final report

FEEDLOTS

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Premium Grains for Livestock Program Component 1: Co-ordination

An overview of outcomes from PGLP 1 & 2

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Table of Contents

Executive Summary

Background

1. The Premium Grains for Livestock Program (PGLP) was established in 1996 as a jointly funded grains and animal industries project. The project arose because of the rapidly increasing demand for grain by the intensive livestock and dairy industries and concern from these industries about a reliable supply of grain meeting quality specifications for their industries. Grain growers had traditionally seen 'feed grains' as down graded grains unsuitable for human consumption and were not encouraged to produce grains for livestock because of the lower price frequently obtained. However, much of the 'feed grain' available was of insufficient quality for animal industries to meet production specifications and deadlines. Consequently, following several joint industry meetings, the grains and animal industries recognised the opportunity to develop an animal grains industry based on the measurement of quality and appropriate payment for this quality. PGLP has been funded by the Grains R&D Corporation, Meat and Livestock Australia, Australian Pork Limited, Rural Industries R&D Corporation through the Chicken Meat Program, Australian Egg Corporation Limited, Ridley Agriproducts and Dairy Australia. The principle objectives of PGLP were to:
   - Identify the characteristics of grains that made them most suitable for different forms of animal production.
   - Develop a process, based on the rapid measurement of grain quality, for the rational trading of grains for livestock within Australia which provides just rewards to both the grain growers and livestock producers.

2. PGLP has been a unique Project, involving scientists from a wide range of backgrounds and disciplines in the most comprehensive effort yet undertaken to understand the characteristics of cereal grains that determine their nutritional value for different classes of livestock including sheep, feedlot cattle, pigs, broiler chickens and laying hens. Cereal grains, because of their high starch content relative to other ingredients, are offered to animals primarily as a source of readily available energy. The most important outcomes from the program are an understanding that the grain characteristics most suitable for production vary widely between animal types, the development of rapid near infra-red spectroscopy (NIR) calibrations for measuring most of these characteristics and the ability to predict the impact of grain type and on animal performance so the economic value of any grain sample can be determined for each major livestock industry. A number of case studies were conducted to determine how best this information can be made available to grain growers, traders and end-users for development of a process for the rational trading of grains for livestock in Australia with the added value being shared equitably across the feed grain industry chain. The NIR calibrations developed within PGLP have been licensed to the Pork CRC for commercial exploitation across the whole feed grain value chain in Australia. A Business Plan setting out the tasks required to help ensure the calibrations will be used as the main basis for trading grains in Australia has been prepared.

3. Prior to commencement of research, a critical review was undertaken in 1996 of current information then available on factors influencing the nutritional value of cereal grains for different livestock species to ensure that novel approaches to the research and 'best practice' methodology were adopted throughout the life of the Program. Over 3300 grains, primarily wheat, barley, oat, triticale and sorghum, with a wide range in chemical and physical characteristics thought to influence their nutritional value for livestock have been collected from germplasm

archives, plant breeders, specifically grown cultivars and farmers. The samples included frost damaged, partially germinated and drought affected grains as well as more normal well-grown and irrigated grains. All grains were scanned with NIR and the extent and rate of digestion of components in selected grains examined with *in vitro* systems simulating rumen fermentation and intestinal digestion. Approximately 194 grains selected on the basis of NIR scans, *in vitro* analyses, genetic background or growing conditions were fed to animals including sheep, cattle, pigs, broiler chickens and laying hens. About 40 of these individual grain samples were offered to ruminants (sheep/cattle), pigs, broilers and layers where voluntary intake and digestibility of the grains were measured. Twenty four grains were fed to sheep at maintenance and cattle *ad libitum*. The regression equation relating digestibility of grains within the two animal types was used to estimate the digestibility and calculated metabolisable energy (ME) content for cattle of all grains offered to sheep except sorghum. Comprehensive chemical and physical analyses have been conducted on all grains fed to animals. There were approximately 110 analyses conducted on each sample and coved the range in grain characteristics that are likely to have the greatest influence nutritional value for different animal types. Light and scanning electron microscopy were used to examine the physical structure of some grains. Common grains were used across animal and *in vitro* experiments and thorough statistical procedures used to account for errors associated with experimental variation when determining final 'corrected' values used in analyses for this report.

4. The value of a grain as a source of energy to an animal depends on the total amount of energy made available for metabolism (MJ/d), which is determined by the energy available from digestion (available energy content of the grain, MJ/kg) and by the amount of grain consumed in the diet (kg/d). Traditionally, only available energy content of the grain has been considered because of its importance in formulating diets. However, animal productivity is determined by the total intake of available energy. Thus, throughout PGLP, grain characteristics that influence both the available energy content and total available energy intake have been considered. Analysis of the results shows that the two measures of available energy are poorly correlated for all animal types examined. Characteristics of a grain that influence digestion are either not the same as those that affect voluntary feed intake or they have a different magnitude of effect on feed intake.

Major research findings

5. The available energy content of grains varied from approximately 1 to over 4 MJ/kg DM for grain samples within a grain species and an animal type. The variation within grain species was greater for pigs and poultry than for ruminants, except for oat grain. Sorghum grain had the highest available energy content for pigs and poultry compared with the other grains offered, whereas sorghum had the lowest digestibility for cattle. The range in ileal digestible energy (DE) values was greater than the range in faecal DE values for grains fed to pigs. Cross animal comparisons with the same grain samples showed that the relative available energy content of individual grain samples was not constant across animal types. Some grain samples were poorly digested by all animal types. However, other grain samples were well digested by ruminants, but not pigs or not poultry and vice versa. There was a wide range in the relative available energy content of individual grain samples between the animal types. When the available energy content of grains was compared across cattle, pigs, broilers and layers for all grains offered, there were a large number of low or negative

correlations. These poor correlations suggest that different grain characteristics are responsible for high rates of digestion for the different animal types and individual grain samples can be selected to be superior for one animal type rather than for another.

