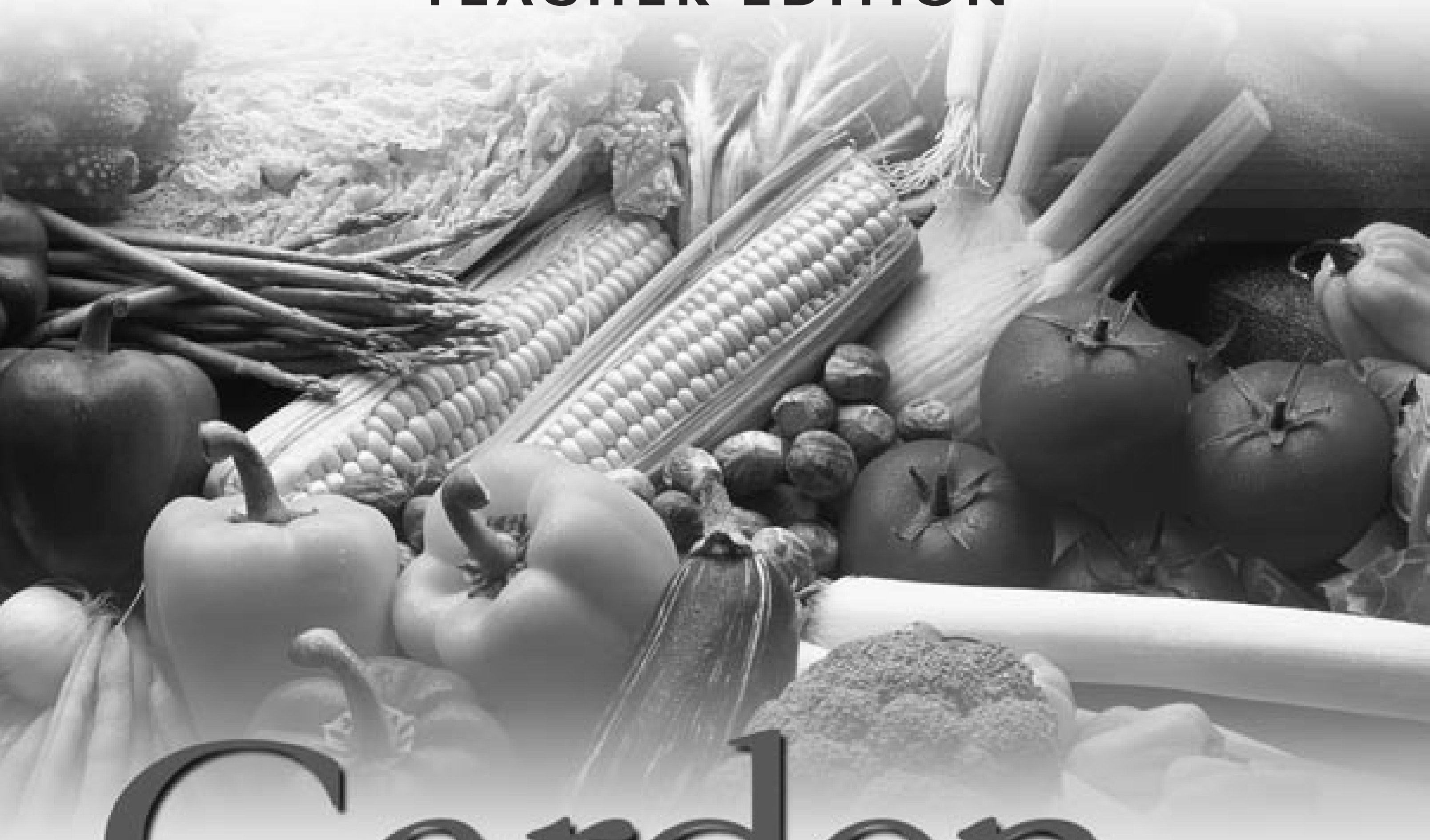
TEACHER EDITION



Garden Genetics:

Teaching With Edible Plants

TEACHER EDITION

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Teaching With Edible Plants

Elizabeth Rice, Marianne Krasny,
and Margaret E. Smith

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Student Edition

ACKNOWLEDGMENTS

Garden Genetics is the result of collaborative effort between Cornell scientists, science educators, and high school and middle school science teachers. Without all their input, the project would never have come to fruition.

The cucumber chapters and activities are based on plant breeding laboratory exercises developed by Cornell University Professor Emeritus Henry Munger, using the Marketmore cucumber varieties that he bred. These activities had further scientific input from Cornell scientists Rebecca Smyth and Martha Mutschler. Tim Setter, Vern Gracen, T. Clint Nesbitt, and Dan Ardia provided scientific input and review of the corn chapters. Theresa Fulton and Yolanda Cruz were involved with the scientific design and review of the tomato chapters.

