentrated sulphuric acid, 1.5, 2 min (12); mechanical, abrasive sand, 15-45 min (12)

Removal of seed covering structures: puncture seed coat of moist seeds at pointed end (12)

IV. Partly-successful dormancy-breaking treatments

T. angustata

Light: white, 100 lux (8)

T. domingensis

Alternating temperatures: 10°/20°C, 20°/30°C (16h/8h) in light, 8h/d (11)

T. latifolia

Constant temperatures: 15°C, 30°C (1); 30°C, 35°C, low light irradiance (9); 37.5°C (12)

Alternating temperatures: 20°/30°C (16h/8h) in dark (9); 15°/35°C (16h/8h) in dark or light, low irradiance (9); 10°/20°C, 20°/30°C (16h/8h), light 8h/d (11)

Pre-chill: -11°C, 5°C, 7d (12)

Warm stratification: 22°C, 27°C, 32°C, 18d, germinate at 22°/32°C (18h/6h) in light (5); 21°C, 7d, then 5°C, 7d, germinate at 21°C (12)

Light: red, 9 J cm^{-2}, 10h, after 6-24h dark (1); daylight (5) Removal of seed covering structures: prick (3)

Scarification: concentrated sulphuric acid, 20-80s (5); concentrated sulphuric acid, 0.5, 1 min (12)

Potassium nitrate: co-applied, 10^{-2}, $2x10^{-2}$ M (5)

Oxygen: below 2.1% (6); 17-20% (6); 21% (9)

V. Successful dormancy-breaking treatments

T. latifolia

Constant temperatures: 30°C in light, seeds under water (9); 30°C, seeds under water, 2.3-4.3 mg/1 oxygen, red light, 9 J cm^{-2}, 10h, after 6-24h dark (1)

Alternating temperatures: 20°/30°C (16h/8h) in light, low irradiance (9); 10°-21°/22°C (16h/8h) in light, $1.8x10^{-3}$ W cm^{-2} (10)

Removal of seed covering structures: (5,6,9); pericarp, remove or rupture (2); prick at embryo end (9); press blunt end of moist seeds with steel probe (12)

Oxygen: 2.1-16.8% (6); 2%, at 30°C in light (9)

VI. Comment

A high temperature (1), a low oxygen partial pressure (1,6,9), a low light irradiance (1,5,9), potassium nitrate (5), alternating temperatures (5,9), and the rupture of seed coats (2,6,12) are reported to be essential for promoting the germination of dormant seeds of Typha spp. Seeds with ruptured seed coats (pericarp) germinate over a wide range of temperatures (6). Consequently it is suggested that the seeds be imbibed in the dark, or under a low irradiance of light, for 24 hours and the pericarps of the moist seeds ruptured at the blunt - that is the embryo - end of the seed. Then test for germination on the top of filter papers moistened with 10^{-2} M potassium nitrate - use more filter papers than is usual to ensure sufficient moisture is available to the seeds throughout the test - in an alternating temperature regime of 20°/30°C (16h/8h) - since it is reported to be superior to 10°/30°C (11) - for 21 days or more with light, low irradiance, applied during the 8 hour periods spent at the higher temperature.

VII. References

1. Bonnewell, V.A. (1981). Typha productivity, mineral nutrition, and seed germination. Dissertation Abstracts International, B, 42, 10.

2. Crocker, W. (1907). Germination of seeds of water plants. Botanical Gazette, 44, 375-380.

3. Jackson, C.V. (1928). Seed germination in certain New Mexico range grasses. Botanical Gazette, 86, 270-294.

4. McNaughton, S.J. (1966). Ecotype function in the Typha community-type. Ecological Monographs, 36, 297-325.

5. Morinaga, T. (1926). Effect of alternating temperatures upon the germination of seeds. American Journal of Botany, 13, 141-158.

6. Morinaga, T. (1926). The favorable effect of reduced oxygen supply upon the germination of certain seeds. American Journal of Botany, 13, 159-166.

7. Morris, E.L. (1911). Germination of cat-tail seeds. Torreya, 11, 181-184.

8. Sharma, K.P. and Gopal, B. (1979). Effect of light intensity on seedling establishment and growth in Typha angustata Bory and Chaub. Pol. Arch. Hydrobiol., 26, 495-500.

9. Sifton, H.B. (1959). The germination of light-sensitive seeds of Typha latifolia L. Canadian Journal of Botany, 37, 719-739.

10. Thompson, K., Grime, J.P. and Mason, G. (1977). Seed germination in response to diurnal fluctuations of temperature. Nature, 267, 148-149.

11. Vasconcelos, T. (1981). [Germination of seeds of common reed (Phragmites australis (Cav.) Steudel) and cattails (Typha domingensis (Pers.) Steudel and T. latifolia L.).] I. Congresso Português de Fitiatria e de Fitofarmacologia e III Simposio Nacional de Herbologia, 1980, 3, 85-91. (From Seed Abstracts, 1982, 5, 2455.)

12. Yeo, R.R. (1964). Life history of common cattail. Weeds, 12, 284-288.

CHAPTER 72. UMBELLIFERAE

The Umbelliferae comprise about 2000 species of mainly herbaceous plants, but sometimes shrubs, within about 250 genera. Many species are cultivated for food providing edible roots (e.g. Arracacia xanthirhiza Bancr., arracacha), herbs (e.g. Petroselinum crispum Nym., parsley), leaf vegetables (e.g. Foeniculum vulgare Mill., fennel) and oils (e.g. fennel), whilst some species are cultivated for medicinal products (e.g. Conium spp.). The fruits are schizocarps containing two (or sometimes more) mericarps (see Chapter 3, Volume I). Seed storage behaviour is orthodox.

SEED DORMANCY AND GERMINATION

B.R. Atwater classifies seed morphology as endospermic seeds with axillary linear embryos (see Table 17.1, Chapter 17). The embryos are comparatively under developed and within an accession may vary considerably in maturity (in essence embryo size). Moreover, a high proportion of seed-like structures may be empty: see Chapter 8, Volume I, for methods of determining the empty seed fraction.

In addition to treatments intended to break dormancy (which can be a considerable problem), other treatments (e.g. "hardening" - i.e. alternate wetting and drying or pre-treatment with a polyethyleneglycol solution) are often applied to seeds destined for field sowings in an attempt to further the development of comparatively under-developed embryos prior to exposure to the harsh, competitive, field environment. In general light, low constant temperatures (or sometimes pre-chilling) and gibberellin treatments tend to promote germination.

Detailed information on seed dormancy and germination is provided in this chapter for the genera Anethum, Apium, Carum, Coriandrum, Cuminum, Daucus, Foeniculum (including synonyms within Anethum), Pastinaca, and Petroselinum (including synonyms within Apium). A summary of recommended germination test procedures and dormancy-breaking treatments for other species is provided in Table 72.1. In addition the algorithm below may be helpful in developing suitable germination test procedures for difficult accessions.

RBG Kew Wakehurst Place algorithm

The first step in the algorithm is to test seeds at constant temperatures of 11°C, 16°C, and 21°C, with light applied for 12h/d. If full germination does not occur but a trend in germination response to constant temperatures is observed then test at more extreme constant temperatures. For example, if the proportion of seeds germinating at 11°C is greater than at the two higher temperatures then test a further sample of seeds at a constant temperature of 6°C with light applied for 12h/d.

TABLE 72.1 Summary of germination test recommendations for species within the Umbelliferae

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
Angelica archangelica L.	TP; BP	20°/30°C	28d	light, pre-chill	ISTA
Anthriscus cerefolium (L.) Hoffm.	TP; BP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Chaerophyllum bulbosum L.	TP	20°/30°C	21d	light	Heit

Chaerophyllum tainturieri Hook. & Arn.	TP	15°C	21d	light, check for empty seeds	AOSA
		15°C	28d	potassium nitrate, 0.2%	Atwater
Didiscus caeruleus (R. Grah.) DC.	TP; BP	20°C	21d	good moisture supply desirable	AOSA
Eryngium spp.		20°C	28d		Atwater
Levisticum officinale Koch	TP; BP	20°/30°C; 20°C	21d		ISTA
Pimpinella anisum L.	TP; BP	20°/30°C	21d		ISTA
	BP	20°/30°C	14d		AOSA
	TP	20°/30°C	14d	check for empty seeds	Heit
Pimpinella major (L.) Huds.	TP; BP	20°/30°C	21d	pre-chill	ISTA
Pimpinella saxifraga L.	TP; BP	20°/30°C	21d		ISTA
Trachymene coerulea R. Grah.		20°C	14d		Atwater

If constant temperature regimes do not promote full germination then the second step of the algorithm is to test a further sample of seeds at an alternating temperature of 23°/9°C (12h/12h) with light applied for 12h/d during the period spent at the upper temperature.

If the second step of the algorithm does not promote full germination then the third step is to pre-chill a further sample of seeds at 6°C for 8w and then test in the most appropriate regime determined from a comparison of the results of steps one and two.

If the third step of the algorithm does not result in full germination then the fourth step is to co-apply 7×10^{-4} M GA_3 to the germination test substrate and test in the most appropriate regime determined from a comparison of the results of steps one to three. If the proportion of seeds germinating in step three is significantly greater than the comparable test in step one or two then this fourth step should include the pre-chill treatment.

If full germination has not been promoted, the fifth step of the algorithm is to estimate viability using a tetrazolium test (see Chapter 11, Volume I).

If the result of the tetrazolium test indicates that the failure to achieve full germination is due to the presence of dead seeds and that one of the above regimes promoted the germination of all, or almost all, the viable seeds, then this regime is used for all subsequent germination tests. If, however, the result of the tetrazolium test indicates that dormancy has not been broken by the regimes applied so far in the algorithm, then experiment with modifications to the above regimes. Clues to possible satisfactory dormancy-breaking treatments and promotory germination test environments can be obtained from the information provided for nine genera in this chapter and from Table 72.1.

ANETHUM

A. graveolens L. dill

I. Evidence of dormancy

After-ripening seeds of A. graveolens for 7 days at 35°C resulted in loss in dormancy in some seed lots (1) - suggesting that dormancy can be present.

II. Germination regimes for non-dormant seeds

BP; TP: 20°/30°C; 10°/30°C (16h/8h): 21d (ISTA)

BP: 20°/30°C (16h/8h): 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Alternating temperatures: 36°/31°C (8h/16h), 16d (3)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 20°C, dark, 21d (2); 15°C, light or dark, 21d (2); 10°-12°C (1)

Alternating temperatures: 10°/32°C (1); 20°/30°C (16h/8h), light or dark, 21d (2); 24°/19°C, 21°/16°C, 18°/13°C, 15°/10°C (8h/16h), 16d (3)

Pre-dry: 35°C, 5-7d (1)

V. Successful dormancy-breaking treatments

Pre-chill (ISTA)

Alternating temperatures: 30°/25°C, 33°/28°C, 27°/22°C (8h/16h), 16d (3)

Pre-wash: 3-4d, then pre-dry, 4-8h (3)

VI. Comment

Germination test temperatures (preferably alternating) between 20° and 30°C are required for A. graveolens (2, 3): germination is reduced at temperatures below 15°C (1, 3) - at least in 16 day tests (3). Consequently it is suggested that the ISTA/AOSA germination test procedures are adequate for non-dormant seeds, and possibly also for dormant seeds. The regime 25°/30°C (16h/8h) is a possible alternative to consider. Low germination in certain accessions may be due to a high proportion of embryoless seeds (2): ensure that this is not confounded with either non-viability or dormancy by ascertaining the proportion of embryoless seeds before or after the germination test.

VII. References

1. Franck, W.J. and Wieringa, G. (1928). Artificial drying and low temperature as means employed in obtaining an increase in germination of some vegetable seeds. Proceedings of the Association of Official Seed Analysts, 19, 24-27.

2. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

3. Putievsky, E. (1980). Germination studies with seed of caraway, coriander and dill. Seed Science and Technology, 8, 245-254.

APIUM

A. graveolens L. var dulce Pers. [A. dulce Mill.; A. celleri Gaertn.]	celery
A. graveolens L. var lusitanicum (Mill.) DC.	wild celery
A. graveolens L. var rapaceum (Mill.) DC. [A. rapaceum Mill.]	celeriac, root celery

I. Evidence of dormancy

The germination of seeds of Apium spp. is fraught with problems, both for seed testers (21,28) and commercial growers (35,39). As in other umbellifers, empty seeds may be present; about 20% empty seeds is common (15). In addition immature embryos can be particularly dormant

(15,42). Differences in the degree of seed dormancy between populations are reported to be correlated with the bolting resistance of the mother plant (37); within a population the degree of dormancy of individual seeds is governed by umbel order (26,38). Dormancy can be induced when the seeds are dried from the imbibed state (2-4) (as would happen if the germination test substrate is allowed to dry out), if the imbibed seeds are exposed to high temperatures during the germination test (6-9,22,29,32), or if seeds are pelleted (40). Strictly speaking in the latter case it is not so much that dormancy is induced, but that the pellet subsequently prevents light from reaching the seeds and breaking dormancy and may also restrict oxygen availability.

II. Germination regimes for non-dormant seeds

A. graveolens

TP: 20°/30°C (16h/8h): 21d (ISTA)

TP: 15°/25°C (16h/8h); 20°C: 21d (AOSA)

III. Unsuccessful dormancy-breaking treatments

A. graveolens var dulce

Alternating temperatures: 15°/35°C in dark (27); 30°/35°C (12h/12h) (29); 5°/35°C, 35°/5°C, 10°/30°C, 35°/22°C (16h/8h) in low light (42); 32°/7°C, 35°/5°C, 5°/35°C (16h/8h) in low light (43)

Light: dark, at 18°C (11,38); dark, above 20°C (3,5,11,20,23,31,32,37,39,40,41,46); light, above 30°C (3,8,19,22,25,28,29,35); far red, 20 min (39)

Potassium nitrate: co-applied, $2x10^{-2}$, 10^{-2} M (24); pre-applied, 6d, 1% plus tribasic potassium phosphate, 1% (26); pre-applied, 5-20d, plus tri-potassium orthophosphate, -10, -15 bars, germinate at 20°C in light (34)

Polyethylene glycol: pre-applied, -12 bars (40); pre-applied, 2-14d, -10 bars (3); pre-applied, 1,2w, -11.7 bars, plus GA_3, 50 ppm, germinate at 25°C in light (25)

Sodium hypochlorite: pre-applied, 2h, 5.25% (26); pre-applied, 2h, 0.5-2%, germinate at 20°/30°C (16h/8h) in dark (35)

Mercuric chloride: (22)

Ether: (22)

Pre-soak: then ether (22); 5°C, 48h, then pre-dry, germinate at 22°C in dark (46)

Zeatin: co-applied, 10^{-7} -10^{-4} M, with or without $GA_{4/7}$, $2x10^{-5}$ M (1,5)

Zeatin riboside: co-applied, 10^{-7} -10^{-4} M, with or without $GA_{4/7}$, $2x10^{-5}$ M (1,5)

N -Benzyladenine: co-applied, 10^{-5} -10^{-4} M (41); co-applied, 10^{-5} M (4)

6-Benzylaminopurine: co-applied, 10^{-7} -10^{-4} M (1,5); co-applied, 10^{-5} -10^{-4} M (41)

Dihydrozeatin: co-applied, 10^{-7} -10^{-4} M, with or without $GA_{4/7}$, $2x10^{-5}$ M (1,5)

Cytokinin: co-applied, 10^{-7} -$5x10^{-6}$ M, with or without $GA_{4/7}$, $2x10^{-5}$ M (1,5)

6-Aminopurine: co-applied, 10^{-7} -10^{-4} M, plus $GA_{4/7}$, $2x10^{-5}$ M (5)

Kinetin: co-applied, 10^{-7} -$5x10^{-6}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5); co-applied, 10^{-5} -10^{-4} M (41)

Kinetin riboside: co-applied, 10^{-7} -$5x10^{-6}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5)

N_6 -Methyladenine: co-applied, 10^{-5} -10^{-4} M, with or without $GA_{4/7}$, $2x10^{-4}$ M (41)

Adenine: co-applied, 10^{-5} -10^{-4} M, with or without $GA_{4/7}$, $2x10^{-4}$ M (41)

Ethephon: co-applied, $3.5x10^{-3}$ M (41)

Daminozide: co-applied, $7.5x10^{-3}$ M (41)

Citric acid: co-applied, $5x10^{-3}$ M (30)

Tartaric acid: co-applied, $5x10^{-3}$ M (30)

Ascorbic acid: co-applied, $5x10^{-3}$ M (30)

Succinic acid: co-applied, 10^{-2} M (30)

GA_3: co-applied, 100 ppm, at 25°C in dark (31)

$GA_{4/7}$: co-applied, 10^{-5} M (30); co-applied, 100 ppm, at 25°C in dark (31); pre-applied, 48h, 5°C, 1000 ppm plus daminozide, 4000 ppm, then pre-dry, germinate at 22°C in dark (46); pre-applied, 48h, 5°C, 1000 ppm plus ethephon, 1000 ppm, then pre-dry, germinate at 22°C in dark (46)

A. graveolens var lusitanicum

Light: dark, at 20°C (32); light, 5 min/d, 1-6d, at 5°C (32); far red, 5 min, at 20°C (32)

A. graveolens var rapaceum

Light: dark, at 10°C, 20°C (32); light, 5-30 min, at 10°C, 20°C (32)

Pre-soak: 5°C, 48h, then pre-dry, germinate at 22°C in dark (46)

$GA_{4/7}$: pre-applied, 48h, 5°C, 1000 ppm plus daminozide, 4000 ppm, then pre-dry, germinate at 22°C in dark (46); pre-applied, 48h, 5°C, 1000 ppm plus ethephon, 1000 ppm, then pre-dry, germinate at 22°C in dark (46)

IV. Partly-successful dormancy-breaking treatments

A. graveolens var dulce

Constant temperatures: 20°C in light (19,20,28,35); 22°C in light (3); 25°C in continuous light (31,32); 13°-18°C in dark (40,41); 10°-15°C in low light (42,43); 5°C in continuous light (32); 10°-22°C (24); 10°C, 20°C, light, red, 5-30 min (32)

Alternating temperatures: 30°/20°C (16h/8h) (15); 10°/15°-38°C, 15°/22°-32°C, 5°/15°-29°C (18h/6h) (24); 20°/30°C, 10°/20°C (16h/8h) in light (28); 20°/35°C, 25°/35°C (12h/12h) (29); 20°/10°C, 30°/10°C, 30°/20°C (12h/12h) (32); 21°/10°C (16-22h/2-8h) in dark (35); 30°/10°C,

25°/15°C, 15°/25°C, 5°-15°/22°C, 25°-30°/22°C (16h/8h) in low light (42); 12°/27°C, 27°/12°C, 10°/30°C, 15°/25°C, 25°/15°C, 30°/10°C (16h/8h) in low light (43); 20°/30°C in light or dark (44)

Pre-chill: 0°C (22)

Warm stratification: 32°C, 3d in dark, then pre-dry (3,4,8)

Pre-soak: 5°C, 48h, then pre-dry, germinate at 17°C in dark or 22°C in light, continuous (46)

Light: red (22); 5 min, at 20°C (32); 5-10 min, at 22°C (39); 1 min/d, at 22°C (39); green, 5 min/8h (32); far red, 10-30 min, at 20°C (32)

6-Benzylaminopurine: co-applied, 10^{-7}-$5x10^{-6}$, $5x10^{-5}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5); co-applied, 10^{-6}-10^{-4} M, plus $GA_{4/7}$, $2x10^{-5}$ M (5)

N6-Benzyladenine: co-applied, 10^{-6}, $3x10^{-6}$, 10^{-5}, $3x10^{-5}$ M (1,9); co-applied, 20 ppm, at 25°C in dark (31); co-applied, 10 ppm, with or without GA_4, 50 ppm, at 25°C, 30°C in light (25); co-applied, 10^{-5}-10^{-4} M, plus $GA_{4/7}$, $2x10^{-4}$ M (41); co-applied, 10 ppm, plus $GA_{4/7}$, 50 ppm (31); pre-applied, 48h, $5x10^{-4}$ M in dichloromethane, germinate at 30°/35°C, 25°/35°C, 20°/35°C (16h/8h) in light (29); pre-applied, 48h, $5x10^{-4}$ M, plus ethephon, 1000 ppm, germinate at 30°/35°C, 25°/35°C (16h/8h) in light (29); pre-applied, 48h, $5x10^{-4}$ M, plus $GA_{4/7}$, $3x10^{-3}$ M in dichloromethane, germinate at 30°/35°C, 25°/35°C (16h/8h) in light (29)

