18. Chemical and physical treatment of roughages to improve digestibility

James Rowe

Learning Objectives

On completion of this topic you should be able to:

- Explain why cereal straws are poorly digested by ruminants
- Describe some chemical treatments that can be applied to low quality feeds to improve their nutritive value to ruminants.
- Explain why particle size can affect the digestion of roughages.
- Describe some physical treatment options for improving the digestibility of low quality roughage sources for ruminants.
- Explain why ammonia or urea is often used for improving the utilisation of low quality roughages.

Key terms and concepts

Chemical treatment; of roughages; physical treatment of roughages; requirement for nitrogen by rumen microorganisms.

Introduction to the topic

The feeding of ruminant livestock in many countries of the world is dependent on readily available low quality roughages or crop residues. In poorer countries that are densely populated, opportunities for supplementing these animals with products such as cereal grain, urea or molasses are limited. In addition, production systems in these countries are typically small but intensive, with one family often owning only a few head of livestock. In such situations, cattle may provide milk for the family, or draft to prepare the soil for planting and reproduction to produce replacement animals.

Poor quality roughages such as rice straw have low digestibility and only move slowly through the rumen. As a result intake is also low and digestible energy intake (feed intake multiplied by digestibility) is also low, so production is limited. Strategies aimed at improving the quality of low quality roughages are therefore needed.

This topic will introduce you to several examples of chemical and physical treatments of roughages that can considerably improve their nutritive value for livestock. Despite the potential value of treatments, adoption has been relatively low.

18.1 Introduction to chemical treatment

Tremendous amounts of fibrous crop residues such as wheat, barley and rice straws are underutilised throughout the world. During the 70s and 80s there was considerable interest in the chemical treatment of straws and other of low quality roughages to improve their quality for ruminant feeding.

In general, plant cell contents are quite highly digestible when compared with their cell wall. The cell wall thickens as the plant matures and so digestibility declines. A cell cross section of a cell shows a lumen, a secondary cell wall, a middle lamella and a primary cell wall on the outside. The middle lamella consists of pectins (digestible carbohydrates). The primary cell wall is thin and consists of structural proteins, hemicelluloses and cellulose fibrils loosely bound to the pectins. The secondary cell wall develops when the cell matures – at first, by the deposition of hemicelluloses and cellulose and later by the infiltration of lignin, starting in the primary cell wall and extending into the secondary wall. The cell dies when lignification of the secondary wall is complete. Cellulose and associated hemicelluloses are structural carbohydrates that are not digested by mammalian enzymes but are digested by the actions of enzymes of rumen microbes. Lignin is the name given to a family of polymers with a complex, cross-linked three-dimensional structure. These polymers are virtually indigestible in the rumen. The matrix formed by these polymers in combination with hemicelluloses and other cell wall components is the 'ligno-cellulose' complex. This complex, chemically linked to various phenolic compounds is the reason for the low digestibility of mature roughages. It is also the major component of the fraction obtained by laboratory analysis for 'crude fibre'.

The principal chemical method used to treat roughages to increase their digestibility is alkali treatment. This breaks (hydrolyses) chemical bonds and releases the digestible carbohydrates in cell walls from the indigestible lignin.

Early research showed very exciting increases in the digestibility of roughages in response to treatment with sodium hydroxide. Sheep and cattle fed alkali-treated roughages showed 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, calcium and potassium hydroxide were investigated as alternative sources of alkali. There was also work on the use of ammonia to treat roughages, particularly from the point of view of treating straw with anhydrous ammonia, urea or, as an alternative source of ammonia, urine.

Although the treatment of low quality roughages with hydroxide is very effective as a way of increasing digestibility, intake 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?

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 rice straw. The high level of ash in rice is mainly because of high silica levels.

