On farm

Premium Grains for Livestock Program

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Meat and Livestock Australia Ltd
Locked Bag 991
North Sydney NSW 2059

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Feedlots

Summary

The Premium Grains for Livestock Program was established to identify the chemical and physical characteristics of cereal grains that determine their nutritional value for different classes of livestock. Rapid methods for measuring the most important characteristics determining grain quality will be developed and ways identified for improving the nutritional value of grains through the use of processing, storage or plant selection techniques. The final outcome of the Program is expected to be a more rational system for trading grains for livestock that is based on the rapid measurement of their value for specific livestock enterprises.

The most striking observation from the Program for the feedlot industry is the extremely low value of sorghum grain for cattle compared with the other animal species examined. The energy value of common sorghum cultivars has been found to be from 20 to 40 % less than for sheep, and pigs and poultry, respectively. However, a waxy-isoline produced by the Queensland Department of Primary Industries was shown to have a much improved availability of energy for cattle compared with common commercially available sorghum. This waxy-isoline also produces pellets of improved durability and hardness.

Although the intrinsic rate of starch digestion was lower for sorghum than for other cereal grains, the primary reason for the low availability of energy in sorghum for cattle is believed to be due to a relatively indigestible protein matrix encapsulating each starch granule in the grain endosperm. It is presumed that other animal species have enzymes better capable of digesting this protein matrix and thereby making the starch within the granules more accessible to starch digesting enzymes than occurs in cattle.

A comparison of the digestibility of a limited number of grains by sheep and cattle suggests that, except for sorghum and perhaps severely frosted grains, values obtained for sheep are applicable for cattle.

Laboratory *in vitro* systems representing the fermentation of grain in the rumen and digestion in the small intestine have been established to act as a screen to identify grains varying widely in nutritional value and to evaluate the effects of various processing and storage strategies. These *in vitro* tests have been shown to be a reasonable representation of digestion within cattle and have been a useful, cheap method for evaluating differences between grains and the likely effectiveness of processing techniques. These *in vitro* systems could be of considerable value for testing the effectiveness of grain processing within the feedlot industry.

Several methods have been examined for improving the nutritional value of sorghum for cattle. These procedures are aimed at either breaking the protein matrix encapsulating the starch granules or selecting cultivars with a more highly digestible or less intact protein matrix.

Fine grinding of sorghum was found to be of little benefit. However, either gelatinisation of the starch with heat and water or germination of the grain was shown to substantially improve energy availability from sorghum. Anaerobic storage of the grain without germination was found to be ineffective. Although laboratory methods for increasing the solubility of the protein matrix were shown to improve the energy value of sorghum *in vitro*, practical methods for use by industry have not yet been developed. The importance of protease enzymes on solubilising the protein matrix is being evaluated. Several plant breeding strategies for reducing the effectiveness of the protein matrix in preventing the accessibility of starch-digesting enzymes to the starch in sorghum have also been identified.

Weather damage through sprouting appears to have little detrimental effect on the energy value of cereal grains for cattle. However, the effect of sprouting on the storage capacity of the grain is

still to be evaluated. In addition, the increased susceptibility of ‘shot-grain’ to fungal attack has not been considered.

Severely frosted grains have lower starch and higher fibre contents than normal grain. Although the starch in the frosted grain is more highly digested than in normal grain, the increased content of fibre in the grain reduces substantially the energy value of severely frosted grain compared with normal grains.

Post-harvest storage of grains appears to have little effect on the digestion of starch in the rumen, but may reduce its digestibility in the small intestines for wheat, barley and triticale, but not for oats. The effects of storage on enzyme digestibility were completed after 6 months.

Starch from oat grain is extremely well digested. Oat cultivars with low hull lignin contents and which are highly digestible could be a valuable feed source for the feedlot industry.

An NIR calibration has been developed to predict the energy value of cereal grains for sheep. This calibration is believed to be suitable for cattle, except for sorghum, and can be used to predict significant differences in digestibility to within 3.5 %-units.

A computer simulation model for feedlot cattle is well advanced. The model should predict the effect of different grain samples, different grain: forage mixtures and grain processing techniques on rumen function, the absorption of nutrients and the growth and body composition of cattle. The model has been linked to an enterprise Decision Support System and should ultimately be used to predict the effect of various feeding and management strategies on enterprise profitability.

1. Background

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. In addition to the domestic market, significant quantities of grains are being exported for consumption by livestock overseas. The animal industries have traditionally used large quantities of 'feed grains', which were judged to be unsuitable for human consumption and were often small grain from screenings or damaged by weather. These grains frequently were not selected for characteristics related to their nutritional value for animals. There has been concern from the livestock producers that insufficient grain of high quality may be available domestically for their expanding industries unless there is an increase in the dedicated production of grains for animals. This deficit of grain for the animal industries was highlighted during the 1994 drought when grain prices rose dramatically and, although some grain was imported; many intensive livestock enterprises became unsustainable.

For grain growers to be attracted to producing grains specifically for livestock, there must be an economic advantage at least equal to the production of grain for human consumption. Consequently, rapid and accurate procedures need to be developed for establishing the nutritional value of grain for the different livestock enterprises so that grain prices reflect their value in terms of animal performance. Similarly, benefits will be derived by the animal industries through the more economical formulation of rations if the nutritional value of grains were known precisely.

The Grains Research and Development Corporation in collaboration with the animal Research and Development Corporations, including MLA, decided in 1996 to establish a new research Program, "Improving Feed Grains Quality". The program was subsequently called the "Premium Grains for Livestock Program" to remove the industry stigma often associating "feed grains" with inferior products. This Report provides an overview of the achievements from the first four years of the Program, particularly as it relates to the Australian cattle feedlot industry.

2. Aims of Program

The Program aims are to:

1. Identify the factors determining the quality of cereal grains for ruminants, pigs and poultry so that improvements in the nutritional value can be achieved through plant breeding and grain processing and storage strategies.

2. Develop rapid tests, suitable for the site of grain collection and/or use, to measure the nutritional value of grains so that they can be priced in accordance with their suitability as an animal feed.

3. Develop a computer simulation model for ruminants to predict accurately the consequences of grain characteristics and of grain processing and storage on the productivity of feedlot cattle and the profitability of feedlot enterprises.

The Program should improve the quality of grains available to the animal industries and provide a more rational basis for trading grains built on a knowledge of the factors determining quality for different livestock enterprises and the rapid measurement of these characteristics at the site of grain delivery. Research within the Program has been confined primarily to determining the availability to different animal types of energy from cereal grains, although the effect of grain type on voluntary feed intake and amino acid availability has been examined in some experiments.

3. 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, 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 infrared 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, and 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 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 has been used to examine the physical structure of some grains.

4. Major determinants of grain quality for the feedlot industry

4.1 Variation between grains and animal types: animal experiments

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. Wheat had a higher energy content for pigs than the other animal species. However, the most striking differences were for sorghum where the energy content for cattle of a normal sorghum isoline (7827) was only 60-61% of that for pigs and broiler chickens. The energy content for cattle of a waxy-isoline (7828) was substantially greater than that of the normal isoline (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 that for the other cereal grains.

A comparison of the site of digestion of starch from sorghum and wheat grain is shown in Table 2 for cattle and broiler chickens. These results confirm that sorghum starch is poorly digested both within the rumen and within the small intestines of cattle compared with starch from wheat grain. However, starch from both grains was completely digested by chickens and the efficiency of digestion within the small intestines was similar for both sorghum and wheat.

