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Author:	Beretta, V.; Kirby, R.M.
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CHAPTER 4. NUTRITIONAL CHARACTERISTICS OF CEREAL GRAINS

V. Beretta[a] and R.M. Kirby[b]

[a]Animal Science, University of Uruguay, Ruta 3 km 363, CP 60000, Paysandu, Uruguay
[b]Department of Agriculture, Dryland Research Institute, Merredin WA 6415

Characteristics of cereal grains

Feed grains are a major source of nutrients for sheep meat production. Winter cereal grains, barley, wheat and oats comprised 54, 16 and 8 per cent, of the total amount of grain consumed by ruminants in Australia during 1990-1991 (Schaefer and Kreitals 1991). Summer cereal grains, sorghum and maize are used extensively for animal feeding in other countries of the world but little used for feeding sheep in Australia (QDPI 2004). The choice of grain used for livestock production is determined mainly by agro-ecological and market differences between regions and the volume of research on each grain reflects the level of use by industry.

Feeding grain to growing and finishing lambs to achieve potential liveweight gains and carcase targets has increased the demand for information about the benefit of including different types of grain in rations. Cereal grains vary in their nutritive value. Part of this variation is associated with differences in chemical and physical properties but some variation will also depend on the interaction between grains and animal characteristics. For example, the level of intake, feeding management, grain to forage ratio, feed processing and adaptation period can all influence the level of nutrients that the animal obtains from grain. Quantitative data of the expected liveweight gain, feed conversion ratio and carcase characteristics associated with various grains under different feeding systems are necessary to evaluate the potential economic benefit of their utilisation.

Table 4.1. Nutrient content and structure of different cereal grains.

Chemical composition[1]	Units	Wheat	Barley	Oats	Maize	Sorghum
Metabolisable energy	MJ/kg DM	13.0	11.6	10.5	13.5	12.4
Crude protein	% DM	13.0	12.0	11.0	10.0	10.0
Rumen undegradable protein[2]	% CP	18	25	30	55	55
Acid detergent fibre	% DM	2.6	5.3	14.0	2.4	2.8
Starch[3]	% DM	70.3	64.3	58.1	75.7	71.3
Ca	% DM	0.04	0.08	0.07	0.02	0.02
P	% DM	0.36	0.37	0.39	0.35	0.30
Grain Structure[4]						
Hulls	% DM		13.0	25.0		
Testa+ pericarp+ aleurone	% DM	15.0	7.7	9.0	6.0	7.9
Starchy endosperm	% DM	82.4	76.2	63.0	82.0	82.3
Embryo	% DM	2.6	3.0	3.0	12.0	9.8

[1] Cottle (1991), Agriculture NSW (2004); [2] Neutze (1991); [3] Herrera-Saldana *et al.* (1990); [4] Evers *et al.* (1999).

The nutritional value of grain can vary widely due to environmental influences such as location and season. For comparative purposes, average chemical composition for winter and summer cereal grains is presented (Table 4.1). Cereal grains consist of the embryo, endosperm, testa or seedcoat and pericarp. The dominant tissue of the grain is the endosperm. The endosperm represents approximately 82 per cent of the mass of wheat, maize and sorghum grain and less in barley and oats due to the presence of hulls (Table 4.1). The endosperm predominantly contains cells filled with starch but has an increasing concentration of protein toward the periphery. Wheat has a relatively high proportion of protein in the endosperm (8-16%, Evers *et al.* 1999) compared to other cereals and the endosperm cells of oats have a relatively high lipid content. The structure of starch granules characteristically differs between cereal grains and this contributes to variation in starch degradation rates between grains.

In general, the metabolisable energy of wheat and maize are higher than sorghum and barley, while oat grain has the lowest metabolisable energy of all cereal grains. Protein content of the winter cereals is generally higher than for maize and sorghum.

