Applied Animal Nutrition 300/500

Module 3

Grain feeding

Topic 14

14. Digestion of Grain

14.1 Principles of starch digestion

14.2 Digestion of carbohydrates in different species of animals

14.3 Starch digestion and fermentation in sheep and cattle

14. Digestion of Grain

Learning Objectives

On completion of this topic you should be able to:

- Discuss the animal factors influencing starch digestion in ruminants.
- Discuss the dietary factors influencing starch digestion in ruminants.
- Describe the biochemical processes of starch digestion and the importance of volatile fatty acid production to this process.

Key Terms and Concepts

Starch, fermentation acetate, propionate, butyrate, volatile fatty acid, site of digestion

Introduction to the Topic

Ruminant animals have evolved with the unique capacity to digest cellulose. The digestive tract of ruminants has developed in a way that allows them to survive and produce on roughage-based diets. In recent years, there has been an increasing incentive to feed concentrate diets based on cereal grains. The feeding of grain-based diets can improve animal production and produce a meat product that is more desirable to the consumer.

As ruminants have evolved to consume roughage-based diets, the provision of grain-based diets can cause digestive problems that may lead to morbidity and mortality. Therefore, careful management of grain-based feeding to ruminants is required. With careful management, significant improvements in the quality and quantity of production (milk, wool, meat and reproduction) can be achieved.

This module will provide you with an understanding of the metabolic implications associated with introducing grain-based diets to ruminant production systems and therefore an understanding of the management strategies available for commercial production.

14.1 Principles of starch digestion

In all animals, digestion occurs via a combination of microbial and enzymic digestion. Microbial digestion relies on enzymes produced by microbes whereas the host's digestion system relies on endogenous enzymes secreted into the digestive tract. Microbes possess a far wider range of enzymes than the animal's digestive system and are able to break down and utilise most feed components.

> Digestion of organic materials in feeds in the absence of oxygen is referred to as fermentation.

The fermentation provides gut microbes with the energy they need to survive and to grow. The end-products of the fermentation are principally the volatile fatty acids (VFA) as well as gases such as hydrogen, methane and carbon dioxide. VFA are rapidly absorbed from the gut and provide an important source of energy for the animal. As the microbes grow, microbial protein is synthesised and, in situations where fermentation occurs prior to gastric digestion, microbes provide a valuable source of amino acids for the host animal. When microbial biomass is produced by hindgut fermentation, the animal is not able to digest the protein or absorb amino acids and they pass from the animal in the faeces.

Enzymic digestion occurs in the gastric stomach and in the small intestine. Protein breakdown occurs in two main steps. The acid conditions in the stomach denature the protein and facilitate the activity of pepsin that mainly produces large peptide fragments and some free amino acids. The peptide fractions and amino acids are important in stimulating cholecystokinin (CCK) release in the duodenum which then plays a major role in gastric digestion by stimulating pancreatic enzyme production and intestinal enteropeptidase secretion. The supply of pancreatic enzymes into the small intestine is very important in providing both trypsinogen and α-amylase. Trypsinogen enters the intestine in pancreatic juice and is converted to trypsin by enteropeptidase produced by the intestinal mucosa. In addition to trypsin, chymotrypsin and elastase are also active in the small intestine and break down a wide range of peptides to amino acids.

The digestion of starch can be considered in three stages. Starch is converted by pancreatic α-amylase to a mixture of maltose, maltotriose, dextrin and glucose. The di- and poly-saccharides are then converted to glucose by glucosidases which are surface enzymes of the small intestinal epithelial cells. The monosaccharides (glucose, galactose and fructose) that result from the digestion of di- and polysaccharides are then absorbed either via the sodium- dependent monosaccharide co-transporter pathway or via sodium-independent facilitated diffusion.

14.2 Digestion of carbohydrates in different species of animals

There are some major differences between animal species in the efficiency of intestinal carbohydrate digestion and these are summarised in Table 14-1.

Maize is poorly digested by the horse—even when finely ground.

Maize is one of the grains with the highest apparent digestibility in poultry but is very poorly digested in the small intestine of the horse even when it is finely ground. Similarly, sorghum grain is well digested by poultry but is poorly digested in either the rumen or intestines of cattle when dry-rolled or ground. The differences in digestive efficiency between animal species is almost certainly related to differences in animal enzyme systems, and/or absorption capacity of the small intestine. An understanding of these differences may create exciting opportunities for new techniques for preparing and feeding cereal grains.

In ruminants, the digestion of starch in the small intestine may be limited by the availability of amylase (Ørskov 1986). Thus, oligosaccharidase activity and monosaccharide transport across the enteroctye are not thought to be the limiting factors. To date the nutritional manipulation of amylase secretion is not readily understood although it appears that protein/peptides entering the small intestine can stimulate amylase production and increase glucose absorption (Taniguchi *et al.* 1995).

Table 14-1 Differences between livestock species in their ability to digest cereal grains.

	Maize	Sorghum	Barley	Wheat	Oats
Whole tract digestibility					
(% of starch intake)					
Cattle[3]	93	87	93	98	98
Sheep	100[10]	97[10]	100[11]		
Pigs		100[4]	99[4]	100[4]	
Poultry	100[6]	99[7]	100[6]	100[6]	100[6]
Small intestine (pre-ileal)					
(% of starch entering stomach)					
Cattle[3]	66	63	73	85	76
Sheep	96[10]	71[10]	73[11]		
Pigs		72[5]-94[4]	93[4]	98[4]	
Poultry	85[9]	85[9]	80[9]	82[9]	
Horses	30	35[1]	25[1, 2]		85
Fermented in rumen					
(% of intake)					
Cattle[3]	76	64	87	89	92
Sheep	86[10]	85	94[11]		

[1] Householder *et al.* (1977); [2] Meyer *et al.* (1995); [3] Huntington (1997); [4] Pethick, Pluske and Van Barneveld (unpublished); [5] Owsley *et al.* (1981); [6] Mollah (1982); [7] Choct and Annison (1990); [8] Riesenfeld *et al.* (1980); [9] Choct *et al.* (unpublished); [10] Beever *et al.* (1970); [11] Ørskov *et al.* (1969)

14.3 Starch digestion and fermentation in sheep and cattle

Sheep are often used in nutritional studies of ruminant digestion and the data are then extrapolated to enable interpretation of results of feeding trials in cattle. With respect to whole tract digestibility of starch, the relationship between the proportion fermented in the rumen and that digested post ruminally, differs in measurements made in sheep and cattle. The reason for the different digestive processes is not entirely clear but it is likely to be related to the different sizes of sheep and cattle intestinal tracts and the dynamics of particle flow through the tract. The findings have highlighted the risk of extrapolating the data from sheep to cattle, particularly when cracked or rolled grain is used.

> The patterns and efficiency of starch digestion are different in sheep and cattle.

The benefits and disadvantages of fermentative and enzymic digestion in different parts of the tract are summarised in Table 14-2. From the animal's point of view, it is beneficial, in most situations, to maximise the digestion of starch and absorption of glucose from the small intestine. This is based on the energetic efficiency of intestinal digestion being approximately 30% higher than fermentative digestion. The digestion of starch in the intestine carries no risk of acidosis and can supply glucose as an important nutrient for marbling in beef production (Pethick *et al.* 1997).

The benefits of microbial protein production associated with fermentation are not likely to be as important in grain feeding systems for high levels of production in ruminants as are the potential risks associated with acidosis and reduced fibre digestibility resulting from an accumulation of acid during fermentation. In hindgut fermenters, such as the pig and horse, no microbial protein from caecal and colonic fermentation is available to the animal.

On the other hand, there are considerable risks, such as laminitis, associated with fermentative acidosis from high levels of starch reaching the hindgut (Godfrey *et al.* 1993; Rowe *et al.* 1995). There appear to be no benefits to any species associated with incomplete and inefficient digestion of starch from the small intestine. The role and manipulation of site of starch digestion is discussed in more detail elsewhere.

Table 14-2 Significance of site of digestion in determining nutritional value of grain (Channon and Rowe 2004).

	Positive Features	Negative Features
Rumen fermentation	• Microbial protein and vitamins available for intestinal absorption. • VFA absorption provides metabolisable energy.	• Acid accumulation and low pH leads to: risk of acidosis, reduced fibre digestion • Energy loss through heat, CH_4 and H_2.
Intestinal digestion	• No fermentation energy losses • Glucose absorbed which can increase marbling	• No microbial protein production
Hind gut fermentation	• VFA absorption provides metabolisable energy	• Acid accumulation and low pH leads to: risk of acidosis, reduced fibre digestion • Energy loss through heat, CH_4 and H_2.

The differences between animals in their digestive capacity with different grains highlight the importance of enzymic digestion. The most marked differences highlighted in Table 14-1 are those between the traditional grain eaters, poultry and pigs and the traditional roughage eaters, cattle and horses, particularly with respect to digestion of grains such as sorghum and maize. It is not clear exactly what enzyme systems within the animal are responsible for these major differences.

Readings

The following readings are available on CD:

- Cheng *et al.* (1998) A review of bloat in feedlot cattle. *Journal of Animal Science*. **76**: 299-308.
- Ghorbani *et al.* (2002) Effects of bacterial direct-fed microbials on rumen fermentation, blood variables and the microbial populations of feedlot cattle. *Journal of Animal Science*. **80**: 1977-1986.
- Huntington (1997) Starch utilization by ruminants: from basics to the bunk. *Journal of Animal Science*. **75**: 852-867.

Self Assessment Questions

1. Rank grains in terms of their efficiency of intestinal starch digestion.
2. Why do you think that poultry are able to digest starch more efficiently than ruminant animals?
3. Do measurements of grain digestibility in sheep give a good indication of the likely digestibility in cattle?
4. What are the benefits of enzymatic starch digestion compared to fermentative digestion?
5. Comment on the value of ground maize as a feed for horses.

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Pethick, D.W., McIntyre, B.L., Tudor, G., and Rowe, J.B. (1997). The partitioning of fat in ruminants—can nutrition be used as a tool to regulate marbling. In '*Recent Advances in Animal Nutrition in Australia.'* (Eds. J.L. Corbett, M. Choct, J.V. Nolan and J.B. Rowe). Pp.151-158. (University of New England, Armidale).

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Taniguchi, K., Huntington, G.B. and Glenn, B.P. (1995). Net nutrient flux by viceral tissues of beef steers given abomasal and ruminal infusions of casein and starch. *Journal of Animal Science* **73,** 236-249.

Topic 15

15. Characteristics of Grain that Influence Starch Digestion

15.1 Characteristics of grain affecting starch digestibility

15.2 Fermentation and digestion of grains measured *in vitro*

15. Characteristics of Grain that Influence Starch Digestion

Learning Objectives

On completion of this topic you should be able to:

- Describe the dietary factors influencing starch digestion in ruminant and monogastric animals.
- Explain the importance of non-starch polysaccharides on the digestibility of grains for monogastric animals.
- Describe the processes of starch digestion in ruminant animals.

Key Terms and Concepts

Starch Digestions; Digestion of Carbohydrates in different species of animals; Starch digestion and fermentation in sheep and cattle.

Introduction to the Topic

The selection of a grain and method of processing should aim to provide a feed that suits the digestive capacity of the animal. Differences between grains are based not only on the macro nutrients such as starch, lipid and protein, but also on components such as non-starch polysaccharides (NSP), which can have a negative effect on intestinal digestion, and lignin which reduces fermentative digestion. The characteristics of starch granules and the endosperm matrix also have important effects on digestibility and response to processing, and must be considered when designing processing techniques.

Cereal grains are primarily used in animal diets as energy sources. A simple estimate of energy utilisation by the animal is the digestible energy. There are, however, limitations in using this gross measure of energy utilisation to determine the nutritive value of grains. Firstly, the animal does not use MJ of energy *per* *se* but rather uses specific nutrients made available from the digestion of the feed. Secondly, the pattern of fermentation and site of digestion can have a significant effect on the nature of the nutrients available and the amount of useable energy available to the animal. For this reason an understanding of the factors that influence the partitioning between microbial fermentation and the animal's enzymic digestion is important in determining the nutritive value. Although there are well established methods of processing grains to achieve efficient digestion across the whole digestive tract in ruminants, pigs and chickens, information on the effect of processing and grain type on the site of digestion within the digestive tract is scarce.

15.1 Characteristics of grain affecting starch digestibility

Seed coat— Each seed is protected by a seed coat, which can include a hull, and always a pericarp protecting the grain from moisture, insects and fungal infection. The seed coat must be cracked by chewing or *mechanical processing to expose the endosperm and starch for* digestion. Once the seed coat is cracked the coat has little impact on the subsequent digestion of starch. The main nutritional significance of the seed coat is the extent to which it dilutes the amount of starch in the diet and this is seen in Table 15-1 for a number of different grains. In oat grain, the hull represents around 25% of the dry matter and its digestibility is important in determining overall nutritive value of the grain particularly as the hulls of some cultivars have high levels of lignin and are almost indigestible On the other hand, grains such as sorghum, the pericarp represents only 3% to 6% of the grain weight and, provided the grain is efficiently cracked, this seed coat has little effect on the overall nutritional value of the grain.

Endosperm—The endosperm contains the individual starch granules surrounded by a matrix consisting of protein and non-starch polysaccharides (NSP). The nature and chemical composition of this matrix has a profound effect on the physical characteristics of the endosperm and the exposure of starch granules to enzyme digestion. In maize and sorghum, the protein matrix coating the starch granules in the corneous and peripheral endosperm is important in reducing digestibility. In wheat the protein matrix consists of gluten which completely surrounds the granules in the case of hard wheats and only partially for soft wheats. The effect of protein levels in wheat and barley on fermentation and digestion does not appear to be well established. However, in wheat, barley, oats and rye the protein matrix is closely associated with NSP such as glucans and arabinoxylans which can have an important effect on digestion (Table 15- 1 and Figure 15-1). Together the NSP and the protein matrix of the endosperm play a very important role in starch digestion and these are discussed below.