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	7827	14.56	9.73	16.06	15.90	15.48
	7828	14.79	13.21	16.40	15.98	15.96
Barley	3828	11.51	11.91	11.70	11.68	11.12
	3829	13.59	13.51	14.89	13.20	13.91
Wheat	1809	13.86	13.84	15.32	13.84	13.53
	1901	14.31	14.23	15.97	14.22	14.27
Triticale	6805	12.26	12.44	12.00	11.21	11.43
	6901	13.66	13.74	13.85	14.36	14.22
Oats	5901	13.41	13.33	-	13.37	14.08
	5902	12.56	12.38	-	12.55	12.71

Table 2. The digestibility of starch from sorghum and wheat grains in different parts of the digestive tract for cattle and poultry (Adapted from Rowe et al., 1999).

Animal species	Sorghum	Wheat
	Whole tract digestibility (% starch intake)	
Cattle	87	98
Poultry	99	100
	Fermented in rumen (% starch intake)	
Cattle	64	87
	Digested in small intestine (% starch entering stomach)	
Cattle	63	85
Poultry	85	82

Table 1 shows also that there can be considerable variation within a grain species in the available energy content for individual animal types. For cattle where a limited number of grains have been examined, the range in energy availability was over 1.5 MJ/kg for barley and almost 1 MJ/kg for oat grain.

The dry matter digestibility of a small number of grains has been compared for sheep and cattle when fed at a rate sufficient only to maintain body weight. (Table 3). These results suggest that the digestibility of grains measured in sheep is applicable to cattle except for sorghum and perhaps severely frosted grains. The results suggest that cattle may digest highly fibrous frosted grains better than sheep.

Table 3. A comparison of the dry matter digestibility of grains fed at a maintenance level to both sheep and cattle.

Grain	Dry Matter Digestibility (%)	
	Sheep	**Cattle**
Sorghum		
7710: Waxy-isoline, Biloela	87.5	80.6
7711: Non-waxy isoline, Biloela	86.6	80.0
Barley		

3717: Reinette, Narrabri	78.1	81.2
3828: Arapiles, Horsham – heavily frosted	72.2	76.4
3902: Galleon, Narrabri	84.5	84.4
Wheat		
1809: Janz, Wallacetown – lightly frosted	84.5	84.4
1901: Sunstate, Narrabri	88.4	88.5
Triticale		
6805: Tahara, Walla Walla – heavily frosted	75.0	78.0
6901: Tahara, Narrabri	84.9	85.4
Oats		
5901: Yarran, Narrabri	78.0	78.8
5902: Echidna, Narrabri	74.3	74.3

Conclusion 1. The availability of energy from sorghum is particularly low for cattle compared with other animal species.

Conclusion 2. With the exception of sorghum and perhaps severely frosted grains, the digestibility values obtained for sheep are applicable to cattle.

4.2 Variation between grains: in vitro experiments

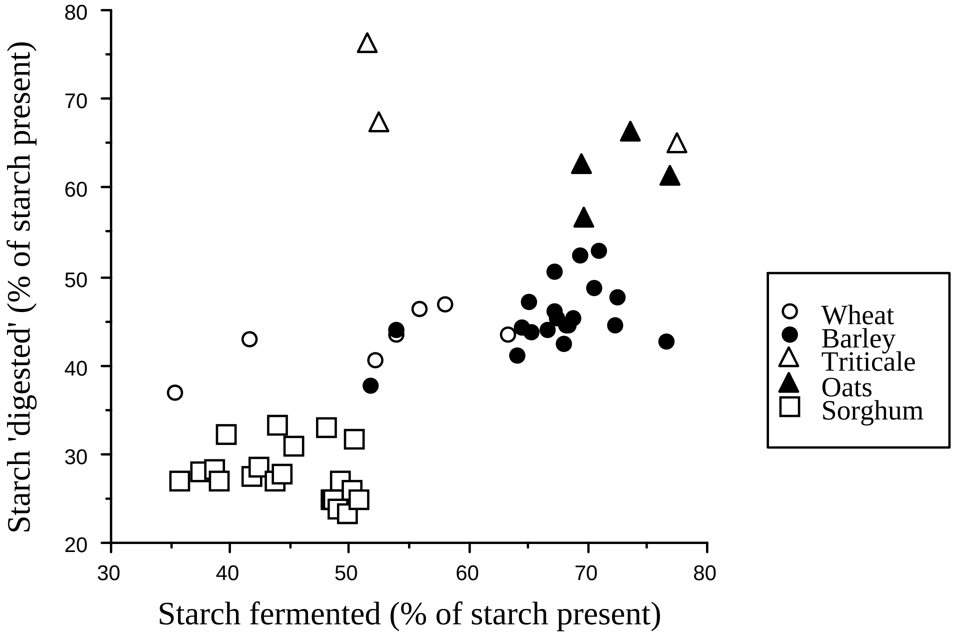
Because of the high cost of animal experiments, *in vitro* laboratory techniques have been used to identify grains that are likely to differ in their capacity to be digested in both the rumen and small intestines of animals. These *in vitro* procedures have been used also to identify the likely effect of processing and storage treatments of grains and the effect of various types of weather damage.

The *in vitro* system representing rumen function incubated 30 g of finely ground grain in a rumen fluid-buffer solution for 5 hours and measured starch disappearance, gas and acid production. The *in vitro* system representing intestinal digestion used a small quantity of ground grain incubated at 39°C for 60 minutes with a mixture of α-amylase and amyloglucosidase and the disappearance of starch determined. The latter assay did not contain proteases, glucanases or xylanases. Figure 1 shows a moderate correlation (R^2 = 0.46) between enzyme digestibility of starch and rumen fermentation of starch across the grains examined, but there were significant differences between the grains. Oat grain starch was highly fermented relative to the sorghum starch and there were substantial differences between the fermentation of individual wheat and barley grain samples. Starch in two of the triticale samples was relatively poorly fermented by rumen microorganisms (52%), but highly digested by the intestinal simulation system (68 and 76%). Such characteristics may be ideal for grain fed to either feedlot or dairy cattle because more of the grain starch would be digested in the small intestines, utilised with higher efficiency and more glucose would be made available for fat or lactose synthesis.

The most striking observation from Figure 1 is the extremely low digestibility of starch from sorghum in the system representing intestinal digestion. The *in vitro* system contained enzymes that should have digested starch. The results represents more closely digestion of sorghum by cattle than it does by pigs and poultry. The results may have been different if enzymes capable of digesting protein and cell walls were included also in the assay.

The *in vitro* enzyme system also showed substantial differences in the extent of starch digestion from waxy and non-waxy isolines of sorghum grain (Table 4), again representing the differences observed in cattle but not in pigs and poultry. The results presented in Figure 1 and Table 4 indicate that the enzymes used in the *in vitro* system were unable to gain complete access to the

Starch fermentation and enzymatic digestion



sorghum starch granules and there were differences in accessibility between the waxy and non-waxy isolines.

Figure 1. ***Relationship between starch digested in the in vitro system representing intestinal digestion and the in vitro system representing rumen fermentation for all cereal grains fed to animals (Bird et al., 1999).***

Table 4. ***In vitro*** **digestion of starch from sorghum 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	45	560
Non-waxy isoline	640	271	330
Conventional	660	297	300

The *in vitro* systems have been used extensively during the research program to evaluate the effectiveness of various processing techniques and to identify grains to be grown out into sufficient quantities to enable the evaluation of hypotheses on factors determining the nutritional value of grains for different livestock species. Further results from the *in vitro* studies are presented throughout this report.