Starch concentration per unit of dry matter is higher for wheat, maize and sorghum than for barley or oats (Table 4.1). This is a consequence of the greater relative importance of the starchy endosperm in the whole grain and to the absence of hulls (Table 4.1, Evers *et al.* 1999). Variation in total starch content may be observed between hybrids and varieties and also associated with changes in agronomic practices, such as plant density or to varying environmental conditions during growth (Defoor *et al.* 2000, 2001). O'Brien (1999) reported important year and location effects, and genotype × environment interactions on the nutritive value of grains. Maize and sorghum registered the lowest coefficients of variation in terms of starch content (2.4 and 3.7% respectively) when compared to wheat, barley and oats (4.1%, 5.2%, 7.1%) as reported by Herrera-Saldana *et al.* (1990). Higher variability for oats compared to other grains has also been reported by Moran (1986).

Winter and summer cereals differ in the rate of fermentation of dry matter, protein and starch, and also the site and extent of digestion. Only 17-27 per cent of protein from winter cereal grains bypasses the rumen. In comparison, more than half of maize and sorghum protein is not degraded in the rumen and passes intact to the small intestine (Table 4.1). Because of this, some authors have suggested that adjustments in terms of rumen degradable protein might be necessary when feeding whole grain diets based on maize or sorghum (Loe *et al.* 2000, 2001).

The rate and extent of rumen fermentation of starch from maize and sorghum are lower than those observed for wheat, barley or oats (Bird *et al.* 1999). The digestibility of starch is influenced by the structure and composition of the granules and the nature of the protein matrix that surrounds the starch granules (Rooney and Pflugfelder 1986). Several reviews have focused on this aspect describing starch differences between cereal grains and the effect on digestion (Huntington 1997; Rooney and Pflugfelder 1986).

The rate of production of fermentation products of different species of grain have been characterised using an *in vitro* gas production technique (Opatpatanakit *et al.* 1994). Gas production was highest in wheat > triticale > oats > barley > maize > rice and sorghum, indicating that rate of fermentation is lower for sorghum and maize than for winter cereals. Variations due to varietal differences (mostly related to horny/floury endosperm ratio or to tannin content) and region of production of the grains were observed. *In situ* trials show that the soluble fraction and rate of fermentation of starch in the rumen is significantly lower for maize and sorghum than for wheat and barley (Herrera-Saldana *et al.* 1990). Although oat grain has a low rate of fermentation, the starch is almost completely degraded (96.6%) (Herrera-Saldana *et al.* 1990). *In vitro* trials by the same authors confirm that after oats, wheat and barley, sorghum and maize rank as the cereal grains with the lowest starch ruminal availability. This lower rate of rumen degradation reduces the risk of acidosis and related metabolic disorders in sheep. Hence maize and sorghum are comparatively safer than barley (Keating *et al.* 1965) or wheat (Kreikemeier *et al.* 1987) when fed in high concentrate rations to sheep.

Processing grains for sheep

The primary purpose of processing grain is to improve the utilisation of cereal starch by gelatinising the starch to allow more effective microbial digestion or to reduce particle size to increase surface area for amylolytic attack. However, the whole-tract digestibility of cereal starch by sheep approaches 100 per cent for common feed grains so there is limited potential for increasing the efficiency of digestion of grains (Table 4.2). This has been noted in many comprehensive reviews (e.g. Hale 1973; Ørskov 1976, 1986; Rowe *et al.* 1999; Rowe and Pethick 1994; Theurer 1986).

Table 4.2. Starch digestion by sheep of whole or minimally processed cereal grain.

	Treatment	Whole tract digestibility (% of starch intake)	Fermented in rumen (% of starch intake)	Reference
Barley	Whole		95	(MacRae and Armstrong 1969)
	Rolled		97	(MacRae and Armstrong 1969)
	Rolled	100	93	(Ørskov *et al.* 1969)
Maize	Whole	97		(Hejazi *et al.* 1999)
	Flaked	100	96	(Beever *et al.* 1970)
Sorghum	Rolled	97	89	(Holmes *et al.* 1970)
	Coarse ground	93		(Buchanan-Smith *et al.* 1968)
		97	85	(Rowe *et al.* 1999)

The increase in digestion by cattle of processed grain over whole grain is well documented (e.g. Huntington 1997 for review). In comparison, whole grain is utilised effectively by sheep due to efficient mastication. Ørskov *et al.* (1974a) evaluated the chewing behaviour of lambs given whole loose or pelleted barley and observed that for the same grain intake, those lambs fed with whole loose barley, spent significantly more time ruminating and regurgitated more boluses of rumen digesta. This effect has been reported not only for lambs but also for ewes (Vipond *et al.* 1985).