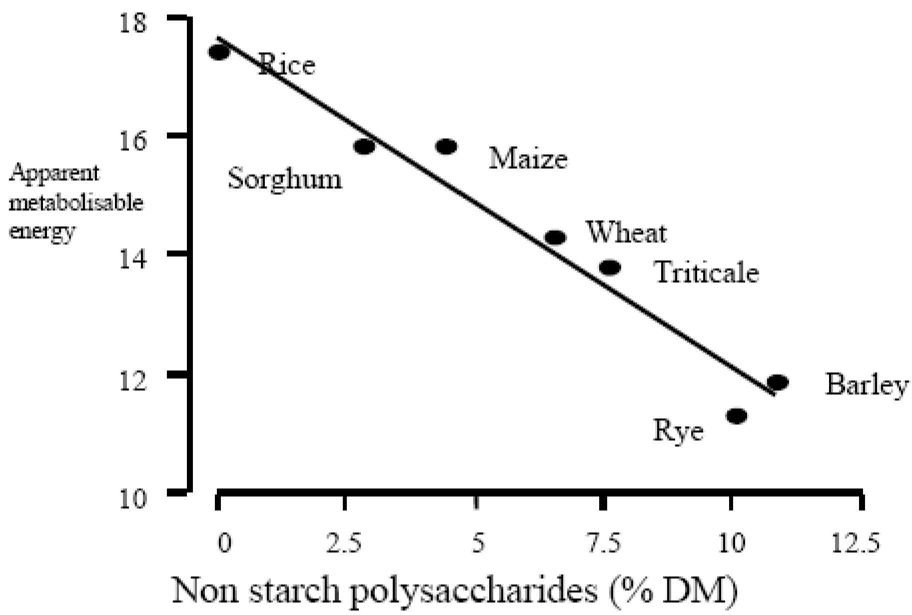
Non-starch polysaccharides—Much of the variation in nutritional value of cereal grain fed to monogastric animals is explained by the soluble NSP content of the endosperm and the adverse effects these compounds have on digesta viscosity and the efficiency of digestion. Figure 15-1 shows the relationship between the NSP content of different grains fed to poultry and the apparent ME derived from these feeds. The soluble NSP play a role in the depression of pre- ileal starch digestion in poultry. For example, the ileal digestibility of starch in a sorghum based broiler diet was 98% but when purefied wheat soluble NSP was added this declined to 92%.

Table 15-1 Characteristics of different cereal grains (from 1 Nocek and Taminga (1991); 2 Huntington (1994); 3 Opatpatanakit *et al.* (1994); 4 Leach (1965) and 5 Choct (1997). The data refers to grains hammermilled or dry rolled.

	Maize	Sorghum	Barley	Wheat	Oats
Starch content (% of DM)[1]	76	75	61	76	42
Solubility (% loss from nylon bags)[1]	26	32	54	68	96
Gas production (ml/g DM after 7 h)[3]	138	104	222	251	237
Temperature of gelatinisation [4]	62-72	69-75	-	52-63	-
Soluble NSP content (% DM)[5]	0.1	0.2	4.5	2.4	
Insoluble NSP content (% DM)[5]	8.0	4.6	12.2	9.0	

The effects of soluble NSP are now well recognised in the poultry industry and grains of low soluble NSP are selected and/or enzymes are used to overcome the problems associated with the NSP fraction. The importance of NSP in the nutrition of other animal species is not well established. In pigs, horses and ruminants, hind gut fermentation ensures that carbohydrate undigested in the small intestine is broken down and efficiently absorbed as VFA. The combination of fermentative and enzymic digestion in these species produces a consistently high value for digestible energy but a pattern of digestion which may be inefficient through higher levels of fermentative digestion and reduced intestinal absorption. It is not only the negative effect of energy loss, through fermentative digestion of NSPs as opposed to intestinal absorption of glucose which reduces the apparent metabolisable energy, but the effect that the NSP have on the viscosity of digesta and the absorption of other nutrients. The effect of NSP on viscosity of digesta may also increase the risk of bloat which results from the formation of a stable foam during fermentation.

Figure 15-1 The relationship between apparent metabolisable energy (MJ/kg DM) and NSP content (% of DM) of grains in broiler chickens. From Choct and Annison (1990).



Protein bodies and the protein matrix—The importance of protein in the endosperm is very well defined in the case of sorghum where it is present in two components in both the peripheral and corneous endosperm. One component is a matrix consisting largely of glutelin and the second, globular protein bodies made up of kafirins. The starch granules in the peripheral, corneous, endosperm are surrounded by far more of these protein globules and a more dense matrix than the granules in the floury endosperm near the centre of the grain which are more accessible to enzyme degradation. While both the protein storage bodies and the glutelins in the endosperm matrix are insoluble in water, it is interesting that the glutelins can be extracted by alkali and that the kafirins are soluble in alcohol. This suggests that chemical treatment using alkali and/or alcohol may be useful in modifying the endosperm and improving starch digestibility of sorghum. Further evidence that the protein content of the endosperm is a primary factor limiting starch digestion is the finding of increased glucose release following pre-treatment of sorghum endosperm with the proteases, 'Pronase' or pepsin.

Starch characteristics—The chemical composition of the starch in cereal grains also determines the rate and extent of digestion.

Starch is primarily a branched chain polymer amylopectin with a smaller amount of the linear polymer amylose. Amylopectin has a less crystalline structure, a greater solubility and is more rapidly broken down by amylase than the linear amylose. A lower temperature is required for gelatinising starches containing low levels of amylose. The waxy genotypes of maize and sorghum, and barley have higher levels of amylopectin (nearly 100%) while the non-waxy varieties have less amylopectin (75%) and more amylose (25%) (Rooney and Pflugfelder 1986). In cattle, the waxy genotypes of maize and sorghum produce increased animal performance even with dry processing (cracking, rolling) compared to the non-waxy varieties, indicating more complete digestion of starch with lower amylose content. With the current perception that starch fermentation in the human hindgut may have benefits for health there is an increased production of high amylose maize which has the property of low intestinal digestion because the straight amylose chains form tight bundles of starch molecules preventing penetration by water and amylolytic enzymes.

Gelatinisation of starch—Moisture and elevated temperatures start the process of gelatinisation which is characterised by a disruption of the matrix binding the starch cells by an expansion of the starch granules. The starch granules do not change in appearance until a certain critical temperature is reached. At this point they swell and lose their characteristic polarisation crosses and this point is easily recognised by microscopic examination. The temperature at which this change occurs is called the gelatinisation temperature and is characteristic of different grains. The temperature ranges over which gelatinisation occurs differs between grains and are summarised in Table 15-1. It is clear that maize and sorghum have far higher temperatures of gelatinisation than wheat. Gelatinisation temperature is not markedly affected by whether or not the grain is of a waxy or non-waxy type. On the other hand high-amylose maize starch shows exceptional behaviour in that it resists gelatinisation even in boiling water. It is thought that this is due to the linear nature of its molecules which are highly associated and able to resist water penetration. The gelatinisation temperature can be altered by various chemicals. For example, sodium nitrateor urea can be used to lower the gelatinisation temperature and to increase swelling. On the other hand, sodium sulphate can be used to reduce granule gelatinisation. This again suggests new ways in which different processing techniques may be adapted to manipulate site and rate of digestion.

Although there are significant differences between grains in the size and characteristics of starch granules it appears that the roles of the protein matrix and NSP in binding the granules together are more important than granule structure per se in determining the rate and extent of fermentation). The digestibility of purified starch granules isolated from different cultivars of sorghum and maize showed sorghum starch to be more digestible than corn starch and emphasises the importance of the endosperm matrix in determining starch digestibility in the animal. Studies also suggest that that the characteristics of the endosperm are more important than the presence or absence of the seed coat in determining rate of digestion of ground grain.

15.2 Fermentation and digestion of different grains measured *in vitro*

Dr Simon Bird and his colleagues developed methods for measuring the rate of rumen fermentation of starch and its digestibility in the small intestine. Some differences between grain identified during these studies are summarized in Table 15-2.

Table 15-2 Fermentation of starch in different grains (% disappearance in 5 hours) and the conversion of starch to glucose by amylase and amyloglucosidase (1 hour). (From Bird *et al* 1999).

Grain type	Fermentation		Enzyme digestion	
	Mean	Range	Mean	Range
Barley	67	52-76	45	37-53
Wheat	48	35-63	43	37-47
Oats	72	70-77	61	57-66
Sorghum	44	35-51	28	23-33
Triticale	60	52-78	70	65-76
Maze	42		29	

The data of Bird *et al.* (1999) shows the significant differences between barley and sorghum grain in terms of rate of fermentation as well as enzymatic digestion of starch. This explains this why sorghum requires extensive processing if it is to be efficiently used by cattle. The data also shows a large range in the rate of fermentation of wheat grain and this partly explains variability in the risk of acidosis when wheat grain is fed to sheep or cattle. It is interesting that grain is such as oats that are known to be safe for ruminant feeding actually fermented more quickly than grain is considered to be more dangerous such as wheat and barley. One possible explanation for this apparent anomaly is the hypothesis that the consequences of fermented of acidosis in the hind gut may actually be more severe than rapid fermentation in the rumen.

The relatively low enzyme digestibility of wheat is consistent with its high level of non-starch polysaccharide and a relatively low contest the digestion indicated in Figure 15-1.

Readings

The following readings are available on CD:

- Bird *et al.* (1999) In vitro fermentation of grain and enzymatic digestion of cereal starch. *Recent advances in animal nutrition in Australia.* **12**: 53-58.
- Owens *et al.* (1997) The effect of grain source and grain processing on the performance of feedlot cattle. *Journal of animal science*. **75**: 868-879.
- Rowe (1999) How much acid in the gut is too much? *Recent advances in animal nutrition in Australia.* **12**: 81-86.

Self Assessment Questions

1. Rank the main feed grains in order of rate of fermentation.
2. Which feed grains are likely to require the most extensive processing in order to increase starch digestibility in cattle?
3. What characteristics of grain influence the rate and extent of digestion and fermentation?
4. Under what conditions does the seed coat influence the digestibility of the grain?
5. Why is the temperature of gelatinisation likely to be an important characteristic of a cereal grain?

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Topic 16

16. Methods of Processing Grain

16.1 Options for grain processing

16.2 Processing and feeding management to manipulate site of digestion

16.3 Summary of objectives when processing grain

16. Methods of Processing Grain

Learning Objectives

On completion of this topic you should be able to:

- Discuss the various types of grain processing available.
- Explain how grain processing can impact on the digestion of grains.
- Discuss the impact of grain type on the selection of processing method.

Key Terms and Concepts

Options for grain processing; Processing and feeding management to manipulate site of digestion; Summary of objectives when processing grain.

Introduction to the Topic

In this lecture we cover two major topics. Firstly there is a description of each type of grain processing. Secondly there is a discussion of the way grain processing can change site of digestion and thirdly, there is discussion of the objectives of grain processing

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16.1 Options for grain processing

Animal and microbial enzyme systems are most effective against hydrated starch, but processing grains to the point of hydrating all the starch is rare for animal feeding. However it occurs, to some extent, during steam-flaking, pelleting and exploding of grains. The minimum processing required to ensure efficient grain digestion by most animals is cracking the pericarp to expose the endosperm. The second level of processing involves the degree of grinding and rolling and the extent to which particle size is reduced. Particle size determines the surface area which is exposed to microbial and digestive enzymes and influences the number of starch granules freed from the protein and non-starch carbohydrate matrix of the endosperm. Even small particles can contain individual starch granules tightly bound within the endosperm matrix and protected from enzymic digestion. The third level of processing deals with the situation when starch granules are tightly held within the endosperm matrix it may be necessary to use high temperatures with or without water to disrupt the granules to expose the starch to enzyme digestion through hydration and/or gelatinisation.

Whole grains can be readily fed to sheep (which can efficiently chew grain) and in chickens (where grains are broken down by a combination of soaking and grinding in the crop and gizzard). The gizzard requires adaptation to allow full development and efficient breakdown of grains. The time taken for adaptation of the gizzard does not present a problem in layers but in broilers, feeding whole grains can reduce FCE because there is less time for the development of efficient crop and gizzard function. Cattle and pigs have only a limited ability to chew cereal grains, especially the smaller grains, and so it is essential to break the seed coat by either mechanical or chemical treatments before feeding. Oat grain represents an exception as it is efficiently used by cattle and horses, even when fed whole and without any processing. Table 16-1 summarises the major types of grain processing, the effects on the grain and consequences for animal digestion. Each of the processing techniques is described in more detail below.

Cracking, dry rolling and grinding

These methods, while not identical, are grouped together since the method of action is to break the seed coat, reduce particle size, and so increase the surface area for digestion. Rolling can be used to crack the seed coat in order to allow entry of bacteria and digestive enzymes while retaining a large particle size which will partially limit the rate and extent of digestion or fermentation. Grinding or milling, on the other hand, can produce extremely fine particles which can be rapidly fermented or digested. The hardness and vitreosity of the grain affect its response to physical processing. The harder the grain, the more the damage to the starch granules during processing. Harder grains are also more prone to shearing and shattering than are softer grains where the starch granules tend to remain intact.

The effect of particle size on the digestibility of starch in pigs (30 kg starting weight) fed sorghum grain is very clear from the work of Owsley *et al.* (1981) who found ileal digestibility increased from 72% for dry rolled sorghum (1.3 mm particle size) to 86% for hammermilled sorghum passed through a 3.2 mm screen (0.5 mm particle size). The effects of particle size on overall diet digestibility are not profound in older pigs although positive responses have been found for sorghum in weaner pigs and maize in finisher pigs. One limitation of reducing the particle size of grains for pigs is the associated increase in the incidence of stomach ulceration.

Table 16-1 Summary of the effect of various processing techniques on the grain and on digestive function (Owsley *et al.* 1981).

Treatment process	Disrupts seed coat layer and/or exposes endosperm	Reduces particle size	Separates starch granules and/or disrupts endosperm matrix	Disrupts starch granules and/or causes hydration and gelatinisation	Processing increases		Improves overall digestibility		
					Fermentation rate	Intestinal digestion	Cattle	Pigs	Poultry
Dry rolling	+++	+			++	+	++	+	
Grinding/milling	+++	+++			++	+	++	++	
Steam flaking	+++	++	+	+	+++	++	+++	+++	++
Extrusion	+++	-	++	+	++	++	+++	+++	++
Pelleting	+++	-	+	+	+	++	+++		++
Reconstitution/Ensiling	+		?	?	++	+			
Micronisation	+	+	?	?	?	++	++	?	?
Popping	++	-	+	+++	?	+++	?	?	?
Microwave			?	?	?	?	?	?	?
NaOH whole grain	+		?	?	+	++	+	?	?
NaOH ground grain			?	?	?	?			
Enzymes (exogenous)									
Amylase					?	++	+	+	+
Glucanase			?	?	?	++	?	++	++
Arabinoxylanase			?	?	?	++	?	++	++
Protease			?	?	++	?	?		