4.3 Comparison of *in vitro* results with observations from cattle

An important component of the research was to confirm that the values obtained from the *in vitro* studies reflected the digestion of grains when fed to cattle. An experiment was conducted where 14 grains of different origin and processing, including waxy and non-waxy sorghum, whole, rolled and urea treated barley and sorghum and steam-flaked sorghum were evaluated *in vitro* and their disappearance from various sections of the digestive tract of cattle measured. When the material used in the *in vitro* fermentation system was in the same form as that fed to cattle and appropriate adjustments made for the reduced extent of digestion *in vitro*, values derived for digestibility from the *in vitro* systems were similar to those measured in cattle. Figure 2, shows strong correlations between starch digestion pre-caecum and throughout the whole digestive tract predicted from the *in vitro* measurements and those observed in cattle.

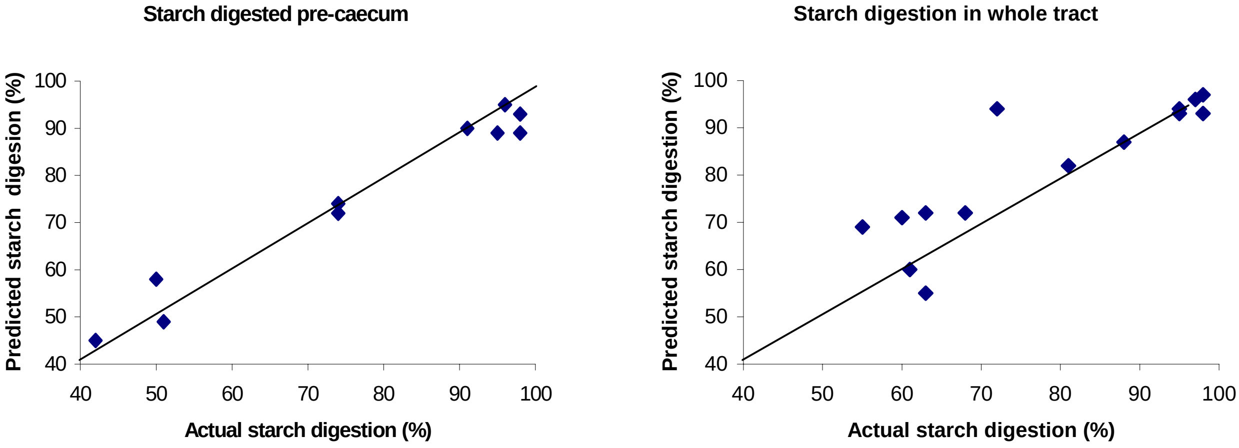


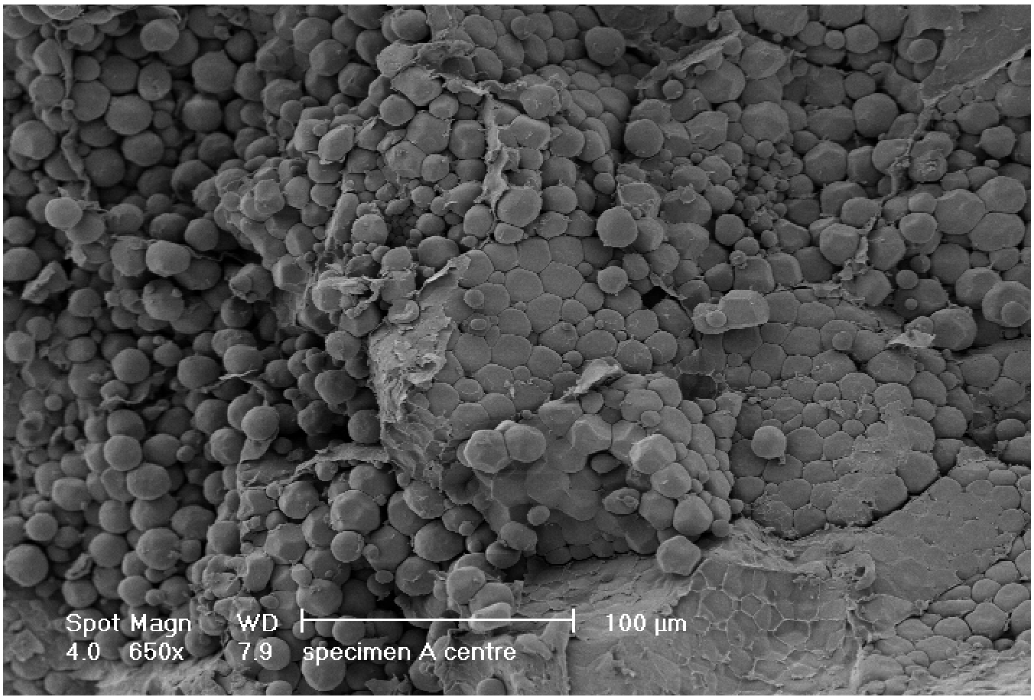
Figure 2. ***The relationship between starch digestion predicted from in vitro measurements and values observed in cattle fed a range of grains processed by various techniques.***

Conclusion 3. The *in vitro* fermentation and enzymic digestion systems reflect adequately the site of digestion along the gut of cattle and can be used satisfactorily to screen grains and processing techniques for their relative nutritional value for feedlot cattle.

4.4 Reasons for the poor digestion of sorghum by cattle

To understand the reasons why sorghum grain is highly digested by pigs and poultry, but poorly and variably digested by cattle, it is necessary to understand critical steps in the digestion process. The extent of grain digestion by animals depends on the availability of enzymes capable of breaking 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. The accessibility of a substrate to an enzyme may be affected by particle size and surface area, physical and chemical barriers and by the physical structure of the substrate molecule.

Sorghum grain contains between 65 and 70% starch and the energy available to any animal depends greatly on its capacity to digest the starch component of the grain, which is located primarily in the endosperm. Sorghum, unlike many other cereal grains, has two distinct morphological regions to the endosperm. The outer, corneous segment is composed of densely packed cells filled tightly with small, polygonal starch granules and large quantities of protein matrix and protein bodies (Figure 3). The inner floury segment is opaque and the cells contain loosely packed, round starch granules with many air voids between the granules. The poor



digestibility of sorghum grain by cattle could be due either to characteristics of the starch or to the accessibility of enzymes to starch within the granules.

Figure 3. ***Scanning electron micrograph of the endosperm of a non-waxy isoline of sorghum showing cells of the corneous region to the right and floury region to the left.***

4.4.1. Characteristics of sorghum starch

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 accessible to digestive enzymes. There are several reports in the literature showing that grains containing high amylose starch are poorly digested compared with grains containing mainly amylopectin starch.

The properties of starch extracted from several sorghum grain samples including those listed in Table 1 have been examined within the Premium Grains for Livestock Program. The results (Table 5) show that the gelatinisation temperature of starch extracted from the normal isoline of sorghum was higher than that for either wheat or maize starch (74.5°C, 69.4°C, 72.4°C, respectively). The gelatinisation temperature of starch from the waxy isoline was considerably lower than for the normal isoline at 70.8°C. Similarly, the susceptibility of starch from the normal sorghum isoline to α-amylase digestion over 3 hours was less than for either wheat or maize starch. However, the susceptibility of starch from the waxy isoline of sorghum to α-amylase was substantially greater than for the other grains. These results suggest that starch from normal sorghum has some intrinsic differences with higher gelatinisation temperature and lower rate of intrinsic starch digestion that would reduce its digestibility relative to other cereal grains and to the waxy isolines. However, these differences are relatively small and unlikely to be the only reason for the poor availability of energy from sorghum for cattle.

Table 5. Gelatinisation temperature and susceptibility to α-amylase digestion of starch isolated from several sorghum isolines, wheat and maize.