6. The total available energy intake (MJ/d) for individual grains within a grain species varied 2-fold in pigs, from 30-60% for laying hens, from 20-30% for broilers and by around 10% for cattle, except for oats where the range was approximately 60%. The high range for pigs may be confounded by the experimental protocol used. Available energy intake has been expressed as an index with values potentially from 0-100+ to provide an indication of the relative productive energy available for all cereal grains within an animal type. The index was regarded as being more meaningful to people working in the animal industries than MJ/day which continually changes as animals grow.

   Low or negative correlations in available energy intake index values across pigs, layers and broilers again suggest that individual grain samples are more suitable for providing productive energy for one animal type than another. Some individual grain samples had high total available energy intake values, but relatively low available energy content values, indicating that these grains would result in high rates of animal performance but low feed conversion efficiencies.

7. There is an extremely large variation in the digestibility of oat grain samples by sheep and cattle. Incubation of whole oat grain samples *in sacco* in the rumen of cattle for 24 hours resulted in dry matter digestibility ranging from 6 to 82%. Oat grain samples with hull lignin content > 5% had *in sacco* digestibility values of less than 50%, whereas those grain samples with hull lignin contents of < 5% had values ranging from 15 to 82%. Eight oat grain samples with *in sacco* digestibility values ranging from 6 to 55% produced a range in dry matter digestibility in cattle from 60-80% and growth rates from 0.41 to 1.27 kg/day. There was a strong correlation between *in sacco* dry matter digestibility and cattle growth rate.

8. In general, available energy content and available energy intake were reduced in frost affected grains. However, the extent of the depression varied with available energy content and energy intake and also with grain sample and animal type. The observation confirms differential responses to frost in grains across animal types and may indicate that the timing of frost damage is important.

9. Grain samples with a high proportion of screenings result in a small negative effect on the available energy content of grains for ruminants. Similarly, for pigs and poultry, small grain size tends to reduce the available energy content of grains within wheat, barley and triticale, but not within sorghum. However, grain size had no effect on total available energy intake of any animal type and therefore should have no negative effect on animal productivity. The lower available energy content of small grains would mean that efficiency of feed use would be reduced in animals consuming smaller grains despite rates of production not being less than in animals fed larger grains.

10. The energy content of sprouted grains for animals was not decreased and in some circumstances may be increased when compared with non-sprouted grain. The effects of germination were particularly favourable for a barley sample fed to broiler chickens and sorghum fed to cattle. However, the effects of storage on the possible deterioration of sprouted grain or of mycotoxins that may develop needs to be examined.

11. Grain characteristics that may be responsible for the observed differences in available energy content and total available energy intake were examined. Correlations between individual grain characteristics and available energy content or available energy intake were established for all grains and animal types. Specific examples where the energy value of individual grains varied widely between animal types were also examined. The main factors affecting the energy value grains differed between grain species and animal types, but the following principal factors were identified:

- *Gross chemical composition:*
  There was a general positive relationship with starch content and negative relationship with fibre content of cereal grains and available energy content for all animal types. Although the negative influence of fibre components is less for ruminants than pigs and less for pigs than poultry because of the role of micro-organisms in digestion, increasing fibre and lignin content of grains also reduces the availability of energy from grains in ruminants. Despite the negative correlated between grain fibre content and available energy content for all animal types examined, feed intake was positively related to fibre components (NDF and/or lignin) for some grain species offered to broilers, layers and pigs but not cattle where increasing fibre resulted in a depression in intake. These differences can be explained by a stimulation of rate of passage of digesta through the gut of mono-gastric animals as the fibre content increased, whereas with ruminants where rumen capacity is limiting intake, an increase in the fibre content of feed will reduce intake.

  The high available energy content of a naked oat sample for laying hens was due to the high proportion of lipid and its higher energy content than other grain components. However, the available energy content for broilers offered the same naked oat sample was 1.6 MJ/kg DM lower than for layers, because of a lower concentration of lipase enzymes and lower digestion of the lipid in the younger birds.

- *Endosperm cell wall composition, thickness and integrity:*
  Endosperm cell walls have little effect on the overall accessibility of starch from cereal grains for ruminants because they are degraded readily by rumen microorganisms. However, thick cell walls take longer to break down than thin walls and slow the rate of starch digestion within the rumen, alter the rate of acid production and reduce the susceptibility of animals to acidosis.

  Contrary to ruminants, endosperm cell walls can have a marked effect on the energy value of cereal grains for non-ruminant animals. Cell walls reduce 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 to the digestion of starch 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 which exposes the starch to amylolytic enzymes.

  The available energy content of cereal grains for poultry was inversely related to the content of soluble non-starch polysaccharides. These compounds increase the viscosity of digesta, reduce the diffusion of digestive enzymes through the digesta and reduce the rate of substrate digestion. Whole grain viscosity was negatively related to both AME and AME intake for some grain species offered to broilers. Chain length of soluble non-starch polysaccharide polymers appears to be more important for reducing AME of wheat for broilers than is the total soluble non-starch polysaccharide content, because of the greater increase in digesta viscosity, which reduces the digestion of starch, amino acids and fatty acids.

- *Protein matrix surrounding starch granules*
  Starch granules in the endosperm of cereal grains are inserted 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 individual starch granules. These proteins must be degraded to expose fully the starch to amylases. The low availability of energy from sorghum grain for cattle is due to the inaccessibility for amylolytic enzymes to the starch granules encapsulated by the protein matrix. Waxy sorghum grains appear to have less protein matrix with a lower proportion of γ-kafirins than normal cultivars and have a higher digestibility in cattle. The marked difference in digestion of sorghum starch by cattle compared with sheep, pigs and poultry is most probably due to differences in the capacity or concentration of proteases from the different animal species to degrade the high disulphide bond proteins in the kafirin protein matrix.

