



Quality Feed Grains - Research highlights and opportunities

John L Black

John L Black Consulting, Locked Bag 21, Warrimoo NSW 2774, Australia

Abstract

The available energy content of cereal grains varies widely both between animal species and between grain cultivars. The Premium Grains for Livestock Program was established to determine the causes of this variation and to identify methods for improving the value of grains for livestock. The digestible energy content of barley grain for sheep has been shown to range from 11.5 MJ/kg for a heavily frosted samples of Arapiles to 15.5 MJ/kg for a sample of the Merlin cultivar. The available energy content of a sorghum grain for cattle was measured at 9.7 MJ/kg compared with approximately 16 MJ/kg when fed to pigs or poultry. These differences in energy values between grains and livestock species can be explained by differences in the gross chemical composition of the grains, physical barriers of the endosperm protein matrix and cell walls limiting enzyme access, the amylose content of the starch and the nature of the animal proteolytic enzymes. There is considerable potential for improving the nutritional value of grains for livestock through plant breeding and processing techniques.

Introduction

The demand for grain by the livestock industries of Australia has increased greatly over recent years with the expansion of intensive animal production and a significant increase in the amount of grain being fed to dairy cattle. Cereal grains provide the major source of energy for animals raised in intensive production systems. However, the energy available from cereal grains can vary widely between both grain and animal species. For example, the digestible energy (DE) content of wheat and barley for pigs has been reported to range from 13.3 to 17.0 and from 11.7 to 16.0 MJ/kg, respectively (van Barneveld, 1999). Similarly, Hughes and Choct (1999) reported a range in apparent metabolisable energy (AME, MJ/kg) for broiler chickens from 10.4 to 15.9 MJ/kg for wheat, 10.4 to 13.5 for barley and 8.6 to 16.6 for triticale. There are also large differences between animal species in their capacity to digest cereal starch. The digestibility of sorghum starch across the whole digestive tract of poultry is 99% compared with 87% for cattle (Rowe *et al.* 1999). Significant variation exists also between grains in the digestibility of starch in the rumen of cattle, with reported

values of 92%, 65% and 62%, respectively, for oats, maize and sorghum (Rowe *et al.* 1999).

The variation in energy available to animals from cereal grains can have a substantial impact on the profitability of intensive animal enterprises. Kopinski (1997) predicted that a change of approximately 5 percent in the DE content of wheat grain (0.70 MJ/kg) could alter the annual profitability of a 200 sow piggery from \$7,500 to \$15,000 depending on grain price. In 1996, the Grains Research and Development Corporation in collaboration with several of the animal Research and Development Corporations and Ridley Agriproducts established a new research program, "Premium Grains for Livestock", with the major aims of improving the quality and marketing opportunities of cereal grains for the livestock industries. A primary objective of the Program is to identify the extent of differences in the nutritional value of cereal grains available within Australia and the reasons for these differences. This paper outlines some of the results from the Program and discusses possible ways for improving the quality of cereal grains for animals.

Research strategies

Over 2000 grains with a wide range in chemical and physical characteristics thought to influence nutritional value have been collected. Many of the grains were obtained from germplasm archives and plant breeders collections, some were grown specifically and others were selected because of suspected wide variation in nutritional value due to severe drought, frost damage or pre-harvest germination. All grains have been scanned with near infra-red spectrometry (NIR) and the extent and rate of digestion of components of selected grains examined within *in vitro* systems simulating rumen fermentation and intestinal digestion. A subset of approximately 100 grains selected on the basis of NIR scans and *in vitro* analyses have been fed to animals including sheep, cattle, pigs, broiler chickens and laying hens. A relatively small number of grains have been offered to all animal types. Measurements made during animal experiments included voluntary intake, ileal and whole tract digestibility of energy and, for pigs and poultry, amino acid availability. The digestibility of several grains when offered at maintenance intake to sheep and cattle has been determined.