High moisture (reconstitution) treatment followed by rolling

This is a refinement on simple cracking or grinding with effects on the seed coat and surface area similar to, but less extreme than dry rolling (i.e. the individual grains typically remain intact). An additional effect is the activation of the endogenous enzymes of the grain, which may induce changes to the grain, making it more soluble and fermentable before feeding.

Pelleting

Pelleting is a common commercial process where small particles are combined into a larger particle by means of a mechanical process in combination with moisture, heat and pressure. Starch is partially gelatinised by the heat and steam used in the conditioning process (usually 10-15 seconds) as well as the heat of friction generated as the feed passes through the dye. A further feature of pelleting is that it allows flexibility with respect to particle size of the feed to be pelleted, and control over the density and the final pellet size. It therefore offers a mechanism for controlling rate and site of digestion.

Steam flaking

This treatment is a process whereby the whole grain is heated with steam for 10-40 minutes and subsequently rolled to varying degree. The process breaks the seed coat and endosperm, thus having a surface area effect although the whole grain does remain as one. In addition, the cooking gelatinises much of the starch making it more susceptible to amylase attack. The amount of cooking is very important in determining the extent of intestinal digestion.

Extrusion

Extrusion of grain involves moisture, high temperature and pressure. The feed being extruded is propelled through a barrel where it encounters resistance to flow, which generates frictional heat. The barrel may be steam jacketed or have steam injected into it. The temperatures of extrusion are high (125-170°C), however, there is a relatively short time (15-30 seconds) at these high temperatures. The principal aim of extrusion is to achieve a high level of starch gelatinisation. While the effect of extrusion cooking on digestibility of various cereals is well understood for human and monogastric nutrition, the interaction between degree of gelatinisation and the physical characteristics of the final feed is not well documented in terms of the combination of fermentation and digestive processes in ruminant animals.

Ensiling

Ensiling of grain allows partial conversion of the starch to organic acids, principally lactic acid, which in turn help preserve the grain. After ensiling, the starch granule is more readily attacked by microbial enzymes. The high moisture levels in silage allow endogenous enzyme activity until the pH drops as a result of fermentation. Provided anaerobic conditions are maintained, silage can be stored for long periods of time.

Micronisation

In this process, the grain is first soaked, then passed over high temperature infrared burners and finally rolled. The action is similar in principle to steam flaking, allowing the grain to remain partly intact but with a reduced density and increased susceptibility to amylolytic digestion.

Microwave treatment

Although well known as an energy efficient and rapid cooking technique in food preparation, it has not been widely evaluated as a means of treating grains for animal feeding. This has possibly been due to the restriction imposed by batch processing associated with traditional microwave technology, but may be useful now that continuous microwave processing is feasible.

Chemical treatment

Treatment of feeds with hydroxides reduces the resistance of the seed coat to digestion and the use of formaldehyde reduces microbial degradation of proteins. The use of formaldehyde to protect protein against microbial attack has been applied to a number of feed components. By coating starch, lipid or other ingredients with formaldehyde-treated protein, the whole complex can be protected against microbial attack. As various protein fractions are soluble in alcohol or alkali, it is possible that these chemicals could be used for pre- treatment of the endosperm, particularly in the case of sorghum grain.

16.2 Processing and feeding management to manipulate site of digestion

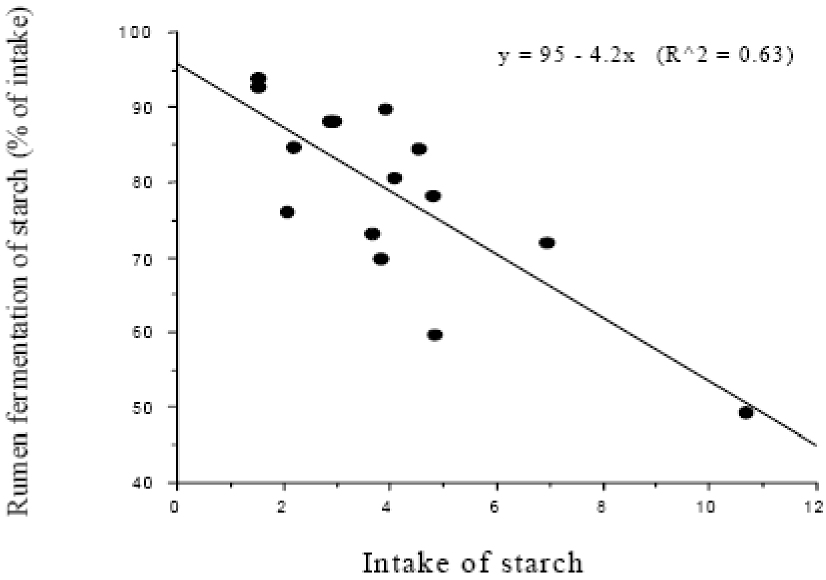
The site of digestion is important in terms of productivity and health in ruminants, horses, pigs and poultry. We will now consider improving intestinal digestion and minimising the risk of adverse effects of rapid fermentation of starch. While there is extensive information on the effect of processing on rumen and post- ruminal digestion, there is less information on the relative contributions of the small intestine and the large intestine to post-ruminal digestion and absorption of nutrients.

The relationship between the total intake of starch and the proportion that is fermented in the rumen is shown in Figure 16-1. With increasing level of intake, starch digestion in the rumen is decreased. This is most probably related to an increased rate of feed particle passage as intake increases, and reduced time for fermentation in the rumen. In horses the level of starch intake also has a major effect on pre-ileal digestion. It appears that with meal sizes greater than 1.8g/kg body weight, an increasing amount of starch passes undigested to the large intestine where it will be rapidly fermented.

> Treatment of proteins with formaldehyde can greatly reduce their digestion by microbial enzymes in the rumen.

While the critical factors limiting intestinal starch digestion in the horse are not well understood, it is likely that digestive enzyme activity, methods of grain processing and rate of passage (digesta resident time) are all involved.

Figure 16-1 Relationship between intake of starch and the percentage of dietary starch fermented in the rumen for a range of different grains and processing techniques (from Huntington, 1997).



Effect of processing on rumen fermentation and post-ruminal digestion

Steam flaking is a very effective form of grain processing since it acts to break the seed coat and endosperm and also to gelatinise the starch. Figure 16-2 summarises the effect of steam flaking on a range of different grains. It is clear that grains such as barley, wheat and oats, which have a naturally high fermentation and intestinal digestion when ground or dry-rolled, are not affected as much by steam flaking as are grains like sorghum and maize. The review by Owens *et al.* (1997) indicates there is a small but significant improvement in productivity associated with steam treatment of wheat, whereas consistent and significant benefits can be obtained for sorghum and maize by steam treatment and re-constitution procedures. Figure 16-2 also shows that the steam flaking process brings most of the grains to a similar level of digestibility and rumen fermentability. It illustrates the potential of both sorghum and maize for manipulation with respect to site of digestion, since both parameters are significantly increased by the physical and chemical transformation which take place during steam pelleting. Sorghum and, to a lesser degree, maize, are far less extensively fermented in the rumen than barley or wheat and this characteristic provides the potential for feeding systems which deliver unfermented starch to the small intestine. The problem with both sorghum and maize is that starch escaping the rumen is only around 60–70% digested in the small and large intestines. The potential challenge is, therefore, to find processing treatments which are effective in improving post ruminal digestion without increasing the extent of rumen fermentation.

Site of digestion in the horse

The site of starch digestion in the horse is markedly affected by grain type and processing. Table 16–2 summarises the links between the pre-ileal starch digestion and the physical changes in starch granules determined by microscopic examination of the jejunal chyme. It highlights the importance of separation between starch granules as well as the process of digestion of individual granules. Kienzle *et al.* (1977) suggest that particle size may have more impact on microbial fermentation than the structure of the starch granule but that, for intestinal enzymic digestion, it is the structure of the granule, rather than the particle size, which is more important. The studies reported by Snow and O'Dea (1981) tend to support this suggestion in the case of barley but indicate significant effects of particle size on rate of enzymic digestion of starch in oat and wheat grains.

Figure 16–2 Effect of steam flaking on rumen fermentation and post- ruminal digestion of different grains. The "unflaked" grain was fed in a ground or dry-rolled form and measurements were made in cattle (from Huntington, 1997).

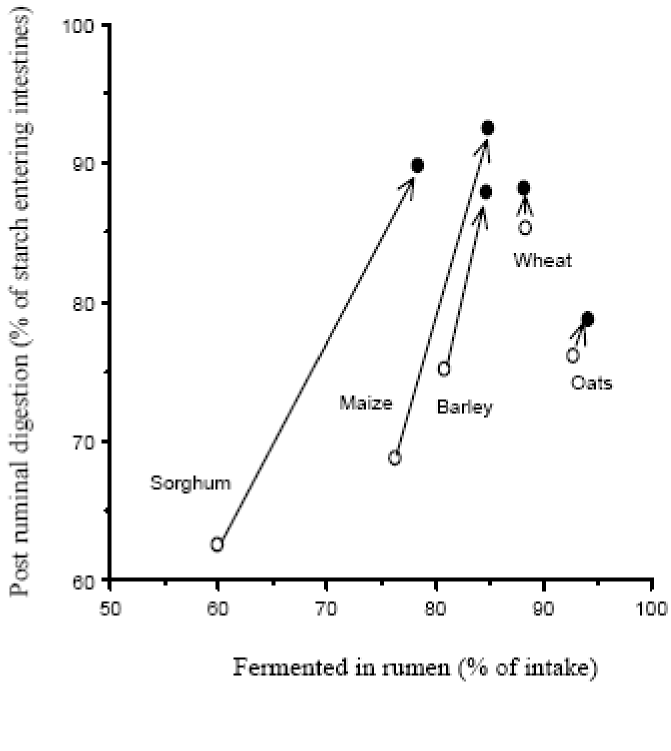


Table 16-2 Relationship between starch structure in jejunal chyme and pre-ileal starch digestion from Kienzle *et al.* 1997).

Grain	Processing	Pre-ileal digestibility granules	Loosening between	Evidence of granule digestion	
				Pin holes	Corrosive areas
Maize	Whole	29	-	++	-
	Ground	47	+	++	-
	Silage	80	++	+++	(+)
Barley	Ground	22	++	+	-
Oats	Ground	80-85	+++	-	+++
Potato		7	-	(+)	(+)

16.3 Summary of objectives when processing grain

Maximising ME and measuring it accurately

Cereal grains are principally fed to provide ME and, as a primary objective, processing techniques must be designed to maximise total digestibility of the diet. Being able to measure or predict the availability of ME is very important and this may not always be straightforward. With ruminants, the negative effect of rumen pH on fibre digestion may actually have the opposite effect on overall diet ME and feed intake to that predicted from measuring *in vitro* digestibility of the grain on its own. Similarly the contribution of high levels of grain to the availability of ME may be different to the overall effect when the grain fed is fed at low levels. It may therefore be necessary to develop a better measure of ME for ruminants animals fed high levels of processed grains where the negative effects of rapid fermentation and low pH may reduce the beneficial contribution of the grain to the nutritive value of the diet.

Maximising digestion of starch in the small intestine

There are three reasons for wanting to maximise intestinal digestion:

- starch digested and subsequently absorbed as glucose represents a more energetically efficient process than fermentation of starch and absorption of VFA;
- to provide specific nutrients such as glucose as opposed to VFA; and
- to reduce the risk of extensive and rapid fermentation in the hindgut increasing the risk of acidosis.

Black (1971) illustrated the relative efficiency of absorbing glucose, as opposed to allowing fermentation of the glucose to VFA, prior to absorption and utilisation by the animal. Fermentation of starch in the rumen is associated with loss of energy as heat and methane or hydrogen. The importance of small intestinal digestion of starch has recently been highlighted in heavy weight cattle fed for the Japanese beef market. Meat for this market requires a high level of intra- muscular fat and recent work by Pethick *et al.* (1997) has identified the importance of glucose supply to increase fat deposition as intramuscular fat.

Reduce the rate and extent of starch fermentation in the rumen of sheep and cattle

The pH during fermentation in the rumen or the hind gut is determined largely by the rate of carbohydrate fermentation and, to a lesser extent, by the salivary and exogenous buffers and the rate of VFA absorption from the gut. Rapid fermentation leads to the accumulation of acid in the rumen: the low pH disrupts the microbial balance which results in fermentation characterised by lactic acid. Lactic acidosis has serious implications for production and health of the animal. The problems associated with acidosis are widely recognised and have a profound effect on the selection of grain, and the methods by which it is fed.

The objective of shifting the site of digestion from the rumen to the small intestine contrasts to some views expressed in the literature. Ørskov (1986) and Huntington (1997) suggested that for both dairy and beef cattle, ruminal starch digestion was overall more desirable than in the intestine. Their view was based on,

(i) an increased supply of microbial nitrogen as a result of starch fermentation in the rumen which will be important for dairy cattle and younger beef animals;

(ii) the negative relationship between extra glucose supply and milk fat, and perhaps most importantly

(iii) the apparent poor digestibility of starch in the small intestine of ruminants and the associated risk of acidosis in the large intestine.

If starch is incompletely digested in the small intestine the proximal part of the large intestine (caecum, proximal colon) can receive a significant and potentially harmful load of fermentable starch. Importantly, increased fermentation of this starch in the large intestine can have negative impacts on animal health. For example hindgut acidosis is the basis of laminitis in horses, and is associated with enteric disease in pigs and adverse behaviour in horses. Minimising the amount of undigested starch passing to the hind gut should therefore be considered as an important objective in grain selection and processing.

Readings

The following readings are available on CD:

- Huntington (1997) Starch utilization by ruminants: from basics to the bunk. *Journal of Animal Science*. **75**: 852-867.
- Oliviera *et al.* (1995) Nutrition, feeding and calves. *Journal of Dairy Science*. **78**: 1318-1327.
- Owens *et al.* (1997) The effect of grain source and grain processing on the performance of feedlot cattle. *Journal of animal science*. **75**: 868-879.
- Rowe *et al.* (1999). Processing cereal grain for animal feeding. *Austr. J. Agric. Res*. 50: 721–36. (Details of references cited in this lecture are included in this paper).

Self Assessment Questions

1. Outline the ways in which steam flaking alters the structure of the grain and the effects of these changes on the site and extent of digestion of sorghum in the digestive tract of cattle.
2. Does steam flaking have as big an effect on extent and the site of digestion of wheat as it does on sorghum? What is the reason for the different responses?
3. Do you think that grain type is more important than the method of processing in determining the site of digestion of starch in horses?