- *Composition of starch*
  Cereal starch is composed primarily of amylose and amylopectin. The tight helical structure of the long chains of glucose in the amylose molecule makes it less accessible to amylases than amylopectin with its branched α-(1-6) linkages. Waxy grains have starches with high proportions of amylopectin. These waxy grains contain starches with lower gelatinisation temperatures and faster rates of digestion than high amylose starches. Waxy sorghum has a metabolisable energy content up to 3 MJ/kg higher than non-waxy isolines in cattle.

- *Starch granule size and surface area*
  There was a positive correlation between starch granule surface area and AME content of wheat, barley and triticale for broilers and layers and available energy intake for pigs.

- *Hydration capacity and grain hardness*
  Previously scientists have suggested that an increase in the time taken for a grain to become hydrated within the digestive tract would increase the time needed for digestion, slow the rate of passage of digesta and thereby reduce feed intake and performance of broiler chickens. However, contrary to these suggestions there was a strong negative correlation between hydration capacity and grain available energy content for most grain species and animal types examined. Also, there was little relationship between hydration capacity and the available energy intake index for each animal type. However, there was a strong negative correlation in the PGLP grains examined between hydration capacity and starch content indicating that the negative correlations between energy availability and grain hydration capacity could be due to the difference in starch content. A model simulating digestion in broilers was used to suggest that, when the effects of gross chemical composition

are removed, hydration capacity had little impact on broiler AME. However, the relationship between the difference in predicted and observed AME and single kernel hardness was strong suggesting that grain hardness may be a major factor affecting broiler AME once the effects of gross chemical composition are removed. Hard grains take up moisture more slowly than soft grains suggesting that the rate of hydration has a greater effect on penetration of enzymes into the grain than the extend of hydration measured after prolonged soaking.

- *Arabinose:xylose ratio in oat grains*
  Evidence was collected to suggest that the oat grains with low lignin content, but high arabinose:xylose ratio have low *in sacco* digestibility.

12. Grain test weight or bulk density expressed as kg/hl is currently used along with screenings percentage by the animal and the livestock feed manufacturing industries as a primary method for estimating the likely energy value of grains for animals. A lack of significant within grain relationships in PGLP suggests that productive energy intake and therefore animal performance is not influenced by the test weight of cereal grains, except for extremely low density grains. Test weight was not a good indicator of the potential energy value of a cereal grain for animals.

13. An acidosis index was developed from *in sacco* rates of starch digestion, *in vitro* rates of total acid and lactic acid production and the starch and fibre composition of grains to predict the 'hotness' of individual grain samples for ruminants and their potential to cause ruminal acidosis. A case study showed that there was a strong relationship between the estimated hotness of a grain and its ability to cause acidosis.

14. The growth rate and efficiency of feed use by broiler chickens consuming the same amount of available energy from wheat based diets was approximately 20% greater than for broilers consuming sorghum based diets. The inefficient use of energy from sorghum was thought to be caused by asynchrony in the release of amino acids and energy for growth. Starch would be made available for digestion soon after the protein matrix envelopes surrounding the starch granules are ruptured in the gizzard, whereas release of amino acids would be delayed due to the slow rate of digestion of the kafirin proteins with their high disulphide bond content. There is an opportunity to increase the rate of digestion of sorghum proteins in broilers.

15. Although sorghum grain has a higher available energy content than other cereal grains for pigs, feed intake from diets containing sorghum was lower and total available energy intake was at least 10% lower. There is an opportunity to increase feed intake of sorghum by pigs.

16. Anecdotal discussion among dairy farmers and some consultants suggest that red feed wheat grown in Tasmania is of lower value for lactating dairy cattle than traditional hard wheat varieties. Results showed that the ruminant ME content of red feed wheats, particularly a sample of Tennant, were higher than for the hard white bread wheats, but their chances of causing ruminal acidosis were greater. The intake by cattle of diets containing red feed wheats was similar to that for hard white bread wheats, but lower than for the soft white biscuit wheats. The productive energy available to growing cattle and their performance was similar between red feed wheats and hard white bread wheats. Soft biscuit wheats provided the greatest performance in cattle because of high digestibility, low

acidosis index and high feed intake. Feed wheats contained less protein than the hard white bread wheats and this needs to be considered when formulating diets for high producing cattle. The superior yield of the red feed wheats in the Tasmanian environment should provide a greater return for grain growers planting these cultivars compared with the conventional Australian hard bread wheats, provided their capacity to provide energy to ruminants is considered.

17. Several experiments were conducted to investigate processing and storage methods for improving the energy availability of cereal grains for different animal types. The aim of these experiments was to disrupt the protein matrix surrounding the starch granules in sorghum when fed to cattle, to break the integrity of cell walls for wheat, barley and triticale fed to pigs and to hydrolyse long-chain non-starch polysaccharides for wheat, barley and triticale fed to poultry.

- The *in vitro* fermentation of starch from normal sorghum was increased from about 30% to approximately 90% by cooking (steam-flaking), extrusion and microwaving. Other processes such as solubilisation of the protein, pelleting and germination increased *in vitro* fermentation of starch to approximately 50%. The value for untreated waxy sorghums was also about 50%.

  A 90 day growth experiment with cattle showed a significant improvement in digestibility of waxy sorghum over the non-waxy isoline. Steam-flaking increased digestibility of the non-waxy material, which was further increased by extrusion. Steam-flaking of waxy sorghum did not result in further improvement in digestibility over the non-waxy isoline. Feed intake of the cattle tended to be negatively related to digestibility, such that animals consuming the unprocessed (dry-rolled) grains grew fastest, but had the lowest feed conversion efficiency. Waxy-isoline and processing significantly improved the efficiency of feed use for growth.

- An experiment designed to disrupt the integrity of endosperm cell walls by either whole grain or ground grain extrusion was conducted with several grain species for pigs and broilers. There were inconsistent effects on faecal DE in pigs, with extrusion significantly increasing DE for 3 of the 4 wheat samples and one of the 2 barley samples. Whole grain extrusion produced higher DE values than ground grain extrusion. However, for one barley sample, whole grain extrusion substantially reduced DE. Extrusion of sorghum and rice had inconsistent effects on DE in pigs.