Comprehensive chemical and physical analyses have been conducted on all grains fed to animals. These analyses cover the range in grain characteristics that may influence nutritional value and included individual carbohydrate, fatty acid and amino acid components, α - and β -amylase, anti-nutritional factors such as lectins, tannins and phytic acid. Physical properties measured included grain weight, hydration capacity, seed colour, seed diameter, seed size distribution, seed hardness index and profile, and the viscosity of whole grain, starch extract and acid soluble extract. Light and scanning electron microscopy have been used to examine the physical structure of some grains.

Variation in the energy value of cereal grains

The available energy content of several individual grains offered to sheep, cattle, pigs, broiler chickens and laying hens is shown in Table 1. There were relatively small

differences in the available energy content of an individual grain when compared across the animal types. For example, the values for Reinette barley ranged from 12.63 MJ/kg for broiler chickens to 13.56 MJ/kg for cattle. The differences between animal species in available energy content of Galleon were greater than for the other cultivars of barley with a value of 14.89 MJ/kg for pigs and 13.20 MJ/kg for broiler chickens. Wheat also showed a higher energy content for pigs than for the other animal species. However, the most striking differences were for sorghum where the energy content for cattle of a normal sorghum isolate was only 60-61% of that for pigs and broiler chickens. The energy content for cattle of a waxy-isoline was substantially greater than that of the normal isolate (13.21 MJ/kg digestible energy compared with 9.73 MJ/kg), but was only 80-82% of the value for pigs and broiler chickens. This difference in energy content between waxy and non-waxy isolines of sorghum was not apparent for any other animal species examined. In addition, for all animal types except cattle, the available energy content of sorghum was higher than the other cereal grains.

Table 1 shows also that there can be considerable variation within a grain species in the available energy content for individual animal types. For example, the available energy content of barley for sheep ranged from 11.51 MJ/kg for a heavily frosted sample of Arapiles to 15.50 MJ/kg for Merlin, which is a hulless, low amylose cultivar. The heavily frosted Arapiles barley and Tahara triticale samples had substantially lower energy availability than normal unfrosted grain. Within the normal barley grain samples, there was also a considerable difference between Reinette and Galleon for pigs and poultry (0.6-1.6 MJ/kg), but the variation was smaller for sheep (0.5 MJ/kg) and non-existent for cattle, reflecting differences in the digestive systems of the animal groups. Another interesting feature of the comparison between grains and animal types was that the naked oat, Numbat, had the highest available energy content of any grain for laying hens, but this was not evident for broiler chickens. There was a difference of over 1.6 MJ/kg in the energy content of Numbat between hens and chickens.

Table 1. Available energy content of grains (MJ/kg DM) fed across animal species as digestible energy for sheep, cattle and pigs and as apparent metabolisable energy for poultry.

Grain	Sheep	Cattle	Pigs	Broilers	Layers
Sorghum					
<i>Waxy isolate</i>	14.56	9.73	16.06	15.90	15.48
<i>Normal isolate</i>	14.79	13.21	16.40	15.98	15.96
<i>Sprouted</i>	14.53	10.17	16.43	16.08	15.38
Barley					
<i>Reinette</i>	13.04	13.56	13.30	12.63	13.00
<i>Arapiles frosted</i>	11.51	11.91	11.70	11.68	11.12

<i>Galleon</i>	13.59	13.51	14.89	13.20	13.91
<i>Merlin</i>	15.50	-	-	-	-
Wheat					
<i>Janz</i>	13.86	13.84	15.32	13.84	13.53
<i>Sunstate</i>	14.31	14.23	15.97	14.22	14.27
Triticale					
<i>Tahara frosted</i>	12.26	12.44	12.00	11.21	11.43
<i>Tahara</i>	13.66	13.74	13.85	14.36	14.22
Oats					
<i>Numbat (naked)</i>	15.90	-	-	14.55	16.18
<i>Yarran</i>	13.41	13.33	-	13.37	14.08
<i>Echidna</i>	12.56	12.38	-	12.55	12.71

Starch disappearance from the four barley cultivars shown in Table 1 has been examined using the *in vitro* laboratory systems simulating rumen fermentation and intestinal enzyme digestion. The latter assay contained a mixture of α -amylase and amyloglucosidase, but did not contain proteases, glucanases or xylanases. There were marked differences between the cultivars in extent of starch disappearance in the two assays (Table 2).