References

Black, J.L. (1971). A theoretical consideration of the effect of preventing rumen fermentation on the efficiency of utilisation of dietary energy and protein in lambs. *British Journal of Nutrition* **25**, 31-55

Huntington, G.B. (1997). Starch utilisation in ruminants, from basics to bunk. *Journal of Animal Science* **75,** 852-867.

Kienzle, E. Pohlenz, J. and Radicke, S. (1997). Morphology of starch digestion in the horse. *Journal of Veterinary Medicine* **44,** 207-221.

Ørskov, E.R. (1986). Starch digestion and utilisation in ruminants. *Journal of Animal Science* **63,** 1624-1633.

Owens, F.N., Secrist, D.S., Hill, W.J. and Gill D.R. (1997). The effect of grain source and grain processing on performance of feedlot cattle, a review. *Journal of Animal Science* **75,** 868-879.

Owsley, W.F., Knabe, D.A. and Tanksley, T.D. (1981). Effect of sorghum particle size on digestibility of nutrients at the terminal ileum and over the total digestive tract of growing-finishing pigs. *Journal of Animal Science* **52,** 557-566.

Snow, P. and O'Dea, K. (1981). Factors affecting the rate of hydrolysis of starch in food. *The American Journal of Clinical Nutrition* **34,** 2721-2727.

Applied Animal Nutrition 300/500

Topic 17

17. Grain Storage, Exogenous Enzymes and Germination

17.1 Storage and grain quality

17.2 Role of exogenous enzymes

17.3 Germination and steeping/reconstitution

17. Grain Storage, Exogenous Enzymes and Germination

Learning Objectives

On completion of this topic you should be able to:

- Define non-starch polysaccharides and their importance to the nutritive value of feeds.
- Explain the implications of oil/fat content of feedstuffs for storage.
- Discuss the impact of the duration of feed storage on feed quality and if this is variable according to feedstuff.

Key Terms and Concepts

Storage and Grain quality; Role of Exogenous enzymes; Germination and steeping/reconstitution.

Introduction to the Topic

The storage of grain is a most important component of any grain feeding production system. Inappropriately managed storage systems can reduce grain quality and even render grain unsuitable for feeding to livestock. For opportunistic grain feeding production systems, grain storage can provide significant financial benefits by allowing the producer to purchase grains at times when demand and therefore prices ($/tonne) are lower than during the peak demand periods. It is not unusually for grain prices to fluctuate by more than 100% between the high and low demand periods.

This topic will introduce you to some of the common problems encountered with grain storage and management options available for addressing and preventing these problems.

17.1 Storage and grain quality

Studies in poultry have shown that the apparent ME values of cereal grains can vary considerably depending on time after harvest. It is also well known that changing from 'old' season stored grains to new batches of grain can have major effects on digestive disorders in feedlot cattle and dairy cows. The reasons for differences between stored and new season grains have not been well understood.

At the time of harvest grains consist of at least two living entities, the grains themselves; and the micro-organisms colonising them. Both entities can bring about various degrees of physical, chemical and biological changes during storage. One such change is the activity of the endogenous enzyme systems within the grain which, with time, can act on the cell wall structures in a similar way to exogenous feed enzymes. This action of the enzymes during storage can result in improved nutritive value of cereals for poultry and could also have important consequences for the efficiency of digestion of cereal grain in other species.

> Post-harvest changes in the nutritive value of grains may be due to endogenous metabolism and microbial activity.

Monogastric animals

Mature cereal grains contain various amounts of glycanases and glycosidases, although the levels are relatively low. After harvest, the grains continue to change through ongoing endogenous biochemical reactions. Slow degradation of the NSP and starch by endogenous enzymes is possible under these conditions. Some well-documented cases demonstrating the importance of endogenous enzymes include large improvements in performance of birds fed germinated, water-treated or rain damaged grains. The nutritive value of wheat improves markedly with storage time, with their AME values for poultry increasing from 10 MJ to 13 MJ/kg dry matter over a 4-month period. Germination of wheat also results in a large decrease in the molecular weight and viscosity of the NSP with no noticeable amounts of monosaccharides released. It is now clearly understood that the improvement in bird performance by enzyme supplementation is not due to a complete breakdown of the NSP to monosaccharides and a subsequent absorption of the released sugars by the animal, but rather due to the partial cleavage of the polymers, thus removing their anti-nutritive effects. Therefore, even very small amounts of enzyme activity can cleave NSP molecules once or twice and result in a large increase in nutrient digestion and absorption.

> Glycan is a general name for a carbohydrate molecule consisting of chains of sugar units, i.e. polysaccharide.

Table 17-1 summarises some data on post-harvest changes in the AME of wheat in broiler chickens. It is worth noting that the improvement in the nutritive value of wheat is not universal and is related to varieties or grain types. Thus some wheats showed significant improvements in both AME and FCR, whereas others were relatively stable.

> Partial cleavage of NSP molecules can reduce their anti-nutritional effects in animals.

While the endogenous enzyme activity and grain quality for chickens can be increased with higher temperatures and moisture levels during storage these conditions also encourage microbial growth, moulds and produce increased fat rancidity and the loss of protein through conversion to ammonia. Some of these adverse side effects can be prevented by the ensiling process where high levels of acids prevent ongoing bacterial and fungal activity. There may be ways of enhancing or accelerating the activity of the endogenous enzyme systems to improve nutritional value in a more repeatable way by subtle increases in temperature and moisture content without creating problems of handling or management of an unstable product. In the case of barley, the brewing industry has identified considerable variation in endogenous enzyme activity amongst different cultivars. This is important because of the role of endogenous enzymes in the malting process. Similar variation may occur in the endogenous enzyme activity of other grains but there is very little known about the comparative activities of enzyme systems between grains. It is possible that endogenous enzymes may work in stored processed feeds, for example in pellets, provided that the temperatures during these processing procedures do not destroy the enzymes. Very long-term storage of grains does not appear to have major advantages or disadvantages over short-term storage in terms of nutritive value as Bartov (1996) reported no change in the AME of maize in poultry over a period of 9 years, although losses in some amino acids occurred.

Table 17-1 Effect of storage for 1 month or 4 months on the nutritive value of wheat for broiler chickens and its predictability by viscosity estimated *in vitro* (from Choct and Hughes, 1997). Inclusion of phytase in poultry diets containing vegetable protein meals can markedly reduce phosphorus levels in excreta.

Grain sample	Extract viscosity (mPa.s)	AME(MJ/kg DM)		Feed conversion	
		1 month	4 months	1 month	4 months
Wheat 1	4.8	10.14	12.73	2.11	1.92
Wheat 2	4.1	10.31	13.30	2.21	1.83
Wheat 3	4.8	12.35	13.95	1.91	1.88
Wheat 4	12.5	11.18	11.10	2.07	2.14
Wheat 5	3.8	12.02	13.94	1.98	1.84
Wheat 6	8.2	11.80	11.98	2.00	2.01

Ruminant animals

Recent studies on the effect of storage on the rate of fermentation and the extent of intestinal digestion (S. Bird *et al.* unpublished observations) indicate that storage effects may be different in ruminant animals compared to monogastrics. It appears that as a result of storage the rate of intestinal, enzymic digestion actually decreases in ruminants in contrast to the increase observed in the monogastric animals. There appears to be a small increase in rate of fermentation as a result of extended periods of storage. These preliminary results in ruminants are based on in vitro tests and do not take any account of changes in viscosity that is so important in poultry nutrition. It is important to appreciate that there may be differences between the animal species and to exercise caution in extrapolating results obtained in monogastric animals to ruminants and vice versa.

17.2 Role of exogenous enzymes

Feed enzymes have come to be regarded by many nutritionists as necessary “ingredients” in today’s diet formulations for monogastric animals. This has occurred mainly during the past five years, but the concept of enhancing animal performance using enzymes is not new. For example, half a century ago, various preparations of amylase were used in an attempt to overcome poor performance of chicks fed barley diets by increasing the availability of starch. The early work focused on the hydrolysis of specific substrates to their simple constituents for absorption, but this approach was not successful. Appreciable advances have since been achieved in the use of enzymes in poultry diets with a clear understanding of the target substrates and the development of microbiological technology to produce specific enzymes. The prime example of this is the use of ß-glucanase in barley diets and xylanase in rye or wheat diets.

> Inclusion of phytase in poultry diets containing vegetable protein meals can markedly reduce phosphorus levels in excreta.

The benefits of using enzymes in monogastric diets include not only enhanced growth performance and FCE, but also less environmental problems due to reduced output of excreta. Increased accuracy and flexibility in least-cost feed formulations and improved well being of animals are other possible benefits of using feed enzymes. As more and more knowledge is gathered on the detailed chemical structures and the physiological activities of NSP in various ingredients, highly sophisticated enzymes will be developed to target these polymers in a precise manner. Therefore use of NSP as energy sources, a more efficient utilisation of animal by-products and industrial wastes and elimination of specific anti-nutritive factors such as protease inhibitors, glucosinolate, alkaloids, saponins and polyphenolics will receive increasing attention from enzyme manufacturers.

Since the substrate concentrations and structure in cereal grains have been more extensively studied than those in grain legumes, there are a number of well- defined enzymes available commercially for use in diets based on various cereal grains.

Barley

The macro-nutrient contents of barley and corn are very similar, but their nutritive value for poultry is vastly different. This led scientists to use various treatments, including enzyme supplementation. These workers used an □-amylase which significantly increased the live-weight gain and FCE of chickens fed barley diets. It is now well-established that the starch in barley is totally hydrolysed by the amylase secreted by chickens and the poor starch digestibility was associated with poor digestion subsequent to the amylase step. Therefore the reported improvements with amylase supplementation were probably due to the impurities in the enzymes used, i.e., the crude enzyme preparation contained ß-glucanase activity. ß-Glucans are glucose polymers containing a mixture of ß1-3 and ß1- 4 linkages that make their physio-chemical properties different from cellulose which is a straight-chain glucose polymer with only ß1-4 linkages. Barley contains a high level of mixed-linked ß-glucan (3-4%) which is responsible for its poor nutritive value in chickens. Since this significant finding, there have been numerous studies on the use of enzymes, in particular ß-glucanases in barley based poultry diets, with increases in growth and FCE. Increases up to 17% in live-weight gain (Broz and Frigg 1986) and 19% in FCE have been reported for broiler chickens fed barley diets supplemented with ß-glucanases. Barley also contains an appreciable amount of soluble NSP other than ß-glucans (arabinoxylanes) and thus the majority of enzymes for barley diets have both ß-glucanase and xylanase activities.

In general, ß-linkages are not attached by animals' digestive enzymes.

Rye

The poor feeding value of rye was reported 60 years ago. In the search for an answer to the problem, Fernandez *et al.* (1973) extracted rye grain with water and freeze-dried the extract. When this extract was added to a corn-based diet, it depressed the growth of the birds and caused sticky droppings, whereas the water-extracted rye was markedly better than normal rye. This water-extractable factor is now known to be soluble arabinoxylan. Thus, addition of xylanases to rye-based broiler diets significantly improves the growth performance and feed conversion efficiency. Supplementation with increasing levels (0.11, 0.22, 0.44, and 0.88 g/kg) of an enzyme preparation having xylanase and ß-glucanase activities to a rye-wheat based diet improved the weight gain of broilers up to 27% and FCE up to 10%. Although enzymes always substantially improve the performance of birds fed rye diets, they do not seem to be very effective in reducing the extent of sticky droppings. This suggests that other compounds may be present in rye which require attention.

Wheat

Although the large variability (variation in apparent ME of up to 4 MJ/kg dry matter) of the nutritive quality of wheat was reported by numerous researchers, the significance of the problem had not been widely appreciated until recently. Connor *et al.* (1976) noticed that the AME value obtained for wheats was 7-25% lower than that of sorghum, and Payne (1976) postulated that some wheats may contain a "slightly toxic inhibitor". Subsequently, two studies indicated that approximately 25% of the Australian wheats had AME values below 13 MJ/kg dry matter. When these "low-ME" wheats are included above 50% in the ration, chickens have sticky and watery droppings accompanied by poor growth and FCE. It is now generally accepted that the occurrence of low- ME wheats is due to an increased level of soluble NSP, in particular the arabinoxylan. Choct *et al.* (1995) demonstrated that supplementation of a low- ME wheat diet with a commercial xylanase preparation increased the AME by 24% and the FCE by 25% in 3-4 week old broiler chickens.

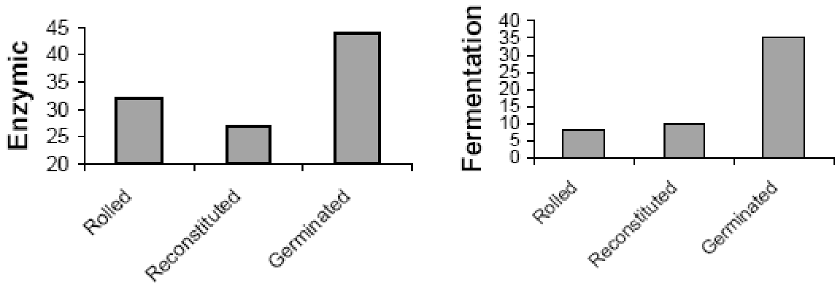
The poultry industry is the largest user of feed enzymes. The majority of feed enzymes are glycanases that catalyse the for degradation of non-starch polysaccharides (NSP). The anti-nutritive activity of NSP in monogastric diets is well characterised with the detrimental effects of NSP resulting from their ability to increase digesta viscosity, to interact with the microflora of the gut, and to alter the physiology and morphology of the digestive tract. The marked effect of glycanases on the nutritive value of cereal grains, such as wheat, rye and barley, is not due to a complete breakdown of the polymers and subsequent absorption of the released monosaccharides. Indeed the current enzymes are not capable of depolymerising NSP to their simple monosaccharide constituents during the digesta transit time of poultry. Therefore the most important mechanism for action of exogenously added enzymes is through partial hydrolysis of the soluble NSP. The increased soluble NSP increased the activity of fermentative microorganims in the small intestine in a detrimental manner. Enzyme supplementation largely eliminated the fermentation in the small intestine and improved nutrient digestibility and overall efficiency. It is postulated that a sudden change in the gut ecology (from an aerobic or facultative anaerobic to strict anaerobic environment) may reduce gastrointestinal function and severely reduce digestive capacity.