  Similarly, extrusion had inconsistent effects on the AME content of grains for broilers and layers. Extrusion caused a significant decrease in AME of the two samples of barley grains for broilers, but only one for layers.

  These inconsistent effects of extrusion on the available energy content of cereal grains for pigs and poultry suggest that there are interactions between heat, moisture and pressure with characteristics of the starch, protein matrix and cell wall constituents that are not understood.

- Several grains fed to broilers were treated with xylanase and glucanase enzymes. There was no significant response in AME or AME intake to the addition on enzymes to sorghum. There were positive responses to enzymes added to several samples of wheat and barley, but not to one sample of triticale. The largest response to enzymes was for naked barley cultivar, Merlin (3725) where AME increased from 12.6 to 14.6 MJ/kg DM.

Results from an experiment conducted by Tom Scott using PGLP grains were analysed to examine the effects of grain characteristics on the response to xylanase and phytase enzyme additions to broiler diets. The addition of enzymes resulted in a wide range of responses in AME and AME intake from negative to highly positive for wheat and triticale and generally negative for sorghum. The magnitude of the responses was shown to be positively related to the soluble cell wall constituents, arabinose, xylose and ß-glucan and negatively related to the tannin, ADF and crude fat content of the grain. A full statistical analysis was undertaken to develop regression equations to predict the magnitude of the response to enzymes from various chemical components of the grains. The most significant equation predicting the effect of enzyme on broiler AME included total tannin, cell wall (β-glucan + soluble arabinoxylan) and crude fat and accounted for approximately 63% of the variation observed in diets containing triticale, sorghum and wheat. A similar set of equations for the grain species accounted for 68% of the variation observed in AME intake. Enzymes decreased the AME in 20 of the 49 samples examined and decreased AME intake in 10 of the samples. Feed intake was reduced in only 3 samples. The equations may be useful as a method for predicting the likely response of broilers to enzyme additions. Further validation of the equations will result from an experiment currently being funded by the RIRDC Chicken Meat Program where approximately 100 cereal grains (wheat, triticale and sorghum) are being evaluated with and without enzymes.

Major deliverables from the Program

NIR calibrations for energy values and chemical/physical characteristics

NIR calibrations were derived using both whole and milled grains for 75 measured or calculated variables including available energy content and total available energy intake for all animal types examined, acidosis index and starch in faeces for cattle, *in vitro* & *in sacco* measurements and chemical & physical variables. The calibrations of most value to the grains and livestock industries and an estimate of their accuracy are provided below.

Calibration type	Measurement (units)	Calibration accuracy
Ruminants		
Sheep	Dry Matter Digestibility (%)	Excellent
Cattle	ME *ad libitum* (MJ/kg)	Good
	Starch in faeces	Excellent
	Acidosis index	Quantitative
Herbivores		
Whole oats	48 hr in sacco DMD (%)	Good
	Hull lignin (%)	Quantitative
	Hull percent of whole grain	Good
Pigs	Faecal DE (MJ/kg)	Good

	Ileal/Faecal DE ratio	High-Low
	DE intake index (0-100)	High-Low
Broilers	AME (MJ/kg)	Good
	AME intake index (0-100)	Quantitative
Layers	AME (MJ/kg)	High-Low
	AME intake index (0-100)	Poor
Chemical component	Crude protein (%)	Excellent
	Crude fat (%)	Excellent
	ADF (%)	Excellent
	NDF (%)	Quantitative
	Starch (%)	Excellent
	ß-glucans (%)	Excellent
	Total insoluble NSP(%)	Excellent
	Xylose (%)	Excellent

Although many of these calibrations have reasonably high accuracy and are of considerable value for differentiating between grains, their accuracy in most cases would be insufficient for legally based trading of grain. Further refinement of the calibrations would strengthen their accuracy. The calibrations are being used currently in a series of case studies to demonstrate that grains selected on the basis of predicted values cause expected differences in animal performance and efficiency of feed use. However, several other calibrations, for example, those for laying hens low accuracy and require additional results or further analysis of information. The Pork CRC and the RIRDC Chicken Meat Program have committed substantial funds to the validation and enhancement of the calibrations for their respective industries. Several of the calibrations are important as a screening tool for plant breeders.

Selection criteria and breeding objectives for plant breeders

Results from PGLP show that selection criteria for breeding grains most suitable for ruminants differ from those most suitable for pigs and poultry. The primary aim for ruminants is to slow the rate of digestion of starch within the rumen, while allowing its complete digestion in the small intestines. The desired characteristics for grains differ both with the grain species and animal type.

Desired grain characteristics for wheat, barley and triticale for ruminants are:
- Thick, intact endosperm cell walls
- High aribinoxylose content
- High whole grain viscosity
- Low acidosis index
- Hard grain to reduce rate of water penetration
- Low fibre and hull content

Desired characteristics for oat grain for ruminants are:
- High *in sacco* digestibility
- Low hull content

Desired characteristics for sorghum for cattle:
- Increased digestibility of kafirin proteins through selection for low S:N ratio
- Protein matrix with non-continuous encapsulation of starch granules
- Waxy endosperm

Desired characteristics for wheat, barley and triticale for pigs and poultry:

- Thin, fragile endosperm cell walls
- Low arabinoxylan and ß-glucan content
- Low whole grain viscosity for poultry
- High starch & low fibre content
- Lipid content of > 5%

Desirable characteristics for sorghum for pigs and poultry:

- Increased digestibility of kafirin proteins through selection for low S:N ratio
- Protein matrix with non-continuous encapsulation of starch granules

Simulation model of cattle

A fully mechanistic model has been developed of rumen function, voluntary feed intake and nutrient digestion and utilisation has been produced as well as a decision support software system for feedlot cattle. The model has been used for developing concepts and research strategies associated with grain use and processing for both the feedlot and dairy industries. Further development of the model is needed so it can deal with feeding of mixed grains and is suitable for lactating dairy cows.