Science education specialists Linda Tompkins, Nancy Trautmann, and Leanne Avery all provided important pedagogical insights and help to design chapter and activity formats. Activities 5 and 6 were designed in partnership with Ithaca High School teacher Nicole Benenati. Teachers at Cornell Institute for Biotechnology (CIBT) and Amherst College Genomics workshops reviewed the activities. The chapters and activities were piloted in the classrooms of Pete Saracino, Thea Martin, Ellen Garcia, Nicole Benenati, Karen Taylor, Teresa Gable, John Fiori, Mary Galliher, and Margaret Brazwell.

The pen and ink drawings that appear in *Garden Genetics* were drawn by Gillian Dorfman. The book was produced by NSTA Press and included participation by director Claire Reinburg, project editor Andrew Cocke, production director Catherine Lorrain, and art director Will Thomas, Jr.

The book was developed while the first author was a fellow in the Cornell Science Interns Partnership Program, with support from the National Science Foundation Graduate Teaching Fellows in K–12 Education Program (DUE #0231913; PI: M. Krasny, co-PI:N. Trautmann) and the College of Agriculture and Life Sciences at Cornell University.

Finally, we thank our families for their support in spite of corn plants growing under the bathroom sink and for their tolerance of the extra hours we put in to bring the project to completion.

INTRODUCTION TO GARDEN GENETICS

Teacher Edition

Why Garden Genetics?

Garden Genetics uses a series of inquiry activities and experiments to teach both traditional and cutting-edge genetics. Throughout the text and activities, connections are made between genetics, evolution, ecology, and plant biology. The activities are targeted for use in grade 9–12 biology classes with students of all levels. Many of the activities are also suitable for middle school science classes. *Garden Genetics* is designed to supplement and enhance the content normally taught in biology classes.

Why *Garden Genetics*? Presenting science in a way that is meaningful to students can be challenging. What better way than to present science in the context of familiar foods? The readings and activities in *Garden Genetics* focus on cucumbers, corn, and tomatoes. They also address issues students are hearing about in the media—like the environmental and social impacts of genetically engineered food plants.

How does *Garden Genetics* present genetic concepts in ways that are new and exciting to students? To learn about Punnett's squares, students taste variations in bitterness of cucumber seedlings and trace these differences back to the parental generations. Students then go on to design and conduct experiments investigating the surprising role that bitterness plays in protecting cucumber plants from insect predation. To learn about the genetics of plant breeding, students re-enact a trial in which farmers sued seed companies to compensate for one billion dollars of U.S. corn crop losses caused by genetic uniformity. Other examples of student activities include creating geographic maps of the origin of food plants and genetic maps of economically important traits like tomato color.

Garden Genetics is designed to be used flexibly in different classroom settings. Each chapter can be used as a separate, stand-alone unit. Alternatively, because each chapter explicitly emphasizes connections to subjects in other chapters, teachers can use multiple chapters or the whole book. In this way, students will gain a more complete understanding of genetics and its connections to other biological disciplines (evolution, ecology, and plant science). The activities utilize a variety of formats, from guided worksheets to open-ended inquiry. The experiments involve working with young plants and thus are relatively short in duration. Suggestions for more in-depth inquiry are included in various chapters.

The activities in *Garden Genetics* were developed by Dr. Elizabeth Rice working hand-in-hand with high school and middle school science teachers. At the time, Dr. Rice was completing her PhD on genetic conservation of corn. She was also a National Science Foundation Graduate Teaching Fellow in K–12 Education (GK–12 Fellow) at Cornell University (see *http://csip.cornell.edu* for other curricula developed by the Cornell GK–12 Fellows). She was assisted in writing this manual by Dr. Marianne Krasny, a Cornell professor of natural resources and director of the Cornell GK–12 program, and Dr. Margaret Smith, a Cornell professor of plant breeding and genetics.

Content

Garden Genetics not only includes innovative content at the cutting edge of biology, but also emphasizes the thinking, problem-solving, and inquiry-based skills increasingly demanded in biology classes today. Its chapters can be divided into three sections focusing on cucumbers, corn, and tomatoes.

Section 1: Cucumbers

Chapter 1, *"It Skips a Generation": Traits, Genes, and Crosses*, begins with Mendelian genetics and applies an understanding of genetics to hybrid cucumbers. In the first activity, students taste cucumber cotyledons and use Punnett's squares to deduce the bitterness of parental generations. In Chapter 2, *Bitterness and Non-Bitterness in Cucumbers: A Story of Mutation*, students explore the history of the bitter gene in cucumbers, which was found in a genebank and traded internationally between cucumber breeders. The students then explore transcription, translation, and the DNA basis for different types of mutations. The activity uses one of the modern tools of genomics—sequences from the GenBank public database—to explore mutation of cucumber genes. In Chapter 3, *Survival Strategies*, students learn about generalist and specialist strategies of insect predation on plants. Students design and implement experiments exploring the relationship of cucumber bitter genes to a predator, the cucumber beetle. Contrary to student expectations, the beetles choose to eat the bitter plants. As students wrestle with this seemingly incongruous finding, they learn valuable lessons about ecology, evolution, and the process of science.