Cytokinin: co-applied, 10^{-5}, $5x10^{-5}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5)

6-Aminopurine: co-applied, 10^{-5}, $5x10^{-5}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5)

6-Benzylaminopurine: co-applied, 10^{-6}, $5x10^{-6}$, $5x10^{-5}$, 10^{-4} M, plus $GA_{4/7}$, $2x10^{-5}$ M (5,41)

1-3-Chloropthalimido-cyclohexanecarboxamide: co-applied, 10-1000 ppm, germinate at 22°C, dark (47); co-applied, 10-1000 ppm, plus $GA_{4/7}$, 66 ppm, germinate at 22°C, dark (47)

1-1-Cyclohexene-1,2-dicarboximido-cyclohexane carboxamide: co-applied, 50-1000 ppm, germinate at 22°C, dark (47); co-applied, 50-1000 ppm, plus $GA_{4/7}$, 66 ppm, germinate at 22°C, dark (47) N4-Pyridyl-N'-phenylurea: co-applied, 20 ppm, plus 1-3-chloropthalimido-cyclohexanecarboxamide, 5-1000 ppm, germinate at 22°C, dark (47); co-applied, 20 ppm, plus 1-1-cyclohexane-1,2-dicarboximido-cyclohexane carboxamide, 5-1000 ppm, germinate at 22°C, dark (47)

N-Dimethylaminosuccinamic acid: co-applied, 2000 ppm (31); co-applied, 1000 ppm, plus $GA_{4/7}$, 50 ppm (31)

N-Phenyl pyridyl urea: co-applied, 10^{-4} M (41) Daminozide: co-applied, $7.5x10^{-3}$ M, plus $GA_{4/7}$, $2x10^{-4}$ M (41)

Hydroxylamine hydrochloride: co-applied, 10^{-3} M, plus $GA_{4/7}$, $2x10^{-4}$ M (41)

Cyclohexanediaminetetraacetic acid: co-applied, 10^{-3} M, plus $GA_{4/7}$, $2x10^{-4}$ M (41)

Sodium ethylenediaminetetraacetate: co-applied, 10^{-3} M (41); co-applied, 10^{-3} M, plus $GA_{4/7}$,

2x10 M (41)

Kinetin: co-applied, 10^{-5}, $5x10^{-5}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5); co-applied, 10^{-5} -10^{-4} M, plus $GA_{4/7}$, $2x10^{-4}$ M (41)

Kinetin riboside: co-applied, 10^{-5}, $5x10^{-5}$ M, plus $GA_{4/7}$, $2x10^{-5}$ M (5)

Citric acid: co-applied, $5x10^{-3}$ M, plus $GA_{4/7}$, 10^{-5} M (30)

Tartaric acid: co-applied, $5x10^{-3}$ M, plus $GA_{4/7}$, 10^{-5} M (30)

Ascorbic acid: co-applied, $5x10^{-3}$ M, plus $GA_{4/7}$, 10^{-5} M (30)

Succinic acid: co-applied, $5x10^{-3}$ M, plus $GA_{4/7}$, 10^{-5} M (30)

GA_4: co-applied, 50 ppm, at 25°C, 30°C in light (25)

$GA_{4/7}$: co-applied, 10^{-5} -10^{-3} M (30,41); co-applied, $2x10^{-4}$ M (37,38,39); co-applied, 330 ppm (47); pre-applied, 48h, $3x10^{-3}$ M in dichloromethane, with or without benzyladenine, $5x10^{-4}$ M (29); pre-applied, 48h, $3x10^{-3}$ M in dichloromethane, plus ethephon, 1000 ppm (29); co-applied, $2x10^{-4}$ M, plus daminozide, $7.5x10^{-3}$ M (38); pre-applied, 48h, 5°C, 1000 ppm plus daminozide, 4000 ppm, then pre-dry, germinate at 17°C in dark or 22°C in light, continuous (46); pre-applied, 48h, 5°C, 1000 ppm plus ethephon, 1000 ppm, then pre-dry, germinate at 17°C in dark or 22°C in light, continuous (46)

Sodium hypochlorite: pre-applied, 2h, 1%, germinate at 10°C, dark (35)

Ethephon: pre-applied, 48h, 1000 ppm (29)

Polyethylene glycol: pre-applied, 14d, -10 bars, at 18°C (33); pre-applied, 27d, -10 bars, at 10°C in light (12); pre-applied, 7,14d, -11.7 bars, plus benzyladenine, 10 ppm, at 20°C in dark (25); pre-applied, 7,14d, -11.7 bars, plus benzyladenine, 10 ppm, plus GA_3, 50 ppm (25)

Potassium nitrate: pre-applied, 14-35d, plus tri-potassium orthophosphate, -10, -12.5, -15 bars (34)

A. graveolens var lusitanicum

Constant temperatures: 5°C in continuous light (32); 10°C, 20°C, 5-30 min/d red light (32)

Alternating temperatures: 30°/20°C, 30°/10°C, 20°/10°C (12h/12h) (32)

Light: red, 5 min/d (32); green, 5 min/d (32)

A. graveolens var rapaceum

Constant temperatures: 10°C, 20°C, light, 10-30 min/d (32); 17°C, dark (46); 22°C, light, continuous (46)

Alternating temperatures: 20°/10°C (12h/12h) (32)

Pre-soak: 5°C, 48h, then pre-dry, germinate at 17°C in dark or 22°C in light, continuous (46)

$GA_{4/7}$: pre-applied, 48h, 5°C, 1000 ppm plus daminozide, 4000 ppm, then pre-dry, germinate

at 17°C in dark or 22°C in light (46); pre-applied, 48h, 5°C, 1000 ppm plus ethephon 1000 ppm, then pre-dry, germinate at 17°C in dark or 22°C in light (46)

V. Successful dormancy-breaking treatments

A. graveolens

Pre-chill, Potassium nitrate (ISTA)

Light (AOSA)

A. graveolens var dulce

Alternating temperatures: 22°/29°C (16h/8h) in light, 8h/d (17); 15°/22°C, 22°/29°C (16h/8h) in light, 8h/d (18); 15°/20°C, 15°/25°C, 15°/30°C (16.5h/7.5h) in light (19); 20°/30°C (18h/6h) in light (20); 15°/35°C in light (27); 21°/10°C (2-8h/16-22h) in dark (35); 15°/25°C (16h/8h) (44); 10°/25°C in dark or light (22)

Pre-chill: 10°C, 5d, germinate at 20°/30°C (16h/8h) (16) Warm stratification: 20°C, 3d, then pre-chill, 1°C, 11d (14); 20°C, 17d, dark, germinate at 20°C in light (35)

Light: continuous, at 10°C, 17°C (2); continuous, $5x10^{-6}$ mol m^{-2} s^{-1}, at 17°C (3,4,6,7,8,38); continuous, at 20°C (23); continuous, at 22°C (37,41); continuous, at 5°-20°C (32); 8h/d, at 9°-17°C (10); 8h/d, at 8°C, 15°C (17); 8h/d, at 8°-22°C (18); 8h/d, 5 W m^{-2}, at 8.5°C (45); at 15°C (19,22); at 15°C, 20°C (25); red, 5 min/d, 6d, at 15°C (32); red, continuous, at 22°C (39); dark, at 15°C (25); dark, at 10°C (35); dark, at 14°-16°C (11); dark or light, at 15°C (22)

$GA_{4/7}$: co-applied, $2x10^{-4}$ M, plus benzyladenine, 10^{-5} M (1,38); pre-applied, 48h, $3x10^{-3}$ M, plus benzyladenine, $5x10^{-4}$ M (29); co-applied, $2x10^{-5}$, $2x10^{-4}$ M, plus cytokinin, 10^{-4} M (5,36,39); co-applied, $2x10^{-5}$ M, plus benzylaminopurine, 10^{-5} M (5); co-applied, $2x10^{-5}$ M, plus aminopurine, 10^{-4} M (5); co-applied, $2x10^{-5}$ M, plus 6-benzylaminopurine, 10^{-5} M (5,41); co-applied, $2x10^{-5}$, 10^{-5} M, plus kinetin, 10^{-4} M (5); co-applied, $2x10^{-5}$ M, plus kinetin riboside, 10^{-4} M (5); co-applied, $2x10^{-4}$ M, plus N-phenylpyridyl urea, 10^{-4} M (41); co-applied, $2x10^{-4}$ M, plus ethephon, $3.5x10^{-3}$ M (41); co-applied, 1000 ppm, plus ethephon, 1000 ppm, germinate at 14°-16°C, dark (11); pre-applied, $3x10^{-3}$ M, plus ethephon, 1000 ppm, germinate at 20°/35°C in light (29); pre-applied, 48h, 5°C in light, continuous, plus ethephon, 1000 ppm, then polyethylene glycol, pre-applied, 14d, -15 bar, 15°C in light, continuous, germinate at 15°-19°C, dark (11); pre-applied 48h, 5°C, 1000 ppm, plus ethephon, 1000 ppm (1,40); pre-applied 48h, 5°C, 1000 ppm, plus daminozide, 4000 ppm (1,40)

Sodium hypochlorite: pre-applied, 2h, 1, 2%, germinate at 19°-22°C in light or 10°/21°C (16h/8h) in dark (35)

Pre-soak: 0.5,3h, germinate at 22°C in light (41)

Polyethylene glycol: pre-applied, 7,14d, -11.7 bars, 15°C in light, germinate at 20°C (25); pre-applied, 5,20d, -10, -15 bars, germinate at 20°C in light (34); pre-applied, 14d, -15 bar, 15°C in light, continuous, plus $GA_{4/7}$, 1000 ppm, plus ethephon, 1000 ppm, germinate at 14°-18°C, dark (11); pre-applied, 14d, -15 bar, 15°C in light, continuous, then $GA_{4/7}$, pre-applied, 48h, 1000 ppm, plus ethephon, 1000 ppm, 5°C in light, continuous, germinate at 15°C, dark (11)

A. graveolens var lusitanicum

Constant temperatures: 15°C, 20°C in continuous light (32)

VI. Comment

It is essential to provide light (2,3,20,23,24,27,28,32,36,38) at either a low constant temperature (2-4,6-8,10,17,19,22,25,32,35,38,45) or - preferably - in an alternating temperature regime (17-20,27,35,44) and to maintain a moist substratum (13,24) in order to promote the germination of seeds of Apium spp. Alternating temperature regimes of 15°/22°C (18), 10°/20°C (28) or 12°-15°/22°-25°C (42,43) are more effective in promoting germination than either 20°/30°C (all 16h/8h in light) or 15°C or 20°C in light (the latter being the more suitable of constant temperature germination test regimes). It is suggested that gene banks use the regime 15°/25°C (16h/8h) with light applied during the period spent at the upper temperature during each diurnal cycle. If it is necessary to use a constant temperature germination test regime then use 15°C. For the most dormant seeds it may be necessary to provide an additional stimulus with $2x10^{-5}$ M, $GA_{4/7}$ plus 10^{-4} M cytokinin, co-applied.

VII. References

1. Biddington, N.L. (1978). Growth regulator interactions in the control of (celery) seed germination. In The effect of interactions between growth regulators on plant growth and yield, pp. 29-36. British Plant Growth Regulator Group, Monograph No. 2, London.

2. Biddington, N.L. (1981). Thermodormancy and the prevention of desiccation injury in celery seeds. Annals of Applied Biology, 98, 558-562.

3. Biddington, N.L., Brocklehurst, P.A., Dearman, A.S. and Dearman, J. (1982). The prevention of dehydration injury in celery seeds by polytheylene glycol, abscissic acid, dark and high temperature. Physiologia Plantarum, 55, 407-410.

4. Biddington, N.L., Dearman, A.S. and Thomas, T.H. (1982). Effects of temperature and drying rate during dehydration of celery seeds on germination, leakage and response to gibberellin and cytokinin. Physiologia Plantarum, 54, 75-78.

5. Biddington, N.L. and Thomas, T.H. (1976). Influence of different cytokinins on the germination of lettuce (Lactuca sativa) and celery (Apium graveolens) seeds. Physiologia Plantarum, 37, 12-16.

6. Biddington, N.L. and Thomas, T.H. (1978). Thermodormancy in celery seeds and its removal by cytokinins and gibberellins. Physiologia Plantarum, 42, 401-405.

7. Biddington, N.L. and Thomas, T.H. (1979). Residual effects of high temperature pre-treatments on the germination of celery seeds (Apium graveolens). Physiologia Plantarum, 47, 211-214.

8. Biddington, N.L., Thomas, T.H. and Dearman, A.S. (1980). The promotive effect on subsequent germination of treating imbibed celery seeds with high temperature before or during drying. Plant Cell and Environment, 3, 461-465.

9. Biddington, N.L., Thomas, T.H. and Dearman, A.S. (1980). The effect of temperature on the germination-promoting activities of cytokinin and gibberellin applied to celery seeds (Apium graveolens). Physiologia Plantarum, 49, 68-70.

10. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. 1. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

11. Brocklehurst, P.A., Rankin, W.E.F. and Thomas, T.H. (1982/1983). Stimulation of celery seed germination and seedling growth with combined ethephon, gibberellin and polyethylene

glycol seed treatments. Plant Growth Regulation, 1, 195-202.

12. Darby, R.J. Salter, P.J. and Whitlock, A.J. (1979). Effects of osmotic treatment and pre-germination of celery seeds on seedling emergence. Experimental Horticulture, 31, 10-20.

13. Doneen, L.D. and MacGillivray, J.H. (1943). Germination (emergence) of vegetable seeds as affected by different soil moisture conditions. Plant Physiology, 18, 524-529.

14. Finch-Savage, W.E. and Cox, C.J. (1982). A cold-treatment technique to improve the germination of vegetable seeds prior to fluid drilling. Scientia Horticulturae, 16, 301-311.

15. Flemion, F. and Uhlmann, G. (1946). Further studies of embryoless seeds in the Umbelliferae. Contributions from the Boyce Thompson Institute, 14, 283-293.

16. Fornerod, C. (1975). Remarques sur la germination des semences potagères en laboratoire. Revue Horticole Suisse, 48, 6-9.

17. Guy, R. (1980). Quelques exemples des effects de la temperature sur la germination des plantes potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 12, 35-37.

18. Guy, R. (1981). Influence de la temperature sur la dureé de germination des semences de dix espèces potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 13, 219-225.

19. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

20. Hicks, G. and Key, S. (1898). Additional notes on seed testing. U.S. Department of Agriculture, Yearbook 1897, 441-452.

21. Hopkins, E.F. (1926). Studies in the germination of celery seed. Proceedings of the Association of Official Seed Analysts, 18, 47-49.

22. Hopkins, E.F. (1928). Further studies of celery seed germination. Proceedings of the Association of Official Seed Analysts, 20, 69-70.

23. Kinzel, W. (1908). Lichtkeimung. Einige bestätigende und ergänzende Bemerkungen zu den vorläfigen Mitteilungen von 1907 und 1908. Bericht der Deutschen Botanischen Gesellschaft, 26a, 631-645.

24. Morinaga, T. (1926). Effect of alternating temperatures upon the germination of seeds. American Journal of Botany, 13, 141-158.

25. Nakamura, S., Teranishi, T. and Aoki, M. (1982). [Promoting effect of polyethylene glycol on the germination of celery and spinach seeds.] Journal of the Japanese Society for Horticultural Science, 50, 461-467.

26. Nettles, V.F. and Poe, L.N. (1973). Germination studies with celery seed. Proceedings of the Florida State Horticultural Society, 86, 172-175.

27. Niethammet-Prag, A. von (1934). Licht, Dunkelheit und Strahlung als Faktoren bei der Samen-keimung. Tabulae Biologicae (Periodicae), 10, 45-77.

28. Nutile, G.E. and Canfield, A.P. (1950). Effect of temperature and light on the germination of celery seed. Newsletter of the Association of Official Seed Analysts, 24, 20-22.

29. Palevitch, D. and Thomas, T.H. (1974). Thermodormancy release of celery seed by gibberellins, 6-benzylaminopurine, and ethephon applied in organic solvent to dry seeds.

Journal of Experimental Botany, 25, 981-986.

30. Palevitch, D. and Thomas, T.H. (1976). Enhancement by low pH of gibberellin effects on dormant celery seeds and embryoless half-seeds of barley. Physiologia Plantarum, 37, 247-252.

31. Palevitch, D., Thomas, T.H. and Austin, R.B. (1971). Dormancy-release of celery seed by a growth retardant, N-dimethylaminosucciamic acid (Alar). Planta, 100, 370-372.

32. Pressman, E., Negbi, M., Sachs, M. and Jacobsen, J.V. (1977). Varietal differences in light requirements for germination of celery (Apium graveolens L.) seeds and the effects of thermal and solute stress. Australian Journal of Plant Physiology, 4, 821-831.

33. Rennick, G.A. and Tiernan, P.I. (1978). Some effects of osmopriming on germination, growth and yield of celery (Apium graveolens). Seed Science and Technology, 6, 695-700.

34. Salter, P.J. and Darby, R.J. (1976). Synchronization of germination of celery seeds. Annals of Applied Biology, 84, 415-424.

35. Taylor, C.A. (1949). Some factors affecting germination of celery seed. Plant Physiology, 24, 93-102.

36. Thomas, T.H. (1976). The role of growth in the control of seed germination and seedling establishment. Journal of the Science of Food and Agriculture, 27, 794.

37. Thomas, T.H. (1978). Relationship between bolting-resistance and seed dormancy of different celery cultivars. Scientia Horticulturae, 9, 311-316.

38. Thomas, T.H., Biddington, N.L. and O'Toole, D.F. (1979). Relationship between position on the parent plant and dormancy characteristics of seeds of three cultivars of celery (Apium graveolens). Physiologia Plantarum, 45, 492-496.

39. Thomas, T.H., Biddington, N.L. and Palevitch, D. (1978). The role of cytokinins in the phytochrome-mediated germination of dormant imbibed celery (Apium graveolens) seeds. Photochemistry and Photobiology, 27, 231-236.

40. Thomas, T.H., Biddington, N.L. and Palevitch, D. (1978). Improving the performance of pelleted celery seeds with growth regulator treatments. Acta Horticulturae, 83, 235-244.

41. Thomas, T.H., Palevitch, D., Biddington, N.L. and Austin, R.B. (1975). Growth regulators and the phytochrome-mediated dormancy of celery seeds. Physiologia Plantarum, 35, 101-106.

42. Thompson, P.A. (1974). Germination of celery (Apium graveolens L.) in response to fluctuating temperatures. Journal of Experimental Botany, 25, 156-163.

43. Thompson, P.A. (1974). Effects of fluctuating temperatures on germination. Journal of Experimental Botany, 25, 164-175.

44. Toole, E.H. and Toole, V.K. (1951). Methods of testing celery seed in relation to seed storage problems. Proceedings of the Association of Official Seed Analysts, 41, 62-65.

45. Wagenvoort, W.A., Boot, A. and Bierhuizen, J.F. (1981). Optimum temperature range for germination of vegetable seeds. Gartenbauwissenschaft, 46, 97-101.

46. Thomas, T.H. (1983). Stimulation of celeriac and celery seed germination by growth regulator seed soaks. Seed Science and Technology, 11, 301-305.

47. Thomas, T.H. (1984). Gibberellin-like stimulation of celery (Apium graveolens L.) seed germination by N-substituted phthalimides. Scientia Horticulturae, 23, 113-117.

CARUM

C. carvi L. caraway

I. Evidence of dormancy

Seeds of C. carvi can show considerable dormancy (2,3,6), which is reportedly due to endogeneous germination inhibitors (3,6).