Grain	Gelatinisation temperature[a] (°C)	α-amylase susceptibility[b]	α-amylase susceptibility relative to maize (100)
Sorghum			
Non-waxy isoline	74.5	23.2	96
Waxy isoline	70.8	30.0	124
Sprouted	71.9	25.2	104
Conventional	72.6	23.5	97
Wheat	69.4	27.1	112
Maize	72.4	24.2	100

[a]RVA 5g/22ml, model 4 standard 1 program. [b]3 hour digest with α-amylase.

4.4.2. Accessibility of sorghum starch

Although the differences observed in characteristics of starch extracted from waxy and normal sorghum could explain part of the higher availability of energy for cattle fed waxy sorghum, the waxy isoline also has a greater proportion of floury endosperm than normal sorghum. The accessibility of amylases to starch granules should be greater in sorghum grains that contain a larger proportion of floury endosperm with its loosely packed granules as is seen in waxy isolines. Cells in the corneous endosperm have a protein matrix that appears to form a continuous interface with each starch granule. Figure 4 shows the protein matrix surrounding each starch granule and several protein bodies embedded in the protein matrix and cell wall. Figure 5 shows, at higher magnification, the protein matrix and its embedded protein bodies surrounding each granule, whereas Figure 6 shows 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.

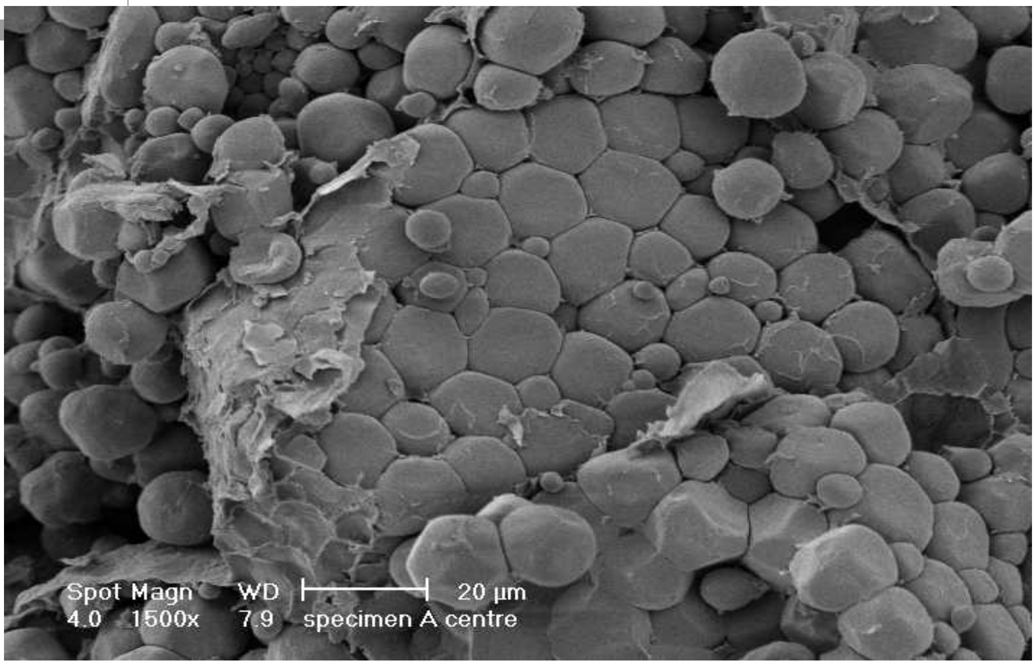


Figure 4. Scanning electron micrograph showing the tightly packed starch granules in the corneous endosperm, the protein matrix surrounding starch granules and protein bodies within the protein matrix and cell wall.

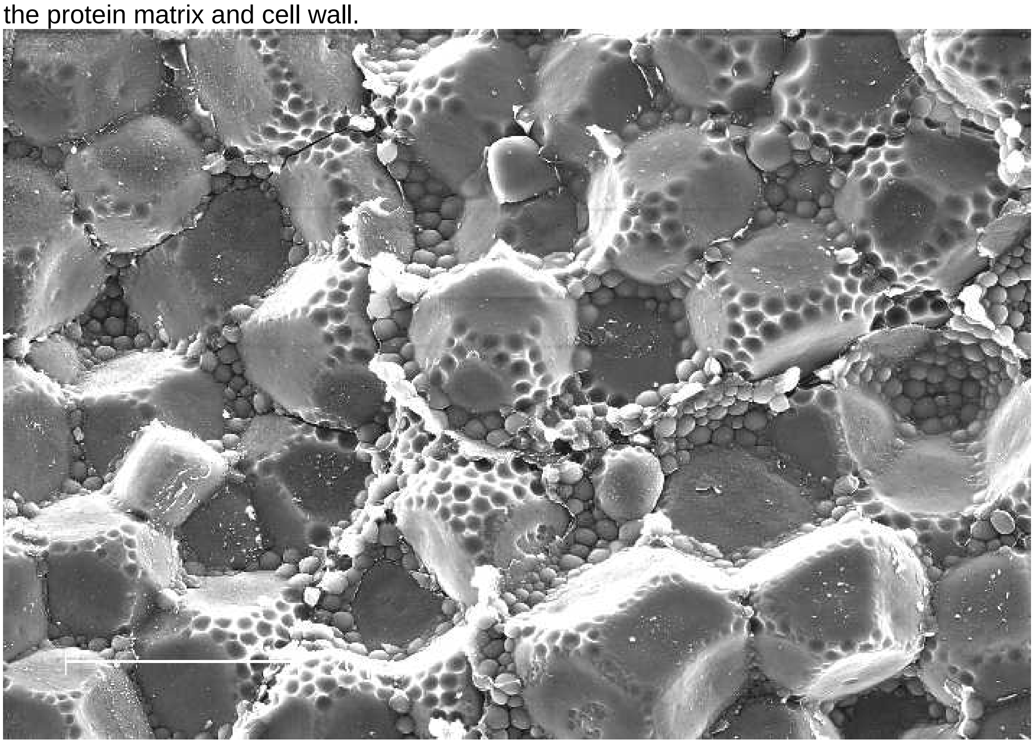


Figure 5. ***A higher magnification of starch granules in the corneous endosperm of sorghum showing the protein matrix with embedded protein bodies surrounding each granule. Indentations from the protein bodies can be seen on the starch granules.***

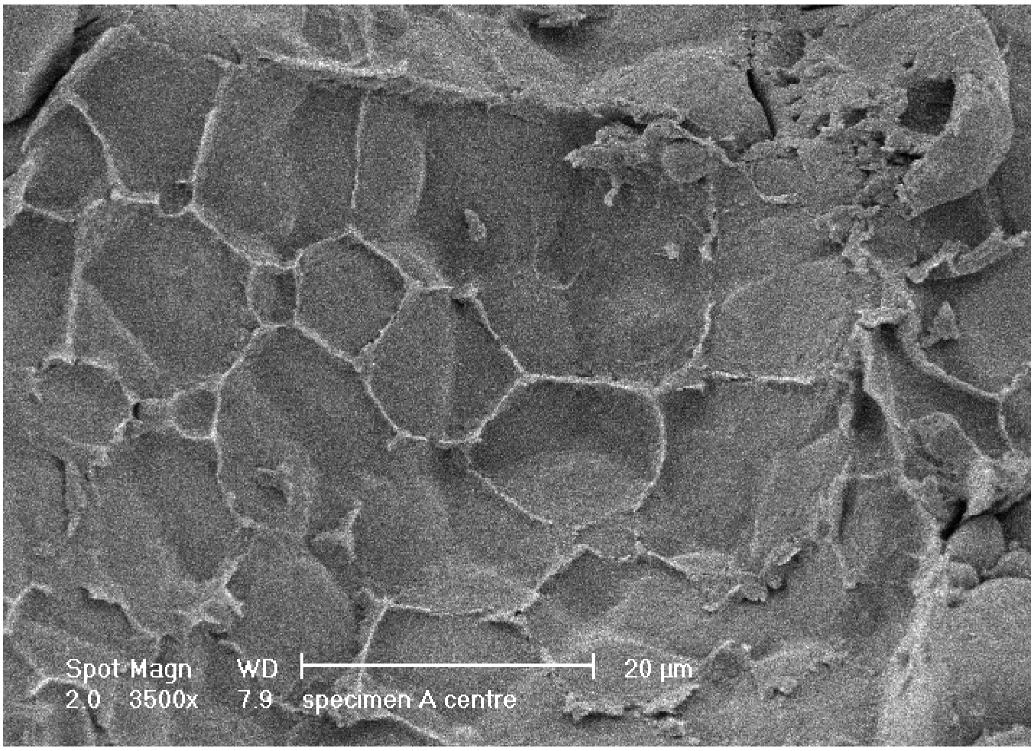


Figure 6. ***Scanning electron micrograph on an inner wall of a cell in the corneous endosperm showing remnants of the protein matrix surrounding starch granules.***