Table 2. *In vitro* disappearance of starch from the grain of four cultivars of barley fed to animals and some aspects of their chemical composition.

Cultivar	Starch disappearance (%)		Chemical composition (%)			
	Rumen fermentation	Enzyme digestion	Starch	Crude protein	NDF ^a	Insoluble NSP ^b
Arapilies	66.4	45.7	44.9	12.2	29.6	11.2
Galleon	85.6	45.4	54.5	14.3	16.0	8.5
Reinette	50.6	40.5	54.3	11.1	20.7	10.5
Merlin	79.4	88.1	53.6	-	-	-

^aNDF, neutral detergent fibre; ^bNSP, non-starch polysaccharides

Starch within Reinette was poorly digested by both the rumen microbes and amylolytic enzymes, whereas starch within Merlin was well digested by in both *in vitro* systems. Starch within Galleon was digested well by rumen microbes, but relatively poorly by the amylolytic enzymes. The values for the frost affected Arapilies tended to be intermediate between the other cultivars. The starch content of the Arapilies sample was substantially lower and the neutral detergent fibre (NDF) content higher than for the other cultivars, indicating the suspension of grain maturation due to the severe frost. The starch content of the other three cultivars was similar. However, Reinette had a higher NDF and insoluble non-starch polysaccharide (NSP) content than Galleon. The full chemical analysis of the Merlin sample is still to be completed.

Reasons for differences between grains in available energy content

To identify the reasons for the differences in nutritional value of grains between animal types and between grains within an animal type, it is necessary to understand the critical steps in the digestion process. The extent of grain digestion by animals depends on the availability of enzymes capable of breaking the specific chemical bonds of each grain component, the ability of the enzymes to come in contact with the bonds and the length of time the enzymes are in association with the substrates.

Glucose units, which contribute the main energy source of grains, are commonly linked by α -(1-4), α -(1-6), β -(1-4) or β -(1-6) glycosidic bonds. The first of these, found predominantly in starch, can be cleaved by digestive enzymes from animals, whereas the β -(1-4) linkages, found in cellulose, requires microbial enzymes for cleavage. The α -(1-6) glycosidic linkages also restrict the action of animal amylases. The predominance of either the α -(1-4) or β -(1-4) bonds within a carbohydrate has a marked effect on energy availability to animals as is seen in the comparison between the digestion of starch by endogenous enzymes in the small intestine and cellulose by microbial enzymes in the rumen or hind gut. Starch is composed of two main compounds, amylose and amylopectin. Amylose consists primarily of long chains of α -(1-4) linked glucose units that form a tight helical structure, whereas amylopectin contains some α -(1-6) linkages that produce branches in the molecule and provides an open structure that is more readily attacked by digestive enzymes. The β -(1-3, 1-4) bonds found in β -glucans, xylans and arabinoxylans also are resistant to digestion by animal enzymes but can be degraded by microbial enzymes.

Grains consumed by ruminants such as sheep or cattle are first exposed to microbial enzymes, which digest fibrous structures as well as starches and proteins before passing to the small intestine where they are exposed to animal secreted amylases, proteases and lipases. Alternatively, grains fed to pigs and poultry are first exposed to animal enzymes and, with pigs, then to microbial enzymes in the hind-gut. Microbial enzymes play little part in the digestion process in poultry, but the gizzard causes substantial structural modifications to grain cell walls as the grain passes through the digestive tract.

The accessibility of an enzyme to a grain component can be affected by particle size and surface area, physical barriers like cell walls or chemical barriers such as the tight

helical structure of amylose chains, hydrophobic properties of lipid molecules or the sequence of amino acids within proteins. The latter affects protein digestibility and may influence the accessibility of enzymes to other substrates within the grain. The rate of passage of digesta through the digestive tract can affect the time enzymes are in association with the grain components and thereby alter the extent of digestion. The main factors thought to contribute to differences in the nutritional value of grains are discussed.