Section 2: Corn

In Chapter 4, *Domestication: Evolving Toward Home*, students follow the fascinating discoveries of scientists studying the origins of corn to learn about domestication—a particular form of evolution. In the associated activity, students use archeological and genetic evidence to explore the timescale of evolution. By examining photos of archeological samples, students discover that corn has had both periods of rapid change consistent with the theory of punctuated equilibrium, as well as slow cumulative changes associated with gradualism. Chapter 5, *The Risks of Improvement: Genetic Uniformity and an Epidemic*, explores the important role of genetic diversity in crops. Using hybrid corn as an example, the text discusses artificial selection and the genetic narrowing that accompanies improvement in traits like yield, as well as explores the ecological and evolutionary consequences of genetic uniformity in crops. In the activity, students re-enact a class-action lawsuit from the 1970s in which farmers sued corn seed companies because of an epidemic caused by lack of genetic diversity.

The series of chapters on corn continues with an exploration of the DNA basis for genetically engineered Bt corn, as well as a discussion of unintended consequences and regulatory issues associated with genetically engineered corn (Chapter 6, *Genetic Engineering*). In the Chapter 6 activity, students hold a congressional hearing and write a short informed opinion paper about the basis of the testimony they have heard. A discussion of corn would not be complete without exploring sweet corn and its genetic basis (Chapter 7, *Sweet Genes in Corn*). In this chapter, students embark on a mouth-watering exploration of the biochemical pathways that lead to conversion of sugars into starches in sweet corn and then design their own experiment to test the effect of seed reserves on germination and seedling growth using starchy, sweet, and super-sweet corn seeds.

Section 3: Tomatoes

Building on the lessons from bitter cucumbers and sweet corn, students turn to tasty tomatoes in the last two chapters. Chapter 8, *Centers of Diversity*, discusses genetic diversity in relation to geographic centers of origin of crop plants. Students use graphs and world maps to understand which biomes have been the most important sources for annual and perennial plants. In the final chapter (Chapter 9, *Quantitative Traits*) students learn about quantitative trait loci (QTL) studies to examine tomato fruit size. In the activity, students use recently published data to create a genetic chromosome map of regions associated with red color in tomato. They then explore the connection between DNA and blockage of biochemical pathways by comparing their QTL map to the genetic locations of color mutations (such as those found in tangerine tomatoes).

Together the chapters present a unique way of looking at food and agriculture—one that applies textbook concepts in an exciting, innovative, and interesting context. We hope you and your students will enjoy this exploration of genetics, evolution, ecology, and plant biology—along with tasty vegetables and healthy learning!

How to Use This Book

For your convenience, this teacher edition is bound with the full student edition. The teacher edition includes specific teacher notes before each activity, giving tips, warnings, and optional directions for using the activities to spur further inquiry in the classroom. The teacher edition provides the answers to the activity questions (in italics), along with special items to note as the students carry out each activity.

How can you avoid searching hundreds of science websites to locate the best sources of information on a given topic? SciLinks, created and maintained by the National Science Teachers Association (NSTA), has the answer.

In a SciLinked text, such as this one, you'll find a logo and keyword near a concept, a URL (*www.scilinks.org*), and a keyword code. Simply go to the SciLinks website, type in the code, and receive an annotated listing of as many as 15 web pages—all of which have gone through an extensive review process conducted by a team of science educators. SciLinks is your best source of pertinent, trustworthy internet links on subjects from astronomy to zoology.

Need more information? Take a tour—*www.scilinks.org/tour/*

"IT SKIPS A GENERATION"

Traits, Genes, and Crosses

Long before they understood why the strategy worked, farmers knew how to crossbreed plants to obtain more desirable traits. Even today, a farmer who knows nothing about genetics can tell you that when a blue type of corn crosses with a yellow one, the offspring are blue. However, the farmer might add, if you cross a corn plant with small ears with a large-eared one, the offspring will have ears that are intermediate in size. Without any knowledge of genetics, the farmer has just told you a great deal about how the genes for blue color and for ear size work.

Gregor Mendel, an Austrian monk often described as the "father of genetics," worked with pea plants in the 1860s to understand how traits are passed from one generation to the next. Mendel made his discoveries by making crosses between **true-breeding** pea plant populations with different characteristics and keeping careful track of the characteristics of their offspring. Sometimes, when he transferred pollen from one tall plant to another tall plant (like in the cross shown in the F1 generation of Figure 1.1), some of the offspring were tall but some also were short. Where was this shortness coming from, if not from the parental populations?

"It skips a generation"—the shortness was coming from the grandparental populations. Shortness, the **recessive trait**, was masked by the tall **dominant trait** in the "**hybrid**" or F1 generation. In essence, the shortness was hidden because of sexual recombination. Each offspring receives one copy of a gene from its mother and one from its father. In this way, gene combinations are shuffled with every generation and new types may appear.