17.3 Germination and steeping/reconstitution

The way in which the process of reconstitution or steeping improves the digestibility of grain such as sorghum is almost certainly due to the initiation of the germination. It can be shown that is when grain is soaked for periods of 21 days under strictly controlled anaerobic conditions, there is no increase in the digestibility. However when the process of germination is possible through soaking followed by storage under anaerobic conditions, there are considerable improvements in the digestibility of the grain. In a recent study by Razaq Balogun at UNE, the benefit of germination and reconstitution has been clearly demonstrated and the results are shown in Figure 17-1. The experiment summarized in Figure 17-1 involved either reconstituting sorghum grain under anaerobic conditions for 21 days or germinating the grain under anaerobic conditions for 5 days followed by 16 days anaerobic storage (Razaq Balogun, PhD thesis).

The major problem with germination is that, under the aerobic conditions, fungal growth can occur and this has the potential to produce mycotoxins. Even if the mould is not toxic, it can reduce voluntary feed intake and animal performance.

Figure 17-1 Changes in rumen fermentation and in intestinal enzymic digestion (Balogun, unpublished).



Readings

The following readings are available on CD:

- Pritchard and Bruns (2003) Controlling variation in feed intake through bunk management. *Journal of Animal Science*. **81**: 133-138.

Self Assessment Questions

1. Is the storage of wheat likely to improve or decrease its digestibility by poultry?
2. What is the main use of exogenous feed enzymes—indicate what grains and for animal species?
3. How does germination differ from steeping (reconstitution)?

References

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Applied Animal Nutrition 300/500

Topic 18

18. Chemical and physical treatment of roughages to improve digestibility

18.1 Introduction to chemical treatment

18.2 Physical treatment of roughages

18. Chemical and physical treatment of roughages to improve digestibility

Learning Objectives

On completion of this topic you should be able to:

- Describe some chemical treatments that can be applied to low quality feeds to improve their nutritive value to ruminants.
- Explain why particle size can impact on the digestion of roughages.
- Describe some physical treatment options for improving the digestibility of low quality roughage sources for ruminants.
- Explain why urea is often used for improving the utilisation of low quality roughages.

Key Terms and Concepts

Chemical Treatment; Physical Treatment of roughages.

Introduction to the Topic

Many countries of the world rely on low quality roughages as the primary source of nutrients for ruminant animals. Australia is an example of this. In poorer nations that are densely populated, opportunities to supplement these animals with products such as cereal grain, urea or molasses is limited. In addition to this, production systems in these countries are typically intensive, with one family owning only a few head of livestock. In such situations, cattle may be used for milk production for the family, draft to prepare the soil for planting and reproduction to produce offspring. These type of production requirements placed significant demands on the animal. Therefore, the need for strategies aimed at improving the quality of available roughages sources is needed.

This topic will introduce you to several examples of chemical and physical treatment of roughages to improve their nutritive value for livestock. These are strategies that are often used in production systems such as those mentioned above.

18.1 Introduction to chemical treatment

During the 70s and 80s there was considerable interest in the chemical treatment of straw and other of low quality roughages for ruminant feeding. There's a tremendous amount of fibrous crop residue that is underutilised and which has the potential for animal feeding. These resources include cereal crops stubbles, rice straw and mature pasture. The principal method of treatment was based on the use of an alkali. Early research showed very exciting increases in the digestibility of roughages in response to treatment with sodium hydroxide. Sheep and cattle fed treated roughages show benefits in terms of increased feed intake in addition to the expected improvements associated with higher digestibility of the roughage. Based on this early success additional research was conducted to examine other sources of alkali and a number of studies investigated the use of calcium or potassium hydroxide as alternatives to sodium hydroxide. There was also a great deal of work on the use of ammonium hydroxide particularly from the point of view of treating straw with anhydrous ammonia and urea.

Although the treatment of low quality roughages with hydroxide is very effective as a way of increasing digestibility and improving animal performance, a number of logistical, safety and environmental issues have limited the use of chemical treatment under commercial conditions.

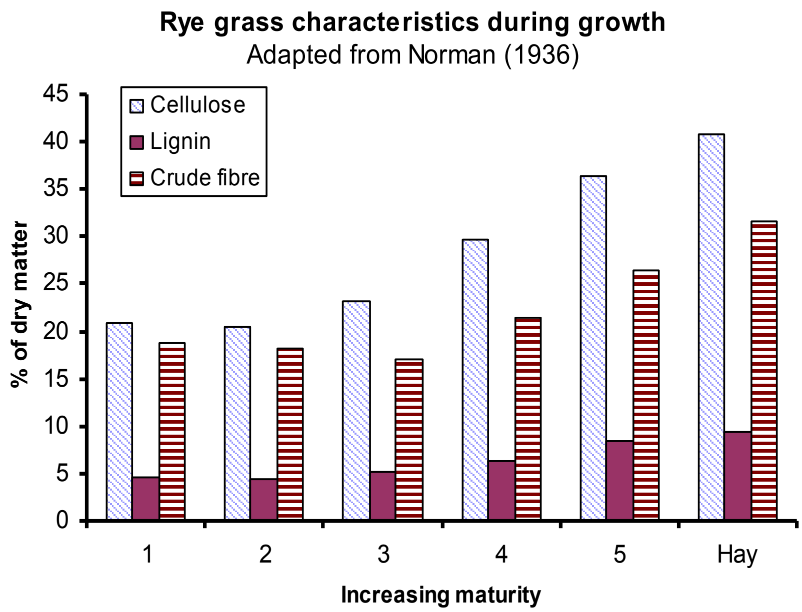
What is straw and what does the hydroxide treatment accomplish?

The major components of straw include structural carbohydrates such as cellulose, non-starch polysaccharides and lignin. It is the amount of lignin and its distribution in the plant material that has the greatest effect on digestibility. The cellulose is made up of glucose molecules connected through □-1-4 linkages. These bonds it cannot be split by mammalian enzymes. However, cellulose can be utilised by bacteria during fermentation and broken down to form the VFA. When lignin surrounds the cellulose, it effectively prevents bacterial attachment and reduces digestibility both through its own inert properties and by forming a barrier to the digestible cellulose. The lignin is mainly present in the stems and nodes: it is also present in reasonably high concentration in some leaf material. Lignin is a family of related polymers of a three-dimensional structure made up of phenol propane units. Lignin has a number of functions which are essential for the plant. Together with other components in cell walls, lignin is responsible for structural strength and has outstanding properties in resisting microbial attack. These characteristics unfortunately present the major impediment to digestion of the plant material by microbes and by the animal's digestive enzymes.

There is little protein in straw and what protein there is, is mainly associated with the cell walls and is not readily digestible. The ash content of straw can vary from around 6% in barley and wheat to around 19% in the case of rice. The high level of ash in rice is mainly because of high silica levels. Silica taken up by the plant roots is deposited in the cell walls and together with lignin has a negative effect on bacterial breakdown of the plant fibre. The combination of lignin and silica in rice straw makes this material almost indigestible.

As shown in Figure 18-1, lignin content does not rise as quickly as cellulose concentration during maturation of the cereal plant but the lignin has a disproportionate effect on digestibility. Alkali treatment forms the basis of the wood pulping process used for paper manufacture. The effect of the alkali is to cleave internal linkages, lignin, the non-starch polysaccharides (NSP) and cellulose. Degradation of the lignin and NSP makes the cellulose more accessible for hydrolysing enzymes. During alkali treatment of fibrous material the structural NSP are also partly solubilised.

Figure 18-1 Rye grass characteristics during growth (adapted from Norman 1936).



The application of heat together with alkaline conditions can solubilise the lignin with formation of free phenols. Steaming at temperatures over 160°C can increase digestibility through auto hydrolysis and because the lignin melts at these high temperatures.

Sodium hydroxide treatment to increase digestibility and intake of roughages

As early as 1942 W. S. Ferguson had shown improved digestibility of fibrous foragers through treatment with sodium hydroxide. In Australia Roy Kellaway and colleagues at Sydney University developed practical ways of treating large quantities of cereal stubbles and the methods were adopted by many producers.

Table 18-2 shows the effect of different methods of alkali treatment of barley straw on in vivo digestibility in sheep (Wanapat *et al.* 1985). Treatment with sodium hydroxide involved soaking of straw for 30 minutes in a solution containing 15 g sodium hydroxide/litre. Aqueous ammonia treatment involved application of 120 g ammonia solution (25%)/kg of straw followed by 8 weeks' storage prior to feeding.

There are three major problems in using sodium hydroxide. The first is the danger to operators and the risk of being splashed with the strong sodium hydroxide solution. It is highly corrosive and particularly dangerous if it comes into contact with skin and eyes. The second issue is the high sodium level and its adverse impact on the environment. High sodium levels can also have adverse effects on the animal and there are reports of kidney damage in dairy cattle fed high levels of sodium over long periods of time. High levels of sodium can also a negative input on the environment. The final aspect, common to all alkali treatment processes, is the corrosion and damage to equipment.

Table 18-2 Effect of sodium hydroxide and aqueous ammonia on digestibility of barley straw by sheep (Wanapat *et al.* 1985).

Treatment of barley straw	In vivo digestibility %
Untreated	50.8
Sodium hydroxide	75.2
Aqueous ammonia	65.7

Treatment with urea or ammonia

Many common bacteria found on plant materials have urease activity and urea is therefore rapidly degraded to carbon dioxide and ammonia if it is added plant biomass under natural conditions. Provided there is sufficient water present, ammonia rapidly forms ammonium hydroxide.

Urea ——> ammonia + water ——> ammonium hydroxide

Urea is far safer to handle than ammonium hydroxide and can be applied to straw in an aqueous solution. There have been numerous studies to determine the optimum concentration of urea and the appropriate time between application and feeding the straw. It is generally agreed that around 5% urea should be used (50 kg urea per tonne of straw) and that the straw should then be covered or ensiled for at least four weeks prior to being used. Once it is in a sealed container or pit, it is stable for long periods of time. The concentration of anhydrous ammonia required for the same effect is closer to 3%. The use of anhydrous ammonia has the advantage of easy application to large stacks of straw as a gas. This method of treatment is still popular in some parts of Europe where large piles of cereal straw are covered with black plastic prior to introducing hydrous ammonia from a mobile tank.

The methods of harvesting, chopping the material, applying the urea/ammonia and the facilities for storage and equipment for feeding out the treated material are all critical in determining the success and attractiveness of this procedure. As it involves large quantities of material, it is highly desirable to have the process of harvesting and filling the pit or silo highly mechanised. In situations where mechanisation is not available the job of harvesting, filling silos and feeding out is tedious and unpopular. The onerous nature of the task makes this a very cost-effective but labour-intensive method of treating crop by-products. The method is of relatively minor importance in many parts of the world where one might think it would be ideal technology.

NOTE: In combination with heat, ammonia can at times form potentially dangerous compounds with carbohydrates. In rare cases, ammoniated straw fed to cattle can cause “bovine bonkers” (Perdok & Leng 1985).

Treatment with other chemicals

The “ideal” chemical for enhancing the digestibility of cereal straw is:

· non-hazardous to handling by humans;

· non-corrosive to machinery;

· non-polluting to soils and water;

· not a source of chemical residues in animals, faeces or urine;

· readily available and cheap relative to improvements in feed value.

Even though many different classes of chemicals including alkalis, acids, salts, oxidising agents, sulphur compounds and surfactants have been tested, no totally satisfactory alternative to sodium hydroxide or urea/ammonia has emerged. Calcium hydroxide appears to be a satisfactory alternative and calcium oxide when used in conjunction with urea has also produced reasonably good results.

Is chemical treatment a practical alternative?

In assessing whether chemical treatment is justified, it is worth considering the alternative of allowing animals to harvest their material in the paddock and to feed a supplement to bring the total diet up to the desired standard. When the animal harvests the material itself by grazing, there are no costs of harvesting, transport, storage or feeding out. When one considers the complete cost of straw treatment, the alternative of using supplements such as lupins or cereal grain for grazing animals often becomes an attractive option.

18.2 Physical treatment of roughages

There are various ways in which the physical characteristics of a roughage may be altered including grinding, chopping and pelleting. These methods can be considered under four categories:

1 ***Particle size***—reducing particle size in order to increase the surface area for microbial fermentation of fibrous components in the rumen or hind gut or to expose more of the material to pre-feeding treatments;

2 ***Handling***—to produce a material that is easier to handle or compact during the processes of ensiling or storage;

3 ***Density***—to increase the density of the material so that animals are able to increase their intake; and

4 ***Mixing***—in order to mix other ingredients with the roughage to balance the nutrients supplied to the animal and improve the animal's ability to digest the fibrous material and/or consume more of it.

Grinding to reduce particle size

Although this is one of the simplest mechanical processes in the treatment of any feedstuff, it is still an expensive and relatively unpleasant task. The efficient handling of the large quantities of roughage requires expensive mechanisation and the process of grinding uses large quantities of energy. Even in large efficient operations the cost of grinding hay or straw is estimated to be over $20/tonne. In addition to the cost is the unpleasant working environment involved in the grinding operation. It is invariably noisy and dusty. Operators are therefore required to wear protective equipment to limit the damage to hearing and the inhalation of dust. The question is therefore whether it is a process that is cost- effective when all of these factors are considered.

There are clear benefits in terms of increased digestibility of fibre via microbial fermentation as the particle size is decreased in both roughages and grains. It is unlikely that the increased digestibility alone pays for the cost and irksome nature of the task in grinding hay or straw (see Table 18-3). Even in situations where feed intake and live-weight gain are increased as a result of grinding, benefits in terms of feed conversion efficiency are rarely achieved. Where the quality of roughage is very low, grinding normally has little if any effect on intake and animal performance. However, in the preparation of completely mixed rations and pelleted diets, it is essential to break down the particle size for effective mixing and/or pelleting.

Table 18-3 Effects of milling hay and straw on intake and growth of cattle. The digestibility use of hay on its own was 51% and straw 30%. The diets contained roughage, lupins and barley to give digestibility of the hay diet of 70% and of these straw diet 55%. (Jones, May and Barker, 1988).

	Straw–based		Hay –based		Least sig diff
	Milled	Long	Milled	Long	LSD (0.05)
Dry matter intake (kg/day)	4.45	4.47	8.81	6.91	0.62
Live–weight gain (kg/day)	0.25	0.27	1.35	0.90	0.17
Intake/gain (kg/kg)	18.6	18.0	6.5	7.7	1.66

Pelleting and cubing

The processes of pelleting and cubing are similar in that the feeds are ground (in the case of pelleting) or chopped into small particles (in the case of cubing) before being compacted under pressure and at elevated temperatures to form pellets or small wafers up to 3 cm in diameter.