There is little response in either starch digestibility (Table 4.2) or dry matter digestibility (Table 4.3) when cereal grains are processed prior to feeding to sheep. Vipond *et al.* (1985) reported an increase in digestibility of rolled barley but not rolled oats compared to the same grain fed whole. In contrast, other authors report no increase, and sometimes even a decrease in digestibility of starch, digestibility of dry matter or animal performance with increasing level of grain processing (Beever *et al.* 1970; Fluharty *et al.* 1999; Hart and Glimp 1991; Hejazi *et al.* 1999; MacRae and Armstrong 1969; Ørskov *et al.* 1969, 1974b).

Table 4.3. Dry matter digestion by sheep of whole or processed cereal grain.

	Digestion of dry matter (%)[1]		Reference
	Whole	Processed	
Wheat	84	88	(Ørskov *et al.* 1974b)
Barley	83	79	(Ørskov *et al.* 1974b)
	68	83	(Vipond *et al.* 1980)
Oats	71	69	(Ørskov *et al.* 1974b)
	72	76	(Vipond *et al.* 1980)
Maize	81		(Vipond *et al.* 1980)
	86	84	(Ørskov *et al.* 1974b)
	86	81	(Hart and Glimp 1991)

[1] Adapted from organic matter digestibility where necessary, by assuming all grains contain 98% organic matter on a dry matter basis.

The extent of starch digestion is not affected by processing, but the rate of starch fermentation is increased when cereal grains are processed, thus increasing the risk of acidosis. Feeding whole grain is beneficial for rumen health compared to feeding processed grain (Ørskov 1976, 1979, 1986). Compared to processed grain, whole grain is fermented more slowly, animals spend more time eating and ruminating and there is higher saliva production and consequently higher rumen pH (Weston 1979). Additional stimulation of rumination through the addition of supplementary fibre to whole grain diets has been shown to further improve the performance of lambs fed whole grain. Hejazi *et al.* (1999) reported that adding soybean hulls or peanut hulls to a whole maize diet increased intake and daily gain, compared to high concentrate diets lacking supplemental fibre. Similarly, Weston (1974) showed an increase in feed intake when straw content of whole wheat diets was increased from 2 per cent to 14 per cent.

Processing does not increase the efficiency of grain utilisation by sheep but it may be desirable to develop processing methods that alter the site of digestion of starch. Starch that bypasses the rumen is available for digestion in the small intestine. The two main objectives for shifting the site of digestion of starch to the small intestine of sheep have been discussed by Rowe *et al.* (1999). It is more energetically efficient for starch to be digested and absorbed as glucose rather than fermented in the rumen with subsequent loss of energy as heat, methane or hydrogen (Black 1971) and the absorbed glucose may promote intra-muscular fat deposition (Pethick *et al.* 1997).

Sorghum shows the most potential for strategic processing to manipulate the site of digestion due to the resistant nature of starch in this grain. The deposition of fat indicated by activity of ATP citrate lyase is higher when sheep are fed steam-flaked sorghum compared to whole sorghum (Pethick *et al.* 1995). Starch from processed sorghum is available for absorption in the small intestine, which increases the amount of absorbed glucose and stimulates fat deposition. The processing method can affect the extent of starch digestion in the small intestine. For example, Mendoza *et al.* (1999) reported that the amount of starch escaping rumen fermentation was 47.1 per cent for dry rolled sorghum compared to only 11 per cent bypass starch reported for steam-rolled sorghum (Holmes *et al.* 1970). Carcase fat characteristics may also be manipulated by exploiting the natural variation in starch characteristics between cereal grains. Stimulation of ATP citrate lyase was greater for maize-based diets than for diets of whole barley, sorghum or wheat (Pethick *et al.* 1995).

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