Many of the early discoveries in genetics occurred in plants. Plants have a few special characteristics that make them ideal for studying genetics. From one known cross, many genetically similar "siblings" are produced. Pea pods, like the ones Mendel worked with, produce about five peas, and a cucumber has hundreds of seeds. Furthermore,

A tall plant population that has all tall offspring (when crossed with itself or another tall population) is **true-breeding**.

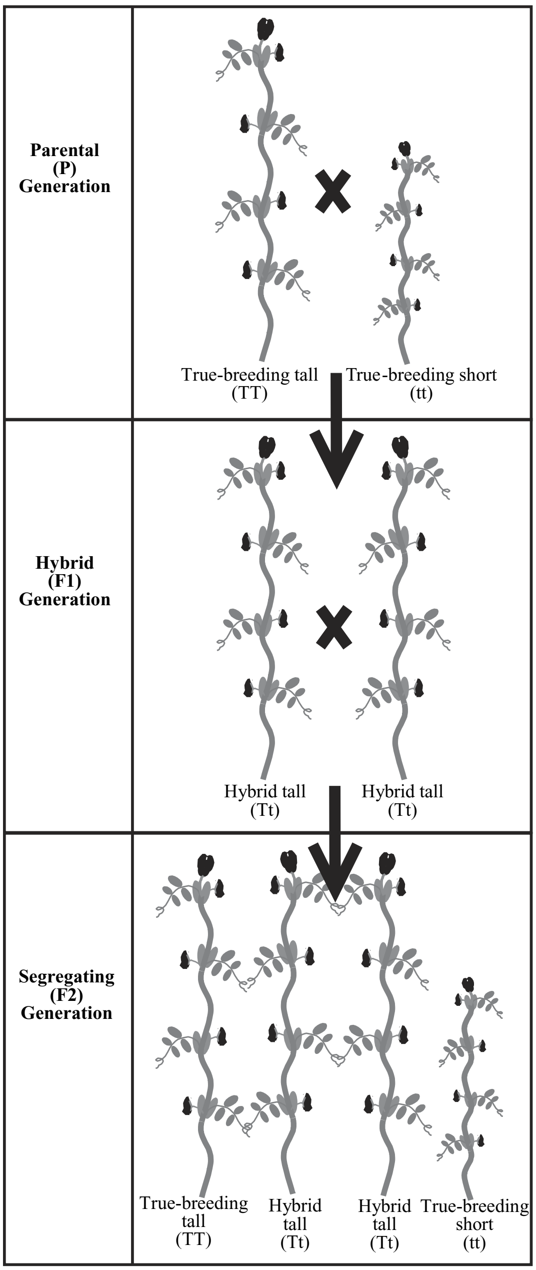
A **recessive trait** is not expressed unless two copies of a gene are present. A single copy of a recessive gene is "hidden" by the presence of a **dominant trait**.

SCILINKS® THE WORLD'S A CLICK AWAY

Topic: Gregor Mendel
Go to: *www.sciLINKS.org*
Code: GG01

Topic: Dominant and Recessive Traits
Code: GG02

Figure 1.1. Crossing Generations. When plant breeders make crosses between plants, they talk about the parental (P), hybrid (F1), and segregating (F2) generations.



some plants (but not all) have the remarkable capability of being able to fertilize their own flowers. This means that the same plant can be both the male and female parent of a seed. Therefore, scientists can easily and naturally create whole populations of genetically identical individuals.

The cross in Figure 1.1 resulted from two true-breeding individuals. The F1 generation would have contained 5–10 seeds that were genetically identical to one another for the alleles that determine height (all had the Tt alleles). To make the F2 generation, Mendel had two options: He could self-pollinate the plants, or he could cross two different individuals of the F1 generation. Regardless of which method he used, in the F2 generation, the individuals would not all be genetically identical!

HYBRID CORN AND SEGREGATION OF TRAITS

Why do seed companies like Dekalb and Pioneer make corn seed, when farmers already have seed they can plant?

The key lies in a concept called hybrid vigor. It's a phenomenon that scientists still don't fully understand, and accounts for most of the increased harvest from farmers' fields since the 1920s. The process works like this: A corn breeder takes two very different, true-breeding types of corn as parents. When the corn breeder makes a cross between the right two corn types, the F1 generation, called the **hybrid** generation, can have a 30% gain in yield compared to the parents. To a farmer, this translates into 30% more money in his or her pocket.

So why would a farmer ever have to buy expensive, new seed again? The corn plant makes seed for the next generation. However, what happens in the F2 generation? Traits begin to segregate, meaning that at all the plant's genes, AA, aa, and Aa genotypes are possible, instead of the uniform Aa in the hybrid generation. As segregation happens, the yield advantage disappears. This can mean 30% less money in the farmer's pocket—a powerful incentive to keep buying hybrid seed.

From the company's perspective, if people are willing to keep buying seed, the company will keep producing new varieties. Thus, the segregation of traits contains the key to an entire seed industry!