Gross chemical composition of the grain

The amount of energy available to an animal from a grain depends on the relative proportion of each chemical constituent, its energy contents and the extent of digestion. The chemical composition of all grains fed to animals within the Premium Grains Program has been determined and the gross energy content of these constituents is known. The extent of digestion of each component depends on the chemical component and the enzymes available. The relatively low available energy content of the heavily frosted sample of Arapilies barley grain shown in Table 1 can be explained largely by its high fibre and low starch content. Similarly, Black (2001) showed that much of the variation between grains in available energy for broiler chickens could be predicted simply from knowledge of the gross chemical composition of the grains. The most accurate predictions were for sorghum and oat grains. However, the predicted values were 1-2 MJ/kg higher than observed values for barley, wheat and triticale samples. These results suggest that there are factors other than chemical constituents in grains that limit the extent of digestion and the characteristics vary between grain types. Reasons for the difference between predicted and observed available energy content of grains may relate to physical barriers limiting enzyme contact with components of the grain. For example, sorghum and oat grains have thin endosperm cell walls compared with the other cereal grains examined. In addition, there are differences between grains in the size of starch granules and there may also be intrinsic differences between the grains in the rate of starch digestion.

Endosperm cell wall composition and thickness

Endosperm cell walls are composed of a cellulose skeleton impregnated with soluble and insoluble arabinoxylans and β -glucans. Although these cell walls have little effect on the availability of energy from cereal grains for ruminants, they can reduce the contact of amylolytic enzymes with starch granules and lower energy availability for non-ruminant animals by acting either as a physical barrier or by increasing the viscosity of the digesta. Endosperm cell walls act more as a physical barrier for pigs than for poultry. Grains eaten by birds are subjected to intense grinding in the gizzard and most endosperm cell walls are ruptured. However, pigs appear to rupture few cells during mastication and the availability of energy from cereal grains is increased substantially by fine grinding (Wondra *et al.* 1995). The likely importance of endosperm cell walls in reducing energy availability from cereal grains in pigs is illustrated with a comparison between barley and sorghum. Barley has relatively thick cell walls compared with sorghum and approximately 80% of barley starch is digested by the end of the small intestines compared with 95 % for sorghum. Similarly,

micrographs show that the barley cultivar Merlin has thin cell walls compared with Galleon and has a higher digestibility of starch in the *in vitro* enzyme assay (Table 2).

There is strong evidence that the availability of energy from cereal grains in poultry is inversely related to the content of soluble non-starch polysaccharides (NSP). Choct and Annison (1990) observed a linear decline in broiler AME from 17.5 MJ/kg for rice to 11 MJ/kg for rye with increasing soluble NSP content of grain. Soluble NSP compounds are thought to increase the viscosity of digesta, reduce the diffusion of digestive enzymes and reduce the rate of substrate digestion. Choct and Annison (1992) demonstrated that the chain length of soluble NSP polymers was more important for reducing AME of wheat for broilers than was the total soluble NSP content, because of the greater increase in digesta viscosity, which reduced the digestion of starch, amino acids and saturated fatty acids. Soluble NSP has a greater impact on energy availability for poultry than for pigs because of inherent differences between the species in both the normal viscosity of digesta and the transit time through the small intestines. The dry matter content of digesta in poultry is 16%-20% compared with 7%-10% in pigs and corresponding rates of passage of digesta through the small intestines are 2 to 4 hours for poultry and 12 to 24 hours for pigs (Bedford and Schulze 1998).

Protein matrix surrounding starch granules

Starch granules in the endosperm of cereal grains are imbedded to varying degrees in a protein matrix. In some grains like sorghum, the protein matrix and embedded protein bodies can form a contiguous layer around the edge of the endosperm and individual starch granules. Figure 1 shows the protein matrix and its embedded protein bodies surrounding each of the starch granules of a sorghum grain. Figure 2 shows the remnants of the protein matrix surrounding starch granules that had been packed against the cell wall prior to being dislodged as the grain was prepared for microscopic examination.