II. Germination regimes for non-dormant seeds

TP: 20°/30°C (16h/8h): 21d (ISTA)

TP: 20°/30°C (16h/8h): 14d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h), light, 14d (1)

III. Unsuccessful dormancy-breaking treatments

Alternating temperatures: 27°/22°C, 30°/25°C, 33°/28°C, 36°/31°C (8h/16h) (5)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 21°/16°C, 24°/19°C (8h/16h) (5); 20°/30°C (16h/8h), light (6)

V. Successful dormancy-breaking treatments

Light (AOSA)

Constant temperatures: 10°C (4)

Alternating temperatures: 15°/10°C, 18°/13°C (8h/16h) (5)

Pre-chill: 4°C (2,3)

Pre-soak: 6d, 15°/10°C (8h/16h), then pre-dry, 15°/10°C (8h/16h), germinate at 15°/10°C (8h/16h) (5)

VI. Comment

A 21-day test in the alternating temperature regime prescribed by ISTA and AOSA is not entirely adequate for either freshly harvested or 4 year old seed lots of C. carvi (6): for non-dormant accessions it is necessary to extend the test duration to at least 35 days (6). However, it would be preferable to test both non-dormant and dormant accessions at lower temperatures (4,5). Whilst testing at 4°C can be satisfactory (2,3), an alternating temperature regime of 15°/10°C (8h/16h) (5) or a constant temperature regime of 10°C (4) are suggested since tests in these regimes can be concluded sooner than those at 4°C.

VII. References

1. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

2. Hradilík, J. and Císaàová, H. (1975). [Studies on the dormancy of caraway (Carum carvi) achenes.] Rostlinná Vy6roba, 21, 351-364. (From Horticultural Abstracts, 1976, 46, 7026.)

3. Hradilík, J. and Fiserová, H. (1980). [The role of abscisic acid in caraway (Carum carvi) seed dormancy.] Acta Universitatis Agriculturae, Brno, A, 28, 39-64. (From Horticultural Abstracts, 1982, 52, 4161.)

4. Putievsky, E. (1977). [Tests on caraway seed germination.] Hassadeh, 57, 1413-1415. (From Seed Abstracts, 1978, 1, 67.)

5. Putievsky, E. (1980). Germination studies with seed of caraway, coriander and dill. Seed Science and Technology, 8, 245-254.

6. Weisaeth, G. (1978). [Germination capacity of Carum carvi seed in relation to the life cycle of caraway plants.] Seed Science and Technology, 6, 685-693.

CORIANDRUM

C. sativum L. coriander

I. Evidence of dormancy

Delayed germination of the seeds is a frequent problem for growers (3) and freshly harvested seeds show considerable dormancy (A).

II. Germination regimes for non-dormant seeds

TP; BP: 20°C; 20°/30°C (16h/8h): 21d (ISTA)

BP: 15°C: 21d (AOSA)

Constant temperatures: 15°C (2)

III. Unsuccessful dormancy-breaking treatments

Alternating temperatures: 36°/31°C (8h/16h) (3)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 27°/22°C, 24°/19°C, 21°/16°C, 18°/13°C, 15°/10°C, 30°/25°C (8h/16h) (3); 20°/30°C (16h/8h) (1)

Pre-chill: 8°-12°C, 7d, germinate at 20°/30°C (16h/8h) (1)

Pre-soak: 3-4d, then pre-dry, 8h, germinate at 27°/22°C (8h/16h) (3)

V. Successful dormancy-breaking treatments

Constant temperatures: 15°C (2)

VI. Comment

Coriander seed germination is severely reduced at temperatures above 30°C or below 10°C (3). Within those alternating temperature regimes listed above as partly-successful dormancy-breaking treatments, the most suitable regime for testing coriander seeds for germination is 27°/22°C (8h/16h) (3). It is suggested that either this regime or that recommended by the ISTA - 20°/30°C (16h/8h) - be used for germination tests, but note that neither regime alone may result in full germination. For example, testing freshly harvested seeds in an alternating temperature regime of 20°/30°C (16h/8h) with continuous light resulted in a very shallow germination progress curve with seeds continuing to germinate after 10 weeks in test (A): cumulative germination at 10 weeks was only 40% (A). Although a constant temperature of

15°C has been recommended (2, AOSA) we suspect that the use of this regime will be less satisfactory than either of the two above alternating temperature regimes since germination in 20-day tests at either 18°/13°C (8h/16h) or 15°/10°C (8h/16h) - where the mean temperature is not too dissimilar to 15°C - was far lower than at 27°/22°C (8h/16h) (3). This may explain why the previous ISTA recommendation (1976 rules) to test dormant coriander seeds at 10°/20°C (16h/8h) has been deleted from the current rules. Further dormancy-breaking agents which are likely to be effective in promoting germination include pre-chilling, gibberellins and light. Because of the problem of embryoless seeds, dissection of non-germinated seeds at the end of germination tests is advised.

VII. References

1. Esnin, S.A., Myakota, B.V. and Sokolova, L.F. (1978). [A method for germinating coriander seeds.] Selektsiya i Semenovodstvo, 3, 56. (From Seed Abstracts, 1979, 2, 941.)

2. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

3. Putievsky, E. (1980). Germination studies with seed of caraway, coriander and dill. Seed Science and Technology, 8, 245-254.

CUMINUM

C. cyminum L. [C. odorum Salisb.] cumin

I. Evidence of dormancy

Low and irregular germination of cumin seeds is a problem for growers (5).

II. Germination regimes for non-dormant seeds

TP: 20°/30°C (16h/8h): 14d (ISTA,AOSA)

Alternating temperatures: 20°/30°C (16h/8h) in light (3)

III. Unsuccessful dormancy-breaking treatments

Indoleacetic acid: (4)

GA_3: (4)

Kinetin: (4)

Ethephon: (4)

IV. Partly-successful dormancy-breaking treatments

GA_3: pre-applied, 24h, 25-100 ppm (5)

Naphthaleneacetic acid: pre-applied, 24h, 10 ppm (2)

1-Naphthyl acetic acid: pre-applied, 24h, 25, 50 ppm (5)

2-Naphthoxyacetic acid: pre-applied, 24h, 25-100 ppm (5)

Maleic hydrazide: pre-applied, 24h, 25-100 ppm (5)

Indolyl-3-acetic acid: pre-applied, 24h, 10 ppm (2); pre-applied, 24h, 25, 50 ppm (5)

Indolyl-3-butyricum acetic acid: pre-applied, 24h, 25-100 ppm (5)

2,4,5-Trichlorophenoxy acetic acid: pre-applied, 24h, 50 ppm (5)

2,4-Dichlorophenoxyacetic acid: pre-applied, 24h, 25, 50 ppm (5)

Colchicine: pre-applied, 24h, 25, 50 ppm (5)

V. Successful dormancy-breaking treatments

Pre-wash: 24h, germinate at 18°C (1)

Indolyl-3-acetic acid: pre-applied, 24h, 100 ppm (5)

VI. Comment

It is suggested that cumin seeds be tested for germination according to the AOSA and ISTA rules: that is in an alternating temperature regime of 20°/30°C (16h/8h).

VII. References

1. Chaturvedi, S.N. and Muralia, R.N. (1975). Germination inhibitors in some Umbellifer seeds. Annals of Botany, 39, 1125-1129.

2. Gandhi, S.M. and Bhatnagar, M.P. (1961). Effect of certain hormones on germination, flowering, fruiting, branching and yield of cumin (Cuminum cyminum L.). Journal of the Indian Botanical Society, 40, 628-634.

3. Heit, C.E. (1948). Laboratory germination results with herb and drug seed. Proceedings of the Association of Official Seed Analysts, 38, 58-62.

4. Hradlík, J. and Císaróvá, H. (1975). The role of abscisic acid (ABA) in achenes of dormant cumin. Acta Universitatis Agriculturae, Brno, A, 23, 747-753. (From Horticultural Abstracts, 1978, 48, 5855.)

5. Sankhla, H.C. and Mathur, R.L. (1968). Effects of growth-regulating substances, inorganic fertilizers, oil cakes and soil pH on germination of cumin (Cuminum cyminum L.) seeds. Indian Journal of Agricultural Science, 38, 270-274.

DAUCUS

D. carota L. var carota	wild carrot, Queen Anne's lace
D. carota L. var sativus (Hoffm.) Thell. [D. carota L. var sativa DC.]	carrot
D. pusillux Michx.	

I. Evidence of dormancy

Freshly harvested seeds of the cultivated carrot (D. carota var sativus) can show considerable dormancy (1,5,6,9-11,17,22,26,31,33,37,38) and as a result germination tests may have to be continued for up to 32 (26), 44 (33), 100 (11) or 150 days (5). Although dormancy is usually thought to be the result of the presence of immature seeds (5,13,17,37), mature seeds can also exhibit dormancy (31,37). At least 3 months' after-ripening is reported to be required to remove dormancy (9,37). Not surprisingly seeds of the wild carrot species (D. carota var carota and D. pusillux) show more pronounced dormancy than seeds of the cultivated species (3,4,8,9,26). For example, seeds of D. pusillux failed to germinate at harvest, and only gave 43% germination after 1 year's after-ripening at room temperature (3,4), whilst seeds of D. carota var carota failed to germinate at all after one year's after-ripening (8).

II. Germination regimes for non-dormant seeds

D. carota

TP; BP: 20°/30°C (16h/8h); 20°C: 14d (ISTA)

BP: 20°/30°C (16h/8h): 14d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (14)

III. Unsuccessful dormancy-breaking treatments

D. carota var carota

Constant temperatures: 10°C, continuous light or dark (16)

Alternating temperatures: (8); 0°-12°/40°C (12h/12h) (16); 0°-12°/40°C (12h/12h), 17d, then 21°-28°C, in light (16)

Pre-chill: 6°C (8); 5°C, 14d (9); 10°C, 8d, in light or dark, then 25°C, dark, 8d, then 25°C in light (16); 10°C, 8d, dark, then 40°C, dark, 4d, then 25°C in dark, 4d, then 25°C in light (16)

Warm stratification: 40°C, 17d, dark, germinate at 25°C in light (16)

Light: 16h/d, at 16°C, 19°C (8); dark, at 15°C, 25°C (16)

Pre-soak: (26); 1,3,6w, 6°C (8); 15,30s, at 60°C, 75°C, 90°C (16)

Scarification: sand paper, germinate at 25°C, dark (16); concentrated sulphuric acid, 0.5,1 min (16) pH: 3-8 (8)

Acetic acid: pre-applied, 24h, 10^{-4}-1 M (16)

Butyric acid: pre-applied, 24h, 10^{-4}-1 M (16)

Citric acid: pre-applied, 24h, 10^{-4}-10^{-1} M (16)

Tartaric acid: pre-applied, 24h, 10^{-4}-10^{-1} M (16)

Malic acid: pre-applied, 24h, 10^{-4}-10^{-1} M (16)

Potassium sulphocyanate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Sodium sulphocyanate: pre-applied, 24,28h, 10^{-4}-1 M (16)

Sodium iodide: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Sulphuric acid: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Potassium sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Ammonium sulphate: pre-applied, 24h, 10^{-4}-1 M (16)

Sodium sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Lithium sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Nickel sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Zinc sulphate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Potassium nitrate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Ammonium nitrate: pre-applied, 24h, 10^{-4}-1 M (16)

Sodium nitrate: pre-applied, 24h, 10^{-4}-1 M (16)

Aluminium nitrate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Cobalt nitrate: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Potassium hydroxide: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Ammonium hydroxide: pre-applied, 24h, 10^{-4}-10^{-2} M (16)

Sodium hydroxide: pre-applied, 24h, 10^{-4}-10^{-1} M (16)

Hydrochloric acid: pre-applied, 24h, 10^{-4}-1 M (16)

D. carota var sativus

Pre-dry: 35°C, 5,7d (15); imbibe/dry (24h/24h), 20°C, 1-3 cycles, germinate at 24°C in light, 10h/d, 5000 lux (2)

Pre-soak: 2-48h, 20°C (26); 10 min, 50°-52°C (31)

Scarification: cut (31); concentrated sulphuric acid, 2 min (31)

Thiourea: pre-applied, 0.1-5% (31)

D. pusillux

Constant temperatures: 20°-35°C (3,4)

Alternating temperatures: 20°/30°C (16h/8h) (3,4)

IV. Partly-successful dormancy-breaking treatments

D. carota var carota

Constant temperatures: 16°-25°C in dark or continuous light (8); 10°-20°C (9); 15°-30°C in continuous light (16); 15°-35°C (25,32)

Alternating temperatures: 20°/10°C (day/night) (9); 20°/30°C, 20°/35°C (16h/8h) in dark (25)

Pre-chill: (26); 0°-12°C, 17d, dark, germinate at 25°C in light (16)

Scarification: sand paper (8)

Removal of seed covering structures: endosperm cap (8)

Oxygen: 40-80% (16)

Hydrogen peroxide: pre-applied, 27h, 5, 20, 50%, in light (16)

Light: 16h/d, at 21°C, 25°C (8); continuous, at 20°-28°C (16); dark, at 16°C (8)

D. carota var sativus

Constant temperatures: 10°-20°C (9,23); 8°C (19); 15°-30°C (21); 10°C (24); 8°-30°C (28); 5°-25°C (35)

Alternating temperatures: 20°/30°C (8h/16h) (13,37); 20°/30°C (16h/8h) (5,11,15,21,26,27,33); 20°/10°C (day/night) (9); 22°/29°C (16h/8h) (20); 15°/20°-35°C, 20°/25°-35°C, 25°/35°C (16.5h/7.5h) (21); 25°/35°C (16h/8h) (37); 16°/5°C (12h/12h) (24); 15°/25°C, 25°/35°C (16h/8h) (27); 4°-11°/25°C, 25°/4°-11°C (16h/8h) (29); 10°/30°C, 15°/20°C (16h/8h) (15)

Pre-chill: 5°C, 14-40d (9)

Removal of seed covering structures: pericarp, hair (1,36)

Pre-soak: 3-4h (36)

Pre-dry: sun (36)

Light: diffuse (1); continuous (17); ultra violet (30)

Dibasic potassium phosphate: pre-applied, 3 cycles, soak/dry, 16h/48h, 10^{-2} M, germinate at 10°C, 20°C (23)

X-rays: (30)

Acetone: (30)

Polyethylene glycol: pre-applied, 6d, -8.6 bars, 15°C, continuous light, $25x10^{-5}$ W cm^{-2}, germinate at 10°C, 10°/5°C, in light (34)

Potassium nitrate: pre-applied, 1-5h, 0.2%, germinate at 20°-25°C in diffuse light (1)

GA_3: pre-applied, 3h, 50, 100 ppm, germinate at 20°-25°C in diffuse light (1)

D. pusillux

Constant temperatures: 10°C, 15°C (3,4)

Alternating temperatures: 10°/20°C, 10°/30°C, 15°/30°C (16h/8h) (3,4)

V. Successful dormancy-breaking treatments

D. carota var carota

Alternating temperatures: 15°/30°C (16h/8h) in light (12)

Pre-chill: 5°C, 40-96d (9); 5°C, 3m, germinate in diffuse light (18); 5°C (32)

Hydrogen peroxide: pre-applied, 27h, 10%, in light (16)

D. carota var sativus

Constant temperatures: 10°C in light (6,39); 5°-25°C in light (17); 8°-29°C (19,20); 20°C in light, continuous (39)

Alternating temperatures: 22°/29°C (16h/8h) (19)

Pre-chill: 5°C, 70-96d (9)

Pre-wash: 24h, germinate at 18°C, dark (7)

VI. Comment

It is surprising that light is not prescribed by either the ISTA or the AOSA, since it is essential to provide light during germination tests of seeds of Daucus spp. (1,8,12,16,18). Under normal circumstances there is no advantage of alternating temperature germination test regimes over constant temperature regimes within the range 15°-25°C for the cultivated carrot (9,15,21,24,26,27,29) - although under water stress alternating temperature regimes are beneficial (24). Seeds of the wild carrot species, however, do require alternating temperature regimes for germination in lots where dormancy is pronounced (3,4,9,12,25): 10°/30°C (16h/8h) is suitable for D. pusillux (3,4); and 10°/20°C (9) or 15°/30°C (12) for D. carota var carota. Nevertheless, alternating temperature and light alone are not likely to promote full germination in the more dormant wild carrot seeds; up to 3 months pre-chilling is also likely to be required (9,18).

The following procedures are suggested. For cultivated carrot a pre-treatment with 50 ppm GA_3, for 3 hours or so (1), with germination tests at 20°/30°C (16h/8h) with light applied during the 8 hour part of each cycle. It may be necessary to allow this test to continue for six weeks or more. The above can be followed for wild carrot seeds, except that 15°/30°C (16h/8h) should replace 20°/30°C, and a 3 month pre-chill treatment at 3°-5°C will also probably be required. It may be possible to apply a pre-treatment in hydrogen peroxide - 24 hours, 10% (16) - to avoid the requirement of the considerable pre-chill periods.

VII. References

1. Aki, S. (1960). [Effect of gibberellin on breaking the dormancy of Kintoki-carrot seeds.] Technical Bulletin of the Faculty of Agriculture, Kagawa University, 12, 73-77.

2. Austin, R.B., Longden, P.C. and Hutchinson, J. (1969). Some effects of 'hardening' carrot seed. Annals of Botany, 33, 883-895.

3. Barton, L.V. (1936). Germination of some desert seeds. Contributions from the Boyce Thompson Institute, 8, 7-11.

4. Barton, L.V. (1962). The germination of weed seeds. Weeds, 10, 174-182.

5. Borthwick, H.A. (1931). Carrot seed germination. Proceedings of the American Society for Horticultural Science, 28, 310-314.

6. Brocklehurst, P.A. and Dearman, J. (1980). The germination of carrot (Daucus carota L.) seed harvested on two dates: a physiological and biochemical study. Journal of Experimental Botany, 31, 1719-1725.

7. Chaturvedi, S.N. and Muralia, R.N. (1975). Germination imhibitors in some Umbellifer seeds. Annals of Botany, 39, 1125-1129.

8. Dale, H.M. and Harrison, P.J. (1966). Wild carrot seeds: germination and dormancy. Weeds, 4, 201-204.

9. Doust, J.L. and Doust, L.L. (1982). Life-history patterns in British Umbelliferae: a review. Botanical Journal of the Linnean Society, 85, 179-194.

10. Durfee, B. (1948). Carrot seed germination observations. Newsletter of the Association of Official Seed Analysts, 22, 17-18.

11. Elliot, G.A. (1929). Germination of carrot seed. Newsletter of the Association of Official Seed Analysts, 3, 12-15.

12. Everson, L. (1949). Preliminary studies to establish laboratory methods for the germination of weed seed. Proceedings of the Association of Official Seed Analysts, 39, 84-89.

13. Flemion, F. and Uhlmann, G. (1946). Further studies of embryoless seeds in the Umbelliferae. Contributions from the Boyce Thompson Institute, 14, 283-293.

14. Fornerod, C. (1975). Remarques sur la germination des semences potagères en laboratoire. Revue Horticulture Suisse, 48, 6-9.

15. Frank, W.J. and Wieringa, G. (1928). Artificial drying and low temperature as means employed in obtaining an increase in germination of some vegetable seeds. Proceedings of the Association of Official Seed Analysts, 19, 24-27.

16. Gardner, W.A. (1921). Effect of light on germination of light-sensitive seeds. Botanical Gazette, 71, 249-288.

17. Gray, D. (1979). The germination response to temperature of carrot seeds from different umbels and times of harvest of the seed crop. Seed Science and Technology, 7, 169-178.

18. Grime, J.P., Mason, G., Curtis, A.V., Rodman, J., Band, S.R., Mowforth, M.A.G., Neal, A.M. and Shaw, S. (1981). A comparative study of germination characteristics in a local flora. Journal of Ecology, 69, 1017-1059.

19. Guy, R. (1980). Quelques exemples des effets de la temperature sur la germination des plantes potagères. Revue Suisse de Viticulture, d'Arboriculture, et d'Horticulture, 12, 35-37.

20. Guy, R. (1981). Influence de la temperature sur la dureé de germination des semences de dix espèces potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 13, 219-225.

21. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

22. Hawthorn, L.R., Toole, E.H. and Toole, V.K. (1962). Yield and viability of carrot seeds as affected by position of umbel and time of harvest. Proceedings of the American Society for Horticultural Science, 80, 401-407.

23. Hegarty, T.W. (1973). Temperature sensitivity of germination in carrots: its frequency of occurrence and response to seed advancement. Journal of Horticultural Science, 48, 43-50.

24. Hegarty, T.W. (1975). Effects of fluctuating temperature on germination and emergence of seeds in different moisture environments. Journal of Experimental Botany, 26, 203-211.