The major components of straw include structural carbohydrates such as cellulose, non–starch polysaccharides and lignin. The cellulose is made up of glucose molecules connected by β–1–4 linkages. These bonds it cannot be split by mammalian enzymes. However, cellulose can be degraded by anaerobic bacteria in the rumen to glucose which is fermented provide energy for the bacteria; VFAs are formed as end-products. 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 in the plant. It is also the major indigestible component in the plant - being non-digestible by microbes and by the animal's digestive enzymes.

It is the amount of lignin and its distribution in the plant material that has the greatest depressing effect on digestibility. When lignin surrounds the cellulose, it effectively prevents bacterial attachment and reduces digestibility both through its own inert properties and by encasing the digestible cellulose. The lignin is mainly present in the stems and nodes, but is also present in reasonably high concentration in some leaf material. Some typical feed lignin concentrations are summarised in Table 18.1 (Bagby *et al.* 1971).

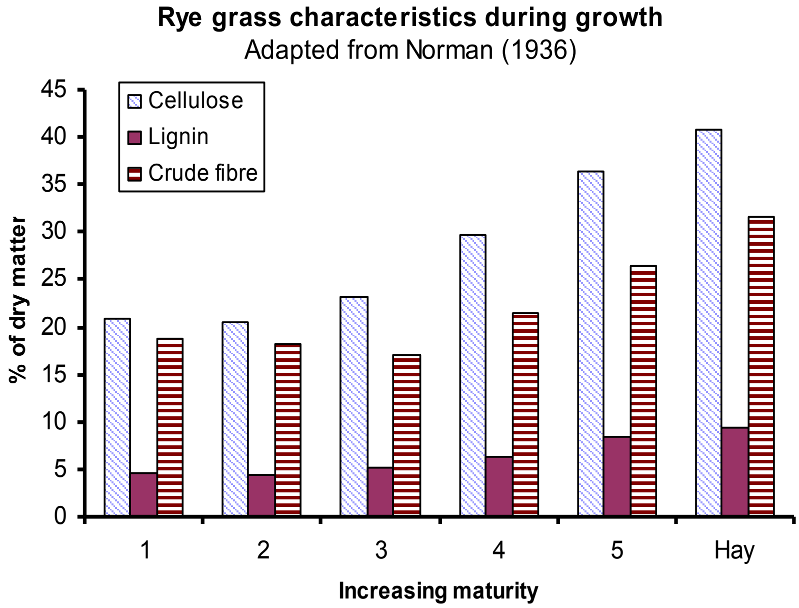
Table 18.1 Lignin content of different crop residues. Source: Bagby *et al.* (1971).

Roughage	Lignin (%)
Bagasse	19.6
Maize stover	15.3
Barley straw	15.0
Oat straw	17.7
Rice straw	12.7
Wheat straw	16.0

Silica taken up by the plant roots is deposited in the cell walls and together with lignin contributes to their low digestibility. The combination of lignin and silica in rice straw gives it the lowest digestibility scores.

As shown in Figure 18.1, lignin concentration in cereal plants does not rise as quickly as cellulose concentration during maturation but the lignin has a disproportionate effect on crude fibre concentrations that lead to low digestibility.

Figure 18.1 Rye grass characteristics during growth.
Source: adapted from Norman (1936).



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.

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

Before the 1920s, scientists had shown that boiling straws in sodium hydroxide (NaOH) solution could improve their feeding value. In Australia, Dr Roy Kellaway and colleagues at Sydney University developed practical ways of treating large quantities of cereal stubbles during the baling process.

There are three major problems in using NaOH. The first is the danger to operators and the risk of being splashed with the strong NaOH 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 have a negative effect on soil structure and the environment. A further problem, common to all alkali treatment processes, is the corrosion and damage to equipment.

As an alkaline agent, ammonium hydroxide is not as strong as NaOH and the gains in digestibility of roughage are generally lower. However, it has compensating benefits – the ammonia increases the availability of rumen degradable N for the rumen microbes to use to make protein and ammonia has a preservative effect inhibiting mould development during treatment.