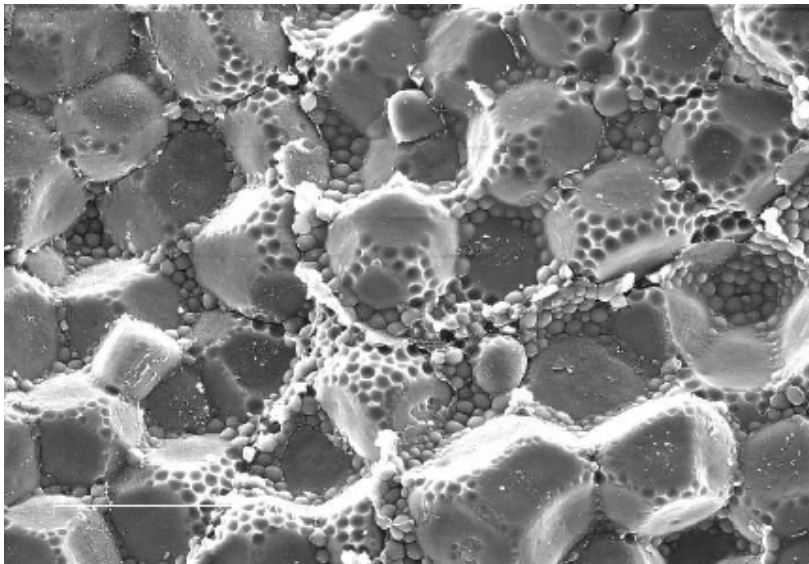


Figure 1. An electron micrograph of starch granules in the endosperm of sorghum showing the protein matrix with embedded protein bodies surrounding each granule. Indentations from the protein bodies can be seen on the starch granules.

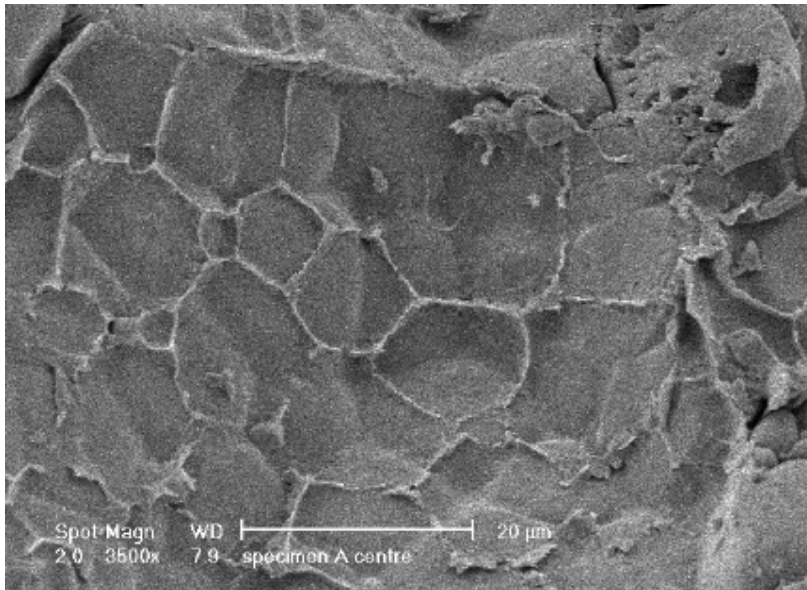


Figure 2. Scanning electron micrograph on an inner wall of a cell in the corneous endosperm showing remnants of the protein matrix surrounding starch granules.