Most sorghum grain protein is found in the endosperm and consist predominantly of α-, β- and γ-kafirins. These proteins contain increasing amounts of cysteine and methionine as they progress from the α- to γ-types and are rich in disulphide bonds that are resistant to digestion by proteases. Sorghum proteins are known to be less digestible than those from other cereal grains, although the digestibility between cultivars has been found to vary from 30 to 70% depending on the proportion of cross-linked kafirin proteins. The digestibility of protein in the corneous segment of the endosperm has also been shown to be less than that of the proteins in the floury region. Heating significantly reduces the digestibility of sorghum proteins because it enhances the cross-linking of disulphide bonds and reduces its solubility. However, a mutant sorghum (P721N) was described recently, which had an *in vitro* digestibility of 85% uncooked and 80% digestibility when cooked (Oria et al., 2000).

The apparent encapsulation of sorghum starch granules, particularly in the corneous endosperm, with a relatively indigestible protein is likely to reduce the accessibility of amylolytic enzymes to the starch. A high proportion of undigested sorghum starch in cattle has been found to be associated with the corneous endosperm. Similarly, Sullins and Rooney (1975) reported less protein matrix and protein bodies in the corneous endosperm of waxy sorghum compared with normal cultivars. It seems probable that this physical protein barrier is a major reason for the relatively poor digestibility of starch in rolled sorghum by cattle. The fact that sorghum grain starch is digested almost completely by pigs and poultry suggests that these species either possess proteases that are more effective for digesting the endosperm proteins or they have higher concentrations of the relevant proteases than cattle that allow more rapid digestion of the encapsulating proteins. If the protein matrix did not limit the accessibility of starch granules to amylases in pigs and poultry, little difference would be expected in the extent of starch digestion by these species between waxy and non-waxy cultivars, as was observed.

Conclusion 4. Sorghum has a low digestibility in cattle because the starch granules are encapsulated in a protein matrix that is relatively indigestible and prevents the starch digesting enzymes reaching the starch molecules.

Conclusion 5. Waxy-sorghum has a higher digestibility than normal sorghum in cattle because there is less protein that is more digestible surrounding the starch granules and the higher proportion of floury endosperm also increases the access of enzymes to the starch granules.

Conclusion 6. Circumstantial evidence suggests that the protease enzymes from the digestive tract of pigs and poultry are superior to those from cattle for digesting the protein matrix surrounding the starch granules of sorghum.

4.5 Methods for improving the value of sorghum for cattle

The evidence presented above indicates that processing and plant breeding strategies that either break the protein matrix surrounding the starch granules or significantly increase its digestibility should improve the nutritional value of sorghum grain for cattle. The effectiveness of several processing techniques for improving the nutritional value of sorghum has been evaluated using the *in vitro* systems.

4.5.1 Processing

4.5.1.1 Milling

The effects of milling sorghum compared with barley and oat grain through a 4.0. 2.0, 1.0 and 0.5 mm screen on the *in vitro* fermentation and intestinal digestion of starch has been examined within the Program (Figure 7). Fine grinding had no effect on the extent of sorghum starch disappearance in the rumen fermentation system, whereas there was a substantial effect on the extent of starch fermentation for barley. Fine grinding improved the digestion of starch from all grains when subjected to the enzyme digestion system. These results suggest that fine grinding probably shattered some of the protein matrix surrounding starch granules in sorghum grain increasing slightly the access of enzymes to starch. However, grinding of sorghum did not improve the digestion of starch to near that of the highly digested oat starch. The results suggest also that either the type or amount of amylases released by rumen bacteria in the fermentation system were less capable of degrading starch than the enzymes used in the system simulating intestinal digestion.

Conclusion 7. Reducing grain particle size does not appear to be a practical option for improving the energy value of sorghum for cattle and has not been used widely in the feedlot industry.

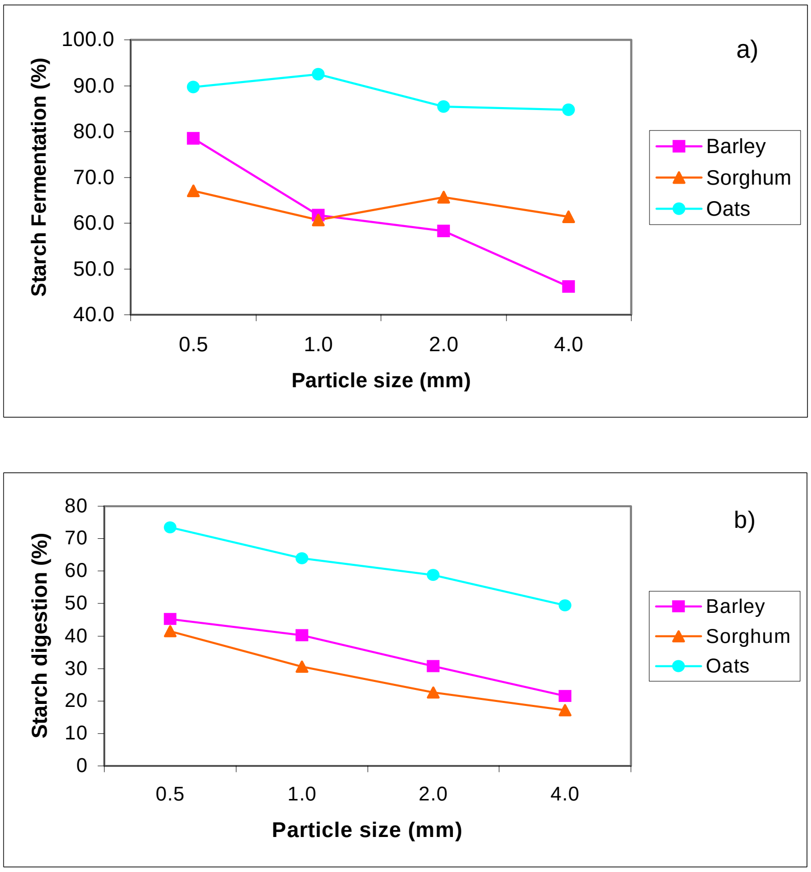


Figure 7. ***Effect of mill screen size (mm) on in vitro starch fermentation and enzyme digestion for sorghum, barley and oat grains.***

4.5.1.2 Heating and gelatinisation

The effect of cooking and gelatinisation on the digestion of starch from sorghum, barley and oat grain has been examined in the *in vitro* rumen fermentation system (Table 6). Cooking ground sorghum significantly increased the rate of starch digestion as shown by a substantial decrease in pH and increase in lactic acid production. Gelatinisation has a smaller effect on the digestion of barley starch and no effect on the digestion of oat starch. These results suggest that the protein matrix can be disrupted by heat, gelatinisation and swelling of the starch. The treatment caused a substantial increase in the digestibility of starch. The results are supported by the observations made by Huntington (1997) where the effects of steam flaking grains on the site of starch digestion in cattle was measured (Figure 8). Steam flaking had a major effect on both the ruminal and intestinal digestion in cattle of starch from sorghum and maize, a moderate effect with barley and little effect with wheat and oats. Maize grain is known also to have a protein matrix that largely surrounds the starch granules, whereas this is not the case for wheat and oat grains. Although cooking sorghum grain improved significantly the digestibility of starch it is probable that the process decreases the digestibility of sorghum protein by enhancing disulphide bond cross-linking.