25. Hendricks, S.B. and Taylorson, R.B. (1976). Variation in germination and amino acid leakage of seeds with temperature related to membrane phase change. Plant Physiology, 58, 7-11.

26. Hoefle, O.M. (1929). Results of a study of Daucus carota seeds. Proceedings of the Association of Official Seed Analysts, 21, 35-36.

27. Jacobsohn, R. and Globerson, D. (1981). Daucus carota (carrot) seed quality: I. Effects of seed size on germination, emergence and plant growth under sub-tropical conditions and II. The importance of the primary umbel in carrot seed production. In Seed Production (ed. P.D. Hebblethwaite), pp. 637-646, Butterworths, London.

28. Kotowski, F. (1926). Temperature relations to germination of vegetable seed. Proceedings of the American Society for Horticultural Science, 23, 176-186.

29. Kotowski, F. (1927). Temperature alternation and germination of vegetable seed. Acta Societatis Botanicorum Poloniae, 5, 71-78.

30. Kwon, O. (1970). Studies on the acceleration of germination in carrot seed. II. The effect of X-rays and ultraviolet light on the germination of carrot seed. Korean Journal of Botany, 13, 15-20. (From Horticultural Abstracts, 1973, 43, 691.)

31. Mann, L.K. and MacGillivray, J.H. (1949). Some factors affecting the size of carrot roots. Proceedings of the American Society for Horticultural Science, 54, 311-318.

32. Martin, J.N. (1943). Germination studies of the seeds of some common weeds. Proceedings of the Iowa Academy of Science, 50, 221-228.

33. Patterson, M.N. (1931). Germination studies of carrot seed. Proceedings of the Association of Official Seed Analysts, 23, 73-75.

34. Szafirowska, A., Khan, A.A. and Peck, N.H. (1981). Osmoconditioning of carrot seeds to improve seedling establishment and yield in cold soil. Agronomy Journal, 73, 845-848.

35. Wagenvoort, W.A., Boot, A. and Bierhuizen, J.F. (1981). Optimum temperature range for germination of vegetable seeds. Gartenbauwissenschaft, 46, 97-101.

36. Watanabe, S. (1955). [On germination of the Kintoki carrot seeds. II. Effects of pericarp removal, soaking and drying, and sun drying of seeds on their germination.] Journal of the Horticulture Association of Japan, 23, 237-244.

37. Watanabe, S. Asano, H. and Maeda, T. (1955). [On germination of the Kintoki carrot seeds. I. Delayed germination.] Kagawa Agriculture College, Technical Bulletin, 7, 27-30.

38. Wilkes, M. (1929). Germination of carrot seed. Newsletter of the Association of Official Seed Analysts, 3, 3-4.

39. Brocklehurst, P.A. and Dearman, J. (1983). Effects of calcium peroxide as a supplier of oxygen for seed germination and seedling emergence in carrot and onion. Seed Science and Technology, 11, 293-299.

FOENICULUM

F. capillaceum Gilib.

F. vulgare Mill. [F. officinale All.; F. Foeniculum Karst.; Anethum Foeniculum L.] fennel

I. Evidence of dormancy

Freshly harvested seeds of fennel can show considerable dormancy (2,6,7) with, for example, no germination being reported at harvest, and only 41% germination after 3 months' after-ripening at room temperature (2), whilst as many as 18 months after-ripening at room temperature may be required to completely remove dormancy (7).

II. Germination regimes for non-dormant seeds

F. vulgare

TP; BP: 20°/30°C (16h/8h): 14d (ISTA)

BP: 20°/30°C (16h/8h): 14d (AOSA)

Alternating temperatures: 20°/30°C (16h/8h) (5,6)

III. Unsuccessful dormancy-breaking treatments

F. vulgare

Pre-chill: 5°C, 14-96d, germinate at 20°/10°C (day/night) (2)

IV. Partly-successful dormancy-breaking treatments

F. capillaceum

Constant temperatures: 6°-30°C in light or dark (9)

Alternating temperatures: 6°/16°C, 16°/25°C, light or dark (9); 6°/25°C in light (9)

F. vulgare

Constant temperatures: 15°C, 20°C (6); 8°-29°C (8)

Alternating temperatures: 20°/30°C (16h/8h) (6,7); 20°/10°C (day/night) (2); 15°/22°C, 22°/29°C (16h/8h) (8)

Pre-dry: room temperature, 3d (6)

Light: dark (7)

V. Successful dormancy-breaking treatments

F. capillaceum

Alternating temperatures: 6°/25°C in dark (9)

F. vulgare

Alternating temperatures: 20°/30°C (16h/8h), 14d, then dry ungerminated seeds, room temperature, 3d, then return to 20°/30°C (16h/8h) (6,7)

Pre-chill: 10°C, 5d, germinate at 20°/30°C (16h/8h) (5)

Warm stratification: 20°C, 14d, then germinate at 20°/30°C (16h/8h) (6)

Pre-wash: 24h, germinate at 18°C in dark (1)

VI. Comment

Dormancy will not be the only problem encountered when attempting to germinate fennel seeds. As with other members of the Umbelliferae the variation in maturity within a plant means that certain "seeds" may lack embryos, whilst others may be immature with only partly-developed embryos. Consequently at the end of germination tests the seeds which have failed to germinate should be cut to determine whether or not they possess an embryo: as many as one third of "seeds" may lack embryos (3,4).

Within the range 8°-29°C, a constant temperature of 15°C is the most suitable for germination tests (8). (Incidentally, previous ISTA rules, 1976, recommended a constant temperature germination test regime of 15°C as a dormancy-breaking procedure.) Alternating temperature regimes of 15°/22°C or 22°/29°C (16h/8h) provided no additional stimulation of germination

beyond that at a constant 15°C (8). However, in another investigation an alternating temperature regime of 20°/30°C (16h/8h) resulted in much greater germination than constant temperatures of either 15°C or 20°C (6). Germination in the dark is reported to be consistently superior to that in the light (7,9).

The following regime is suggested for fennel seed germination tests: a 5-day pre-chill at 10°C, then transfer to an alternating temperature regime of 20°/30°C (16h/8h) in the dark. If this proves inadequate for the more dormant accessions then impose a pre-wash treatment prior to pre-chilling.

VII. References

1. Chaturvedi, S.N. and Muralia, R.N. (1975). Germination inhibitors in some umbellifer seeds. Annals of Botany, 39, 1125-1129.

2. Doust, J.L. and Doust, L.L. (1982). Life-history patterns in British Umbelliferae: a review. Botanical Journal of the Linnean Society, 85, 179-194.

3. Flemion, F. and Hendrickson, E.T. (1949). Further studies on the occurrence of embryoless seeds and immature embryo in the Umbelliferae. Contributions from the Boyce Thompson Institute, 15, 291-297.

4. Flemion, F. and Uhlmann, G. (1946). Further studies of embryoless seeds in the Umbelliferae. Contributions from the Boyce Thompson Institute, 14, 283-293.

5. Fornerod, C. (1975). Remarques sur la germination des semences potagères en laboratoire. Revue Horticole Suisse, 48, 6-9.

6. Guy, R. (1979). Observations sur la dormance et la germination des semences de fenouil. Revue Suisse d'Agriculture, 11, 131-133.

7. Guy, R. (1979). Nouvelle observations sur la maturité, la dormance, la germination et la levée des semences de fenouil. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 11, 215-217.

8. Guy, R. (1981). Influence de la temperature sur la durée de germination des semences de dix espèces potagères. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture, 13, 219-225.

9. Styk, B. (1970). [The effect of different temperatures and light on the germination of fennel, Foeniculum capillaceum.] Annales Universitatis Mariae Curie-Sklodowska, E, 1969, 24, 277-288. (From Horticultural Abstracts, 1972, 42, 1957.)

PASTINACA

P. sativa L. parsnip

I. Evidence of dormancy

Freshly harvested seeds of cultivated and, particularly, wild parsnips may show considerable dormancy (1,2,4,9,11). For example, despite 3 months after-ripening at room temperature, wild parsnip seeds did not germinate (2), and buried seeds in soil required 5 months overwintering (i.e. pre-chilling) before germination would occur (11). Successful after-ripening periods reported by others range between 1 month (10) and 2 years (9). As with other umbellifers, considerable problems in interpreting results of germination tests are caused by the presence of seeds without embryos or with only immature embryos. These may represent, for example, 8% and 44% respectively of seed-like structures within an accession (5,6).

II. Germination regimes for non-dormant seeds

BP; TP: 20°/30°C (16h/8h): 28d (ISTA)

BP; S: 20°/30°C (16h/8h): 28d (AOSA)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 10°C, 15°C, 20°C (2); 15°-30°C (8)

Alternating temperatures: 10°/20°C (night/day) (2); 25°/30°C, 30°/35°C (16.5h/7.5h) (8); 15°/6°C, 35°/20°C (12h/12h) in dark (1)

Pre-chill: 5°C, 12w, germinate at 30°/15°C, 35°/20°C (12h/12h) in light or dark (1); 1°C, 2-10d, germinate at 20°C (4)

Pre-dry: 103°C, 2h (9); 95°C, 4h (9); imbibe/dry (24h/48h), 1-8 cycles (7); imbibe/dry (8h/24h), 6 cycles (7); imbibe/dry (48h/48h), 1-4 cycles (7)

Polyethylene glycol: pre-applied, 5-20d, -10, -15 bar (7)

Potassium nitrate: pre-applied, plus tripotassium orthophosphate, pre-applied, 5-20d, -10, -15 bar (7)

IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 30°/15°C, 35°/20°C, 20°/10°C (12h/12h) in light, 2100 lux, 14h/d (1); 15°/20°C, 15°/25°C, 20°/25°C, 15°/30°C, 20°/30°C, 15°/35°C, 20°/35°C (16.5h/7.5h) (8); 15°/25°C (16h/8h) (9)

Pre-chill: 5°C, 12w, germinate at 15°/6°C, 20°/10°C (12h/12h) (1); 5°C, 14-74d (2)

Warm stratification: 20°C, 1-6d, then pre-chill, 1°C, 2d (4)

Polyethylene glycol: pre-applied, 10d, -10 bar, 20°C (4)

Pre-dry: 60°C, 4d (9)

V. Successful dormancy-breaking treatments

Constant temperatures: 15°C (9)

Alternating temperatures: 20°/30°C (16h/8h) (9); 20°/30°C (16h/8h) in light (3); 15°/20°C (16h/8h) (9)

Pre-chill: 5°C, 3m (2)

Warm stratification: 20°C, 1-6d, then pre-chill, 1°C, 6-10d (4); 20°C, 3d, then pre-chill, 1°C, 8-12d (4)

VI. Comment

Dormant parsnip seeds require long pre-chill treatments (1,2,4,11), alternating temperatures (1,3,8,9) and light (1,3) for germination. It is suggested that the AOSA/ISTA prescriptions for the germination test regime be followed (see above), but with light applied (3,9) plus, where dormancy is encountered, substantial - up to 12 weeks for wild parsnip - pre-chill treatments at 3°-5°C.

VII. References

1. Baskin, J.M. and Baskin, C.M. (1979). Studies on the autecology and population biology of the weedy monocarpic perennial Pastinaca sativa. Journal of Ecology, 67, 601-610.

2. Doust, J.L. and Doust, L.L. (1982). Life-history patterns in British Umbelliferae: a review. Botanical Journal of the Linnean Society, 85, 179-194.

3. Everson, L. (1949). Preliminary studies to establish laboratory methods for the germination of weed seed. Proceedings of the Association of Official Seed Analysts, 39, 84-89.

4. Finch-Savage, W.E. and Cox, C.J. (1982). A cold-treatment technique to improve the germination of vegetable seeds prior to fluid drilling. Scientia Horticulturae, 16, 301-311.

5. Flemion, F. and Henrickson, E.T. (1949). Further studies on the occurrence of embryoless seeds and immature embryos in the Umbelliferae. Contributions from the Boyce Thompson Institute, 15, 291-297.

6. Flemion, F. and Uhlmann, G. (1946). Further studies of embryoless seeds in the Umbelliferae. Contributions from the Boyce Thompson Institute, 14, 283-293.

7. Gray, D. and Steckel, J.R.A. (1977). Effects of pre-sowing treatments of seeds on the germination and establishment of parsnips. Journal of Horticultural Science, 52, 525-534.

8. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agriculture Research, 23, 295-332

9. Joseph, H.C. (1929). Germination and keeping quality of parsnip seeds under various conditions. Botanical Gazette, 87, 195-210.

10. Myers, A. (1935). The viability of parsnip seed. Agricultural Gazette of New South Wales, 46, 672.

11. Roberts, H.A. (1979). Periodicity of seedling emergence and seed survival in some Umbelliferae. Journal of Applied Ecology, 16, 195-201.

PETROSELINUM

P. crispum Nym. [P. sativum Hoffm.; P. hortense Hoffm.; Apium petroselinum L.; Apium crispum Mill.] parsley

I. Evidence of dormancy

Seed dormancy in both cultivated and wild parsley accessions is reported to be only slight (2). Nevertheless the germination of seeds of the cultivated parsley is slow and the total proportion of seeds which eventually germinate low (3). This is mainly due to high proportions of immature - up to 35-50% (4) - and empty - up to 36% (5) - seeds.

II. Germination regimes for non-dormant seeds

BP; TP: 20°/30°C (16h/8h): 28d (ISTA)

BP; S: 20°/30°C (16h/8h): 28d (AOSA)

Alternating temperatures: 30°/20°C (16h/8h) (5)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 20°C in light (3)

Pre-chill: 5°C, 40-96d (2)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 10°C, 15°C, 20°C (2)

Pre-wash: 24h, germinate at 15°C in dark (3)

Polyethylene glycol: pre-applied, 2,3w, -9, -12 bar, germinate at 15°C in dark (3)

V. Successful dormancy-breaking treatments

Constant temperatures: 3°-17°C (1); 0°-20°C (7); 5°-25°C (3)

Alternating temperatures: 30°/20°C (16h/8h) (5); 10°/20°C (night/day) (2)

Pre-chill: 5°C, 2w (2)

Pre-wash: 24h, then polyethylene glycol, pre-applied, 2,3w, -9, -12 bar, germinate at 15°C in light or dark (3)

VI. Comment

Full germination occurs over a wide range of constant (1,3,7) and alternating temperature regimes (5). Within the constant temperature range 15°-25°C and alternating temperatures between a minimum of 15°C and a maximum of 30°C there is reported to be no advantage to any one regime (6). However, results from comparisons of the germination of more dormant seeds in constant and alternating temperature regimes show a very great advantage from testing at alternating temperatures (2). Consequently it is suggested that the seeds be tested for germination under alternating temperature regimes; preferably 10°/20°C (2), but the regime 20°/30°C prescribed by ISTA/AOSA may be adequate.

VII. References

1. Bierhuizen, J.F. and Wagenvoort, W.A. (1974). Some aspects of seed germination in vegetables. I. The determination and application of heat sums and minimum temperature for germination. Scientia Horticulturae, 2, 213-219.

2. Doust, J.L. and Doust, L.L. (1982). Life-history patterns in British Umbelliferae: a review. Botanical Journal of the Linnean Society, 85, 179-194.

3. Ely, P.R. and Heydecker, W. (1981). Fast germination of parsley seeds. Scientia Horticulturae, 15, 127-136.

4. Flemion, F. and Henrickson, E.T. (1949). Further studies on the occurrence of embryoless seeds and immature embryos in the Umbelliferae. Contributions from the Boyce Thompson Institute, 15, 291-297.

5. Flemion, F. and Uhlmann, G. (1946). Further studies of embryoless seeds in the Umbelliferae. Contributions from the Boyce Thompson Institute, 14, 283-293.

6. Harrington, G.T. (1923). Use of alternating temperatures in the germination of seeds. Journal of Agricultural Research, 23, 295-332.

7. Thompson, P.A. and Fox, D.J.C. (1976). The germination responses of vegetable seeds in relation to their history of cultivation by man. Scientia Horticulturae, 4, 1-14.

CHAPTER 73. URTICACEAE

The Urticaceae comprise about 500 species of herbaceous plants, shrubs, and trees within about 40 genera, of which Boehmeria nivea (L.) Gaud. (ramie) is grown for fibre and Urtica spp. provide leaf vegetables or flavourings. The fruits are usually dry, small, achenes and are likely to be enclosed within the calyx. Seed storage behaviour is orthodox. For example, Boehmeria polystachya and Urtica pilulifera are maintained in the long-term seed store at the Wakehurst Place Gene Bank.

SEED DORMANCY AND GERMINATION

Detailed information on seed dormancy and germination in the Urticaceae is limited to the genus Boehmeria including synonyms within Urtica). In order to develop techniques for difficult accessions, the RBG Kew Wakehurst Place suggests, as a first step, testing seeds at a constant temperature of 16°C with light applied for 12h/d. If this regime is unsatisfactory, then experiment with further treatments. Clues to likely promotory treatments can be obtained from the information on Boehmeria.

BOEHMERIA

B. nivea Gaud. [Urtica niveaL.] ramie, rhea, China grass

I. Evidence of dormancy

Seeds of B. nivea are reported to exhibit dormancy (2).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

Light: dark (2)

IV. Partly-successful dormancy-breaking treatments

Light: white, at 25°C (2)

GA_3: co-applied, 100 ppm (2)

V. Successful dormancy-breaking treatments

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VI. Comment

Germination of seeds of B. nivea requires light (2), but treatment with gibberellins appears to substitute for the light requirement and promote germination in the dark (2). It is suggested that the seeds of Boehmeria spp. be tested for germination on top of filter papers in petri dishes (1,2) at a constant temperature of 25°C in diffuse light - see Chapter 6. Seeds should begin to germinate within about 4 days and germination may be complete after 21 days (1). It is suggested that co-application of gibberellins at a low concentration (see above) be used as

an additional stimulus to germination when required.

VII. References

1. Fierro, A.F. and Redondo, B.D.A. (1980). [Evaluation of 3 methods of propagating ramie for agro industrial use.] Acta Agronomica, 30, 99-109.

2. Nakamura, S., Watanabe, S. and Ichihara, J. (1960). Effect of gibberellin on the germination of agricultural seeds. Proceedings of the International Seed Testing Association, 25, 433-439.

CHAPTER 74. VITACEAE

The Vitaceae comprise more than 500 species of woody vines, shrubs and small trees within 12 genera, some of which provide edible fruits (e.g. Vitis spp., grape, vine). The fruits are small berries and the seeds show orthodox storage behaviour.

SEED DORMANCY AND GERMINATION

Dormancy can be a considerable problem. Detailed information on seed dormancy and germination is provided in this chapter for the genus Vitis.

VITIS

V. vinifera L. grape, wine grape
V. vulpina L. riverbank grape

I. Evidence of dormancy

Freshly extracted seeds of Vitis spp. usually show a high proportion of dormant seeds. For example, in one study only two of eight seed lots gave more than 6% germination in control germination tests (4). Dormant seeds often require considerable treatment periods before they will germinate. For example, 3 months storage at room temperature (after-ripening) failed to break dormancy (16) and in another case 5 months storage was required to increase germination from 0% to 62% (12). In addition to V. vinifera, the information summarised for Vitis includes results from investigations with seeds of other, unspecified, Vitis spp. and hybrids between these species and V. vinifera: the AOSA methods are for V. vulpina.