A process for predicting the durability of pellets formed from cereal grains

Over 200 grains have been evaluated for their suitability to produce hard and durable pellets using an experimental pelleting machine at Ridley Agriproducts. Experiments are currently being completed to ensure sufficient connectivity between results so that values corrected for know apparatus variation can be obtained. Once the statistically corrected values have been obtained, grain factors determining pellet durability will be identified. In addition, a NIR calibration will be developed for predicting the likely durability of pellets produced from grains.

An extremely comprehensive database on chemical, physical and morphological characteristics of cereal grains that can be linked to animal performance measurements

An analytical data-base has been developed that is unique in its size and in the diversity of grains included. It also has the advantage of analytical consistency as most grains were analysed in the same laboratories using the same methods and equipment. As such it is a resource with value to all of grain science and needs to be preserved for the Australian Grains industry and in an appropriate form published in the World Literature so that others will know of its existence and can use it in their work. Associated with the chemical/physical database is a database containing results from all animal experiments. The combined database provides a unique opportunity for further examine reasons for differences between grains in their capacity for animal production.

A process for the rational trading of grains for livestock

A process is proposed for the rational trading of grains for livestock based on estimating the value of any parcel of grain in terms of animal performance, with grains most suitable for different livestock industries and end uses being identified and valued commercially. The steps in the proposed process are:

- Use a single NIR scan for a parcel of cereal grain at the site of collection/delivery to predict ruminant ME, acidosis index, pig DE, pig DE intake index, broiler AME, broiler AME intake index, crude protein, NDF, crude fat and starch content.

- Make the scan results available to grain growers, livestock industries and other relevant people across the feed grain value chain.

- Use the scan results in combination with other information in spreadsheets or simulation models such as the AUSPIG or AusBeef to assess the impact of feeding the grain on the performance of different animal types and on enterprise profitability.

- Use the economic information to determine an appropriated price for the grain grower/trader and end user.

The research from PGLP has demonstrated clearly that using NIR calibrations in is far superior to the current methods for assessing the energy value of grains based on measurement of test weight and screenings percentage. For successful adoption of the proposed process, NIR calibrations must be continually updated to allow for year to year variation, to clarify predictions for 'outliers' and to ensure that there are sufficient records for each grain type for accurate within grain predictions .

A significant communication and education program must be initiated to ensure that NIR measurement of grain quality becomes the accepted method of specifying and trading grains for livestock in Australia. One grain trader suggested that the procedure would need to be adopted by 80% of the industry for it to become standard practice.

Opportunities for further investment

Following are the major opportunities for further investment to gain the greatest benefit for the 10 years of research in PGLP.

- A major communication and education program must be initiated to ensure that NIR measurement of grain quality becomes the accepted method for specifying and trading grains for livestock in Australia.

- GRDC must establish a viable, long-term strategy to ensure that the NIR calibrations are readily available to all sectors of the feed grain value chain and updated as required. Recent licensing of the Pork CRC to distribute the NIR calibrations for commercial use across the feed grain value chain is a first step in this strategy.

- Further improvement and validation of NIR calibrations is essential if they are to be used reliably for the trading of grain, formulation of diets in the animal industries and to assist plant breeders. The latter require grain species specific calibrations rather than cereal grain global calibrations as have been established at present. Continual updating of the calibrations will be essential as characteristics of grains change over time as a result of plant breeding programs. Improved prediction of the energy value of weather damaged grains for each animal type is required.

- Work closely with cereal breeders to improve the nutritional value and yields of grains for specific types of livestock. Separate selection criteria need to be established for breeding grains for use by ruminants and pigs or poultry.

- Understand the reasons for varying effects of different processing methods on the availability of energy in cereal grains for pigs and poultry.

- Refine theoretical models for predicting broiler AME, pig DE and ruminant ME content and intake so they can be used as a means for evaluating outliers obtained when NIR calibrations are used commercially.

- Further analysis of PGLP data and data mining. There are still a large number of analyses that need to be undertaken to gain the most from the current extensive information obtained within PGLP.

- Ongoing storage of grain samples, collection of grains for Pork CRC for enhancement of NIR calibrations and case studies, analysis of case study results and maintenance of the chemical/physical and animal relational database. Maintenance of the stored grain samples and database is essential for any ongoing research relating to PGLP outcomes.

- Modification of the AusBeef model improved predictions for the feedlot and dairy industries.

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. 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 and 2002-03 drought periods when grain prices rose dramatically. 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 is known precisely.

The Grains Research and Development Corporation in collaboration with several animal Research and Development organisations including Meat and Livestock Australia, Australian Pork Limited, Australian Egg Corporation Limited and Rural Industries Research and Development Corporation Chicken Meat Program and Dairy Australia, established in 1996 a new research Program, "Improving Feed Grains Quality". The program was extended in 2000 and called the "Premium Grains for Livestock Program" (PGLP) to remove the industry stigma often associating "feed grains" with inferior products. Dairy Australia withdrew from the Program in 2000 and was replaced with funds from Ridley Agriproducts. Funding for the Program was subsequently extended in 2003, 2005 and 2006 with a final completion date 30 June 2008. Research has been provided by University of Sydney, University of New England, South Australian Research and Development Institute, Department of Primary Industries Victoria, Department of Primary Industries New South Wales, CSIRO and several consultants.

This Report provides an overview of the major findings from the Program and a summary of achievements in relation to the contracted outcomes for PGLP phase 2. The primary goal of the Program has been to develop a process for the rational trading of cereal grains for livestock based on rapid and accurate measurements of their nutritional value for different classes of livestock. Cereal grains, because of their high starch content relative to other ingredients, are offered to animals primarily as a source of readily available energy. Consequently, research has focussed on measuring the variation that exists between and within cereal grain species in their capacity to provide energy for different classes of animals and on identifying the reasons for this variation.