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 (250 g NH_4Cl/L) per kg of straw followed by 8 weeks' storage prior to feeding.

Table 18.2 Effect of sodium hydroxide and aqueous ammonia on digestibility of barley straw by sheep. Source: 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 to plant biomass under natural conditions. Provided there is sufficient water present, ammonium hydroxide is quickly formed.

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

Urea is far safer to handle than ammonium hydroxide and can be applied to straw as 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 with plastic sheeting or ensiled for at least 4 weeks prior to being used. Once the treated straw is sealed in an air-tight container or pit, it is stable for long periods.

Ammonia gas (anhydrous ammonia) can be used instead of ammonia solutions. The concentration of anhydrous ammonia required for the same effect is about 3%. Anhydrous ammonia has the advantage of easy application to large stacks of straw as a gas and is still popular in some parts of Europe where large piles of cereal straw are covered with black plastic prior to introducing gaseous ammonia from a mobile tank[1]. It is potentially a dangerous procedure as the gas is toxic and flammable.

The methods of harvesting the roughage, chopping it and applying the urea/ammonia, and having the right facilities for storage and suitable equipment for feeding out the treated material are all critical in determining the success and attractiveness of this procedure. As it can involve large quantities of material, it is highly desirable to have highly mechanised methods for harvesting and filling the pit or silo.

In situations where mechanisation is not available, the job of harvesting, filling silos and feeding out is an onerous and time consuming one. The method is of relatively minor importance in many parts of the world where one might think it would be ideal technology. A study by Nguyen Xuan Tract (2004) from the

[1] **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 and Leng 1987).

Hanoi Agricultural University gives insights as to why smallholder farmers may not adopt straw treatment. In a demonstration trial with participating farmers in a rice growing area, 20 raised their cattle by usual methods (grazing roadside grass and giving rice straw *ad libitum*) and the other 20 applying the same feeding method except that they used 4% urea-treated rice straw. After a pre-experimental period of 3 weeks, the effect of straw treatment was determined over 3months (Table 18.3).

Table 18.3 Liveweight gain in young cattle given urea-treated rice straw or untreated straw in village conditions in Vietnam. Source: Nolan (2006).

	Untreated straw	Treated straw
Straw DM intake (kg/d)	1.81	2.69
Initial weight (kg)	152.8	152.2
Final weight (kg)	176.2	186.6
Weight gain (kg/d)	0.260	0.383

The benefits of treatment were clearly apparent and confirmed the positive effects of treatment shown repeatedly by others (e.g. Doyle et al. 1986). During and after the trial, all participants were enthusiastic about the benefits to be gained from straw treatment, but 9 months later none was continuing to use straw treatment. In response to a survey of all the participants at this time, 30 % said that money to invest in a silo and for purchase of urea was a problem. Some participants (20 %) said they feared their cattle might be poisoned by the urea and they could not accept that risk. Others said treating straw was inconvenient (difficulty finding space to treat the straw; treating the straw was difficult; it disrupted routine farm activities) and the economic benefits were unclear. The author concludes that straw treatment is clearly an effective way to increase production but it will not be adopted for a variety of reasons related to the small scale of production in the Hanoi countryside.

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 inexpensive 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, although slow acting, 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 feeding 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 roughages may be altered to improve digestibility and/or intake. These include grinding, chopping and pelleting. These methods can be considered in 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 18.4 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%.
Source: Jones *et al.* (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 when the costs 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.