II. Germination regimes for non-dormant seeds

TP: 20°/30°C (16h/8h): 28d (AOSA)

Constant temperatures: 25°-30°C (1); 20°C, 25°C (6)

III. Unsuccessful dormancy-breaking treatments

Constant temperatures: 20°-35°C (1); 20°C, 35°C (4)

Alternating temperatures: 20°/30°C (16h/8h) (4)

Warm stratification: 30°C, 2d, then 20°C (1); 18°C, 150d (15)

Storage: 21°-37°C, 3m (16); 0°C, room temperature, 3-12w (17)

Pre-soak: 24h, 27°-54°C (10); 20°C, 60°C, 20 min (17)

Pre-wash: 24h (17)

GA_3: co-applied, 2, 20 ppm (1); 1000 ppm (6); pre-applied, 48h, 500, 1000, 2500 ppm (9); pre-applied, 48h, 1000 ppm, plus kinetin, 1000 ppm (9); pre-applied, 48h, 2000 ppm, plus kinetin, 2000 ppm (9); pre-applied, 48h, 1000 ppm, plus thiourea, 1% (9); pre-applied, 48h, 2000 ppm, plus thiourea, 2% (9); pre-applied, 48h, 1000-2500 ppm, then pre-chill, 5°C, 15d (9); pre-applied, 24h, 50 ppm (11); pre-applied, 24h, 50-2000 ppm (12, 13)

$GA_{4/7}$: pre-applied, 24h, 100, 250, 1000 ppm (11)

GA_{13}: pre-applied, 24h, 50, 250, 500, 1000 ppm (11)

Indoleacetic acid: pre-applied, 24h, 1-1000 ppm, germinate at 28°C (7); pre-applied, 24h, 50-500 ppm (13)

Kinetin: pre-applied, 24h, 5-200 ppm (13)

Benzyladenine: pre-applied, 8000 ppm (17)

Ethephon: pre-applied, 24h, 1-1000 ppm, germinate at 28°C (7)

Thiourea: pre-applied, 24h, 0.5-2% (12); pre-applied, 24h, 0.5-5% (13)

Succinic acid-2,2-dimethylhydrazide: pre-applied, 28h, 500 ppm (10)

Cyclocel: pre-applied, 28h, 500 ppm (10)

Indolebutyric acid: pre-applied, 28h, 100 ppm (10); pre-applied, 24h, 50-500 ppm (13)

Scarification: concentrated sulphuric acid, 15 min (14); sulphuric acid, 25%, 15 min (14); sulphuric acid, 75%, 15,60 min (14)

IV. Partly-successful dormancy-breaking treatments

Constant temperatures: 26°C (1)

Alternating temperatures: 5°/25°C, 10°/33°C, 15°/33°C, 20°/30°C (16h/8h) (1); 1°/30°C (16h/8h), 14d, then 20°C (1)

Warm stratification: 27°-36°C, 1,2d, then 20°C (1); 18°C, 30-120d (15); 18°C, 30,60d, then 5°C, 15,30d, germinate at 30°C in light, 12h/d (15)

Pre-chill: 1°C, 3-19m (1); 1°-5°C, 90-120d (2); 4°-5°C, 30-90d (3); 3°-5°C, 21d, germinate at 20°C (4); 1°-5°C, 3-15w (8); 5°C, 15d (9); 5°C, 15d, then GA_3, pre-applied, 48h, 2000 ppm (9); 4°C, 6w (10); 5°C, 40-120d (12); 5°C, 40-90d, plus GA_3, pre-applied, 24h, 50-2000 ppm (12); 1°-5°C, 30-75d (13); 1°-5°C, 30-75d, then GA_3, pre-applied, 24h, 50-2000 ppm (13); 1°-5°C, 30-75d, then kinetin, pre-applied, 24h, 5, 25 ppm (13); 5°C, 3,4m (14); 5°C, 30-150d, germinate at 30°C in light, 12h/d (15); 1°-5°C, 3m (16); 0°C, 2-12w (17)

Scarification: disc, plus GA_3, pre-applied, 24h, 1, 10, 100 ppm (10); rotating sand paper disc, hilar end, plus GA_3, pre-applied, 10, 100 ppm (17)

GA_3: co-applied, 200 ppm (1); pre-applied, 24h, 2000 ppm, germinate at 20°C (4); pre-applied, 48h, 1000-2500 ppm, then pre-chill, 5°C, 8-30d (9); pre-applied, 28h, 5000 ppm (10); pre-applied, 24h, 100-1000 ppm (11); pre-applied, 24h, 50-10000 ppm, germinate at 30°C in light, 12h/d (15); pre-applied, 24h, 50-10000 ppm, pre-chill, 5°C, 60d, then germinate at 30°C in light, 12h/d (15); pre-applied, 10, 100, 1000 ppm (17)

$GA_{4/7}$: pre-applied, 24h, 50, 500 ppm (11)

GA_{13}: pre-applied, 24h, 100 ppm (11)

Pre-wash: 4-16d (9)

Pre-soak: 24h (15)

Nitric acid: pre-applied, 15 min, 3.5-11% (1)

Storage: 1°-5°C, 120d (2); 4°-5°C, 60d (6); 18°-20°C, 5m (12); 5°C, 10-14w (12); 5°C, 10-14w, then GA_3, pre-applied, 24h, 100-2000 ppm (12); 5°C, 10-14w, then thiourea, pre-applied, 24h, 0.5-2% (12)

Hydrogen peroxide: pre-applied, 24h, 1 M, germinate at 20°C (4); pre-applied, 1 M, then GA_3, pre-applied, 24h, 2000 ppm, then pre-chill, 3°-5°C, 21d, germinate at 20°C, 25°C, 30°C, 20°/30°C, 20°/35°C (16h/8h) (4)

Kinetin: pre-applied, 24h, 1-1000 ppm, germinate at 28°C (7) Cyclic adenosine monophosphate: pre-applied, 24h, 1-100 ppm, germinate at 28°C (7)

Morphactin: pre-applied, 28h, 100 ppm (10)

Ethephon: pre-applied, 28h, 5000 ppm (10)

Ethrel: pre-applied, 24h, 5-200 ppm, germinate at 30°C in light, 12h/d (15); pre-applied, 24h, 50-200 ppm, then pre-chill, 5°C, 60d, then germinate at 30°C in light, 12h/d (15)

Thiourea: pre-applied, 24h, 0.25-5%, germinate at 30°C in light, 12h/d (15); pre-applied, 24h, 0.25-5%, then pre-chill, 5°C, 60d, germinate at 30°C in light, 12h/d (15)

Indolebutyric acid: pre-applied, 24h, 50-500 ppm, germinate at 30°C in light, 12h/d (15); pre-applied, 24h, 50-500 ppm, then pre-chill, 5°C, 60d, germinate at 30°C in light, 12h/d (15)

Indoleacetic acid: pre-applied, 24h, 50-500 ppm, germinate at 30°C in light, 12h/d (15); pre-applied, 24h, 50-500 ppm, then pre-chill, 5°C, 60d, germinate at 30°C in light, 12h/d (15)

V. Successful dormancy-breaking treatments

Pre-chill (AOSA)

Pre-chill: 5°C, 12w (5)

Warm stratification: 27°-33°C, 2d, then 20°C (1)

GA_3: pre-applied, 8000 ppm (17)

Hydrogen peroxide: pre-applied, 24h, 0.5 M, then GA_3, pre-applied, 24h, 1000 ppm, then pre-chill, 3°-5°C, 21d, germinate at 20°/30°C (16h/8h), 42d (4)

VI. Comment

The AOSA rules for V. vulpina suggest a 90-day pre-chill at 3° to 5°C. Plant breeders have used very long pre-chill treatment periods to break seed dormancy, but despite this have rarely been completely successful in promoting the germination of all dormant seeds. For example, a pre-chill treatment to seeds of 14 hybrid crosses at 5°C for 12 weeks resulted in a mean germination of only 40% in subsequent germination tests with a range of individual test results from 8% to 62% (16).

Consequently treatment with gibberellin has been used. Gibberellins are more effective in promoting the germination of dormant seeds of Vitis spp. than other growth substances (9), or various other chemicals (15), and GA_3 is more reliable than either $GA_{4/7}$ or GA_{13} (11), but - as the preceding sections illustrate - only treatments with very high GA concentrations have

been successful (17) where GA_3 is the only dormancy breaking treatment. Unfortunately high concentrations of GA_3 influence subsequent seedling growth (11,13,17) - for example, producing abnormal seedlings - and cannot, therefore, be recommended for application in gene banks. The solution to this problem has been to combine treatment with GA_3 with other treatments, the most common additional treatment being that of pre-chill. Treatment with GA_3 before the pre-chill treatment is more effective than the pre-chill before treatment with GA_3 (9, 15). Unfortunately, however, the GA_3 concentrations required to promote germination in such combined treatments can result in the death of some seeds within accessions, for example at 2000 ppm (4). Consequently it is necessary to reduce the GA_3 concentration and introduce a further dormancy-breaking treatment.

The following combination of treatments has been devised and found to be successful for promoting the germination of dormant seeds of Vitis spp. whilst at the same time is not damaging to the seeds: a 24-hour pre-treatment in 0.5 M hydrogen peroxide, a further 24 hour pre-treatment in 1000 ppm GA_3, followed by a 21 day pre-chill treatment at 3°-5°C with subsequent testing of the seeds in a diurnal alternating temperature regime of 20°/30°C (16h/8h) for 42 days (4). Staff in gene banks are recommended to use this procedure.

In passing it is worth noting that a 12 hour cycle alternating temperature regime has been suggested for germination tests of grape seeds, viz. 20°/30°C (9h/3h) (1). There would appear to be no harm in using this regime, but neither does there appear to be any advantage of it compared to a diurnal alternation of 20°/30°C (16h/8h) (1). Thus it is recommended that the diurnal alternating temperature regime be used in preference to the 12 hour cycle.

VII. References

1. Balthazard, J. (1979). Contribution a l'amelioration de la germination des graines de vigne. Ph.D. Thesis, Dijon University.

2. Chadha, K.L. and Manon, V.N. (1968). Studies on germination of grape seed. 1. Effect of different type of after-ripening treatments on seed germination. Journal of Research, Ludhiana, 5, 212-219.

3. Chohan, G.S. and Dhillon, B.S. (1976). Seed dormancy and endogenous growth substances in Anab-e-Shahi grapes. Vitis, 15, 5-10.

4. Ellis, R.H., Hong, T.D. and Roberts, E.H. (1983). A note on the development of a practical procedure for promoting the germination of dormant seed of grape (Vitis spp.). Vitis, 22, 211-219.

5. Flemion, F. (1937). After-ripening at 5°C favors germination of grape seeds. Contributions from the Boyce Thompson Institute, 9, 7-15.

6. Forlani, M. and Coppola, V. (1977). Effetti della frigoconservazione, dell'acido gibberellico e della temperatura sulla germinazione dei vinaccioli di Vitis vinifera L. Rivista di Viticoltura e di Enologia, 30, 445-451. (From Seed Abstracts, 1978, 1, 1247.)

7. Forlani, M. and Coppola, V. (1978). Influenza di alcuni fitoregolatori e del c-AMP sulla germinazione dei vinaccioli della "Raboso Piave". Rivista di Viticoltura e di Enologia, 31, 99-104. (From Seed Abstracts, 1978, 1, 2778.)

8. Harmon, F.N. and Weinberger, J.H. (1959). Effects of storage and stratification on germination of Vinifera grape seeds. Proceedings of the American Society for Horticultural

Science, 73, 147-150.

9. Kachru, R.B., Singh, R.N. and Yadav, I.S. (1972). Physiological studies on dormancy in grape seeds (Vitis vinifera var. Black Muscat). II. On the effect of exogenous applications of growth substances, low chilling temperature and subjection of the seeds to running water. Vitis, 11, 289-295.

10. Manivel, L. and Weaver, R.J. (1974). Effect of growth regulators and heat on germination of Tokay grape seeds. Vitis, 12, 286-290.

11. Pal, R.N., Singh, R., Vij, V.K. and Sharma, J.N. (1976). Effect of gibberellins GA_3, $GA_{4/7}$ and GA_{13} on seed germination and subsequent seedling growth in Early Muscat grape (Vitis vinifera). Vitis, 14, 265-268.

12. Randhawa, G.S. and Negi, S.S. (1964). Preliminary studies on seed germination and subsequent seedling growth in grapes. Indian Journal of Horticulture, 21, 186-196.

13. Randhawa, G.S. and Pal, N.C. (1968). Further studies on seed germination and subsequent seedling growth in grape (Vitis spp.) Indian Journal of Horticulture, 25, 148-158.

14. Scott, D.H. and Ink, D.P. (1950). Grape seed germination experiments. Proceedings of the American Society for Horticultural Science, 56, 134-139.

15. Selim, H.H., Ibrahim, F.A., Fayek, M.A., El-Deen, S.A.S. and Gamal, N.M. (1981). Effect of different treatments on germination of Romi red grape seeds. Vitis, 20, 115-121.

16. Singh, S.N. (1961). Germination of grape (Vitis vinifera L.) hybrid seeds by chilling. Current Science, 30, 62.

17. Yeou-Der, K., Weaver, R.J. and Pool, R.M. (1968). Effect of low temperature and growth regulators on germination of "Tokay" grapes. Proceedings of the American Society for Horticultural Science, 92, 323-330.

CHAPTER 75. ZINGIBERACEAE

The Zingiberaceae comprise about 1400 species of herbaceous plants within about 47 genera which provide spices (e.g. Curcuma domestica Val., turmeric) and medicines (e.g. Languas galanga (L.) Stuntz, greater galangal). The fruits are generally dehiscent capsules or fleshy barries. Seed storage behaviour, where known, is orthodox, but in many genera seed production is irregular and there is little experience of seed storage.

SEED DORMANCY AND GERMINATION

The seeds are generally surrounded by an aril, and possess a linear embryo and both perisperm and endosperm. Dormancy can be considerable. Much of the problem is associated with the seed covering structures and can be reduced by appropriate treatments (see Chapter 7, Volume I). Comparatively high germination test temperatures (e.g. 25°C) may be necessary. Because of the irregularity of fruiting and seed production comparatively few investigations have been undertaken on seed dormancy and germination in the Zingiberaceae. Consequently the information on seed dormancy and germination provided in this chapter is limited to the genera Amomum and Elettaria.

AMOMUM

A. subulatum Roxb. larger cardamom

I. Evidence of dormancy

A. subulatum shows orthodox seed storage behaviour and seed dormancy can be considerable with the seeds remaining dormant for 7 to 8 months in nursery sowings (1). Consequently germination is low and the pattern of germination very irregular (1).

II. Germination regimes for non-dormant seeds

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III. Unsuccessful dormancy-breaking treatments

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IV. Partly-successful dormancy-breaking treatments

Alternating temperatures: 30°/17°C (day/night) (1)

V. Successful dormancy-breaking treatments

-

VI. Comment

It is suggested that seeds of Amomum spp. be tested for germination on top of filter papers at 25°C or (preferably) 20°/30°C (16h/8h) in light for at least 3 months. Chipping the imbibed seeds in the germination test may reduce the time taken to germinate.

VII. References

1. Bhowmick, T.P. and Chattopadhyay, S.B. (1960). Germination of seeds of larger cardamom. Science and Culture, 26, 185-186.

ELETTARIA

E. cardamomum Maton cardamom

I. Evidence of dormancy

E. cardamomum shows orthodox seed storage behaviour (7), although, of course, longevity is short when air-dry seeds are stored in ambient conditions in the tropics (1,6). Germination is often poor and very irregular (4), with some seeds taking over a year to germinate (4): that is under natural conditions the seeds can remain dormant for considerable periods (1,4). The hard, stony, seed coat is reported to be responsible for the delay to germination in seeds of Elettaria spp. (1).

II. Germination regimes for non-dormant seeds

-

III. Unsuccessful dormancy-breaking treatments

Pre-soak: 12h (1)

IV. Partly-successful dormancy-breaking treatments

Scarification: mechanical, shake with coarse sand (1); concentrated nitric acid, 5 min (3); nitric acid, 25%, 10 min (7,8); acid (2); acid plus 2,4-dichlorophenoxyacetic acid (2); acid, then pre-soak (2); acid, then ethrel, pre-applied (2); concentrated nitric acid, 3,5,10 min (5); nitric acid, 25, 50%, 3 min (5); concentrated acetic acid, 3,5,10 min (5); acetic acid, 50%, 3,5,10 min (5); concentrated hydrochloric acid, 3,5,10 min (5); hydrochloric acid, 50%, 3 min (5); hydrochloric acid, 25%, 3,5,10 min (5)

V. Successful dormancy-breaking treatments

Scarification: acetic acid, 25%, 3,5,10 min (5); nitric acid, 25, 50%, 5,10 min (5); hydrochloric acid, 50%, 5,10 min (5)

VI. Comment

It is evident that the dormancy reported in seeds of Elettaria spp. results from the impermeable seed coat: any procedure which enables the seeds to imbibe moisture promotes germination (1-3,5,7,8). The information summarised above concerns nursery sowings, and information of the precise conditions for germinating seeds of Elettaria spp. is lacking. It is known, however, that relatively high temperatures are required for seed germination, around 25°C or higher (1,3,7). Light and alternating temperatures are probably also beneficial judging from the response of the seeds in the wild (1,4).

It is therefore suggested that seeds of Elettaria spp. be tested for germination on top of filter papers at 25°C or 20°/30°C (16h/8h) in light after chipping the seeds. If acid scarification is preferred then, for one seed lot at least, a 10 minute treatment in either 25% acetic acid or 25% nitric acid was very effective in promoting germination (5). The germination test period should be at least 3 months (1,7,8).

VII. References

1. Abraham, P. (1958). New knowledge for cardamom growers. Indian Farming, 8, 34-38.

2. Anonymous (1978). Cardamom. University of Agricultural Sciences, 14th Annual Report, 1977/1978, Bangalore, India, pp. 147-148.

3. Kololgi, S.D., Pattanshetti, H.V. and Prasad, A.B.N. (1973). Germination of cardamom seeds can be improved by treatment with nitric acid and sowing in plastic house. Current Research, 2, 3.

4. Purseglove, J.W. (1972). Elettaria. In Tropical Crops. Monocotyledons, pp. 528-533. Longmans, London.

5. Reddy, B.G.S., Siddaramaiah, A.L. and Parameswar, N.S. (1973). Ten minutes presowing treatment of cardamom with 50 per cent hydrochloric acid ensures good germination. Current Research, 2, 22.

6. Singh, H.B. (1974). Cardamom (Eletaria cardamomum). In Handbook of plant Introduction in Tropical crops, pp. 130-132, Plant Production and Protection Division, FAO, Rome.

7. Sulikeri, G.S. and Kololgi, S.D. (1977). Seed viability in Cardamom (Elettaria cardamomum Maton). Current Research, 6, 163-164.

8. Sulikeri, G.S. and Kololgi, S.D. (1978). Phyllanthus leaves - a suitable much for cardamom nursery beds. Current Research, 7, 3-4.

CHAPTER 76. GERMINATION TEST ENVIRONMENTS AND DORMANCY-BREAKING TREATMENTS FOR SPECIES IN OTHER FAMILIES

This chapter provides a summary of recommended germination test procedures and dormancy-breaking treatments for seeds of species within more than 70 families which have not been included in the previous chapters. Some caution may be needed when applying this information to diverse germplasm - see the comment on germination test prescriptions in Chapter 17. For several of the families listed here additional guidance on suitable dormancy-breaking treatments is available in Tables 17.1 and 17.2, Chapter 17.

The information in this chapter is not limited to those species showing orthodox seed storage behaviour: germination test procedures are also provided for species which are believed to exhibit recalcitrant seed storage characteristics. This is provided to assist both those handling recalcitrant seeds in short-term storage (moist and warm or cool environments), e.g. when collecting or transporting material, and those wishing to improve our knowledge of the physiology of these seeds with a view to increasing the periods for which they can be conserved. For more information on the recalcitrant seeds see the references listed in Chapter 1, Volume I.