The process of pelleting normally describes feeds containing high levels of cereal grain finely ground and treated with steam to produce gelatinisation of starch before the mixed feed is extruded through dies of 0.2 to 1 cm in diameter. In order to remain intact during handling and feeding out, pellets must be made out of material with the particle length less than half the diameter of the pellets. Pelleted feed is easy to handle in bulk and can be fed out automatically using tubular distribution systems. This ease of handling, the high density of the feed and the flexibility of this feeding method to deliver a complete balanced diet are attractive features. The process of pelleting comes at a reasonably high price and is only economically attractive where the cost of labour or storage are significant factors. The pelleted feeds are also very convenient for smaller scale operators not wishing to invest in mixing and storage equipment. When buying in the pelleted feeds there is also no need to maintain stocks of lots of individual ingredients covering mineral, vitamin and amino acid supplements.

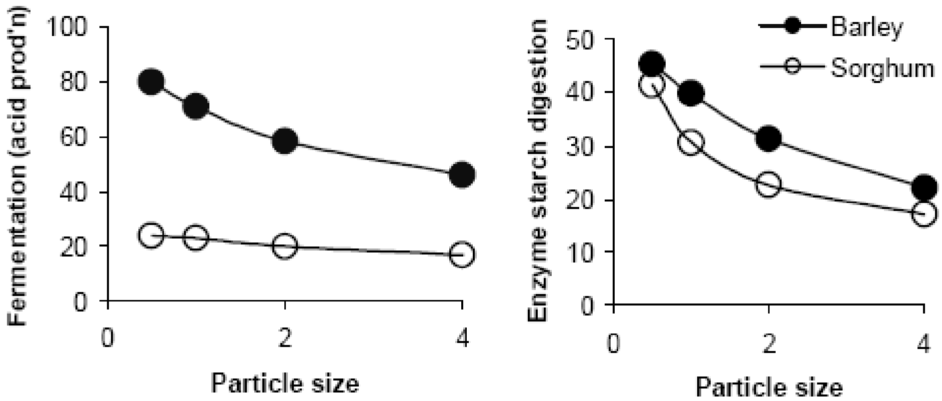
The process of cubing is mainly used for hay transport and feeding. It is a process that is very popular in the United States for preparing lucerne hay for export and for feeding lucerne hay to dairy cattle and horses. It is best described as a “micro hay baler” and produces “chunks” of compressed feed approximately 3 cm x 3 cm that are easily handled using conveyor belts and mechanical shovels and have a sufficiently high density for export in container loads. This method of feed preparation has also become popular in the live animal export industry where it is well suited to limited storage and cramped on-board feeding systems.

The processes of cutting (or chaffing), cubing or pelleting can also do a lot to reduce wastage of roughage. When long hay is fed to cattle or sheep there is often wastage due to trampling and spreading the feed around. However there are additional costs in terms of feed troughs required to take advantage of the chopped, high density mixed diets and these additional expenses must be considered against the benefits. Roughages can be efficiently utilised by implementing good management practices such as use of the “waste not” feeder for round-bale hay and mobile silage carts.

Particle size and grain feeding

Particle size can have a large effect on the rate of fermentation and intestinal digestion of cereal grains. It is also significant that the relationship between particle size and rate of fermentation or digestion is not the same for all grains. Adjusting particle size when preparing grain for cattle feeding therefore provides a significant management tool to alter the site and extent of digestion. The results summarised in Figure 18-2 show the differences between barley and sorghum grain in their response to grinding through different screen sizes. These results suggest that finely grinding sorghum does not significantly affect rate or extent of fermentation but has a very significant effect on intestinal digestion. On the other hand the particle size of barley grain has a similar effect on rate of fermentation as it does on intestinal digestion.

Figure 18-2 Effect of particle size on fermentation and intestinal digestion of barley and sorghum (Bird *et al.* 1999).



Readings

The following readings are available on CD:

- Djajanegara and Doyle (1989) The intake and utilisation of urea-treated rice straw by sheep in deffering body condition. *Australian Journal of Agricultural Research*. **40**: 1037-1045.

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Self Assessment Questions

1. What are the advantages and disadvantages in NaOH treatment of cereal straw?
2. How does the alkali treatment improve digestibility?
3. Compare the benefits and costs of feeding long hay or chaff to cattle.
4. What are the benefits in using pelleted diets for dairy cows?

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Topic 19

19. Hormonal Growth Promotants and Nutritional Requirements

19. Hormonal Growth Promotants and Nutritional Requirements

Learning Objectives

On completion of this topic you should be able to:

- Describe why hormonal growth promotants are used in the Australian beef industry.
- Discuss the banning of HGP usage in some countries.
- Describe the mechanisms by which improved growth is achieved from the use of HGP's and production situations in which their use is not appropriate.

Key Terms and Concepts

Growth promoting substances related to the sex steroids; HPG-free Accreditation Scheme in Australia.

Introduction to the Topic

Although hormonal growth promoters (HPGs) are not strictly nutritional inputs their use in animals alters animals' nutrient requirements: it is important to understand how to manage the diet of animals treated with these compounds. There are a number of agents that can have a profound effect on nutrient utilisation and tissue metabolism. In this lecture, we will consider these agents under three categories: hormones related to the sex steroids that are all used for ruminant production; growth hormone and its use in dairy cattle and pig production; beta agonists and other tissue growth factors.

19.1 Growth promoting substances related to the sex steroids

A wide range of steroid agents are used in ruminant production and some of these are summarised in Table 19-1. The effectiveness of each preparation depends on the sexual status of the animal and various agents should be selected for specific classes of animals in order to get a repeatable increase in production. If the androgen trenbalone acetate is used with steers, it has little benefit whereas good responses are obtained in heifers. However if trenbalone acetate is administered to steers in conjunction with oestrogen the response is excellent. Responses to anabolic steroids in terms of live-weight gain can vary from 10 to 40% depending on the status of the animal and the combination of agents used.

> HPG refers to veterinary chemicals that have hormonal activity in animals. They are mainly androgens, oestrogens and progestins.

Substances such as diethyl stilbestrol and melengestrol acetate are orally active and are not recommended for use in food producing animals. This is in order to ensure that no anabolic material enters the human body when people eat meat from animals treated with steroids. The safety issue is an extremely important one and careful planning is required before hormonal treatments are used as they can restrict the market opportunities. Currently Europe requires that all animals treated with anabolic steroids be identified in any country wishing to export animal products to the European Community. Safety is a highly emotive and complex issue.

The naturally occurring substances which are used for growth promotion such as progesterone, testosterone and oestradiol-17-ß are present in the human body at concentrations far higher than they occurring in animal tissue and the chance of contaminated meat having any effect on the human hormonal balance is negligible. The hormones present in meat from bulls, pregnant cows and from certain vegetables are far more likely to have physiological effects. Although one can assume that those hormonal growth promoters registered for use in Australia are safe and effective, it is essential to bear in mind that the perception of the consumer is the ultimate deciding factor as to whether or not to use these compounds.

Table 19-1 Summary of some of the major anabolic steroids (from Buttery 1988).

Oestrogens	Androgens	Progestagens	Combinations
diethyl stilbestrol acetate	testosterone	progesterone	oestradiol–17–ß & trenbalone hexestrol
oestradiol–17–ß	trenbalone acetate	melengestrol acetate	testosterone & oestradiol–17–ß
zeranol	methyl– testosterone		zeranol & trenbalone acetate
oestradiol–17–ß benzoate			progesterone oestradiol–17–ß

Since there are significant improvements in feed conversion efficiency, growth rate and lean muscle production in response to hormone implants, it is important to use these implants when preparing cattle for markets that do not discriminate against their use. The implant will often facilitate more rapid muscle deposition in animals and the principal nutritional change that should be implemented when animals have been treated with anabolic steroids is to ensure they ingest sufficient protein to allow them to respond in the appropriate way. Particularly in the young and growing animals, there is a need for bypass protein to ensure sufficient amino acid for unrestricted muscle deposition.

ß-agonists

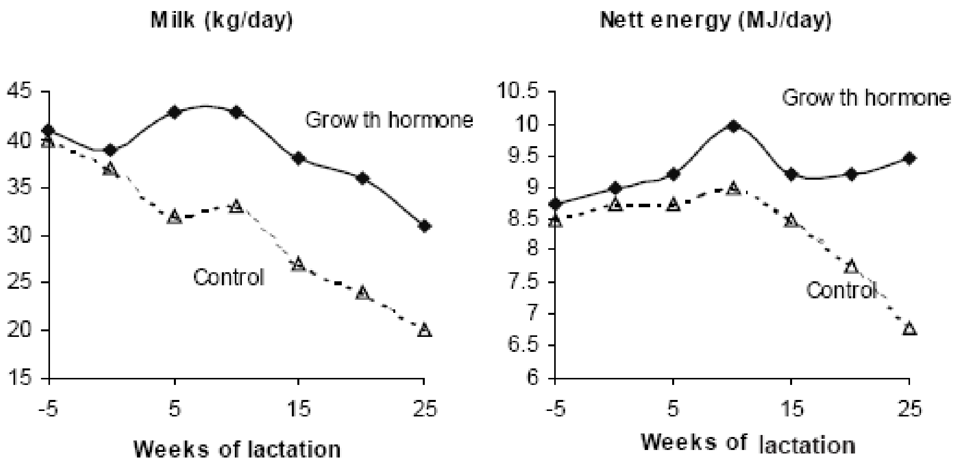
ß-agonists increase the synthesis of muscle and stimulate the breakdown of fat through lipolysis. The net result is an animal that deposits muscle protein more quickly and produces a carcass that has less fat than it would otherwise have. These characteristics are ideally suited to many modern market specifications and the use of the beta agonists is therefore an attractive proposition. There are, however, adverse side-effects associated with the use of beta agonists such as increased heart rate. This is considered to be an issue from the point of view of animal welfare and has also raised concerns about possible side-effects in humans should there be any transfer of active beta agonists through the food chain. One of the beta agonists widely used in experimental work has been clenbutoral and there are reports of the significant improvements in muscle growth and decreased subcutaneous fat in sheep and cattle. No beta agonists products are currently registered for use in animal production in Australia.

Only certified HPG-free beef products can be exported to EU markets.

Growth hormone use in dairy cattle and pigs

Ever since it has been possible to produce bovine growth hormone by recombinant DNA techniques in the early 1980s, it has been theoretically feasible to dramatically increased milk production in dairy cows. The major limitation to the use of bovine growth hormone has been to produce a slow-release of hormone over a sufficiently long period of time to facilitate less frequent injections of the hormone. The use of frequent injections to maintain adequate levels of exogenous growth hormone is not a management strategy that many dairy operators have adopted. There are nevertheless many commercial dairies, particularly in the United States, using bovine growth hormone on a regular basis. The major implication for nutritional management is that cows treated with growth hormonal require significantly more feed than their untreated counterparts. The change in milk production and the nett energy intake associated with this change are summarised in Figure 19-1.

Figure 19-1 Changes in milk production and nett energy requirements of dairy cows given bovine growth hormone (Bauman *et al.* 1985).



Porcine growth hormone also has the same problems as its bovine "counterpart" in that there is still no reliable slow release formula that remains biologically active over a long enough time for practical application. Its use, however, remains cost-effective and there are a number of pig producers who use porcine growth hormone regularly to achieve faster growth rates and leaner carcases.

19.2 HPG-free Accreditation Scheme in Australia

In Australia, the Department of Agriculture, Fisheries and Forestry Australia (AFFA) in Canberra overseas the HPG free Accreditation Scheme. This Scheme "allows the full traceability of all animals within the Scheme through the National Livestock Identification Scheme (NLIS). The NLIS links individual animal identification to a central database and all animals in the Scheme are registered on that database. To further address EU market requirements for beef, all cattle within the HPH free Scheme must not have been treated with HPGs at any time in their lives." (see: www.affa.gov.au/content).

Readings

The following readings are available on CD:

- Bortolussi and Bird (1998) Effect of growth promotant implants on liveweight change, wool growth and carcass characteristics of mature wethers. *Australian Journal of Experimental Agriculture*. **23**: 789-794.

- Bortolussi *et al.* (2004) Effect of hormonal growth promotant implants in weaner and hogget ewes on subsequent growth and reproductive performance. *Australian Journal of Experimental Agriculture*. **44**: 755-761.

- Bortolussi *et al.* (2005) The northern Australian beef industry – a snapshot. *Australian Journal of Experimental Agriculture*. **45**: 1093-1108.
- Huston *et al.* (1990) Effect of supplemental feed with or without ionophores on lambs and angora kid goats on rangeland. *Journal of Animal Science*. **68**: 3980-3986.
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Self Assessment Questions

1. What is the mechanism of action of HPGs when they increase protein deposition in cattle?
2. What changes in diets of dairy cows do managers need to consider when HPGs are being administered?
3. What is the major limitation to the use of HPGs (eg. bovine somatotrophin or bGH) as a means of increasing milk production in cattle?

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Bauman, Eppard, DeGeeter and Lanza (1985) Responses of high-producing dairy cows to long-term treatment with pituitary somatotropin and recombinant somatotropin. *Journal of Dairy Science*. **68**: 1352-1362.

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Topic 20

20. Growth Promotants for Pigs and Poultry

20. Growth Promotants for Pigs and Poultry

Learning Objectives

On completion of this topic you should be able to:

- Discuss the need for alternatives to antibiotic use in monogastric feeding systems.
- Define probiotics and prebiotics and how they can be used to improve production in monogastric production systems.
- Describe how organic acids and feed enzymes can be used in monogastric diets to achieve improved production.
- Describe why hormones are not used in commercial poultry production systems

Key Terms and Concepts

Antibiotics, mechanism of action and current status; Alternatives to antibiotics; Probiotics; Feed enzymes; Organic acids; Prebiotics.

Introduction to the Topic

Animal production in the last 50 years has become much more intensive. Intensification has imposed a need to maintain consistently high production rates and a greater degree of disease control. This quest for increased animal performance and health status has resulted in reliance on application of low doses of antibiotics in feeds. Between 1950 and 1970, most classes of antibiotics were used as growth promotants, primarily in pigs and poultry, at inclusion rates in diets of about 50 ppm. Responses in production were consistently of the order of 10 to 15 %, and improvements in feed conversion averaged 5%, although the level of response has depended on environmental factors and, of course, pathogen loads present. Consistent growth responses to these antibiotics have been maintained over the years, and have provided livestock managers with a reliable tool to maintain good production levels.

> ***Antibiotic***. Compound that kills bacteria without affecting the host.

The emergence of antibiotic-resistant human pathogens, and public concern over the routine use of antibiotics in livestock production has led to a search for alternative growth promoters for use in the animal industries. Probiotics added to feeds have been considered as a possible alternative to antibiotics.