The proteins surrounding the starch granules must be degraded to expose fully the starch to amylases. The protein matrix surrounding the starch granules in sorghum grain contains a high concentration of γ -kafirins with many disulphide bonds, which are resistant to some enzymes (Rooney and Pflugfelder 1986). There is now strong evidence that the low availability of energy from sorghum grain for cattle is due to the inaccessibility of amylolytic enzymes to the starch granules embedded in the protein matrix (Black *et al.* 2001). The marked difference in digestion of sorghum starch between cattle and horses compared with pigs and poultry could be due to differences in the capacity of proteases to degrade the protein matrix

The degree of starch granule encapsulation, amino acid composition of the protein matrix, nature of proteases and anti-nutritional factors like tannins and trypsin inhibitors will affect starch digestion. There is evidence that the presence of the protein matrix affects the extent of starch digestion in maize and barley grains when incubated with mixed microorganisms from the rumen of cattle (McAllister *et al.* 1993). Incubation of ground barley with proteases was shown to increase significantly the digestion of starch. Figure 3 shows the extent of encapsulation of starch granules

by protein bodies in a barley grain. It is probable that the susceptibility of the protein matrix to proteases within the digestive tract of animals varies between barley grain cultivars as has been shown for sorghum cultivars (Silano, 1977; Oria *et al.* 2000).

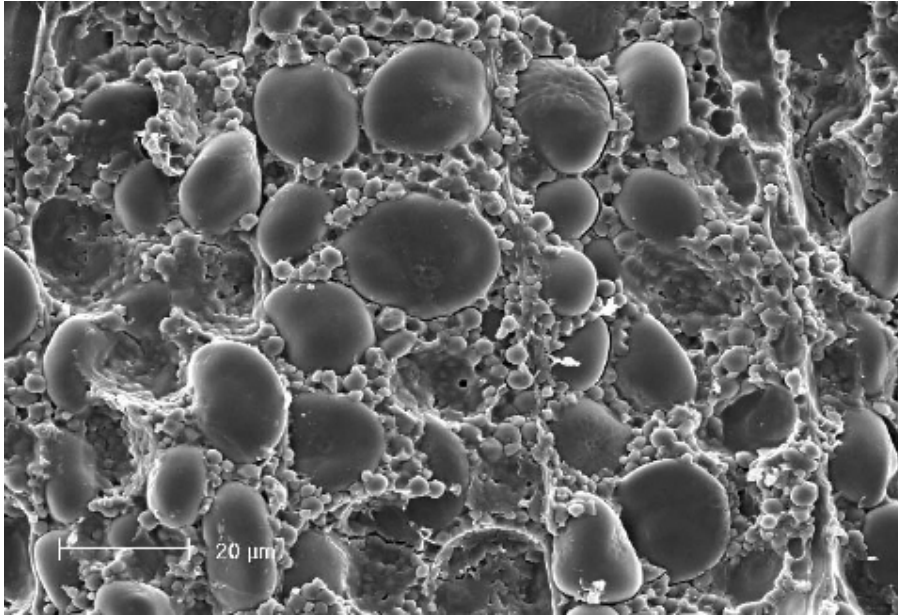


Figure 3. A scanning electron micrograph of the endosperm of barley showing starch granules of various sizes embedded in a protein matrix containing numerous protein bodies.

Starch composition

Cereal starch is composed of amylose and amylopectin. The tight helical structure of the amylose molecule makes it less accessible to amylases than amylopectin with its branched α -(1-6) linkages. The effect of the proportion of amylose in starch on the *in vitro* enzyme digestion of starch for several grains examined in the Premium Grains for Livestock Program is shown in Table 3. These results confirm that the digestibility of starch is increased as the amylose content declines. Pettersson and Lindberg (1997) observed in pigs a significantly higher digestibility in the small intestines of starch when amylopectin rich barley (9:91, amylose:amylopectin) was compared with normal barley (30:70, amylose:amylopectin).

Table 3. *In vitro* digestion of starch from sorghum and maize genotypes varying in the ratio of amylose:amylopectin.