TABLE 76.1 Summary of germination test recommendations for species within families not considered in the previous chapters

Species and Authority	Substrate	Temperature	Duration	Additional directions	Source
				ACANTHACEAE	
Crossandra infundibuliformis (L.) Nees	TP	20°/30°C	28d	light	AOSA
Thunbergia alata Bojer	BP; TP	20°/30°C; 20°C	21d		ISTA
	BP	20°/30°C	12d		AOSA
				ACERACEAE	
Acer palmatum Thunb.	TP; S	20°C	21d	pre-chill, 1°-5°C, 4m, remove pericarp	ISTA
Acer platanoides L.	TP; S	20°C	21d	pre-chill, 1°-5°C, 2m, remove pericarp	ISTA
Acer pseudoplatanus L.	TP; S	20°C	21d	pre-chill, 1°-5°C, 2m, remove pericarp	ISTA
Acer rubrum L.	TP; S	20°C	21d		ISTA
Acer saccharinum L.	TP; S	20°C	21d		ISTA
Acer saccharum Marsh.	TP; S	20°C	21d	pre-chill, 1°-5°C, 2m, remove pericarp	ISTA
Acer spp.	TP	18°-22°C	14d	excise embryos, or remove pericarp and pre-chill, 3°-5°C, 2m	AOSA
				warm stratification, 25°C, 4w,	G&R

				and/or pre-chill, 1°-5°C, 4-24w	
				AIZOACEAE	
Dorotheanthus bellidiformus (Burm.f.) N.E. Br.	TP; BP	15°C; 20°C	35d	pre-chill, potassium nitrate	ISTA
	TP	15°C	16d		AOSA
Mesembryanthemum criniflorum L.		15°C	28d	not sensitive to light	Atwater
Mesembryanthemum crystallinum L.		20°C	21d	pierce centre of seed	Atwater
Tetragonia tetragonioides (Pall.) Kuntze	BP; S	20°/30°C; 20°C	35d	remove pulp, pre-wash	ISTA
	S	10°/30°C	28d	keep substratum on dry side	AOSA
	BP	15°C	21d	remove pulp	AOSA
	S	10°/20°C	35d	pre-wash	Fornerod
				AMARYLLIDACEAE	
Hippeastrum hybridum Hort.	TP; BP	20°/30°C	28d		ISTA
				APOCYNACEAE	
Carissa spp.			16d	pre-soak, 24h	Riley
Catharanthus roseus (L.) Don	TP; BP	20°/30°C	23d	light, maintain good moisture supply	AOSA
		20°/30°C	14d		Atwater
Vinca minor L.	TP	20°/30°C; 20°C	14d		ISTA
				ARALIACEAE	
Brassaia actinophylla Endl.		20°C	40d		Atwater
Cussonia spicata Thunb.		20°C	50d	dormant seeds remain	Atwater
Dizygotheca elegantissima Vig. & Guill.	TP; BP	20°/30°C	28d		ISTA
		20°C	40d		Atwater
Fatsia japonica Decne. & Planch.	TP	20°/30°C; 20°C	28d		ISTA
		20°C	21d		Atwater
				ASCLEPIADACEAE	
Asclepias tuberosa L.	TP	10°/30°C	14d	light, pre-chill, 3°-5°C, 21d	AOSA
				BALSAMINACEAE	
Impatiens balsamina L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill, potassium nitrate	ISTA
	TP	20°/30°C; 20°C	8d	light, potassium nitrate	AOSA
		25°/35°C; 20°C; 25°C	10d	pre-chill, 5°C, 2w, or GA, 50mg/1, or clip	Atwater
Impatiens wallerana Hook.f.	TP; BP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA

	TP	20°C	18d	light, avoid higher temperatures	AOSA
		20°C	21d	potassium nitrate, higher temperatures unfavourable	Atwater
				BEGONIACEAE	
Begonia evansiana Andr.		29°C		light, 12h/d, 6d	Atwater
Begonia semperflorens Link & Otto	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Begonia x tuberhybrida Voss	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Begonia spp.	TP	20°/30°C	16d	light	AOSA
		20°/30°C	14d	fluorescent light, 12h/d, 430 lux	Atwater
				BERBERIDACEAE	
Berberis thunbergii DC.	TP	18°-22°C	10-14d	excise embryos	AOSA
Berberis vulgaris L.	TP	18°-22°C	10-14d	excise embryos	AOSA
Berberis spp.				pre-chill, 1°-5°C, 6-13w	G&R
Mahonia aquifolium Nutt.				pre-chill, 1°-5°C, 6-13w	G&R
				BOMBACACEAE	
Durio zibethinus Murr.	S	25°-35°C	35d	light, continuous	CHML
				BORAGINACEAE	
Amsinickia intermedia	TP	20°C			M&O
Anchusa azurea Mill.	TP; BP	20°/30°C; 20°C	21d		ISTA
	TP; BP	20°/30°C	14d		AOSA
		20°/30°C	21d	dormant seeds present	Atwater
Anchusa capensis Thunb.	TP; BP	20°/30°C; 15°C	21d		ISTA
	TP	15°C	16d	sensitive to temperatures above 15°C	AOSA
		15°C	21d	dormant seeds present	Atwater
Borago officinalis L.	TP; BP	20°/30°C; 20°C	14d		ISTA
	TP	20°C	10d	light	AOSA
	TP	20°C	10d		Heit
Brunnera macrophylla (Adams) Johnston	TP; BP	20°/30°C; 20°C	21d		ISTA
	TP	20°/30°C	21d		AOSA
		20°/30°C	40d	dormant seeds present	Atwater
Cynoglossum amabile Stapf & Drumm.	TP; BP	20°/30°C; 20°C	14d	light, pre-chill, potassium nitrate	ISTA
	TP; BP	20°/30°C	10d	light, potassium nitrate	AOSA
		15°C	21d	potassium nitrate, 0.2%	Atwater
Echium fastuosum Jacq.	TP; BP	20°/30°C; 20°C	14d		ISTA
		20°C	14d	excise embryos	Atwater
Echium lycopus L.				excise embryos	Atwater
Echium plantagineum L.	TP; BP	20°/30°C;	14d		ISTA

		20°C			
Heliotropium arborescens L.	TP	20°/30°C; 20°C	21d		ISTA
		20°/30°C	21d	light, potassium nitrate, 0.2%	Atwater
Heliotropium spp.	TP	20°/30°C; 20°C	21d	light	AOSA
Myosotis alpestris F.W. Schmidt	TP	20°C	12d	sensitive to drying out in test	AOSA
Myosotis hybrida Hort.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Myosotis scorpioides L.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°C	12d	sensitive to drying out in test	AOSA
		20°C	14d	light, potassium nitrate, 0.2%	Atwater
Myosotis sylvatica Ehrh. ex Hoffm.	TP; BP	20°/30°C; 15°C; 20°C	21d	light, pre-chill	ISTA
				BUXACEAE	
Simmondsia chinensis		26°C	7d	pre-soak, 24h	Riley
				CACTACEAE	
Cactaceae	TP	20°/30°C	18d	light, good moisture supply	AOSA
Carnegiea gigantea (Engelm.) Britt. & Rose	TP	20°/30°C	20d	light, good moisture supply	AOSA
		20°/30°C	14d	light	Atwater
Cereus peruvianus Mill.			14d	light	Riley
Echinocereus engelmanii (Perry ex Engelm.) Ruempl.		20°/30°C	14d	fluorescent light, 12h/d	Atwater
Ferocactus wislizenii (Engelm.) Britt. & Rose	TP	20°/30°C	10d	light, good moisture supply	AOSA
		20°/30°C	14d	light	Atwater
Opuntia tuna (L.) Mill.		20°C	65d	light, clip seeds	Atwater
				CAMPANULACEAE	
Campanula carpatica Jacq.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°/30°C	16d	light	AOSA
Campanula fragilis Cyr.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Campanula garganica Ten.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Campanula glomerata L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Campanula lactiflora Bieb.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Campanula medium L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°/30°C; 20°C	12d		AOSA
Campanula persicifolia L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
	TP	20°/30°C	16d	light	AOSA

Campanula portenschlagiana Schult.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Campanula pyramidalis L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Campanula rapunculus L.	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Legousia speculum-veneris (L.) Chaix	TP; BP	20°/30°C; 20°C	21d	light, pre-chill	ISTA
Platycodon grandiflorus (Jacq.) DC.	TP	20°/30°C	21d	light	AOSA
				CAPPARIDACEAE	
Cleome hasslerana Chodat	TP	20°/30°C	14d	light, potassium nitrate, sensitive to low temperatures	AOSA
		20°/30°C	28d	clip seeds	Atwater
Cleome pungens Willd.	TP	20°/30°C; 20°C	28d	potassium nitrate	ISTA
				CAPRIFOLIACEAE	
Sambucus glauca Nutt.		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 16w	G&R
Sambucus nigra L.		20°/30°C		light, 8h/d, warm stratification, 25°C, 10w, then pre-chill, 1°-5°C, 12w	G&R
Sambucus racemosa L.		20°/30°C		light, 8h/d, warm stratification, 25°C, 10w, then pre-chill, 1°-5°C, 12w	G&R
Sambucus spp.			30d	scarify, abrade with sand, or file or nick seed coat, then pre-chill, 1°-5°C, 90d	Riley
Symphoricarpos rivularis Suks.		20°/30°C		light, 8h/d, warm stratification, 25°C, 12-16w, then pre-chill, 1°-5°C, 18-26w	G&R
Viburnum lantana L.		20°/30°C		light, 8h/d, but no satisfactory method for overcoming dormancy	G&R
Viburnum lentago L.		20°/30°C		light, 8h/d, but no satisfactory method for overcoming dormancy	G&R
Viburnum opulus L.		20°/30°C		light, 8h/d, but no satisfactory method for overcoming dormancy	G&R
Viburnum trilobum Marsh.		20°/30°C		light, 8h/d, but no satisfactory method for overcoming dormancy	G&R
				CARYOPHYLLACEAE	
Agrostemma githago	TP	20°C	5d		SGCF
Agrostemma spp.		20°C	14d		Atwater
Arenaria serpyllifolia	TP	15°C		light	M&O
Cerastium tomentosum L.	TP; BP	20°/30°C; 20°C	21d	potassium nitrate	ISTA
	TP	15°C	14d	light, potassium nitrate	AOSA
		20°C	21d	light	Atwater
Cerastium vulgatum	TP	20°/30°C	7d	potassium nitrate, pre-chill	SGCF

	TP	20°/30°C		light	M&O
Dianthus x allwoodii Hort. Allwood	TP	20°C	8d		AOSA
Dianthus barbatus L.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP	20°C	8d		AOSA
Dianthus caryophyllus L.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP	20°C	8d	problem of broken seedlings	AOSA
Dianthus chinensis L.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP	20°C	7d	problem of broken seedlings	AOSA
Dianthus deltoides L.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP	20°/30°C	10d	light	AOSA
Dianthus plumarius L.	TP; BP	20°/30°C; 20°C	14d	pre-chill	ISTA
	TP	20°C	7d		AOSA
Dianthus spp.		20°C	10d		Atwater
Gypsophila elegans Bieb.	TP; BP	15°C; 20°C	14d	light	ISTA
	TP	20°C	7d	light, potassium nitrate	AOSA
	TP	15°C	8d	if sensitive to temperatures above 18°C	AOSA
		20°C	14d		Atwater
Gypsophila elegans Bieb. var carminea		15°C	14d	potassium nitrate, 0.2%	Atwater
Gypsophila pacifica Kom.	TP	15°C	8d	sensitive to temperatures above 18°C	AOSA
Gypsophila paniculata L.	TP; BP	15°C; 20°C	14d	light	ISTA
	TP	20°C	7d	light, potassium nitrate	AOSA
Gypsophila repens L.	TP; BP	15°C; 20°C	14d	light	ISTA
	TP	15°C	8d	sensitive to temperatures above 18°C	AOSA
Lychnis alba Mill.	TP	20°/30°C	7d	potassium nitrate	SGCF
	TP	23°/30°C		light, during period at 23°C	R&S
	TP	20°/30°C			M&O
Lychnis chalcedonica L.	TP	20°/30°C; 20°C	21d	light	ISTA
	TP	20°/30°C	14d	light	AOSA
Lychnis coronaria (L.) Desr.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	14d	light	AOSA
		20°/30°C	14d		Atwater
	TP	20°/30°C		light	M&O
Lychnis viscaria L.	TP	20°/30°C	14d	light	AOSA
Saponaria calabrica Guss.	TP; BP	10°C; 15°C	21d	light, pre-chill	ISTA
Saponaria ocymoides L.	TP; BP	10°C; 15°C	21d	light, pre-chill	ISTA

	TP	15°C	16d	sensitive to warm temperatures	AOSA
		15°C	21d	potassium nitrate, 0.2%	Atwater
Saponaria officinalis L.	TP; BP	10°C; 15°C	21d	light, pre-chill	ISTA
	TP	20°/30°C	14d	pre-chill, 1w, plus potassium nitrate	SGCF
Saponaria vaccaria L.	TP	15°C; 20°C			M&O
Saponaria vaccaria pyramidata Medic.	TP	15°C	16d	sensitive to warm temperatures	AOSA
Silene conoidea	TP	20°/30°C			M&O
Silene cseri	TP	20°/30°C; 15°C; 20°C			M&O
Silene noctiflora	TP; S	20°/30°C	14d	light	Everson
	TP	20°/30°C	7d		SGCF
Silene pendula L.	TP; BP	20°/30°C; 20°C	28d	potassium nitrate	ISTA
Silene spp.		20°C	10d	light	Atwater
Spergula arvensis L.	TP	20°C	10d		ISTA
Stellaria media	TP	20°/30°C	7d	potassium nitrate	SGCF
Vaccaria hispanica (Mill.) Rauschert	TP; BP	10°C; 15°C	21d	light, pre-chill	ISTA
				CASUARINACEAE	
Casuarina spp.	TP; BP	20°/30°C	14d	light	AOSA
				CELASTRACEAE	
Celastrus spp.	TP	18°-22°C	10-14d	excise embryos	AOSA
Euonymus europaea L.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 45d	ISTA
				warm stratification, 25°C, 8-12w, then pre-chill, 1°-5°C, 8-16w	G&R
				CISTACEAE	
Cistus incanus L.		20°C	21d	pre-soak, warm water, 24h	Atwater
Helianthemum nummularium (L.) Mill.	TP; BP	20°/30°C; 20°C	28d	potassium nitrate	ISTA
Helianthemum spp.		15°C	28d	dormant seeds present	Atwater
				CORNACEAE	
Cornus alba L.		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 12-14w	G&R
Cornus amomum Mill.			21d	pre-chill/warm stratification, cycle, 120d	Riley
Cornus controversa Hemsl.		20°/30°C		light, 8h/d, warm stratification, 25°C, 8-12w, then pre-chill, 1°-5°C, 8-12w	G&R
Cornus drummondii Mey.		20°/30°C		light, 8h/d, warm stratification, 25°C, 4-8w, then pre-chill, 1°-5°C, 4-8w	G&R
Cornus florida L.	TP; BP	20°/30°C	28d	pre-chill, 3°-5°C, 90-120d	AOSA
	TP	18°-22°C	10d	excise embryos	AOSA
		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 12-14w	G&R
Cornus kousa Hance		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 12-14w	G&R

Cornus mas L.		20°/30°C		light, 8h/d, warm stratification, 25°C, 16w, then pre-chill, 1°-5°C, 4-16w	G&R
			21d	pre-chill/warm stratification, cycle, 120d	Riley
Cornus nuttallii Audubon		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 12-14w	G&R
Cornus sanguinea L.		20°/30°C		light, 8h/d, warm stratification, 25°C, 8w, then pre-chill, 1°-5°C, 8-12w	G&R
Cornus stolonifera Michx.	TP	18°-22°C	10d	pre-chill, 3°-5°C, 90d, excise embryos	AOSA
				CORYLACEAE	
Alnus cordata (Lois.) Duby	TP	20°/30°C	21d		ISTA
Alnus glutinosa (L.) Gaertn.	TP	20°/30°C	21d		ISTA
Alnus incana (L.) Moench	TP	20°/30°C	21d		ISTA
Alnus rubra Bong.	TP	20°/30°C	21d		ISTA
Alnus spp.				pre-chill, 1°-5°C, 4w	G&R
Betula papyrigera Marsh.	TP	20°/30°C	21d		ISTA
Betula pendula Roth	TP	20°/30°C	21d		ISTA
Betula pubescens Ehrh.	TP	20°/30°C	21d		ISTA
Betula spp.	TP	20°/30°C	21d	light	AOSA
		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 4w	G&R
Carpinus betulus L.	S	20°C	42d	warm stratification, 20°C, 1m, then pre-chill, 3°-5°C, 4m	ISTA
		15°/25°C		light, 8h/d, warm stratification, 25°C, 4w, then pre-chill, 1°-5°C, 12-14w	G&R
Carpinus caroliniana Walt.				warm stratification, 25°C, 8w, then pre-chill, 1°-5°C, 8w	G&R
Corylus americana Marsh.			30d	pre-chill/warm stratification, cycle	Riley
Corylus avellana L.	S	20°/30°C; 20°C	35d	remove pericarp, pre-chill, 3°-5°C, 2m	ISTA
				pre-soak, cold water, 2d, then pre-chill, 1°-5°C, 12-16w	G&R
			30d	pre-chill/warm stratification, cycle	Riley
Ostrya carpinifolia Scop.		20°/30°C		light, 8h/d, warm stratification, 25°C, 8w, then pre-chill, 1°-5°C, 16-20w	G&R
Ostrya virginiana (Mill.) Koch		20°/30°C		light, 8h/d, warm stratification, 25°C, 8w, then pre-chill, 1°-5°C, 16-20w	G&R
				CRASSULACEAE	
Kalanchoe blossfeldiana von Poellnitz	TP	20°/30°C; 20°C	21d		ISTA
	TP	20°C	16d	light, continuous	AOSA

Kalanchoe crenata Haw.	TP	20°/30°C; 20°C	21d		ISTA
Kalanchoe globulifera Perrier	TP	20°/30°C; 20°C	21d		ISTA
Sedum acre L.	TP	15°C	14d	light, 8h/d or more	AOSA
Sedum spp.		20°C	10d	light	Atwater
Sempervivum spp.	TP	20°C	14d	light, 8h/d or more	AOSA
				CUPRESSACEAE	
Calocedrus decurrens (Torr.) Florin	TP	20°/30°C	28d	pre-chill, 3°-5°C, 28d	ISTA
Chamaecyparis lawsoniana (A. Murr.) Parl.	TP	20°/30°C; 20°C	28d		ISTA
Chamaecyparis nootkatensis (D. Don) Spach	TP	20°/30°C; 20°C	28d	pre-chill, 3°-5°C, 21d	ISTA
Chamaecyparis obtusa Sieb. & Zucc.	TP	20°/30°C	21d		ISTA
Chamaecyparis pisifera Sieb. & Zucc.	TP	20°/30°C	21d		ISTA
Chamaecyparis thyoides BSP	TP	20°C	28d	pre-chill, 3°-5°C, 90d	ISTA
Chamaecyparis spp.	TP	20°C	28d	potassium nitrate	AOSA
Cupressus arizonica Greene	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light, pre-chill, 20d	AOSA
Cupressus macrocarpa Hartw.	TP	20°/30°C	35d		ISTA
Cupressus sempervirens L.	TP	20°C	28d		ISTA
Juniperus communis L.	TP; S	20°C	28d	pre-chill, 3°-5°C, 90d	ISTA
			60d	pre-chill, 1°-5°C, 30-60d	Riley
Juniperus occidentalis			60d	pre-chill, 1°-5°C, 30-60d	Riley
Juniperus scopulorum Sarg.	TP; S	15°C	42d	warm stratification, 20°C, 60d, then, pre-chill, 3°-5°C, 40d	ISTA
Juniperus virginiana L.	TP; S	15°C	28d	warm stratification, 20°C, 60d, then, pre-chill, 3°-5°C, 45d	ISTA
Libocedrus decurrens Torr.	TP; BP	20°/30°C	28d	pre-chill, 3°-5°C, 30d	AOSA
Thuja occidentalis L.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Thuja orientalis L.	TP	20°C	21d		ISTA/AOSA
Thuja plicata Donn ex D. Don	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light, potassium nitrate	AOSA
				CYTINACEAE	
Brugmansia arborea (L.) Lagerheim	BP	20°/30°C	21d		AOSA
				DIPSACEAE	
Cephalaria alpina (L.) Roem. & Schult.		20°C	40d		Atwater