20.1 Antibiotics: mechanism of action and current status

The mechanisms by which antibiotics improve growth or feed efficiency of animals are not well understood. A simplistic explanation is that the intestinal microflora are modified such that the ability of the host to respond to a fixed feed intake is maximised. Different antibiotics have different effects on bacteria— some affect bacterial cell walls and others protein synthesis in microorganisms; some antibiotics are absorbed through the gut wall, others are not. The turnover rate of intestinal mucosal cells is much lower in antibiotic-fed animals.

> ***Probiotic.*** Literally 'for life'; 'pro = for, 'bios' = life; the opposite of antibiotic. Probiotics are mono- or mixed-cultures of live microorganisms that provide benefits to the animal by improving the properties of the indigenous microflora.

The indiscriminate use of all classes of antibiotics for growth promotion, and concerns about residues in animal products for human consumption, led to a series of inquiries globally (eg. The Swan Report, HMSO, London, 1969). The outcomes were decisions to restrict the use of antibiotics as growth promotors to those not in use for either human or veterinary therapeutic purposes. In Britain, for example, the important recommendations were that supply of penicillin, chlortetracycline and oxytetracycline without prescription should be stopped, and that tylosin, nitrofuran and sulphonamides should only be available on prescription. Defined 'feed' antibiotics should be available without prescription for pigs and poultry, and for calves up to 3 months' old. 'Feed' antibiotics included bacitracin, virginamycin, flavomycin and nitrovin.

‘Therapeutic’ antibiotics were only to be used in animals if prescribed by a veterinarian for a treatment of a specific disease condition.

In more recent times, there has been a global trend, led by Sweden and Denmark, to prohibit use of all antibiotics as animal growth stimulants. This has occurred because of a growing concern that regulations developed in the 1970s were being flouted, and that producers have continued to use ‘therapeutic’ antibiotics as growth stimulants. The detection of residues has not been the main concern, but rather the development of gastrointestinal bacteria with drug resistance.

In 1986 Sweden decided to ban the use of all antibiotics as animal growth promotants. When Sweden joined the European Community in 1995, it was allowed to retain this ban until 1998, at which time it would have to argue its case with the other European nations to maintain the ban, or fall into line with them. Accordingly, the Agriculture Ministers of the 15 EU nations met in December 1998 and decided to ban four antibiotics used as growth promotants — tylosin phosphate, bacitracin zinc, spiramycin and virginiamycin. EU farmers were given until June 1999 to comply. Another four drugs were also listed for further consideration for banning.

When first introduced, the bans led to huge increases in mortality and morbidity rates and a drop in production. In the poultry industry, the most significant consequence has been the sporadic outbreaks of necrotic enteritis which causes sub-clinical losses in production and, in severe cases, high mortality. The EU estimates that the increase in costs of pig production due to the banning of antibiotic use in feeds has been 8-15%. However, necrotic enteritis is largely a management problem.

> ***Hormones*** are chemical substances, simple molecules, complex peptides) synthesised by various tissues in the body that elicit responses either locally or remotely.

In the USA, authorities have not yet moved to restrict the use of antibiotics as growth promotants. Indeed, the USA still allows antibiotics such as penicillin and chlortetracycline to be used, arguing that the case against their use is not convincingly proven. Several years ago the National Academy of Sciences in the USA was commissioned to determine whether low doses of antibiotics given to livestock posed a risk the development of anti-biotic resistant bacteria. The Academy was unable to resolve this issue. (There are, of course, political elements affecting these questions involving both sales by pharmaceutical manufacturers and world agricultural trade.)

> ***Agonists*** are substances that elicit the same response as a hormone naturally secreted in the body.

In Australia, the consensus of the Joint Expert Advisory Committee on Antibiotic Resistance in 1999 was that the excessive use of antibiotics as growth promotants could lead to the development of antibiotic-resistant bacteria (JETACAR 1999).

Swine dysentry in pigs in Australia is regarded as one of the most economically important diseases costing more than $100/sow per year on affected farms. Heavy reliance on antibiotics to control the disease has led to the development of resistant strains of *S. hyodysenteriae*. The good news is that research has suggested that the dysentry is controllable by dietary manipulation (it is reduced in pigs given diets low in rapidly fermentable fibre (ie. soluble NSP, oligosaccharides and/or resistant starch. The Australian pig and poultry industries are now also committing resources to investigate and evaluate alternatives to antibiotic growth promotants.

> ***Prebiotics*** are non-digestible feed ingredients (polysaccharides) that benefit the animal by selectively stimulating the growth

20.2 Alternatives to antibiotics

The bans on use of antibiotics have led, at least in Europe, to an urgent search for reliable alternative growth promotants. Alternatives being considered, developed and evaluated include: somatrophins (BST for dairy cattle milk production and PST for pig meat production), cytokines, enzymes, anabolic growth hormones, ß-adrenergic agonists, prebiotics and probiotics, organic acids (eg., sodium n-butyrate in pigs), synthetic growth stimulants (eg., nitrovin, carbadox, olaquinox), and polyether ionophore antiobiotics (monensin, lasalocid and salinomycin). The bans in Sweden have been a test case and Swedish producers, using strict hygiene programs and modified feed formulations along with alternatives such as organic acids, prebiotics (mainly oligosaccharides) probiotics and feed enzymes, have actually seen an improvement in overall health status of poultry.

> ***'ß-Adrenergic'*** refers to a subdivision of the adrenergic system that influences physiological responses in the body

Probiotics

Probiotic bacteria, principally various species of *Lactobacillus* and *Enterococcus faecium* (which appear to improve production by enhancing the properties of indigenous micro-flora in the gut) have been used in pigs, poultry and calves since 1970. Responses have been variable: they have depended on the quality and nature of the probiotic preparation used, and on the disease status of the animals. Table 20-1 is a summary of some trials with pigs and calves.

> ***Bovine somatrophin*** (BST) is a protein that is produced naturally by the pituitary gland of cows and stimulates milk production by enhancing the partition of circulating nutrients towards the mammary gland. Porcine Somatotrophin (PST) is the similar protein in pigs

Table 20-1 Summary of positive and negative results for growth and feed efficiency in trials with pigs and calves fed probiotics (UNE Animal Science database).

Type of animals	Number of trials	Growth response		FCR response	
		+	–	+	–
Piglets	26	16	9	8	9
Grower pigs	9	6	3	2	4
Calves	17	13	4	0	0

Similarly indeterminate results have been found with broiler and layer poultry. Where improvements in weight gains have occurred, these have averaged about 5%. However, Table 20-1 also clearly shows that gains have been inconsistent and that probiotic treatments can even reduce weight gain and feed conversion. As mentioned already, the proposed mechanisms of action by probiotic bacteria on the health and growth of the host are unclear. This is largely because of the complexity of gut ecosystems. Clearly, the probiotics have an ability to suppress harmful bacteria. This has been demonstrated both *in vitro* and *in vivo*, and both in animal models and in humans. However, this effect on pathogens does not necessarily translate into consistently improved live-weight gains or improvements in feed conversion efficiency. There are three possible mechanisms by which probiotic bacteria can elicit their effect on the growth performance and well-being of the animal. Probiotic bacteria may act to:

a) suppress pathogens by production of antibacterial compounds (organic acids, bacteriocins, other antimicrobials), competition for nutrients, and competition for colonization sites;

b) change microbial/host metabolism by production of enzymes which support digestion (e.g. ß-galactosidase), decreased production of ammonia, and improved gut wall function; bifidobacteria, in particular, use many prebiotic carbohydrates preferentially as carbon sources, which could permit improved feed utilisation by the host;

c) improve the immune response of the host by increasing antibody levels, and macrophage activity. Research into the modification of the immune system by probiotic bacteria is in its infancy, but it is conceivable that effects may include enhanced production of growth factors, which in turn could allow improved weight gain in the host. It is perhaps important to distinguish the use of probiotics to prevent infectious diseases by increasing the barrier function of the gut microflora, and as microbial growth promotants by being a source of enzymes to improve feed utilization and rate of growth important for regulatory approval reasons in the feed industry.

Competitive exclusion (CE) is an example of a specific mechanism where addition of mixed cultures of microorganisms have consistently improved survival of chicks, and lowered *Salmonella* levels in the flock. CE is the name usually reserved for treatment of day-old chicks with a mixed microflora resulting in colonisation resistance towards potentially pathogenic microorganisms, especially *Salmonella* spp. The treatment is usually given only once. Usually cultures of ill-defined composition are used, often derived originally from caecal or faecal contents of adult chickens. In contrast to the variable results obtained with a continuous treatment of probiotic lactic acid bacteria in older animals, CE cultures have been consistently beneficial in reducing *Salmonella* and *Campylobacter* loads. The principle of CE treatment is that young chicks are more susceptible to pathogen infection than older birds because a complex inhibitory gut flora is not present in the newly hatched birds. This flora takes some weeks to develop in hygienic hatcheries, as there is a lack of contact with adult birds. This allows a 'Greenfield' opportunity for pathogens to colonise the gut without competition. Studies specifically targeting the displacement of *Clostridium perfringens* using probiotics have yielded promising results. *Future of probiotics.*

Current evidence clearly indicates that probiotic bacteria have not yet been shown to consistently improve animal production or improve feed conversion efficiency. This is in contrast to data where antibiotics as growth promotants have been shown to consistently improve performance, and this gain has not decreased in magnitude over the last 45 years since the practice was adopted by the animal industries. Can we therefore realistically hope that probiotics will be able to provide an economic alternative in the future? The greatest weakness in probiotic treatment to date has been in the selection and testing of suitable probiotic strains with properties appropriate to the application; maintaining their viability in sufficient numbers in feeds; and preparing them in a manner which ensures their delivery to the appropriate gut compartment of the animal. There are opportunities to combine their administration with a prebiotic carbohydrate, such as an oligosaccharide, lactulose, lactitol, or resistant starch, to enhance their effectiveness. Nothing is known of the interaction between probiotic bacteria and proteins with growth stimulating ability, such as certain whey protein fractions, somatotrophins, and cytokines.

In the future, probiotic packages may offer the opportunity to consistently improve animal production but at this stage their effectiveness is still uncertain. To demonstrate this will require much effort and money. Regardless of the rights and wrongs of the global debate on the future of antibiotics as growth promotants, bans on antibiotic use in animals will assist in determining the value of probiotics for such uses, and will lead to a much better understanding of gastrointestinal microbiology in important domestic animal species.

Feed enzymes

The benefits of antibiotics in feeds are gut-flora related and therefore investigation of diet-induced changes in the gut ecosystem is a good starting place for the search to find replacements for antibiotics. A sudden change in diet can disturb this ecosystem and introduction of a diet rich in NSP (wheat, barley) favours the proliferation of anaerobic microbes such as Clostridia. However, the use of feed enzymes to promote NSP breakdown in the gut of broilers can almost eliminate the development of an anaerobic fermentation in the small intestine and this effect coincides with improved production. Recent studies at UNE have also shown that populations of *C. prefringens* can be manipulated by diet and by the use of feed enzymes.

> The use of feed enzymes is discussed elsewhere as a method of grain treatment.

Organic acids

Organic acids are included in diets in Europe to inhibit growth of gut pathogens such as salmonella in both raw feed ingredients and in finished feed. Organic acids in their undissociated form can diffuse through the cell wall into bacteria and then they dissociate releasing hydrogen ions which lower the pH inside the cell and cause it to expend energy trying to restore the intracellular conditions. This use of energy for its survival minimises its capacity to grow and divide. At the same time, the anions produced from the dissocation of acids can disrupt DNA and protein synthesis which further affects cell replication. Benefits of organic acids on feed efficiency and animal performance have been reported, especially in young animals, but these seem to be greater for birds than for pigs. The benefits of inclusion of organic acids in diets may also depend on the composition of the diet and its buffering capacity.

Prebiotics

Small fragments of polysaccharides in the diet can selectively stimulate particular species of microbes in the gut and can thereby potentially bring about changes in the balance of the gut microflora that may improve animal production. There are potentially hundreds of potential fragments that could act as beneficial prebiotics but the ones currently available commercially for inclusion in diets are mainly oligosaccharides made up of the sugars galactose, fructose or mannose. These prebiotics appear to act by selectively feeding and favouring the 'good' bacteria at the expense of the harmful ones. It is claimed, however, that the prebiotic mannan oligosaccharides from yeast cell walls apparently act differently —by providing specific binding sites for gut pathogens. This reduces the chances of the pathogens attaching to the intestinal wall. The mannan oligosaccharides may also bind to, and cause detachment of, harmful microbes already attached to the gut wall and carry them out of the gut.

> The prebiotics industry worldwide has grown largely because a range of prebiotic oligosaccharides can now be manufactured by enzymatic bio-technological methods. In Japan, for example, lactulose production reached 20 thousand tonnes in 1995.

Readings

The following readings are available on CD:

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Self Assessment Questions

3. What is a 'probiotic' additive for feeds? What is its likely mode of action if it improves animal production?

3. How can addition of organic acids to feeds act as a growth promotant?

3. What has promoted the European countries to ban the use of antibiotics in feed?

3. How do antibiotics promote growth and feed efficiency in animals?

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Pluske, J.R., Siba, P.M., Pethick, D.W., Durmic, Z., Mullan, B.P. & Hampson, D.J. (1996). The incidence of swine dysentery in pigs can be reduced by feeding diets that limit the amount of fermentable substrate entering the large intestine. *Journal of Nutrition* 126, 2920–2933.

Siba, P.M., Pethick, D.W. & Hampson, D.J. (1996). Pigs experimentally infected with Serpulina hyodysenteriae can be protected from developing swine dysentery by feeding them a highly digestible diet. *Epidemiology and Infection* 116, 207–216.

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Topic 21

21. Acidosis and its control in ruminants

21.1 Understanding acidosis

21. Acidosis and its control in ruminants

Learning Objectives

On completion of this topic you should be able to:

- Describe the dietary conditions that expose ruminants to high risk of acidosis.
- Apply feeding management strategies that will minimize the risk of acidosis and maximize production outcomes.
- Discuss the mechanisms of managing acidosis by the use of antibiotics and probiotics.
- Explain how grain processing and manipulating the site of digestion can be used as strategies for managing acidosis.

Key Terms and Concepts

Rumen bacteria, volatile fatty acid, lactic acid, *Streptococcus bovis*, fermentation, probiotics, ionophores, rumen modifiers.