Mendelian and quantitative traits

Bitterness in cucumbers is a Mendelian trait, meaning that it is controlled by a single gene—just like the traits that Mendel studied in peas (round versus wrinkled, or yellow versus green). Mendelian traits are also sometimes called **single-gene traits**, or traits under simple genetic control. With a single-gene trait, inheritance and behavior are fairly easy to understand.

Many traits, like yield, flowering time, plant height, and color, are more complex and are controlled by multiple genes. These complex traits are called **quantitative traits**. Table 1.1 has examples of both Mendelian and quantitative traits. Note that some traits like plant height can be both Mendelian and quantitative. For example, plant height in normal plants is influenced by many genes. However, in plants with dwarfing genes, plant height behaves as a Mendelian trait. In essence, a single dwarfing gene overrules the otherwise quantitative trait of plant height. Table 1.1 also shows the abbreviations that scientists often give single gene mutations, like "dw1" for a dwarfing gene or "y" for a yellow gene.

A **Mendelian** or **single-gene trait** is controlled by a single gene.

Quantitative traits are controlled by many genes.

SCILINKS THE WORLD'S A CLICK AWAY

Topic: Mendel's Laws
Go to: ***www.sciLINKS.org***
Code: GG03

Topic: Explore Mendelian Genetics
Code: GG04

Table 1.1. Mendelian and quantitative traits.

	Mendelian (single-gene)	**Quantitative** (multi-gene)
Cucumber	Spiny—controls the production of small spines on the fruit, producing a prickly cucumber.	
	Bushy—controls whether the plant grows as a bush or as a vine.	
Tomato		Fruit size—About 12 genes control fruit size by impacting characteristics like cell division in the fruit and growth hormones.
Corn	Dwarf (dw1)—controls the production of gibberellin, a plant hormone responsible for vertical growth.	Plant height—More than 20 genes are important in plant height in corn.
	Yellow (y)—controls whether a kernel is yellow or white.	Kernel color—Many genes modify exactly what shade of yellow a corn kernel will be, from canary yellow to a pale cream.
		Yield—The most important trait of all is influenced by dozens of genes that affect things like number of rows on an ear, number of kernels, kernel size, kernel density, and plant tolerance of competition in a field.

Questions for further thought

Evolution: What evolutionary advantage might reshuffling genes, caused by sexual reproduction, give to a new generation of plants?

Reshuffling genes leads to genetic flexibility (i.e., new gene combinations that allow populations to respond to changing environmental conditions).

What disadvantages could it have?

Reshuffling could lead to the loss of good genetic combinations or beneficial alleles.

Genetics: When a blue type of corn crosses with a yellow type of corn, the offspring are blue. What type of trait is involved?

A dominant trait (likely at a single [Mendelian] locus [site]).

When a corn plant with large ears crosses with a small-eared plant, the offspring will have intermediately sized ears. What type of trait is involved?

A quantitative trait.
(Though given the information above and in their textbook, students could correctly answer incomplete dominance. Incomplete dominance is actually still a single gene or Mendelian trait.)

If a true-breeding spiny cucumber plant crossed with a non-spiny cucumber always had spiny offspring, how many copies of the spiny allele would it have?

Assuming that it is a diploid cucumber, it would have two copies of the dominant spiny allele. Any true-breeding diploid individual has two copies of whatever allele is in question—it is homozygous. Remember that the notion of true-breeding predates our understanding of DNA and the genetic basis for traits by many years.

How do geneticists and plant breeders know if a plant is true-breeding?

This is a deceptively simple question. The short answer is that plant breeders keep very careful records of how crosses were made, and the phenotypes of the offspring. A plant breeder would cross the plant to itself (or to a near relative if self-fertilization isn't possible) and observe the next generation!

But there's a problem… most agricultural species like peas, corn, and cucumbers live only a few months and reproduce only once. Therefore, how could you know that a plant is true-breeding until after you've planted it or its progeny?

The key lies in the fact that when talking about crosses in plant genetics, we are dealing with populations of (nearly or completely) genetically identical plants, not just individuals. Often a population is derived from a single cross in a previous generation. Think of an ear of corn. From one cross of known parents, 500 genetically similar offspring are produced.

Furthermore, many (not all) plants are self-fertile, meaning that their pollen can fertilize their own ovules. Self-fertilization quickly leads to two identical copies of an allele at a locus (homozygosity)—the genetic basis for "true-breeding" plants. Because an ear of corn or a pea pod produces more than one offspring, a plant breeder can: (1) make crosses to determine if the population is "true-breeding" and (2) simultaneously reserve some seed from the population for future crosses.

Chapter 1 Teacher Notes

Overview and Concepts

Overview

Chapter: Building from Mendel's crosses with peas, students review plant breeding populations and crosses. Emphasis is placed on recessive and dominant traits as well as Mendelian and quantitative traits. Questions focus on genetics and evolution.