Dipsacus fullonum L.		20°C	14d		Atwater
Scabiosa atropurpurea L.	TP; BP	20°/30°C; 20°C	21d	pre-chill	ISTA
	BP	20°C	12d		AOSA
		20°C	14d		Atwater
Scabiosa caucasica Bieb.	TP; BP	20°/30°C; 15°C; 20°C	21d	pre-chill	ISTA
	BP	15°C	18d		AOSA
		15°C	21d	excise embryos	Atwater
				DIPTEROCARPACEAE	
Dryobalanops aromatica Gaertn.	S	25°-30°C	10d	light, continuous	CHML
Shorea acuminata	S	25°-30°C	15d	light, continuous	CHML
Shorea leprosula Miq.	S	25°-30°C	14d	light, continuous	CHML
				ELAEAGNACEAE	
Elaeagnus angustifolia L.		20°/30°C		light, 8h/d, scarify, concentrated sulphuric acid, 30-60 min, warm stratification, 25°C,	G&R
				0-4w, then pre-chill, 1°-5°C, 8-12w	
Elaeagnus multiflora Thunb.			21d	pre-soak, 24h, pre-chill, 1°-5°C, 30-60d	Riley
Elaeagnus philippensis			21d	pre-soak, 24h	Riley
Elaeagnus pungens Thunb.			21d	pre-soak, 24h, pre-chill, 1°-5°C, 30-60d	Riley
Elaeagnus umbellata Thunb.				pre-chill, 1°-5°C, 8-12w	G&R
Hippophae rhamnoides				pre-chill, 1°-5°C, 12w	G&R
Shepherdia argentea Nutt.			60d	scarify, abrade with sand, or file or nick seed coat, pre-chill, 1°-5°C, 30-60d	Riley
				FLACOURTIACEAE	
Dovyalis spp.			21d	pre-soak, 24h	Riley
Flacourtia indica Merr.			21d	pre-soak, 24h	Riley
				FUMARIACEAE	
Dicentra chrysantha (Hook. & Arn.) Walp.		15°C	70d	GA, 400ppm	Atwater
				GENTIANACEAE	
Gentiana acaulis L.	TP	20°/30°C; 20°C	28d	pre-chill	ISTA
Gentiana andrewsii Griseb.		20°C	60d	pre-chill, 5°C, 2m	Atwater
Gentiana spp.		15°C	60d	pre-chill, 5°C, 2m, GA, 400ppm	Atwater
				GERANIACEAE	
Erodium cicutarium (L.) Ait.	BP	20°/30°C	14d	clip seeds	AOSA
Geranium hybridum Hort.	TP; BP	20°/30°C	28d	pierce, chip or file cotyledon end of testa	ISTA
Geranium spp.	BP	20°/30°C	28d	continue test for a further 5d if	AOSA

				(reversible) hard seeds have begun to imbibe	
Pelargonium zonale Hort.	TP; BP	20°/30°C; 20°C	28d	pierce, chip or file off fragment of testa	ISTA
Pelargonium spp.		27°C	21d	clip hard seeds	Atwater
				GESNERIACEAE	
Episcia spp.	TP	20°C	21d	light, continuous	AOSA
Saintpaulia ioliantha Wendl.	TP	20°/30°C; 20°C	28d		ISTA
Saintpaulia spp.	TP	20°C	28d	light, continuous	AOSA
Sinningia speciosa (Lodd.) Hiern	TP	20°/30°C; 20°C	28d	pre-chill	ISTA
	TP	20°/30°C; 20°C	21d	light	AOSA
				GUTTIFERAE	
Garcinia mangostana L.	S	25°-30°C	28d	light, continuous	CHML
Garcinia spp.			21d	pre-soak, 24h, then warm stratification	Riley
Mammea americana L.			21d	pre-soak, 24h, then warm stratification	Riley
				HAMAMELIDACEAE	
Hamamelis mollis Oliv.		20°/30°C		light, 8h/d, warm stratification, 25°C, 8w, then pre-chill, 1°-5°C, 16-24w	G&R
Hamamelis virginiana L.		20°/30°C		light, 8h/d, warm stratification, 25°C, 8w, then pre-chill, 1°-5°C, 16-24w	G&R
Liquidambar styraciflua L.	TP	20°/30°C	21d	sensitive to drying out in test	ISTA
	TP	20°/30°C	28d	light, sensitive to drying out in test	AOSA
				pre-chill, 1°-5°C, 4-12w	G&R
				HIPPOCASTANACEAE	
Aesculus hippocastranum L.	TS; S	20°/30°C; 20°C	21d	pre-soak, 48h, cut off 1/3 at scar end of seed, but do not remove testa from the sown	ISTA
				portion, pre-chill	
				pre-soak, warm water	G&R
Aesculus indica (Lamb.) Hook.		20°/30°C; 20°C		pre-soak, warm water	G&R
Aesculus pavia L.	TP	20°/30°C	28d		AOSA
				HYDROPHYLLACEAE	
Nemophila aurita Lindl.	TP; BP	10°C; 15°C	21d	pre-chill	ISTA
Nemophila maculata Lindl.	TP; BP	10°C; 15°C	21d	pre-chill	ISTA
	TP	10°C	16d	sensitive to temperature	AOSA
Nemophila menziesii Hook. & Arn.	TP; BP	10°C; 15°C	21d	pre-chill	ISTA
	TP	15°C	10d	sensitive to tem perature above 18°C	AOSA
		15°C	14d		Atwater

		15°C	14d	dark, 72h, or remove seed coat over radicle	Atwater
Phacelia campanularia Gray	TP; BP	10°C; 15°C	21d	potassium nitrate, pre-chill	ISTA
	TP	15°C	12d	light, potassium nitrate, sensitive to temperatures above 18°C	AOSA
Phacelia minor (Harvey) F. Zimmerman	TP	15°C	12d	light, potassium nitrate, sensitive to temperatures above 18°C	AOSA
Phacelia tanacetifolia Benth.	TP; BP	20°/30°C; 15°C; 20°C	14d	pre-chill, no light	ISTA
	TP	15°C	12d	light, potassium nitrate, sensitive to temperatures above 18°C	AOSA
		15°C	14d		Atwater
		15°C	14d	dark, 72h, or remove seed coat over radicle	Atwater
				HYPERICACEAE	
Hypericum calycinum L.		15°C	30d	GA, 400ppm	Atwater
			60d	potassium nitrate, 0.2%	Atwater
Hypericum formosum Kunth.	soil		22d		Atwater
Hypericum perforatum L.	TP	20°/30°C; 20°C	21d		ISTA
				IRIDACEAE	
Freesia refracta (Jacq.) Klatt	TP; BP	15°C; 20°C	35d	pierce, chip or file off fragment of testa, pre-chill	ISTA
Gladiolus spp.	TP; BP	20°C	16d	dewing, ensure good moisture supply	AOSA
Iris kaempferi Lem.	TP	20°/30°C	18d	pre-chill, 3°-5°C, 20-25d	AOSA
				LARDIZABALACEAE	
Akebia quinata Decne.			21d	pre-chill, 1°-5°C, 30-60d	Riley
Akebia trifoliata Koidz.			21d	pre-chill, 1°-5°C, 30-60d	Riley
				LAURACEAE	
Persea americana Mill.	S	25°-30°C	33d	light, continuous	CHML
			21d	warm stratification	Riley
				LOBELIACEAE	
Lobelia cardinalis L.	TP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
		15°C	40d	light, potassium nitrate, 0.2%	Atwater
Lobelia erinus L.	TP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C	10d	light	AOSA
		20°/30°C	10d	light	Atwater
Lobelia fulgens Willd.	TP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
				MAGNOLIACEAE	
Liriodendron tulipifera L.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 60d	ISTA
	TP; BP	20°/30°C	28d	pre-chill, 3°-5°C, 60d, excise embryos	AOSA
				pre-chill, 1°-5°C, 7-20w	G&R

Magnolia grandiflora L.	TP; BP	20°/30°C	42d	pre-chill, 3°-5°C, 45d	AOSA
				MALPIGHIACEAE	
Malpighia glabra L.			21d	pre-soak, 24h	Riley
				MARTYNIACEAE	
Proboscidea louisianica (Mill.) Thell.	TP	20°C	10d	light, excise embryos	AOSA
				MELIACEAE	
Cedrela spp.	TP	20°/30°C	28d		ISTA
Sandorium koetjape			21d	pre-soak, 24h	Riley
				MYRISTICACEAE	
Myristica fragrans Houtt.	S	25°-30°C	18d	light, continuous	CHML
				NYCTAGINACEAE	
Abronia umbellata Lam.		20°C	25d	remove calyx and outer seed coat	Atwater
Mirabilis jalapa L.	TP; BP; S	20°/30°C; 20°C	14d	light, pre-chill	ISTA
	BP	20°/30°C	12d		AOSA
		20°/30°C	14d		Atwater
				NYSSACEAE	
Davidia involucrata Baill.				warm stratification, 25°C, 12-20w, then pre-chill, 1°-5°C, 12-16w	G&R
Nyssa aquatica L.	TP	20°/30°C	21d	pre-chill, 3°-5°C, 30d	AOSA
				pre-chill, 1°-5°C, 4-16w	G&R
Nyssa sylvatica Marsh.	TP; BP	20°/30°C	28d	pre-chill, 21d	AOSA
				pre-chill, 1°-5°C, 4-16w	G&R
				ONAGRACEAE	
Clarkia amoena (Lehm.) Nelson & J.F. Macb.	TP; BP	20°/30°C; 15°C	14d	Light, pre-chill	ISTA
	TP	15°C	8d	light	AOSA
		15°C	14d		Atwater
Clarkia pulchella Pursh.	TP	20°/30°C; 15°C	14d	light, pre-chill	ISTA
Clarkia unguiculata Lindl.	TP	20°/30°C; 15°C	14d	light, pre-chill	ISTA
	TP	15°C	7d		AOSA
		15°C	14d		Atwater
Fuchsia spp.	TP	15°C	28d	light, 8h/d or more	AOSA
Gaura spp.		20°C	28d	dormant seeds present	Atwater
Godetia whitneyi Hort.	TP; BP	20°/30°C; 15°C	14d	light, pre-chill	ISTA
Oenothera erythrosepala Borb.		20°/30°C	14d		Atwater
Oenothera hookeri Torr. & Gray		20°C	21d		Atwater
Oenothera missouriensis Sims	TP; BP	20°/30°C; 20°C	21d	potassium nitrate	ISTA
				PINACEAE	

Abies alba Mill.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
Abies amabilis Dougl.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	15°/25°C	28d	light, pre-chill, 0°-5°C, 14d, or 3°-5°C, 21d	AOSA
Abies balsamea (L.) Mill.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 28d	AOSA
Abies cephalonica Loud.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
Abies cilicica (Ant. & Kotschy) Carr.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
Abies concolor (Gord.) Engelm.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light, pre-chill, 3°-5°C, 21d	AOSA
Abies firma Sieb. & Zucc.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
Abies fraseri (Pursch) Poir.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 28d	AOSA
Abies grandis (Dougl. ex D. Don) Lindl.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light, pre-chill, 3°-5°C, 14d, or dark, pre-chill, 3°-5°C, 21d	AOSA
Abies homolepis Sieb. & Zucc.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 21d	AOSA
Abies lasiocarpa (Hook.) Nutt.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light	AOSA
Abies magnifica A. Murr.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	pre-chill, 3°-5°C, 28d	AOSA
Abies nordmanniana (Steven) Spach	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
Abies numidica Delannoy ex Carr.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
Abies pinsapo Boiss.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
Abies procera Rehd.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light, pre-chill, 3°-5°C, 14d, or dark, pre-chill, 3°-5°C, 21d	AOSA
Abies sachalinensis (F. Schmidt) Mast.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 21d	ISTA
Abies veitchii Lindl.	TP	20°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light	AOSA
Cedrus atlantica (Endl.) Manetti ex Carr.	TP	20°/30°C; 20°C	21d	pre-chill, 3°-5°C, 21d	ISTA
Cedrus deodora (D. Don) Don	TP	20°/30°C; 20°C	21d	pre-chill, 3°-5°C, 21d	ISTA
Cedrus libani A. Rich.	TP	20°/30°C; 20°C	21d	pre-chill, 3°-5°C, 21d	ISTA
Cedrus spp.	TP	20°C	21d	pre-chill, 3°-5°C, 14d	AOSA

Larix decidua Mill.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Larix eurolepis Henry	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Larix gmelinii (Rupr.) Kuzen-Proch.	TP	20°/30°C	21d		ISTA
Larix kaempferi (Lamb.) Carr.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	16d	light, pre-chill, 3°-5°C, 21d	AOSA
Larix laricina (Du Roi) Koch	TP	20°/30°C	21d		ISTA
Larix occidentalis Nutt.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, pre-chill, or potassium nitrate	AOSA
Larix sibirica (Muenchh.) Ledeb.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Larix sukaczewii Dylis	TP	20°/30°C	21d		ISTA
Picea abies (L.) Karst.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	16d	or test at 20°C or 25°C	AOSA
Picea engelmannii Parry ex Engelm.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	16d	light, potassium nitrate, sensitive to excessive moisture	AOSA
Picea glauca (Moench) Voss	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 14-21d	AOSA
Picea glehnii (F. Schmidt) Mast.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	14d	pre-chill, 3°-5°C, 21d	AOSA
Picea jezoensis (Sieb. & Zucc.) Carr.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	14d	pre-chill, 3°-5°C, 21d	AOSA
Picea koyamai Shiras.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Picea mariana (Mill.) BSP	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	16d	light	AOSA
Picea omorika (Panc.) Purkyne	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	16d	light	AOSA
Picea orientalis (L.) Link	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Picea polita (Sieb. & Zucc.) Carr.	TP	20°/30°C	21d		ISTA
	TP	20°C	21d		AOSA
Picea pungens Engelm.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	16d	or test at 20°C or 25°C	AOSA
Picea rubens Sarg.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	28d	light	AOSA

Picea sitchensis (Bong.) Carr.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, more than 8h/d, potassium nitrate	AOSA
Pinus albicaulis Engelm.	TP	20°/30°C	28d	pre-chill, 3°-5°C, 28d	ISTA
	TP	18°-22°C	10-14d	excise embryos	AOSA
	TP	20°/30°C	28d	light, pre-chill, 3°-5°C, 28d	AOSA
Pinus aristata Engelm.	TP	20°/30°C	14d		ISTA/AOSA
Pinus banksiana Lamb.	TP	20°/30°C	14d		ISTA
	TP	20°/30°C	14d	light	AOSA
Pinus canariensis C. Smith	TP	20°C	28d		ISTA
	TP	20°C	21d	pre-soak, 1d, light, sensitive to warm temperatures	AOSA
Pinus caribaea Morelet	TP	20°/30°C	21d		ISTA
	TP; BP	20°/30°C	21d		AOSA
Pinus cembra L.	S	20°/30°C	28d	pre-chill, 3°-5°C, 6-9m, or excise embryos	ISTA
	TP	18°-22°C	10-14d	excise embryos	AOSA
	TP; S	20°/30°C	28d	pre-chill, 3°-5°C, 6-9m	AOSA
Pinus cembroides Zucc.	S	20°C	28d	pre-chill, 3°-5°C, 21d	ISTA
	TP; BP	20°C	28d	excise embryos	AOSA
Pinus clausa (Chapm.) Vasey	TP; TS	20°C	21d	sensitive to excess moisture	ISTA
	TP	22°C	21d	sensitive to excess moisture	AOSA
Pinus contorta Dougl. ex Loud.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	28d	light, more than 8h/d, pre-chill, 3°-5°C, 28d	AOSA
Pinus contorta var latifolia Wats.	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 28d	AOSA
Pinus coulteri D. Don	S	20°/30°C	28d	pre-chill, 3°-5°C, 60-90d, or excise embryos	ISTA
	TP	18°-22°C	10-14d	excise embryos	AOSA
	TP; S	15°/25°C	28d	pre-chill, 3°-5°C, 8-12w	AOSA
Pinus densiflora Sieb. & Zucc.	TP	20°/30°C	21d	pre-chill, 14d	ISTA
	TP	20°/30°C	21d	light	AOSA
Pinus echinata Mill.	TP	20°/30°C	28d		ISTA
	TP	20°/30°C	28d	light, 8h/d, sensitive to drying out	AOSA
	TP	22°C	28d	light, 16h, two tests: with and without pre-chill, 3°-5°C, 28d	AOSA
Pinus edulis Engelm.	TP	20°/30°C	28d	light, 16h	ISTA
Pinus elliottii Engelm.	TP	20°/30°C; 22°C	28d		ISTA
	TP	20°/30°C	28d	light, 8h/d, sensitive to drying out	AOSA
	TP	22°C	28d	light, two tests: with and without pre-chill, 3°-5°C, 28d	AOSA
Pinus flexilis James.	TP	20°/30°C	21d	pre-chill, 3°-5°C, 21d	ISTA

	TP; BP	20°/30°C	21d	pre-chill, 3°-5°C, 21d	AOSA
Pinus glabra Walters	TP	20°/30°C	21d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	16d	light, pre-chill, 3°-5°C, 21d	AOSA
Pinus halepensis Mill.	TP	20°C	28d		ISTA
	TP	20°C	28d	sensitive to warm temperatures	AOSA
Pinus heldreichii Christ	TP	20°/30°C	28d	pre-chill, 3°-5°C, 42d, or excise embryos	ISTA
Pinus heldreichii Christ var leucodermis	TP	20°/30°C	28d	light, pre-chill, 3°-5°C, 40d	AOSA
Pinus jeffreyi Grev. & Balf.	TP; S	20°/30°C	28d	pre-chill, 3°-5°C, 28d, or excise embryos	ISTA
	TP; S	20°/30°C	21d	light, excise embryos, or pre-chill, 3°-5°C, 4, 8w	AOSA
Pinus kesiya Royle & Gord.	TP	20°/30°C	21d		ISTA
Pinus khasya Englem.	TP	20°/30°C	21d	light	AOSA
Pinus koraiensis Sieb. & Zucc.	S	20°/30°C	28d	warm stratification, 25°C, 2m, then pre-chill, 3°-5°C, 3m, or excise embryos	ISTA
Pinus lambertiana Dougl.	TP; S	20°/30°C	28d	pre-chill, 3°-5°C, 60-90d, or excise embryos	ISTA
	TP	18°-22°C	10-14d	excise embryos	AOSA
	TP; S	20°/30°C	28d	pre-chill, 3°-5°C, 8, 12w	AOSA
Pinus luchuensis Mayr	TP	20°/30°C	21d	light	AOSA
Pinus merkusii Junghuhn & DeVriese	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Pinus monticola Dougl. ex D. Don	TP	20°/30°C	28d	pre-chill, 3°-5°C, 60-90d, or excise embryos	ISTA
	TP	18°-22°C	10-14d	excise embryos	AOSA
	TP; S	20°/30°C	28d	pre-chill, 3°-5°C, 8-12w	AOSA
Pinus mugo Turra	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	14d	light	AOSA
Pinus muricata D. Don	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Pinus nigra Arnold	TP	20°/30°C	21d		ISTA
also var poiretiana	TP	20°/30°C	14d	light	AOSA
Pinus oocarpa Schiede	TP	20°/30°C	21d		ISTA
Pinus palustris Mill.	TP; S	20°C	21d		ISTA
	TP	20°C	21d	light, 8h/d	AOSA
Pinus parviflora Sieb. & Zucc.	S	20°/30°C	28d	pre-chill, 3°-5°C, 6-9m, or excise embryos	ISTA
	TP	18°-22°C	10-14d	excise embryos	AOSA
Pinus patula Schiede & Deppe	TP	20°/30°C; 20°C	21d		ISTA
	TP	20°C	18d	light, sensitive to temperature	AOSA
Pinus peuce Griseb.	S	20°/30°C	28d	pre-chill, 3°-5°C, 6m, or excise embryos	ISTA

Pinus pinaster Ait.	TP	20°C	35d	light, 16h/d, but no more, two tests: with and without pre-chill, 3°-5°C, 28d	ISTA
	TP	20°C	28d	light, sensitive to temperature and possibly moisture, pre-chill	AOSA
Pinus pinea L.	TP	20°C	28d	pre-soak, 1d	ISTA
	TP	20°C	21d	light, pre-soak, 1d, sensitive to warm temperatures	AOSA
Pinus ponderosa Dougl.	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	21d	light, pre-chill, 3°-5°C, 28d	AOSA
Pinus pumila (Pall.) Regel	S	20°/30°C	21d	pre-chill, 3°-5°C, 4m	ISTA
Pinus radiata D. Don	TP	20°C	28d		ISTA
	TP	20°C	25d	light, more than 8h/d, prefers good moisture supply, pre-chill, 3°-5°C, 21d	AOSA
Pinus resinosa Sol.	TP	20°/30°C; 25°C	14d		ISTA
	TP	20°/30°C; 25°C	14d	light not essential for maximum germination	AOSA
Pinus rigida Mill.	TP	20°/30°C	14d		ISTA
	TP	20°/30°C	14d	light	AOSA
Pinus serotina Michx.	TP	22°C	21d		AOSA
Pinus strobus L	TP	20°/30°C; 22°C	28d	pre-chill, 3°-5°C, 28d	ISTA
	TP	20°/30°C	21d	light, more than 8h/d, sensitive to drying out, pre-chill, 3°-5°C, 28-42d	AOSA
	TP	22°C	28d	light, 16h/d, pre-chill, 3°-5°C, 28-42d	AOSA
Pinus sylvestris L.	TP	20°/30°C; 20°C	21d	pre-chill, 3°-5°C, 21d	ISTA
	TP	20°/30°C	14d	light, pre-chill, 3°-5°C, 21d	AOSA
Pinus tabulaeformis Carr.	TP	20°/30°C	14d		ISTA
Pinus taeda L.	TP	20°/30°C; 22°C	28d		ISTA
	TP	20°/30°C	28d	light, more than 8h/d, sensitive to drying out	AOSA
	TP	22°C	28d	light, 16h/d, two tests: with and without pre-chill, 3°-5°C, 28d	AOSA
Pinus taiwanensis Hayata	TP	20°/30°C	21d		ISTA
Pinus thunbergii Parl.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light, more than 8h/d	AOSA
Pinus virginiana Mill.	TP	20°/30°C	21d		ISTA
	TP	22°C	21d	light, 16h/d	AOSA
	TP	20°/30°C	21d	light, 8h/d	AOSA
Pinus wallichiana A.B. Jackson	TP	20°/30°C	28d		ISTA
	TP	20°/30°C	28d	light, more than 8h/d	AOSA