Emphasis of the research has been on determining the digestibility, site of digestion and intake of cereal grains in sheep, feedlot cattle, pigs, broiler chickens and laying hens. Near infra-red spectrophotometry (NIR) has been used as the primary method for rapid assessment of the energy value of grains, their digestion characteristics and chemical and physical composition. Research has been directed also towards identifying processing techniques that may improve the energy value of individual grain samples for the different classes of livestock. The major activity of Component 5 of the Program has been to develop a computer model that simulates the intake, digestion and utilisation of cereal grains and other feed ingredients by feedlot cattle. The model predicts the economic consequences of using different feed ingredients, grain processing techniques and management strategies within a feedlot.

Component 6, Technology Transfer and Commercialisation, was introduced into the Program in July 2003 to facilitate adoption of research outcomes and demonstrate through 'case studies' the implications across the feed grains value chain. Activities during 2005 to 2008 were concentrating on analysis of results obtained from experiments and on developing the case studies to demonstrate the value to the livestock, grain grower and grain trading industries of an ability to predict accurately the energy value of individual parcels of grain.

The Components of the Program are:

Component 1: Coordination
Component 2: Production, storage and distribution of grain samples
Component 3: Rapid and objective analytical tests
Component 4: Enhancing nutritive value of grains through processing, storage and identified breeding objectives
Component 5: Modelling feed grain utilisation by feedlot cattle
Component 6: Technology transfer and commercialisation

Components 3, 4 and 5 were terminated in 2004. Final Reports describing in detail outcomes from these Components have been submitted to GRDC.

PGLP Objectives

The principal objectives of the Program have been to:

1. Identify the factors determining the quality of cereal grains for ruminants, pigs and poultry so that improvements in their ability to provide energy can be achieved through selecting specific grain samples, plant breeding, 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.

4. Provide the grain trading industry with the 'tools' necessary for developing a rational system for trading grains for livestock that is based on:
    - knowledge of the factors determining the nutritional value of cereal grains for different types of animal production,
    - methodology for the rapid measurement of these grain characteristics at the site of grain delivery,

- assessment through simulation models and case studies of the likely economic consequences for each animal industry of variation in the nutritional value of individual parcels of grain.

Research Strategy

Major PGLP component

The first activity for the Program was a critical review of current information on factors influencing the nutritional value of cereal grains for different livestock species to ensure that novel approaches to the research and 'best practice' methodology were adopted throughout the life of the Program. The resulting reviews covered the structure, chemical and physical characteristics of grains, determinants of nutritional value of grains for ruminants, pigs and poultry, the effects of genotype x environment interactions on nutritional value, forage-grain interactions in ruminants, procedures for chemical and physical analyses of grains, the importance of grain contaminants, as well as *in vitro* and *in vivo* techniques for assessing the nutritional value of grains for ruminants, pigs and poultry. The reviews were published as a special issue of the *Australian Journal of Agricultural Research* (Volume 50, Number 5, 1999) and represent a unique aggregation of information on factors determining the nutritional value of grains for livestock and on analytical methods for assessing this value.

Over 3300 grains with a wide range in chemical and physical characteristics thought to influence their nutritional value for livestock have been collected. Many of the grains were obtained from germplasm archives and plant breeder's lines, 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. A summary of the grains collected is given in Table 1. A sample of approximately 2 kg of each grain was stored at -20°C for possible future assays.

Table 1. The amount and type of cereal grain samples collected form 1996 – 2004.

Cereal Species	Breeder Samples 0.5-2kg	Farmer Grown Samples 1-20t	Narrabri Increased Samples		Total
			Small < 5kg	Large 1-10t	
Wheat	460	57	154	21	692
Barley	715	64	49	21	849
Oats	983	16	55	14	1068
Sorghum	592	44	3		639
Triticale	76	16	27	12	131
Total	**2826**	**197**	**288**	**68**	**3379**

All grains have been scanned with NIR and the extent and rate of digestion of components of selected grains examined with *in vitro* systems simulating rumen fermentation and intestinal digestion. Details of the *in vitro* systems are given in the Final Report for Component 4 (GRDC Project UNE 47). A subset of approximately 194 grains selected on the basis of NIR scans, *in vitro* analyses, genetic background or growing conditions have been fed to animals including sheep, cattle, pigs, broiler chickens and laying hens (Table 2). A relatively small number of grains have been offered to all animal types. However, approximately 40 individual grains were offered to ruminants (sheep/cattle), pigs, broilers and layers

Measurements made during animal experiments included voluntary intake and whole tract digestibility of energy, dry matter and, for some experiments, starch. Digestion of energy to the end of the ileum was determined for pigs and broilers and amino acid availability was determined in the initial two years of experiments. Measurements on amino acid digestion were not made in subsequent years because of the high cost of the analyses and a decision to concentrate on defining the energy value of cereal grains for the different livestock types. The digestibility of grains when offered at maintenance intake to sheep has been determined. Digestibility of 11 of these grains when offered to cattle at maintenance intake was also determined. The intake and digestibility of 24 grains in growing cattle was measured and digestibility values compared with those obtained for the same grains from sheep fed at maintenance. An equation adopted by the Australian Fodder Industry Association was used to convert organic matter digestibility to metabolisable energy (ME) for ruminants (AFIA, 2005).

Common grains were used across animal and *in vitro* experiments and thorough statistical procedures used to account for errors associated with experimental variation when determining final 'corrected' values used in analyses. Results from all experiments conducted within the Program have been incorporated into a specially designed relational database to assist the ready retrieval of information. Results from individual treatments, mean values and statistically corrected values are included in the database. The full database and operating manual have been provided to GRDC. Details of the procedures used throughout the whole Premium Grains for Livestock Program are given in the Final Reports for the individual Program Components.