Activity: Students taste the bitter or non-bitter phenotypes of a population of cucumber seedlings. Using Punnett's squares and logic, they deduce the genotypes of their unknown population as well as of its parents. Students make a hypothesis about the behavior of the cucumber bitterness gene and use statistics to evaluate their hypothesis.

Concepts covered

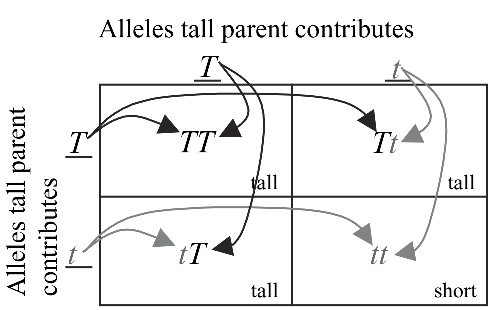
Dominant and recessive traits, crosses, hybrids, segregation of traits, Mendelian (single-gene) and quantitative (multi-gene) traits, Punnett's squares, statistics

Prior knowledge required

The text and activities of *Garden Genetics* are intended to apply and supplement textbook concepts. Students should have familiarity with the following:

- **Genes and alleles: Genes** are the unit of inheritance. They are segments of DNA that code for proteins. **Alleles** are different versions of a gene. We have two alleles for each gene, one from each parent.
- **Crosses and sexual recombination: Sexual recombination** takes one set of alleles from one parent and combines them with another set of alleles from a second parent. Long before farmers understood why it worked, they used sexual recombination to make **crosses** between plants with different characteristics. Remember Mendel used crosses to understand inheritance in his peas.
- **Punnett's square:** A chart showing the possible gene combinations for the offspring of a cross. To the left is a Punnett's square for a cross between two tall hybrid pea plant parents (like Mendel used).
- **Genotype:** A **genotype** is a representation of the genetic make-up of an individual. The parents in the cross on the left have the genotypes Tt.

Teacher Figure
Punnett's square



- **Phenotype:** A **phenotype** is a physical description of a trait. The parents in the cross on page 8 both have tall phenotypes. The offspring have three tall phenotypes and one short phenotype.

Activity notes

Preparation prior to the activity

- Order seeds several weeks in advance of planting date. Seed companies can be slow to deliver.
- Plan on 10 to 14 days between planting seeds and time of activity.

Time frame

- Day 1: Students taste plants.
- Day 2: Students finish worksheets and do statistical exercise.

Materials

Seed sources

Seed Company	Bitter Variety	Non-Bitter Variety	Website	Phone	Fax
Yankee Gardener	Marketmore 76 (#HSV 2029, $1.29)	Marketmore 97 (#HSV 2030, $1.69)	*www.yankeegardener.com/seeds/hartseed4.html*	(203) 776-2091	(203) 776-1089
Peaceful Valley Farm Supply	Marketmore 76 (#SNV8048, $1.99)	Marketmore 80 (#SNV9014, $1.99)	*www.groworganic.com*	(888) 784-1722	
Specialty Seeds	Marketmore 76 ($1.49)	Marketmore 97 ($1.69)	*www.specialtyseeds.com*	(860) 721-9617	

Ideally, you want to use seed from similar genetic backgrounds so you're comparing the effects of the gene of interest, instead of effects of many other genes. Marketmore 76 and 80 are nearly identical genetically, except for the bitter gene. The non-bitter variety Marketmore 97 is also similar to Marketmore 80. Other bitter varieties: Poinsett 97 and Tablegreen 65. Tablegreen 72 is non-bitter.

Seed preparation for planting

- Instead of investing the time in making crosses and tending 2 generations of cucumber plants, you can simulate your own "segregating" population by mixing the bitter and non-bitter seeds. Mix seeds in a ratio of 3 bitter to 1 non-bitter. (The bitter gene is dominant to the non-bitter one.)
- Save a few seeds of each type as taste controls.
- Mix at least 20% more seeds than the class will need, to reflect the role of probability in segregation ratios. Therefore, if a class needs to plant 40 seeds, mix a minimum of 12 non-bitter + 36 bitter seeds for a total of 48 seeds. The students will then choose 40 seeds from the cup and plant them. Eight will not be planted at all.

Planting seeds

- Students should plant enough individuals of their "unknown" population to get segregation ratios close to 3:1. Minimum 20 plants for a class. Ratios will be closer to 3:1 with more plants.
- At the same time the students plant their "unknown," you or they should plant at least 2 bitter and 2 non-bitter taste "controls" per class.

Safety notes

- This lab violates all normal prohibitions against students eating in the laboratory by asking students to taste the leaves of young cucumber plants.
    - If possible, the tasting portion of the activity should be conducted somewhere other than the laboratory (the cafeteria, a home economics classroom, the hallway, etc.).
    - If students must do the tasting portion in the lab, please emphasize that this is the exception to the rule that one should NEVER put anything in a laboratory into one's mouth.
    - The tasting should be optional. If a student doesn't want to taste, someone else in his or her group can do it.
    - All students should wash their hands after handling the plants and again after the activity.
- Cucumber leaves and stems, especially those of young cucumbers, are edible. They sometimes appear in recipes, though they are usually cooked. Students should not consume large quantities of leaves, because of their potential emetic properties (induce vomiting). We piloted this activity with more than 250 students and no student had a problem with tasting cucumber leaves. For further information see *http://allallergy.net/fapaidfind.cfm?cdeoc=469*.