Grain	Starch content (g/kg)	Amylose in starch (g/kg)	Starch enzyme digestion (g/kg)
Sorghum			
Waxy isoline	630	240	560
Non-waxy isoline	640	350	330
Conventional	660	460	300
Maize			
Cultivar 1	638	0	550
Cultivar 2	663	300	350
Cultivar 3	586	570	210
Barley			
HB240	494	60	818
Richard	592	350	301

Phenolic acids bound to lignin and proteins

There is evidence from the Premium Grains for Livestock Program that the digestibility of oat grain is influenced significantly by the characteristics of the hulls. The whole tract digestibility in sheep of four cultivars of oats grown in the same location has been examined. Digestibility of the grain varied from 62.4 to 76.2 % and was associated closely with the lignin content of the grain (Table 4).

Table 4. Digestibility of dry matter in the whole tract of sheep fed different cultivars of oat grain grown at the same site.

Cultivar	Dry matter digestibility (%)	Grain lignin content (%)
Echidna	62.4	3.0
Dalyup	65.8	2.9
Mortlock	68.2	2.6
Yarran	76.2	1.3

Approximately 400 samples of oat grains have been collected and differ widely in cultivar and growing environment. The hulls were removed from the grains and the *in vitro* digestibility of organic matter in the hulls determined. The results (Figure 4) show that oat cultivars bred in Western and South Australia generally have higher lignin contents and lower hull digestibility. Those oat grains with hulls containing more than about 6.5% lignin had poor digestibility. Whereas oat grain hulls with lignin contents less than 6.5% could have either high or low digestibility. A possible reason for differences in digestibility between oat hulls with low lignin content is the nature of the chemical bonds between phenolic acids, polysaccharides and lignin (Iiyama *et*

al., 1994). These can be either ester or ether linkages. The ester linkages are more easily broken than the ether links and the number of these linkages could alter digestibility of the hulls. The hypothesis is currently being tested.

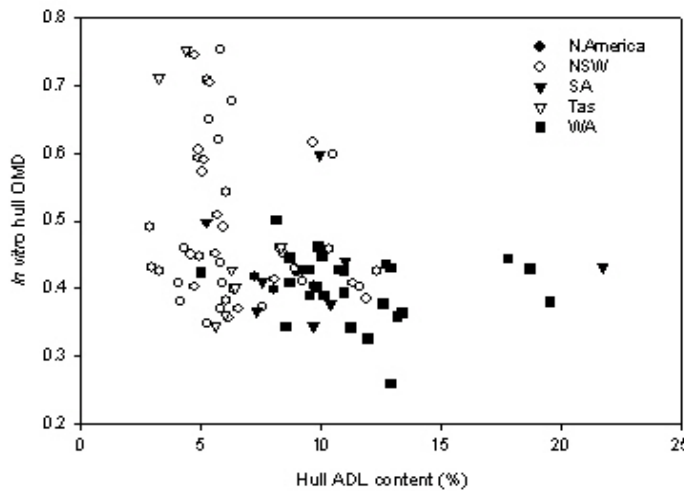


Figure 4. Relationship between hull lignin content (ADL) and hull in vitro digestibility of organic matter (OMD) on a region of origin basis.

Opportunities for improving the energy value of barley grain

The results presented in Tables 1 and 2 show that there is a considerable range in the available energy content of barley cultivars for different animal species. The observed differences between cultivars in the disappearance of starch from the fermentation and amylolytic digestion assays provide information on which possible reasons for the variation in energy availability can be proposed. The Reinette sample examined had a low digestibility in all animal species and also the lowest values for starch disappearance in both the fermentation and amylolytic enzyme assays. The poor digestion of starch in both *in vitro* assays suggests that the accessibility of starch within endosperm cells is restricted for both microbial and amylolytic enzymes. The disappearance of starch within the fermentation assay for the Galleon sample examined was high, but it was relatively low for the amylase assay. On the contrary, the disappearance of starch from the Merlin sample was high for both the fermentation and amylase assays. Because microbial enzymes would be expected to readily degrade the cell walls of the endosperm cells, a low disappearance of starch with the fermentation assay may suggest that a relatively indigestible protein matrix is restricting the access of amylolytic enzymes to starch in the Reinette cultivar. Alternatively, the substantial disappearance of starch in the fermentation assay for the Galleon sample, would suggest that the protein matrix provides little restriction for