Table 2. The number of samples[#] of grain fed to all species of animals in the Premium Grains for Livestock Program.

	Cattle	Sheep	Pigs	Broilers	layers
Wheat	10	24	42	45	48
Barley	9	32	42	45	38
Triticale	4	9	8	11	8
Sorghum	7	7	23	26	13
Oats	10	18		3	3
Rice			6	6	6
Other (eg/peas)		10			
Total	**40**	**100**	**121**	**136**	**116**

[#] All grain samples, regardless of processing and condition

Case studies

The case studies comprised the major activities in PGLP Component 6: Technology transfer and commercialisation. The primary objective of the case studies was to evaluate the usefulness of the NIR calibrations for different industry sectors along the feed grain value chain and to suggest pathways for commercialisation of these calibrations. A full report for Component 6 has been prepared by Dr John Spragg from JCS Solutions Pty Ltd and is provided as one of the supporting documents to this Final Report.

Six case studies were completed:

- ABB Grain Limited – representing the grain bulk handling industries. The aim of the study was to determine the range in quality of barley and wheat samples collected in South Australia. Grain was analysed from different years, silo and region locations, cell and individual load deliveries. The grain collected included 281 barley samples from 2004-05, 671 barley samples and 656 wheat samples from 2005-06 and 45 barley reference samples covering 9 years.
- Ingham Enterprises – representing the chicken meat industries. The aim of this study was to demonstrate the difference in bird performance that would result from using the PGLP developed NIR calibrations to select grain with different AME and AME intake index values. Wheat samples were selected from 37 different locations across Victoria and NSW following the 2005-06 harvest. All grains were scanned using NIR technology and, on the basis of the NIR predicted values, two samples were selected for inclusion in diets for rearing broiler chickens and compared with an internal Ingham control wheat sample. The AME (MJ/kg) and AME intake index (0-100) values for the three grains used in the experiment were: high-13.10, 69.33; Ingham control-12.79, 67.44; low-12.48, 64.16. The low and high grains were fed with and without enzymes to broilers, while the Ingham control was fed only with enzymes. Growth rate and feed efficiency of broilers were measured from day-old to 42 days of age and to a sale weight of 2.45kg.
- QAF Meat Industries Pty Ltd – representing the pig industry. The aim of this case study was to demonstrate the difference in cost of diets and performance of weaner pigs when fed diets containing grains with different DE (MJ/kg) and DE intake index (0-100) values. The same 37 wheat samples for the Ingham Enterprises study were used to select seven samples with a range in DE and DE intake index values. These grains were incorporated into weaner diets which contained 64.8% wheat from each source. The diets also contained antibiotic and xylanase enzyme additives. The pigs used in the experiments were weaned at 28 days of age and after 5 days acclimatisation were offered the diets for 21 days. Cost of the diets, growth rate and feed conversion efficiency were measured.
- Ridley Agriproducts – representing stockfeed manufacturers. The aim of this case study was to quantify the likely benefits from either increasing or reducing the energy content of cereal grains for pigs, broilers or cattle. The known energy value of grains was allowed to vary by 1 MJ/kg and the effect on price of a diet determined using traditional, least-cost feed formulation software. The energy content of each grain included in a ration was allowed to change for one grain only or for all grains in the diet.
- GrainSearch – representing short grain supply chain. The aim of this case study was to determine the value of the PGLP NIR calibrations for measuring the quality of grain supplied by a grain breeding organisation and to identify the relative effects of grain cultivar and agronomic conditions on quality measures. Three experiments were conducted. In the first experiment, eight cultivars of wheat were grown at two locations, with fungicide being applied to treatments at one location. In a second experiment, one cultivar was grown at 11 locations in southern Victoria. In the third experiment, five cultivars of barley were grown at one location. The NIR calibrations were used to determine the energy content of grains for ruminants, pigs and broilers and available energy intake index values for pigs and broilers.
- Bovine Research Australia – evaluation of the rumen acidosis NIR calibration. Acidosis is a major factor affecting performance of dairy and feedlot cattle fed high amounts of cereal grains. Grain species and individual grain samples are

known to vary widely in their capacity to cause rumen acidosis. A NIR calibration for predicting an ‘acidosis index’ with values from 0-100 was developed in PGLP from a theoretical model based on the rate of *in vitro* fermentation and the chemical composition of the grain. Twenty grain samples (3 oat, 3 sorghum, 4 barley, 4 triticale and 6 wheat) were selected from a wide range of grains that had been scanned using NIR technology and their NIR acidosis index predicted. The predicted values for the selected grains ranged from approximately 10 to 95. These grains were fed as a single meal to cattle and samples of rumen fluid obtained at intervals after feeding. The pH of the rumen sample and concentrations of individual volatile fatty acids, lactic acid and ammonia were measured. A combination of the concentrations of valerate, butyrate and ammonia at 4 hours after feeding, known as the cluster T4 analysis, along with valerate concentration alone had been shown previously by the research group to be the best predictors of acidosis. The NIR predicted acidosis values were compared with the cluster analysis and valerate calculated values (converted to an index by adjusting the highest T4 cluster analysis and valerate values to be of similar magnitude to the PGLP calculated index – Acidosis T4 index & Acidosis valerate index) to assess the usefulness and accuracy of the PGLP calibration.

Associated projects

Three studies, termed associated studies, have been conducted using PGLP experimental protocols but were outside the funding arrangements of PGLP. The results from these studies have been used or will be used to strengthen the PGLP developed NIR calibrations. Analyses of the experiments were included in the milestones for the last two years of PGLP Component 1.