- As many of the compounds present in cucumber fruits (also squash, zucchini, and melon) are present in cucumber leaves, **students who are allergic to cucumbers, squash, melon, and zucchini should NOT taste the cucumbers**. Someone else in their group can taste for them.

Lab notes

- This activity provides an excellent opportunity to remind students of the importance of math skills in biology. Mendel's insights came from the fact that he viewed his results in the form of ratios. His colleagues, many whom were doing similar experiments, all viewed their results as decimals, and therefore could not see the patterns that Mendel did. One cannot do science without the useful tool of mathematics.
- It's easiest to do this lab in pairs (or small groups). Students can consult about taste.
- Students should work in pencil, in case they need to change answers and hypotheses.
- You may want to skip the statistics section (Part IV) if it is too complicated for your students. The conclusions section (Part V) is designed to be relevant without Part IV.
- Disposal:
    - The plants can be used for Activity 3 as well. If you are not planning to reuse the plants, they can be thrown away. Alternately, students may enjoy the process of watching them grow for a longer period of time. Cucumbers in a warm greenhouse environment will produce seed in about three months. You can have students make crosses between bitter and non-bitter plants using a paintbrush or a bee glued onto a stick.
    - The planting containers and soil can be reused. The container should be washed out with soap and water. Ideally, to prevent accumulation of soil-borne diseases, soil should be autoclaved or baked in an oven between 180 and 200 degrees. The soil (not the just the oven) should be above 180 degrees for at least 30 minutes. (Higher temperatures can produce toxins.) Alternately, the soil can be sterilized in the microwave—90 seconds per kilogram (2.2 pounds) on full power.

Taking it further

You can also create other "unknown" genetic scenarios and have students deduce the genotypes of the parents, given the output.

Cross	Offspring	Simulate with
Bb x bb	Bb, Bb, bb, bb	2 bitter seeds : 2 non-bitter seeds
BB x anything	B?, B?, B?, B?	All bitter seeds

Further reading

Genetic action of the bitter gene in cucumbers

Robinson, R., A. Jaworksi, P. M. Gorski, and S. Shannon. 1988. Interaction of cucurbitacin genes. *Cucurbit Genetics Cooperative* 11: 23.

A-maize-ing photos of corn mutant plants

Neuffer, G., E. H. Coe, and S. R. Wessler. 1997. *Mutants of maize.* Woodbury, NY: Cold Spring Harbor Laboratory Press.

Activity 1.

Edible Punnett's Squares—Segregation Ratios You Can Taste

In the student edition, this activity begins on page 7.

Objective

To discover whether the bitter gene in cucumber plants is dominant or recessive.

Background

Cucumber plants, as well as their close relatives the squashes and melons, make a unique protein called cucurbitacin. Cucurbitacin tastes bitter to humans. Bitterness in cucumbers is caused by a single gene that has a recessive and a dominant allele. Your task in this assignment is to use your knowledge of genetics, particularly your understanding of crosses and Punnett's squares, to figure out how this bitter trait behaves. (Is bitterness dominant or recessive?) This is how scientists traditionally have learned about genes. They use populations of cucumbers or other organisms, make crosses, and use statistics to test their hypotheses about how genes behave.

Topic: Punnett Squares
Go to: *www.sciLINKS.org*
Code: GG05

Materials

- A population of "unknown" plants at cotyledon stage—about 10 days old
- Populations of bitter and non-bitter plants to act as taste controls—about 10 days old
- Plant tags
- Pencil
- Calculator (optional), for Part IV statistical analysis

Safety Notes

- Under normal circumstances, you should never taste anything in a biology laboratory. However, this laboratory makes an exception by asking you to taste a tiny piece of a cucumber plant's leaf.
- Students who are allergic to cucumbers, squash, melon, or zucchini should NOT taste the plants.
- If you are allergic or not comfortable tasting the plants, please ask someone else in your group to do it for you.
- You should wash your hands after handling the plants.
- You should wash your hands AGAIN at the end of the activity.

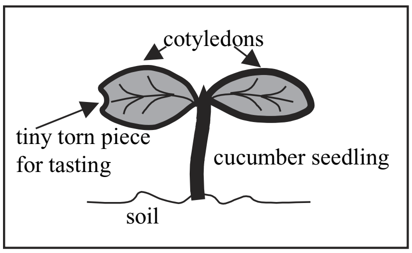
Activity

Part I. Your unknown population

1. Taste* the controls your teacher has set out. Tear a tiny piece off the edge of one of the cotyledons (see Figure 1.2). Chew the leaf between your front teeth, biting into it many times, and letting the flavor wash over your tongue. Can you tell the difference between bitter and non-bitter? Do you and your partner agree?