Pseudotsuga menziesis (Mirbel) Franco	TP	20°/30°C	21d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
(vars caesia, glauca, and menziesii)	TP	20°/30°C	21d	light, pre-chill (except glauca), 3°-5°C, 21d	AOSA
Tsuga canadensis (L.) Carr.	TP	15°C	28d	pre-chill, 3°-5°C, 28d	ISTA
	TP	15°C	28d	light, pre-chill, 3°-5°C, 28d	AOSA
Tsuga heterophylla (Raf.) Sarg.	TP	20°C	35d	two tests: with and without pre-chill, 3°-5°C, 21d	ISTA
	TP	20°C	28d	light	AOSA
				PITTOSPORACEAE	
Billardiera spp.			21d	pre-chill, 1°-5°C, 30-60d	Riley
				PLANTAGINACEAE	
Plantago lanceolata L.	TP; BP	20°/30°C; 20°C	21d		ISTA
Plantago major L.	TP	20°/30°C		light, pre-chill, 1-4w	M&O
Plantago purshii	TP	20°/30°C; 15°C		light	M&O
				PLATANACEAE	
Platanus occidentalis L.	TP	20°/30°C	14d		AOSA
Platanus spp.	TP	20°/30°C	21d		ISTA
				PLUMBAGINACEAE	
Armeria maritima (Mill.) Willd.	TP; BP	20°/30°C; 15°C	21d	potassium nitrate	ISTA
		15°C	21d		Atwater
Armeria spp.	BP	15°C	14d		AOSA
Goniolimon tataricum (L.) Boiss.	TP; BP	10°C; 15°C	21d	pre-soak, 24h	ISTA
Limonium bonduellii (Lestib.f.) Kuntze	TP; BP; S	15°C; 20°C	21d	pre-soak, 24h	ISTA
Limonium latifolium (Smith) Kuntze	TP; BP	10°C; 15°C	21d	pre-soak, 24h	ISTA
Limonium reticulatum L.	TP; BP	10°C; 15°C	21d	pre-soak, 24h	ISTA
Limonium sinuatum (L.) Mill.	TP; BP; S	10°C; 15°C	21d	pre-soak, 24h	ISTA
	BP	15°C	18d	germinate flower heads as a unit	AOSA
Plumbago auriculata Lam.	TP	20°/30°C; 20°C	18d		AOSA
Psylliostachys suworowii (Regel) Roshk.	TP; BP	10°C; 15°C	21d	pre-soak, 24h	ISTA
	BP	15°C	18d	germinate flower heads as a unit	AOSA
				POLEMONIACEAE	
Cobaea scandens Cav.	TP; BP	20°/30°C; 20°C	21d		ISTA
	BP	20°/30°C	18d	sensitive to low temperatures	AOSA
		20°/30°C	21d		Atwater
Gilia tricolor Benth.	TP; BP	20°/30°C; 15°C	14d		ISTA

		15°C	10d	dormant seeds may be present	Atwater
Gilia spp.	TP	15°C	8d	sensitive to warm temperatures	AOSA
Ipomopsis rubra (L.) Wherry		20°C	21d		Atwater
Phlox drummondii Hook.	TP; BP	20°/30°C; 15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
	TP	15°C	16d	potassium nitrate	AOSA
		20°C	21d	test at 15°C, treatment with fungicide may be necessary for some seed lots	Atwater
Phlox maculata L.		15°C	28d	variable germination, treat with fungicide	Atwater
Phlox paniculata L.	TP; BP	15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
Phlox perennis L.	TP; BP	15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
Phlox subulata L.	TP; BP	15°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
Polemonium coeruleum L.		15°C	21d	potassium nitrate, 0.2%	Atwater
				PRIMULACEAE	
Anagallis arvensis L.	TP	20°/30°C; 15°C	21d	potassium nitrate, pre-chill	ISTA
	TP	15°C	21d	potassium nitrate, sensitive to temperatures above 15°C, test at 10°C	AOSA
		15°C	21d	potassium nitrate, 0.2%	Atwater
Anagallis monelli L. var linifolia (L.) Maire	TP	15°C	21d	potassium nitrate, sensitive to temperatures above 15°C, test at 10°C	AOSA
Cyclamen africanum Boiss. & Reut.	TP; BP	20°C	28d	ensure good moisture supply	AOSA
Cyclamen persicum Mill.	TP; BP; S	15°C; 20°C	35d	pre-soak, 24h, then potassium nitrate	ISTA
		20°C	40d		Atwater
Primula auricula L.	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula denticulata Smith	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula elatior (L.) Hill	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula japonica Gray	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula x kewensis Hort.	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula malacoides Franch.	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula obconica Hance	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula sinensis Sabine ex Lindl.	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula veris L.	TP	20°/30°C; 15°C; 20°C	28d	potassium nitrate, pre-chill	ISTA
Primula vulgaris Huds.	TP	20°/30°C;	28d	potassium nitrate, pre-chill	ISTA

		15°C; 20°C			
Primula spp. (hybrids)		20°C	28d	GA, 400ppm	Atwater
Primula spp.	TP	15°C	28d	light, ensure good moisture supply	AOSA
				RANUNCULACEAE	
Adonis vernalis L.	TP; BP	10°C; 15°C	35d	pre-chill, potassium nitrate	ISTA
Anemone coronaria L.	TP	15°C; 20°C	28d	pre-chill	ISTA
		15°C	28d		Atwater
		10°/20°C	28d	partial removal of pericarp	Atwater
Anemone pulsatilla L.	TP	15°C	28d	sensitive to temperatures above 15°C	AOSA
Anemone silvestris L.	TP	15°C; 20°C	28d	pre-chill	ISTA
Aquilegia alpina L.	TP; BP	20°/30°C; 15°C	28d	light, pre-chill	ISTA
	TP	20°/30°C	16d	light, pre-chill, 3°-5°C, 14-21d, with potassium nitrate	AOSA
Aquilegia caerulea James	TP	20°/30°C	30d	light, pre-chill, 5°C, 3-4w	AOSA
		20°/30°C; 15°C	100d	pre-chill, 3°-5°C, 2w	Atwater
Aquilegia canadensis L.	TP; BP	20°/30°C; 15°C	28d	light, pre-chill	ISTA
Aquilegia chrysantha Gray	TP; BP	20°/30°C; 15°C	28d	light, pre-chill	ISTA
	TP	20°/30°C	30d	light, pre-chill, 5°C, 3-4w	AOSA
Aquilegia x cultorum Bergmans	TP; BP	20°/30°C; 15°C	28d	light, pre-chill	ISTA
Aquilegia x hybrida Hort.		20°/30°C	28d	test at 15°C	Atwater
Aquilegia longissima Gray	TP	20°/30°C	30d	light, pre-chill, 5°C, 3-4w	AOSA
Aquilegia vulgaris L.	TP; BP	20°/30°C; 15°C	28d	light, pre-chill	ISTA
Aquilegia spp.	TP	20°/30°C	21d	Light	AOSA
Consolida ambigua (L.) P.W. Ball & Heywood	TP; BP	10°C; 15°C; 20°C	21d	pre-chill	ISTA
	TP; BP	15°C	21d		AOSA
		15°C	28d		Atwater
Consolida regalis Gray	TP; BP	10°C; 15°C; 20°C	21d	pre-chill	ISTA
Delphinium belladonna Hort.	TP; BP	10°C; 15°C; 20°C	21d	pre-chill, light	ISTA
Delphinium bellamosum L.	TP; BP	10°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Delphinium cardinale Hook.	TP; BP	10°C; 15°C; 20°C	21d	pre-chill	ISTA
	TP; BP	15°C	28d	very sensitive to warm temperatures	AOSA
		15°C	28d	pre-chill, 3°-5°C	Atwater
Delphinium cultorum Voss	TP; BP	10°C; 15°C; 20°C	21d	light, pre-chill	ISTA

		20°C	21d	test at 15°C	Atwater
Delphinium elatum L.	TP; BP	20°/30°C; 20°C	16-18d	sensitive to drying out in test	AOSA
Delphinium formosum Boiss. & Huet	TP; BP	10°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Delphinium grandiflorum L.	TP; BP	10°C; 15°C; 20°C	21d	light, pre-chill	ISTA
Delphinium spp. (wild types)		5°-8°C	28d	GA, 400ppm	Atwater
Nigella damascena L.	TP; BP	20°/30°C; 15°C; 20°C	21d	potassium nitrate, 15°C, dark, 14d, then 20°/30°C, or pre-chill	ISTA
	TP	15°C	16d	sensitive to drying out in test	AOSA
		15°C	21d	pre-soak, 24h, dark, 72h	Atwater
Nigella hispanica L.	TP; BP	20°/30°C; 15°C; 20°C	21d	potassium nitrate, 15°C, dark, 14d, then 20°/30°C, or pre-chill	ISTA
Nigella sativa L.	TP; BP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate, test at 15°C	ISTA
Pulsatilla vulgaris Mill.	TP	15°C; 20°C	28d	pre-chill	ISTA
Ranunculus asiaticus	TP; S	15°C; 20°C	28d		ISTA
Ranunculus spp.	TP	15°C	30d	slow to germinate, check for empty seeds	AOSA
		15°C	40d		Atwater
Thalictrum spp.		20°C	50d	Light	Atwater
				RESEDACEAE	
Reseda odorata L.	TP; BP	20°/30°C; 15°C	14d	Light	ISTA
	TP	20°/30°C; 20°C	10d	Light	AOSA
				RHAMNACEAE	
Ceanothus sanguineus Pursh.				pre-soak, 90°C	Atwater
Ceanothus spp.				pre-soak, boiling water	Atwater
Hovenia dulcis Thunb.			30d	scarify, abrade with sharp sand, or file or nick seed coat, pre-chill, 1°-5°C, 30-60d	Riley
Rhamnus cathartica L.	S	20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 2-4w	G&R
Rhamnus frangula L.	S	20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 8w	G&R
Zizyphus jujuba Mill.			21d	complete removal of seed covering structures, then pre-soak, 24h	Riley
Zizyphus mauritiana Lam.			21d	complete removal of seed covering structures, then pre-soak, 24h	Riley
Zizyphus mucronata			21d	complete removal of seed covering structures, then pre-soak, 24h	Riley
				SALICACEAE	
Populus spp.	TP	20°/30°C	10d		ISTA

		20°/30°C	14d	light	AOSA
Salix spp.	TP	20°/30°C	14d		ISTA
				SAPOTACEAE	
Achras zapota L.	S	25°-30°C	29d	light, continuous	CHML
Chrysophyllum cainito L.			21d	warm stratification	Riley
Manilkara zapotilla			30d	pre-soak, 24h	Riley
Mimusops elengi	S	25°-30°C	66d	light, continuous	CHML
Pouteria spp.			21d	warm stratification	Riley
				SCROPHULARIACEAE	
Antirrhinum majus L.	TP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
		20°/30°C	14d	light, test at 15°C	Atwater
Antirrhinum spp.	TP	20°/30°C	12d	light, pre-chill, or test at 15°C with potassium nitrate	AOSA
Calceolaria x herbeohybrida Voss	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Calceolaria polyrrhiza Cav.	TP	20°/30°C; 15°C	21d	pre-chill, potassium nitrate	ISTA
Calceolaria spp.	TP	15°C	18d	light	AOSA
Castilleja californica Abrams		15°C	21d	potassium nitrate, 0.2%, but dormant seeds remain	Atwater
Cymbalaria muralis Gaertn., Mey & Scherb.	TP	10°C; 15°C	21d	pre-chill	ISTA
Digitalis lanata Ehrh.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
Digitalis purpurea L.	TP	20°/30°C; 20°C	14d	pre-chill	ISTA
		20°/30°C	14d	light	Atwater
Digitalis spp.	TP	20°/30°C	7d	light	AOSA
Linaria bipartita Willd.	TP	10°C; 15°C	21d	pre-chill	ISTA
Linaria maroccana Hook. f.	TP	10°C; 15°C	21d	pre-chill	ISTA
		10°C; 15°C	14d		Atwater
Linaria vulgaris Mill.	TP	10°C; 15°C	21d	pre-chill	ISTA
Linaria spp.	TP	15°C	8d	test at 5°-10°C	AOSA
Mimulus cardinalis Dougl. & Benth.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Mimulus cupreus Hort. ex Dombr.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Mimulus guttatus DC.	TP	20°/30°C			M&O
Mimulus hybridus Hort. ex Siebert	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
	TP	15°C	14d	light	AOSA
Mimulus longiflorus Grant		20°C	28d	potassium nitrate, 0.2%, light	Atwater
Mimulus luteus L.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
Nemesia strumosa Benth.	TP; BP	15°C; 20°C	21d	light, pre-chill	ISTA
		15°C	21d		Atwater

Nemesia versicolor E. Mey. ex Benth.	TP; BP	15°C; 20°C	21d	light, pre-chill	ISTA
Nemesia spp.	TP	15°C	10d	sensitive to temperatures above 18°C	AOSA
Penstemon barbatus (Cav.) Roth	TP	20°/30°C; 15°C	21d	pre-chill	ISTA
	TP	15°C	18d	light	AOSA
Penstemon grandiflorus Nutt.	TP	15°C	18d	light	AOSA
Penstemon hartwegii Benth.	TP	20°/30°C; 15°C	21d	pre-chill	ISTA
		20°/30°C	14d		Atwater
Penstemon hirsutus (L.) Willd.	TP	15°C	18d	light	AOSA
Penstemon hybridus Grondl. & Rumpl.	TP	20°/30°C; 15°C	21d	pre-chill	ISTA
Penstemon laevigatus (L.) Ait.	TP	15°C	18d	light	AOSA
Penstemon spectabilis Thurber ex Gray		15°C	21d	GA, 400ppm	Atwater
Penstemon spp.		10°/20°C; 3°/28°C	28d	pre-chill, 5°C, 2-4w	Atwater
Torenia fournieri Lind.	TP	20°/30°C	14d	potassium nitrate	ISTA
	TP	20°/30°C	8d	light	AOSA
Verbascum blattaria	TP	20°/30°C			M&O
Verbascum densiflorum Vis.	TP	20°/30°C	21d	pre-chill	ISTA
Verbascum phlomoides L.	TP	20°/30°C	21d	pre-chill	ISTA
Verbascum thapsus L.	TP	20°/30°C	21d	pre-chill	ISTA
	TP	20°/30°C			M&O
Veronica austriaca L.	TP	20°/30°C	16d	light	AOSA
Veronica spicata L.	TP	20°/30°C	16d	light	AOSA
				SIMARUBACEAE	
Ailanthus altissima Swingle	TP	20°/30°C	21d	pre-soak, 24h, then remove pericarp	ISTA
	TP	20°/30°C	21d		AOSA
				pre-chill, 1°-5°C, 8w	G&R
				TAXACEAE	
Taxus spp.	S	20°/30°C	28d	pre-chill, 3°-5°C, 9m	ISTA
				TAXODIACEAE	
Cryptomeria japonica (L. f.) D. Don	TP	20°/30°C	28d		ISTA
Sequoia sempervirens (D. Don) Endl.	TP	20°/30°C	21d		ISTA
	TP	20°/30°C	21d	light	AOSA
Sequoiadendron giganteum Lindl.	TP	20°/30°C	28d		ISTA
	TP	20°/30°C	28d	light, sensitive to drying out	AOSA

Taxodium distichum (L.) Rich.	S	20°/30°C; 20°C	28d	pre-chill, 3°-5°C, 30d	ISTA
				THYMELAEACEAE	
Daphne mezereum L.				scarify, concentrated sulphuric acid, or warm stratification, 25°C, 8-12w, then pre-chill,	G&R
				1°-5°C, 14w	
				TROPAEOLACEAE	
Tropaeolum majus L.	TP; BP; S	20°/30°C; 15°C; 20°C	21d	pre-chill	ISTA
Tropaeolum peltophorum Benth.	TP; BP; S	15°C; 20°C	21d	pre-chill	ISTA
Tropaeolum peregrinum L.	TP; BP; S	15°C; 20°C	21d	pre-chill	ISTA
Tropaeolum spp.	BP	18°C	14d		AOSA
				ULMACEAE	
Celtis occidentalis L.		20°/30°C		light, 8h/d, pre-chill, 1°-5°C, 8-12w	G&R
Ulmus americana L.	TP	20°/30°C; 20°C	14d	remove pericarp	ISTA
	TP	20°/30°C	14d	light	AOSA
Ulmus parviflora Jacq.	TP	20°/30°C; 20°C	14d	remove pericarp	ISTA
	TP	20°C	10d		AOSA
Ulmus pumila L.	TP	20°/30°C; 20°C	14d	remove pericarp	ISTA
	TP	20°C	10d		AOSA
Zelkova serrata Thunb. ex Murr.	TP	10°/30°C	28d	two tests: with and without pre-chill, 3°-5°C, 14d	ISTA
				pre-chill, 1°-5°C, 2-6w	G&R
				VALERIANACEAE	
Valeriana locusta (L.) Laterr.	TP; BP	15°C; 20°C	28d	pre-chill	ISTA
	BP	15°C	28d	test at 10°C	AOSA
	BP	10°/20°C	28d	pre-chill, 10°C, 5d	Fornerod
	TP	15°C	14-21d		Heit
Valeriana officinalis L.	TP	20°/30°C; 20°C	21d	pre-chill	ISTA
				VERBENACEAE	
Duranta repens L.	TP	25°-30°C	42d	light, continuous	CHML
Lantana camara L.	BP	20°/30°C	30d	pre-soak fruit, 1-3d, then remove pulp from seeds	AOSA
Lantana montevidensis (Spreng.) Brig.		20°/30°C	30d	pre-soak and remove pulp	Atwater
Tectona grandis L.f.	S	30°C	28d	pre-soak then pre-dry, 3d, repeat 6 times	ISTA
Verbena bonariensis L.	TP	20°/30°C; 15°C	28d	pre-chill, potassium nitrate	ISTA
Verbena canadensis (L.) Britt.	TP	20°/30°C; 15°C	28d	pre-chill, potassium nitrate	ISTA

Verbena x hybrida Voss	TP	20°/30°C; 15°C; 20°C	28d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C; 20°C	18d	light	AOSA
		20°/30°C	14d		Atwater
Verbena officinalis L.		20°/30°C	30d		Atwater
Verbena rigida Spreng.	TP	20°/30°C; 15°C	28d	pre-chill, potassium nitrate	ISTA
				VIOLACEAE	
Viola cornuta L.	TP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
	TP	20°/30°C; 20°C	12d		AOSA
		15°C	14d		Atwater
Viola odorata L.	TP	10°C; 20°C	21d	potassium nitrate, pre-chill	ISTA
		10°C; 15°C; 20°C	90d	dehull, GA, 400ppm	Atwater
Viola tricolor L.	TP	20°/30°C; 20°C	21d	pre-chill, potassium nitrate	ISTA
		20°/30°C; 20°C	12d		AOSA
		20°C	14d		Atwater
				ZYGOPHYLLACEAE	
Larrea tri-dentata (DC.) Cov.			9d	dehull	Atwater