Table 6. Effect of gelatinisation on the rate of digestion of sorghum, barley and oat grain as indicated by a change in the production of lactic acid and pH in the *in vitro* fermentation system.

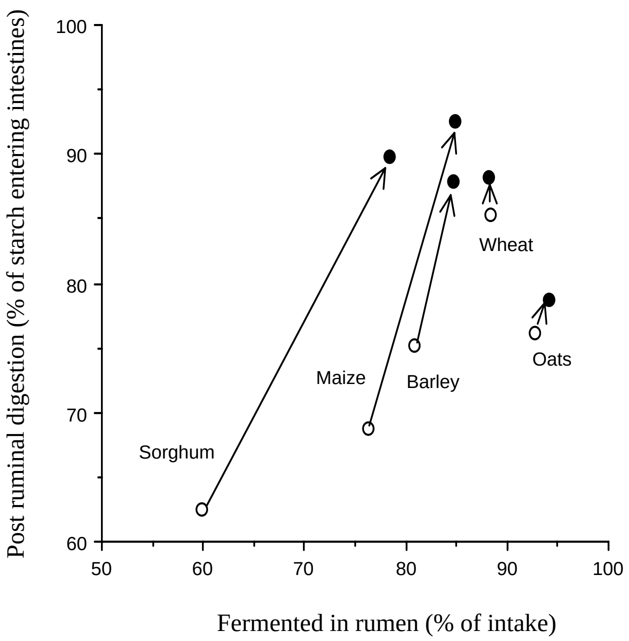
Grain	Treatment	Lactate production	pH
Sorghum	Uncooked	3	6.7
	Cooked	37	5.3
Barley	Uncooked	37	4.9
	Cooked	51	4.8
Oats	Uncooked	51	4.9
	Cooked	49	4.8

Figure 8. ***Effect of steam flaking on rumen fermentation and intestinal digestion of starch from different grains compared with dry-rolled material (Rowe et al., 1999).***

Conclusion 8. The wet heating of sorghum grain sufficient to cause gelatinisation of the starch increases starch digestion substantially, presumably because the swelling of the starch breaks the protein matrix encapsulating the starch granules.

4.5.1.3 Protein solubilisation – extraction

The digestibility of sorghum endosperm proteins has been increased greatly by treatment in laboratories with reducing agents such as metabisulphite and mercaptoethanol that break disulphide bond. Within the Premium Grains for Livestock Program, sorghum grain has been extracted sequentially with sodium chloride to remove albumin and globulin, sodium hydroxide to remove glutelin and tert-butanol plus dithriothreitol to remove prolimin containing the kafirin proteins. Over 58% of the sorghum nitrogen was extracted and this resulted in an increase from 33 to 48% of the starch being digested in the *in vitro* enzyme digestion system. An increase in starch digestion of approximately 12 percentage units was observed also for the rumen fermentation system. These results provide support for the concept that the protein matrix limits the access of amylase enzymes to starch granules and that removal of these proteins increases starch digestion. Further research is planned to determine whether a practical method can be developed to increase the solubility of sorghum matrix proteins, particularly the role of added proteases.



Conclusion 9. Chemical removal of the protein matrix encapsulating starch granules increases starch digestibility, but practical methods for achieving this have not been identified. The potential use of added proteases needs investigation.

4.5.1.4 Germination and reconstitution

Germination results in the activation of grain enzymes that breakdown the proteins, starch and other components of the seed to supply nutrients for the growing plant embryo. The release of these enzymes during germination of sorghum grain has been shown to digest protein bodies and disrupt the protein matrix surrounding the starch granule. These observations indicate that the release of grain enzymes during germination should increase the digestion of sorghum starch by cattle. The wetting of sorghum grain and its anaerobic storage, or ensiling, has been a recent practice within the cattle feedlot industry. The relative advantages on starch digestion of germinating, ensiling or both germinating and ensiling sorghum grain has been investigated within the Program. The results (Table 7) showed that germination of sorghum for 10 days increased both the *in vitro* fermentation and digestion of starch, whereas ensiling for 21 days had relatively little effect. The greatest improvement in starch digestion was seen when a 5-day germination period was followed by a 16-day ensiling period. Germination for 10 days caused a significant loss of starch from the grain. These results indicate that germination of sorghum grain prior to the common industry practice of ensiling would increase significantly the nutritional value of the grain for cattle.

Table 7. The effect of germination and anaerobic ensiling on starch content of sorghum grain and on the *in vitro* digestion of starch.

Grain processing	Total starch (%)	Starch fermentation (%)	Enzymic starch digestion (%)
Unprocessed	69.5	7.7	32.2
Germinated 5 days	68.4	19.7	35.1
Germinated 5 days, ensiled 16 days	68.5	35.9	52.5
Aerobic ensiling 21 days	70.5	9.4	33.2
Steeping in water 1 day	71.3	9.4	36.2
Germinated 10 days	65.8	29.9	ND

Conclusion 10. Germination significantly increases the digestibility of starch in sorghum grain, but anaerobic ensiling without germination has little positive effect.

4.5.2 Plant breeding and selection

Several plant breeding strategies aimed at increasing the accessibility of digestive enzymes to the starch granules also offer potential for improving the nutritional value of sorghum grain for cattle.

4.5.2.1 Waxy cultivars

There is a clear advantage to cattle from feeding waxy sorghum compared with normal sorghum (Table 1). However, the response seen with waxy sorghum for the *in vitro* digestion of starch is less than that obtained from steam flaking. A current disadvantage with waxy sorghum production is that yields are considerably less than for normal cultivars. However selection pressure during plant breeding programs should produce waxy sorghum cultivars with yields approaching those of normal cultivars.

Sorghum is particularly difficult to pellet. Research by Ridley Corporation within the Premium Grains for Livestock Program has investigated the effect of waxy compared with non-waxy cultivars on pellet hardness and durability using an experimental pelleter. The procedure involved a standard grinding and measurement of mean particle size prior to entering the pelleting process. A summary of the results for the differences between waxy and non-waxy sorghum and a commercial cultivar is given in Table 8.

Table 8. Influence of sorghum cultivar on particle size following a standard grinding, pellet durability and pellet hardness.

Measurement	Sorghum variety		
	Buster (7712)	**Waxy-isoline (7710)**	**Non-waxy isoline (7711)**
Pellet durability (%)	87	96	76
Particle size (mm)	651	388	454
Pellet hardness (kg)	13	21	15
Comments		Required more Amps and tended to block pelleter	

The experiment shows that the waxy isoline has grains that are more easily broken down into small particles during standard grinding and produce more durable and harder pellets than the normal sorghum lines. The improved pelletability of waxy sorghum is likely to be due to the lower gelatinisation temperature and weaker protein matrix surrounding the starch granules. Although chemical and physical analyses were not undertaken for the two samples used in the pelleting experiment, analyses of the same isolines harvested a year later indicate that there are differences in physical characteristics between the isolines (Table 9).