   The difference between bitter and non-bitter should be very clear to most people if they truly bite into the leaf. We have not heard of people lacking the ability to taste this bitterness.

Figure 1.2. Tasting the cotyledons of a cucumber seedling.



*Students who are allergic to cucumbers, squash, zucchini, or melon should not taste the plants.

Many of the compounds present in cucumber fruits (also squash, zucchini, and melon) are present in cucumber leaves. Students who are allergic to one of the above should NOT taste the cucumbers. Someone else in their group can taste for them. See teacher notes for more information.

2. Taste your own plants. Are they bitter? Non-bitter?

3. Once you have decided whether each of your plants is bitter or non-bitter, label that plant with a tag and place the tag in the soil next to the plant.

4. Taste your partner's plants. Are they bitter? Non-bitter?

   4a. Do your answers agree? Why or why not?

   Even though the differences between bitter and non-bitter plants are distinct, partners may not agree. Make sure students are really biting into the leaf. It is very bitter, so some students want to avoid this. They can re-taste controls, re-taste their own plants, taste each other's plants, and/or draw others into the discussion in order to resolve differences. It is a good idea to make sure students re-taste all non-bitter plants. Sometimes they don't chew the leaf enough to get a strong taste.

   4b. What can you do to improve your measurement?

   This is a real-world problem for scientists. Their major strategy is to replicate measurements. In this case, plants could be tasted multiple times and results could be averaged. Another strategy could be to create a tasting panel of "expert" tasters and accept the judgment of this panel for all plants.

   In all cases, the more data a student or scientist has, the less important any one data point is. Therefore, if one data point is wrong (and this happens!) it doesn't invalidate the results.

5. Collect the totals for the class. (Sample below)

Sample calculation	**Bitter**	**Non-bitter**	**Total**
Number of plants	40	15	55
Percentage	40/55 = 0.727 = 72.7%	15/55 = 0.272 = 27.2%	55/55 = 1.0 = 100%
Ratio	40/15 = 2.7 ≈ 3	15/15 = 1	*3:1*

To find the percentage, divide the number of plants in the bitter and non-bitter categories by the total number of plants. To find the ratio, divide the larger of the bitter or non-bitter number of plants by the smaller number of plants. Your results will probably not be perfect, whole numbers.

6. To figure out the genotypes of the parental generations, you need to know which genotypes go with which phenotype.

   6a. What is a phenotype? What are the phenotypes of your plants?
   A phenotype is the physical manifestation of the trait. Usually, the phenotype is how a plant looks or behaves. In this case, it is how the plant TASTES. Your phenotypes are bitter and non-bitter.

   6b. What is a genotype?
   A genotype is the genetic structure underlying the trait. Usually, we assign letters to represent the gene, so genotypes for these plants might be: AA, Aa, or aa.

7. Which phenotype is there more of?
   Bitter

At this point we don't know which allele is dominant. But you can make a hypothesis (an educated guess) using your data. In Part IV you will test whether or not the data support this hypothesis. Right now, there isn't a "right" answer, but there are two logical ones.

8. Make a hypothesis about which trait (bitter or non-bitter) is dominant. This will be the hypothesis you test in this activity. Support your hypothesis.
   Any logical reasoning for a hypothesis should be an acceptable answer. The students will test the hypothesis with the rest of the activity.

   Most students will choose "bitterness is a dominant trait" as their hypothesis. Most will give the abundance of the bitter phenotype as their reason. In general, as in this case, the dominant trait will be more abundant.

(However, in the world beyond bitter cucumber plants, there are many exceptions to this explanation because dominance and abundance are two independent concepts. Dominance relies on gene action. Abundance is a function of gene frequency. For example, human achondroplasia (a type of dwarfism) is a dominant gene that is at very low frequencies in human populations. As a result, very few people are dwarves even though the trait is dominant.)

9. Using your hypothesis from the last step, what symbol do you choose to represent the bitter allele? (Remember that dominant alleles are usually given a capital letter. Recessive alleles are usually given the same letter, but lowercase.)
   B (Another capital letter is acceptable.)

10. What symbol do you choose to represent the non-bitter allele?
    b (lowercase of letter in question 9.)

11. To summarize, fill in the table according to your hypothesis from step 8.

	Bitter	**Non-bitter**
Number		
Possible Genotypes	BB, Bb	bb

You may want to check students' work at this point. If they proceed with a "wrong" hypothesis, for example that non-bitterness is dominant, their results ultimately won't make sense. This is certainly the way it happens in laboratory science. Once they get to the end and see that their guesses are not consistent with the data they'll have to double back and redo these sections.

If students are seeing the material for the first time, or you're working together as a class, you may want agreement at this point. If students are advanced or working independently, you may want to let them proceed with "incorrect" assumptions.