Introduction to the Topic

Acidosis is a digestive condition that can result from the feeding of grain sources to ruminant animals. Acidosis can be fatal and if not fatal, can result in long-term reductions in productivity. Acidosis is considered one of the major health and welfare issues facing the intensive feeding sectors of the Australian sheep and cattle industries.

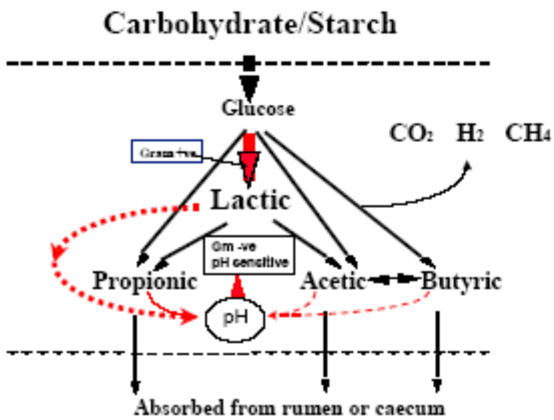
Acidosis can be managed. This topic will cover many of the strategies used for managing acidosis and you will be introduced to the metabolic conditions that result in acidotic events. With a greater understanding of the mechanisms by which acidosis can occur you will be better equipped to apply strategies for managing acidosis.

21.1 Understanding acidosis

When carbohydrates are digested under anaerobic conditions by microbes (i.e.

fermented) in the rumen, the starches—which are long chains of glucose polymers—are broken down to the simple sugars (glucose) and then to the volatile fatty acids (acetic, propionic, and butyric, ie. VFA). During this process, lactic acid is a very important intermediate compound that is produced by one group of bacteria and then the rapidly converted to the VFA by another group of bacteria. The utilisation of lactic acid is normally very rapid and, although a lot of carbon passes through lactic acid, lactic acid is rarely detectable in the rumen or hind gut. This process of carbohydrate fermentation is summarised in Figure 21-1.

Figure 21-1 Summary of the major pathways of carbohydrate fermentation and end product formation. The dotted line shows the harmful effects of acid production on pH in rumen contents and on the growth of Gram -ve bacteria that utilise lactic acid (UNE Animal Science Database).



Three things in Figure 21-1 need to be emphasised:

1. The bacteria producing lactic acid from glucose are predominantly Gram +ve bacteria whereas those converting lactic acid to VFA are predominantly Gram -ve bacteria.
2. Lactic acid, unlike VFA, is not absorbed from the rumen or the caecum.
3. Lactic acid and VFA buildup has a big effect on pH. Because lactic acid is not absorbed as rapidly as are the VFA, it has a greater impact on acidity.

The study by Allison *et al.* (1975) showed a dramatic increase in numbers of lactic acid producing bacteria in the 24 hours after an increase in intake of grain (see Figure 21–2). It is the ability of the lactic acid producing bacteria to grow and multiply more rapidly than the lactic acid utilisers, especially when pH falls, that leads to a buildup of lactic acid and the development of acidosis.

We have come to understood most of the adverse effects of acidosis only after we developed ways of controlling it. Before we gained this understanding, there was a lot of confusion about the role of protein and of other of non-starch feeds: in particular, many of the benefits associated with a reduced acidosis were attributed to additional protein. For this reason, we will first discuss ways of preventing acidosis before detailing the benefits associated with its control.

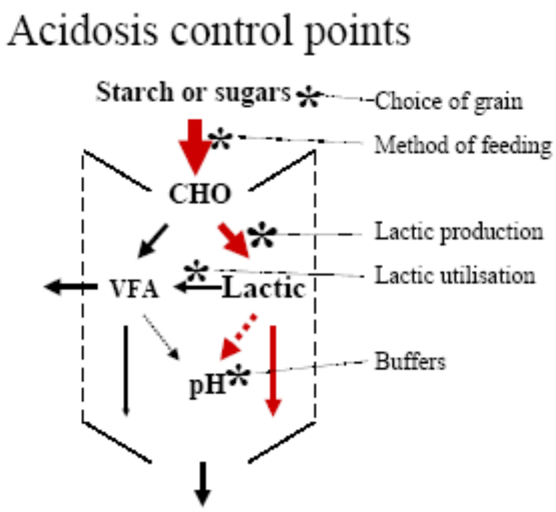
The ways of controlling acidosis

Specific issues in control of acidosis are summarised in Figure 21–3.

1. Choosing a type of grain (carbohydrate) that that does not promote the disease.
2. Processing the grain to reduce rate of fermentation and alter site of digestion.
3. The method of grain feeding and the size of each meal—these factors can have a big effect on 'fermentation load'.
4. Controlling lactic acid producing bacteria—this helps to maintain a balanced fermentation and prevent lactic acid buildup.
5. Use of a probiotic preparation of lactic acid utilising bacteria can help to reduce lactic buildup.
6. Inclusion of buffers and clays in the diet is considered by some practitioners to be useful in preventing acidosis.

Figure 21–2 Changes in the population densities of the major lactic acid producing bacteria in the rumen of cattle following introduction of wheat (Allison *et al.* 1975).

Figure 21-3 Diagram showing of the major fermentation pathways and points at which acidosis can be tackled (UNE Animal Science Database).



These points of control are discussed in detail below:

Choice of grain

It is well known that wheat poses the greatest risk of acidosis. This is probably due to its higher fermentability than barley, maize or sorghum. The fermentation rate of sorghum is sufficiently slow for acidosis to be a very minor problem when this grain is fed to ruminants. Oats grain is interesting in that it is highly fermentable but, because of its relatively low starch content, it is a safe grain for almost all classes of livestock.

Processing and site of digestion

Rate of fermentation is influenced by particle size, and ground grain is therefore more likely to produce acid accumulation in the rumen than whole grain or larger particles. The particle size can be influenced relatively easily through choice of screen size for grinding, or alteration of roller settings in the process of steam flaking. While larger particles may reduce rumen acid accumulation, they may also reduce starch digestion in the small intestine. This may have serious consequences for hind gut acidosis if too much undigested starch enters the caecum. Not enough attention has been paid to potential problems of hind gut acidosis.

Many US feedlot operators process grain to maximise rumen digestion and this is also likely to minimise the amount reaching the hindgut. However, small intestine starch digestion is likely to be influenced more by extent of gelatinisation than by particle size. Processes such as extrusion and steam flaking are likely to improve intestinal starch digestion and decrease the risk of hind gut acidosis.

Level of feeding and interval between feeds

The amount and rate of grain ingestion has a very significant effect on fermentation load and potential acid accumulation. Small amounts of starch ingested throughout the day at regular intervals provide an ideal pattern of intake to minimise the risk of acidosis. This is difficult to achieve under practical conditions. Weekly feeding of grain as a feed supplement to grazing animals is an extreme example of how not to feed. Whenever animals consume a single large meal of grain, the risk of acidosis will be significantly higher than if the same amount of grain is consumed in small quantities over at an extended period. This management strategy is easiest to implement with dairy cows and in a bunk management in feedlots.

Managing lactic acid producing bacteria

Antibiotic compounds active against the Gram +ve bacteria are generally effective against acidosis. Compounds such as avoparcin, virginiamycin, thiopeptin and some ionophores reduce the risk and/or the severity of acidosis. Rowe and colleagues identified virginiamycin as having excellent efficacy in controlling acidosis and subsequent testing has supported this choice. Table 21-1 summarises the effects of avoparcin and virginiamycin on pH and lactic acid during in vitro fermentation. Table 21-2 shows the effectiveness of avoparcin compared to the buffer, sodium bicarbonate, in preventing acidosis.

The use of antibiotic feed additives in agricultural production is under intense scrutiny and several have been banned in Europe. Research based on these antibiotic compounds has been very useful in identifying the key bacteria responsible for acidosis and has initiated an investigation of the possible application of vaccine technology to control lactic acid producing bacteria during grain feeding.

Probiotics

As mentioned earlier, when there is rapid fermentation of starch in the rumen, the lactic acid producing bacteria normally increase more rapidly than the lactic acid utilising organisms. To achieve a balance between production and utilisation of lactic acid, it is possible to treat animals prior to, or at the time of, grain feeding with bacteria capable of utilising lactic acid. While there have been a number of successful demonstrations of this theory, there are a number of practical difficulties associated with its implementation of this method of acidosis prevention. The major problem is in storage and stability of the live bacteria that are required to be almost immediately active once they enter the rumen.

Buffers and clays

The lack of effective control of acidosis by using bicarbonate is evident in Table 21-2. Lack of control is also characteristic of bentonite clays. Table 21-2 clearly illustrates the significant difference between efficacy of antibiotic feed additives (even avoparcin) and buffers. Buffers do not seem to be an effective way of managing fermentative acidosis by altering conditions in the rumen, but they may play a role in balancing the animal's electrolyte and buffer systems.

Table 21-1 Control of lactic acid and pH during *in vitro* fermentation of hind gut digesta in the presence of high levels of glucose (Rowe *et al.* 1995).

	Avoparcin		Virginiamycin	
(μg/ml)	pH	Lactate	pH	Lactate
0	5.3	47	5.3	47
2	6.1	9	6.6	0.2
4	6.2	12	6.7	0.2
8	6.3	11	6.7	0.2
16	6.4	10	6.6	0.0

The benefits of controlling acidosis

The benefits of minimising acidosis incude:

(a) *Better use of roughages and more flexibility.* Figure 21-4 shows how digestibility of fibre (cellulose) and decreases with increasing acidity of the rumen digesta. By preventing or reducing the severity of acidosis, the digestibility of fibrous feeds is maintained. Using virginiamycin to control acidosis allows barley to be used as effectively as lupins and Figure 21-5 shows that, even when fed at intervals of one or two weeks, barley with virginiamycin can provide a safe and effective supplement.

Feeding supplements at extended intervals enables 'shy feeders' to eat when dominant animals have finished eating. (It is clearly not safe to feed barley at weekly or fortnightly intervals without a method for controlling acidosis.)

(b) *Control of diarrhoea*. Fermentation and acid accumulation in the hindgut, leading to diarrhoea, is a very important consequence of acidosis. Most workers have only studied the rumen situation when investigating acidosis. It is easy to sample rumen fluid and then to measure pH, and VFA and lactic acid concentrations. However, in most situations even after a big meal of grain, fermentation in the rumen can be quite normal while, at the same time, there is bad diarrhoea.

Table 21-3 shows the pH and lactic acid concentrations in rumen and caecal digesta following a grain challenge.

Table 21-2 Comparison of the effectiveness of the buffer, sodium bicarbonate (2% of grain) and the antibiotic feed additive, avoparcin (0.04% of grain) in lowering the incidence of acidosis in sheep dosed with ground wheat (Rowe unpub. data).

Treatment	Incidence of acidosis (% of animals)
Control	55
Bicarbonate	48
Bentonite	45
Avoparcin	3

Table 21-3 Acidosis in the rumen and hindgut of sheep following grain overload. (Rowe *unpub. data*)

	Control	Virginiamycin	s.e.d.
Rumen pH	5.7	5.8	0.19
Rumen lactic (mmol/L)	0.9	0.6	
Caecal pH	5.4	5.9	0.26
Caecal lactic (mmol/L)	61	14	9.14

Figure 21-4 Influence of pH of rumen digesta on cellulose (fibre) digestibility (adapted from Mullholland *et al.* 1976).

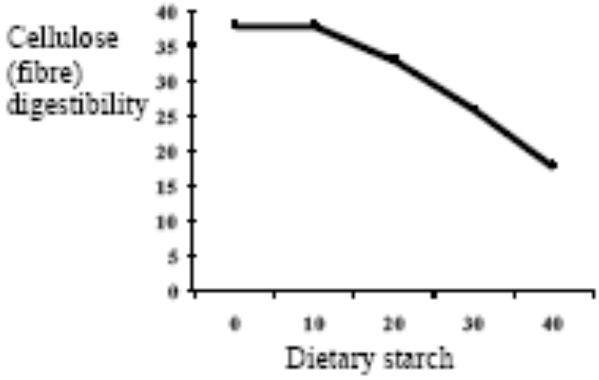
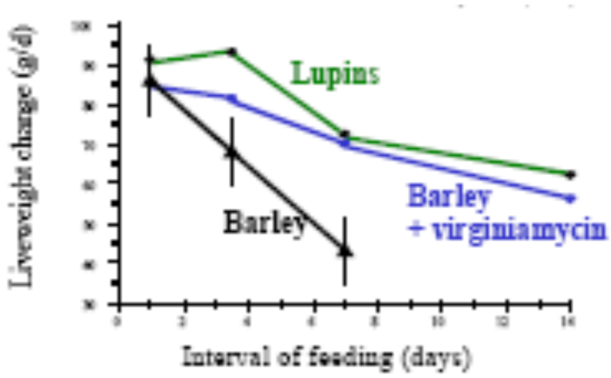


Figure 21-5 Live-weight change (g/day) of sheep fed 200 g/day of barley, or barley with virginiamycin, or the same amount of ME as lupin grain. Many veterinarians use rumen fluid from abattoir material to dose sheep and cattle following acidosis (Godfrey *et al*. 1993).



(c) *Tensile strength of wool.* A decline in the general health of animals and specifically, a decline in feed intake following grain overload and acidosis, generally leads to reduced tensile strength of wool.

(d) *Deaths due to acidosis*. When Henry sheep are put straight onto wheat they are at a significant risk. In a trial summarised in Table 21-4, the mortality was 20% in the control group. The reason is clear. There were very high levels of lactic acid and very low pH. In this situation the inclusion of virginiamycin was effective in preventing buildup of lactic acid in the rumen, and a fall in pH, and in preventing deaths.

Table 21-4 Benefits of Virginiamycin (VM) in reducing lactic acid concentration in rumen fluid, maintaining pH and decreasing deaths in sheep exposed to wheat (Rowe unpub. data).

	pH	Lactate (mmol/L)	Deaths (%)
Wheat alone	4.72	86.9	20
Wheat + VM	5.47	20.3	0
Significance	<0.05	<0.01	<0.01

(e) *Respiratory disease and lameness.* It is almost certain that lameness and a range of non-specific feedlot diseases are a direct result of acidosis. We know that fermentative acidosis in horses on grain or grazing lush pastures leads to laminitis and it is likely that the same damage occurs in cattle that are rapidly introduced to high levels of grain. The question of respiratory diseases and their link to acidosis is not as clear as it is in the case of lameness.

Readings

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Self assessment questions

1. What is ‘acidosis’ in ruminants?
2. Can acidosis be controlled without the use of chemicals?
3. What are the reasons for controlling acidosis in cattle?

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