Table 9. Amylose content and physical characteristics of waxy and non-waxy sorghum cultivars.

	Amylose (%)	**Hardness (Index)**	**Hydration capacity (%)**	**100 grain weight (g)**	**Acid extract viscosity**
Non-waxy 7827	27.1	85.97	33.1	3.1	1.64
Waxy 7828	4.5	84.65	44.5	2.7	1.71

These results suggest that the waxy isoline has a greater hydration capacity and lighter grains than normal sorghum. The increased hydration capacity could have a significant effect on the degree of gelatinisation occurring during the conditioning phase of the pelleting process. It is likely also that steam flaking will be more effective with waxy isolines.

Conclusion 11. Waxy cultivars of sorghum have higher digestibility in cattle, improved pellet durability and hardness and are likely to be easier to steam-flake.

4.5.2.2 Floury endosperm cultivars

There is evidence suggesting that the digestibility of sorghum starch is positively related to the proportion of floury endosperm in the grain. An improvement in the energy value of sorghum for cattle could be expected, therefore, if grains were selected for high floury endosperm content. There is little knowledge about the heritability of corneous: floury endosperm ratio or about the association between floury endosperm content and grain yield. Further research into these characteristics could be valuable.

4.5.2.3 High digestibility and low sulphur content endosperm proteins

The digestibility of sorghum matrix proteins has been shown to vary widely and to be linked closely to the content of sulphur amino acid rich kafirins. An improvement in the accessibility of sorghum starch to cattle digestive enzymes may result from the selection of grains that have a high digestibility of the kafirin proteins. This could be achieved by selecting for proteins with low sulphur content. Techniques need to be developed for the rapid assessment of the solubility of the proteins in sorghum grain.

4.5.2.4 Redistribution of γ-kafirin proteins

Oria et al., (2000) showed that the protein bodies in a mutant sorghum isoline had different morphological characteristics and distribution of γ-kafirin proteins than seen in normal sorghum. The *in vitro* digestibility of the protein in the mutant line was significantly higher than for normal sorghum. The authors suggested that the higher digestibility was caused by a greater surface area of the invaginated protein bodies and the location of γ-kafirin proteins in concentrated regions within these bodies. The concentration of γ-kafirin proteins reduced their association with α-kafirins and therefore increased the digestibility of the endosperm protein. An improvement in protein digestion could be achieved by selecting sorghum plants that had the capacity to concentrate the γ-kafirin proteins in specific regions with reduced association with other endosperm proteins.

Conclusion 12. Sorghum cultivars with higher than normal digestibility of endosperm proteins should be of higher nutritional value for cattle. Methods need to be developed for the rapid measurement of sorghum protein digestibility.

4.6 Effect of weather damage on the nutritional value of grains

Weather damaged grains have been collected on an opportunistic basis by the Program and grains affected by sprouting and frost have been examined. Only one sprouted grain has been tested to date. However, a special project has been initiated to examine the effect of controlled sprouting on the starch content, falling-numbers values, α-amylase content and *in vitro* fermentation and enzyme digestibility of the grain. Wheat and barley samples will be sprouted in July 2001, with 3 germination times before being dried with 40°C heat and stored at ambient temperature. The nutritional value of the sprouted grain will be examined also following 6 and 12 months storage. Sprouted sorghum will not be examined until after the 2002 harvest because the difficult 2001 season prevented the collection of suitable grain for sprouting. The impact on nutritional for animals of 'pinched' grain and small grains from screenings has not been examined systematically within the Program. However, these grains are to be collected during the 2001-2002 season and a comprehensive evaluation of the nutritional value of small grains will be undertaken.

4.6.1 Sprouted grains

The single sprouted sample of sorghum was collected from a farmer in Moree in 1999 and Grainco had significantly downgraded it. Values for either falling numbers or α- amylase content for this sample were not available and there was no unsprouted control sample. However, its starch content and *in vitro* fermentation and digestion were compared with the mean values from all other sorghum samples examined. The results (Table 10) suggest that the starch content and nutritional value of sorghum were unaffected by sprouting. The same grain was fed to pigs and broiler chickens and the available energy content measured to be 16.25 MJ/kg for pigs and 16.08 MJ/kg for broilers was similar to the values obtained for non-weather damaged grain (Table 1). In addition, the results presented in section 4.5.1.4 above showed a substantial positive effect of germination of sorghum on its digestibility. These results suggest, at least for sorghum, that sprouting does not reduce and may improve the value of grain for cattle. However, the effects of storage time on the deterioration of the grain or of mycotoxins that may develop needs to be examined.

Table 10. Effect of sprouting on the starch content and *in vitro* starch digestion of sorghum.

Grain	Total starch (%)	Starch fermentation (%)	Enzymic starch digestion (%)
Sprouted sorghum	69	44.5	28.0
Normal Sorghum (mean)	67	44.0	28.0

Conclusion 13. The sprouting of sorghum grain does not appear to be detrimental and may improve its nutritional value. However, the influence of sprouting on storage time or the impact of mycotoxins that may develop on sprouted grain has not been examined. The influence of sprouting on the nutritional value of wheat and barley is to be examined in controlled experiments.

4.6.2 Frost damaged grain

The *in vitro* digestibility of a lightly and heavily frosted samples of Janz wheat grown in the Wagga district has been compared with a non-frosted sample from the same area. The results in Table 11 show that the starch content of the frosted grain was significantly reduced, but the digestibility of the starch was increased compared with the normal sample. In addition the gas production during the 5-hour period of fermentation was greatest for the heavily frosted sample. These results from the *in vitro* digestion studies show that the starch from frosted grain is readily digested. However, samples of heavily frosted barley and triticale were also fed to sheep, cattle, pigs and poultry. The results for grains 3828 and 6805 in Tables 1 and 2 show that the digestibility and available energy content of frosted grain is substantially below the values for normal grains. When considered together, these results show that although the starch from frosted grain is readily digested, the higher fibre content of the grain reduces its overall energy value for all animal species examined.

Table 11. Effect of frost damage on the starch content and *in vitro* starch digestion of Janz wheat grown in the Wagga district.

Grain	Total starch (%)	Gas production during fermentation (ml)	Starch fermentation (%)	Enzymic starch digestion (%)
Unfrosted Janz wheat	62	1345	50.6	39.2
Lightly frosted Janz	56	1198	50.3	40.7
Heavily frosted Janz	46	1613	60.0	46.5

Conclusion 14. Although the starch in heavily frosted grain is rapidly digested the proportion of starch in the grain is decreased and the proportion of fibre increased with the result that the availability of energy from the grain can be reduced by more than 1 MJ/kg.

4.7 Effect of storage on the nutritional value of cereal grains

The effect of storage of grain after harvest on the *in vitro* fermentation and enzyme digestibility has been examined for wheat, barley, triticale and oat grains. Between 2 to 6 samples of grain for each species were examined immediately after harvest and at intervals up to 12 months following storage at room temperature. The results showed no effect of storage on the rumen fermentation of the grains. However, storage decreased the enzyme digestion of starch in wheat, barley and triticale by from 10 to 25% after 6 months, with little further effect to 12 months (Figure 9).