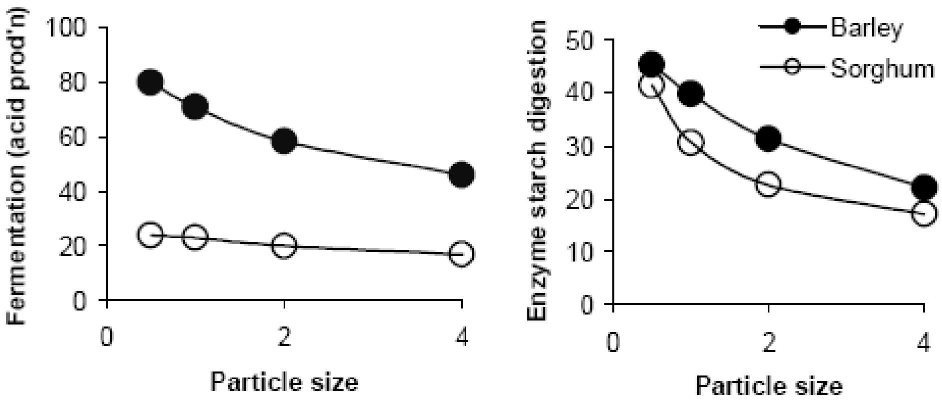
The process of cubing is mainly used for hay transport and feeding. It is a process that is very popular in the United States for preparing lucerne hay for export and for feeding lucerne hay to dairy cattle and horses. It is best described as a “micro hay baler” and produces “chunks” of compressed feed 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 represents a significant management tool, enabling alteration of the site and extent of digestion. The results 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 ruminal fermentation and intestinal digestion of barley and sorghum. Source: Bird *et al.* (1999).



Readings

The following readings are available on CD:

1. Djajanegara, A. and Doyle, P.T. 1989. ‘The intake and utilisation of urea-treated rice straw by sheep in deffering body condition’. *Australian Journal of Agricultural Research* vol 40 pp 1037-1045.
2. Liu, T.X., Susbeth, A. and Sudekum, K.H. 2002. ‘In vitro gas production measurements to evaluate interactions between untreated and chemically treated rice straws, grass hay and mulberry leaves’. *Journal of Animal Science* vol 80 pp 517-524.
3. Moran, J.B., Satoto, K.B. and Dawson, J.E. 1983. ‘The utilization of rice straw fed to zebu cattle and swamp buffalo as influenced by alkali treatment and leucaena supplementation’. *Australian Journal of Agricultural Research* vol 34 pp 73-84.

Activities

Available on WebCT

Multi-Choice Questions

Submit answers via WebCT

Self Assessment Questions

1. Why are mature roughages poorly digested in the rumen?
2. How does alkali treatment improve digestibility?
3. What are the advantages and disadvantages in NaOH and ammonia treatment of cereal straw?
4. Compare the benefits and costs of feeding long hay or chaff to cattle.
5. Why has the undoubted benefit of straw treatment for animal production not lead to widespread adoption?
6. What are the benefits in using pelleted diets for dairy cows?

Useful Web Links

Available on WebCT

Assignment Questions

Choose ONE question from ONE of the topics as your assignment. Short answer questions appear on WebCT. Submit your answer via WebCT

Summary

Summary Slides are available on CD

References

Bagley, M.O., Nelson, G.H., Helman, E.G., Clark, T.F. 1971. 'Determination of lignin in non-wood plant fibres'. *Journal Tappi* vol 54 (11).

Bird, S.H., Rowe, J.B., Choct, M., Stachiw, S., Tyler, P., Thompson, D. 1999. 'In vitro fermentation of grain and enzymatic digestion of cereal starch'. *Recent Advances in Animal Nutrition in Australia* vol 12 pp 53–61.

Jones, W.M., May, P.J., Barker, D.J. 1988. 'The effects of milling hay and straw on intake and growth of cattle'. *Animal Production in Australia*, vol 17 pp 210-213.

Perdok, H.B., Leng, R.A. 1987. 'Hyperexcitability in cattle fed ammoniated roughages'. *Animal Feed Science and Technology* vol 17 pp 121-143.

Wanapat, M. 1985. 'Improving rice straw quality as ruminant feed by urea treatment in Thailand'. In Wanapat M and Devendra C (eds). 'Relevance of Crop Residues as Animal Feeds in Developing Countries'. Funny Press. Bangkok, Thailand. pp 121-145.