access of the amylolytic enzymes to the starch granules. Nevertheless, the relatively low disappearance of starch from Galleon in the amylase assay indicates that the cell walls can provide a significant barrier between the amylase and the starch granules. The high disappearance of starch from the Merlin sample in both the fermentation assay and amylase assay indicate that neither the protein matrix nor cell walls form a major barrier between the enzymes and the starch granules. A comparison of light micrographs of the endosperm cells for the Galleon and Merlin samples show that the cell walls are substantially thicker for Galleon, supporting the hypothesis that barley cell walls can be a barrier to digestion.

The information described in this paper suggests that the availability of energy from barley grain for animals could be increased by breeding grains with thin endosperm cell walls, low amylose content and a highly digestible protein matrix. Alternatively, the nutritional value of barley can be increased by various processing techniques such as fine grinding and the addition of xylanase and glucanase enzymes to reduce the effect of cell wall constituents on digesta viscosity. Further research is needed to determine the importance of other factors such as size and surface area of individual starch granules.

Acknowledgements

The Premium Grains for Livestock Program is funded in part by the Grains Research and Development Corporation, Meat and Livestock Australia, the Pig and Dairy Corporations, the Rural Industries Research and Development Corporation's Chicken Meat and Egg Programs and Ridley Agribusiness. The research reported was conducted by the collaborating scientists and their inputs to the Program are gratefully acknowledged.

References

1. Bedford, M.R. & Schulze, H. (1998) *Nutr. Res. Rev.* 11: 91-114.
2. Black, J.L. (2001) *Proc. Aust. Poultry Sci. Symp.* 13:22-29.
3. Black, J.L., Blakeney, A.B. and Bird, S.H. (2001). In: *Proc. 4th Australian Sorghum Conference*. Borrell, A.K. and Henzell.R.G. (ed.) Range Media, Australia. CD-rom format.
4. Choct, M. and Annison, G. (1990) *Brit. Poultry Sci.*, 31: 811-822.
5. Choct, M. and Annison, G. (1992) *Brit. Poultry Sci.*, 33: 821-834.
6. Hughes, R.J. and Choct, M. (1999) *Aust. J. Agric. Res.*, 50: 689-701.
7. Iiyama, K., Lam, T.B.T. and Stone, B.A. (1994) *Plant Physiol.*, 104: 315-320.
8. Kopinski, J. (1997) Characteristics of cereal grains affecting energy value. Final Report, Pig Research and Development Corporation, Canberra.
9. McAllister, T.A., Phillippe, R.C., Rode, I.M. and Cheng, K.J. (1993) *J. Anim. Sci.* 71:205-212.
10. Oria, M. P., Hamaker, B.R., Axtell, J.D. and Huang, C-P. (2000) *Proc. Natl. Acad. Sci. USA.* 97:5065-5070.
11. Pettersson, A. and Lindberg, J.E. (1997) *Anim. Feed Sci. Tech.*, 66: 97-109.

12. Rooney, L.W. and Pflugfelder, R.I. (1986) *J. Anim. Sci.*, 63: 1607-1623.
 13. Rowe, J.B., Choct, M. and Pethick, D.W. (1999) *Aust. J. Agric. Res.*, 50: 721-736.
 14. Silano, V. (1977) In: *Nutritional Evaluation of Cereal Mutants. Proc. Advisory Group Meeting on Nutritional Evaluation of Cereal Mutants. Internat. Atomic Energy Agency, Vienna.* p 13-46.
 15. Van Barneveld, R.J. (1999) *Aust. J. Agric. Res.*, 50: 667-687.
 16. Wondra, K.J., Hancock, J.D., Behnke, K.C. & Stark, C.R., (1995) *J. Anim. Sci.* 73: 2564-2573.
-