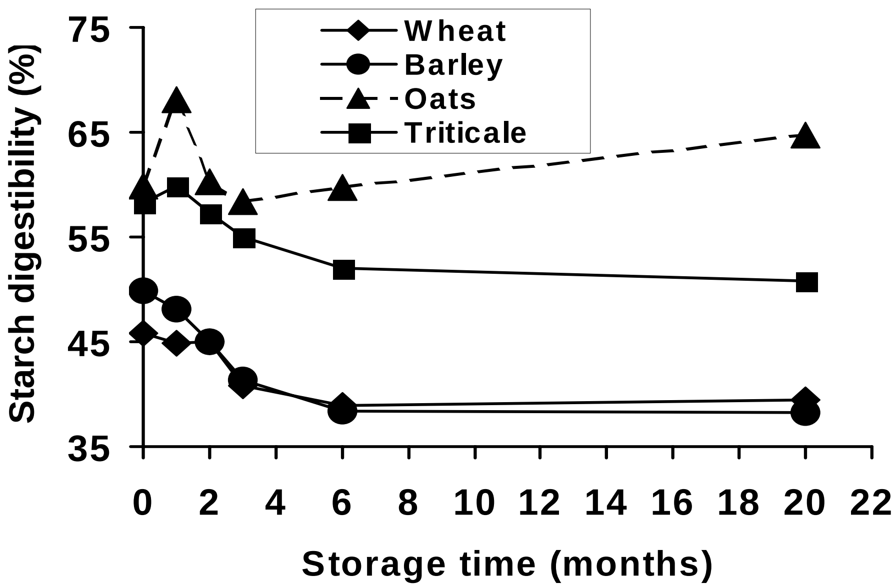


Figure 9. ***Effect of post-harvest storage time on the in vitro enzyme digestion of starch in wheat, barley, tritical and oat grains.***

Conclusion 15. Storage of grains post harvest appears to have little effect on the digestion of starch in the rumen, but may reduce starch digestion in the intestines for wheat, barley and triticale.

4.8 Value of oat grain for ruminants

Evidence presented in Figures 1, 7 and 8 show that the starch from oat grains is readily digested because of its thin endosperm cell walls and small, uniform starch granules. However, the overall energy content of oat grain is low because of the relative small proportion of starch and high fibre content from the grain hulls. 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 within the Program. Digestibility of the grain varied from 62.4 to 76.2 % and was associated closely with the lignin content of the grain (Table 12).

Table 12. 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 10) 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 6.5% lignin had low digestibility; whereas oat grain hulls with lignin contents less than 6.5% could have either very high or very 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. 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. This hypothesis is currently being tested.

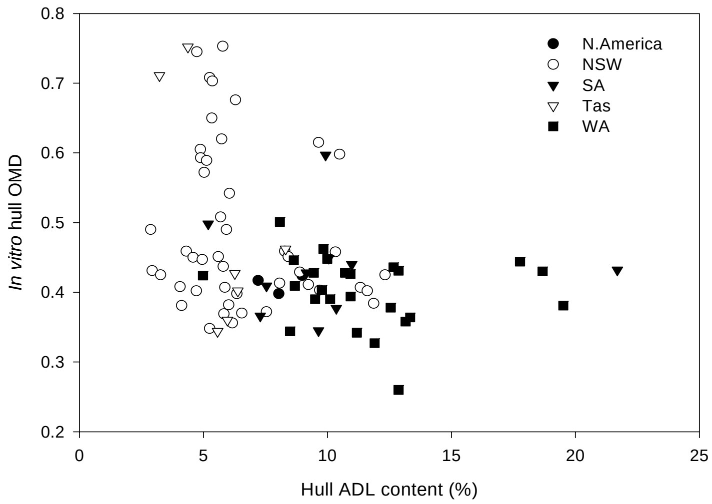


Figure 10. ***Relationship between hull lignin content (ADL) and hull in vitro digestibility of organic matter (OMD) on a region of origin basis.***

Conclusion 16. Selected oat cultivars with low lignin content have high digestibility for cattle and could be a valuable source of starch and fibre for the feedlot industry.

5. Rapid measurement of grain quality

A major goal of the Program is to develop rapid methods for predicting the nutritional value of individual grains for ruminants and for assessing how the nutritional value may be affected by processing techniques. Three approaches are being pursued. The first is to use near-infrared spectroscopy (NIR) scans of whole grains to predict digestibility and available energy content. The second is to understand for each grain type the factors determining nutritional value for cattle and then developing rapid methods for measuring these factors. The third is to develop a computer model to simulate rumen function, nutrient absorption and nutrient utilisation to predict growth and body composition in relation to specific grains and forages offered to the animals.

Significant progress has been made with predicting the energy value of grains using NIR scans and with development of the feedlot cattle model.

5.1 Prediction of the energy value of grains using NIR

An NIR algorithm has been developed for whole tract digestibility of dry matter in sheep using the 60 grains examined in the Premium Grains for Livestock Program. In addition, 13 of the grains have been fed to cattle to assess the suitability of the sheep algorithm for predicting the energy value of grains for cattle. No statistical difference was found in the digestibility of these grains between sheep and cattle. This result suggests that a reasonable estimate of the nutritional value of grains for cattle can be made using the NIR predictions developed for sheep, except for sorghum.

The NIR calibration for predicting *in vivo* dry matter digestibility of grains in sheep was established across grain species with a range in digestibility from 61.9 to 92.3 %. The analyses indicate that NIR could be used to predict *in vivo* dry matter digestibility of grain to within 3.6 % units for 95% of samples. The *in vivo* dry matter digestibility predicted from the NIR equation is compared with the observed values in Figure 11.

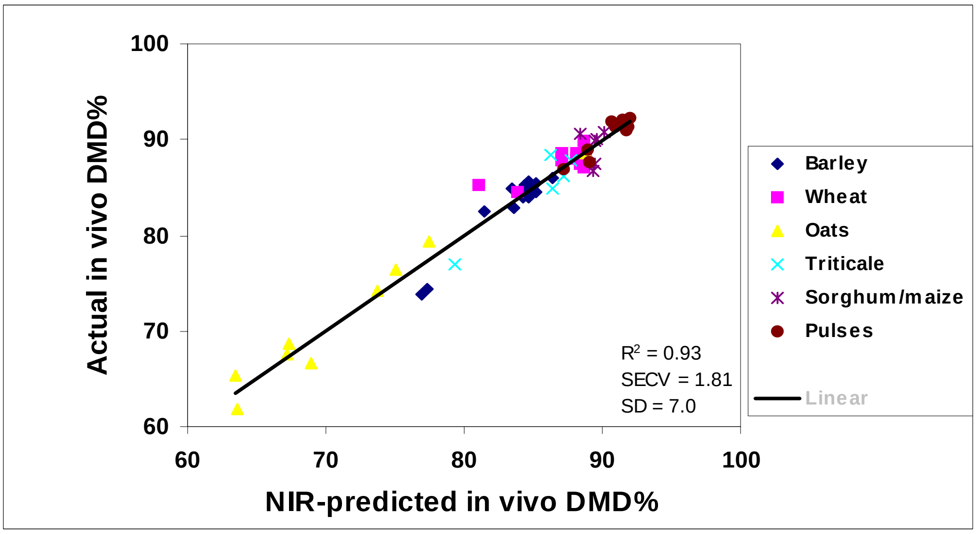


Figure 11. ***NIR predicted in vivo dry matter digestibility of grains for sheep compared with observed results. The prediction can also be used for cattle, except for sorghum.***

Conclusion 17. The NIR equations developed for predicting the digestibility of grains for sheep are applicable to cattle, except for sorghum grains, and can be used to predict digestibility within about 3.5% units.

5.2 Cattle feedlot model

The primary method for predicting the energy value of grains for cattle will be through the ruminant model. This model is proceeding well and will predict the rate and extent of digestion of grain components within the rumen and the effect of nutrients flowing from the rumen on the growth and body composition of feedlot cattle. The model has been linked to a Decision Support Software system called FARMWI$E, which, when completed, should allow the profitability of an enterprise to be predicted in relation to specific feeding strategies.

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