Energy value of sorghum for broilers

An experiment funded by the RIRDC Chicken Meat Program and conducted by the Queensland Department of Primary Industries and Fisheries was undertaken in part to provide more AME and AME intake values for sorghum for the PGLP NIR calibrations. The first experiment in this project determined the AME content and feed intake by broiler chickens of grains using the protocol established for PGLP experiments, but the diets were prepared and the experiment conducted in Queensland rather than at Roseworthy in South Australia. The aim of the experiment was to determine the variation in sorghum samples collected across the major sorghum growing regions of eastern Australia. Eighteen sorghum samples were collected from northern NSW, south-eastern and central Queensland for the experiment. In addition, three wheat samples and one sorghum sample from the PGLP grains were used for statistical connectivity. The ‘connectivity’ sorghum sample was also processed by microwaving to determine the effects of severe disruption of the protein matrix encapsulating the starch granules of sorghum and gelatinisation of the sorghum starch.

Energy value of pearl millet cultivars for pigs

An experiment funded by Australian Pork Limited and conducted by James Cook University and Queensland Department of Primary industries and Fisheries was undertaken to provide ileal DE and faecal DE values for two new cultivars of pearl millet developed by QDPI&F. The experiment was conducted using the same protocol and experimental procedures as for the pig experiments in PGLP. The diets were prepared at Roseworthy in South Australia using the same personnel and equipment as used for preparation of PGLP diets. The digestibility experiments were conducted at James Cook University. Two new cultivars of pearl millet, NPM3 and

NPM4, were evaluated in the experiments with one sorghum sample and two wheat samples form PGLP used as ‘connectivity’ grains.

Validation and upgrade of NIR calibrations for pigs

The Pork CRC in collaboration with GRDC is investing additional funds to strengthen the NIR calibrations for pigs. A series of experiments are planned to evaluate approximately 30 grains per year for several years. Particular emphasis is being placed on creating and evaluating weather damaged grains and on evaluating cultivars from new genetic lines of triticale, barley and sorghum. The first experiment has been completed and the results used to validate and enhance the PGLP NIR calibrations developed for ileal and faecal DE.

Thirty two grains including 9 wheat, 7 barley, 5 triticale and 11 sorghum samples were included in the experiment. Six of these grains, 4 wheat samples and 2 barley samples, were from PGLP and used as ‘connectivity’ grains. One sample of sorghum was treated with an enzyme product from the ginger plant called Zingibain, supplied by Natbio Pty Ltd, Queensland. The diets were prepared by QDPI&F and the experiments conducted at Wacol in Queensland. The results were analysed statistically using the same procedures as for PGLP experiments. The results were used first to evaluate the accuracy of the existing PGLP NIR calibrations and then combined with the PGLP values to establish new calibrations. The accuracy of predictions for the old and new calibrations was compared.

Definition of available energy and effect of digestive process

The value of a grain as a source of energy to an animal depends on the total amount of energy made available for metabolism (MJ/d), which is determined by the energy available from digestion (available energy content of the grain, MJ/kg) and by the amount of grain consumed in the diet (kg/d). Energy available following digestion is normally defined as the energy in chemical components, digested and absorbed, which can be used in metabolic processes within the animal. The available energy content of a grain (MJ/kg) is used traditionally by the animal industries to formulate diets with predefined energy content, whereas total available energy intake (MJ/d) is correlated strongly with animal performance. Thus, it is important when determining the energy value of a grain, to measure both the available energy content of the grain and the total intake of available energy from the grain.

Energy released from grains during digestion is expressed traditionally as digestible energy (DE, energy in feed less energy in faeces) for pigs, apparent metabolisable energy (AME, energy in feed less energy in faeces which includes uric acid) for poultry and metabolisable energy (ME, energy in feed less energy in faeces, urine and expelled methane) for ruminants. This convention has been used when comparing the energy made available to different forms of livestock within the PGLP.

The value of energy released during digestion varies substantially depending on whether digestion is a result of animal secreted enzymes or enzymes of microbial origin. In the latter case, dietary constituents are converted into growing microbes, volatile fatty acids and other compounds with the release of methane, ammonia and heat of fermentation. This microbial fermentation process can result in loss from the animal of 10-20% of the energy in digested material as heat of fermentation and methane depending on diet composition, conditions of fermentation and species of microbes present. Nevertheless, the fermentation process is important for some animals because microbial enzymes can cleave chemical bonds in cellulose, arabinoxylans, ß-glucans and other plant materials that cannot be broken by enzymes secreted by mammals and birds. Many oligosaccharides also have chemical bonds that are cleaved by microbial enzymes, but not enzymes secreted by animals. The lignin content of grains, which consists of a range of phenolic polymers, is indigestible by animal enzymes and most microbial enzymes.

The value of microbial fermentation to an animal depends on the proportion of compounds in the diet that cannot be digested by animal enzymes and the location of the fermentation process within the digestive tract. Digestion involving microbial activity is most appropriate for animals consuming diets high in plant fibre. The anatomy of the digestive tract (Figure 1) and the digestive process varies widely between livestock species.

Feed consumed by ruminants is subjected to microbial fermentation within the rumen before it passes to the stomach and small intestines where animal enzymes are secreted. The starch in cereal grains is first subjected to microbial action and, if readily accessible to microbial enzymes, can result in a rapid digestion, increased acid production, low pH and lactic acidosis with severe disruption to the digestive process, a reduction in plant fibre digestion and in feed intake and ulceration of the rumen wall. Accessibility of starch granules to microbial enzymes depends on disruption to endosperm cell walls and the protein matrix during grain processing, mastication or microbial digestion. The greatest amount of energy would be made available to ruminants when starch granules are exposed for animal enzymic digestion as they leave the rumen. Starch, which is digested to glucose by animal enzymes and absorbed from the small intestine is used with greater efficiency by the animal than the volatile fatty acids released when starch is degraded by microbial enzymes.

Grain consumed by pigs passes to the stomach and small intestine where it is exposed to animal secreted enzymes before moving to the hind-gut which can contain high concentrations of microbes. Pigs masticate feed poorly and unless the grain is processed before ingestion to disrupt the endosperm cell walls, large quantities of starch can be fermented in the hind-gut resulting in loss of energy, reduced feed intake and susceptibility to enteric diseases.

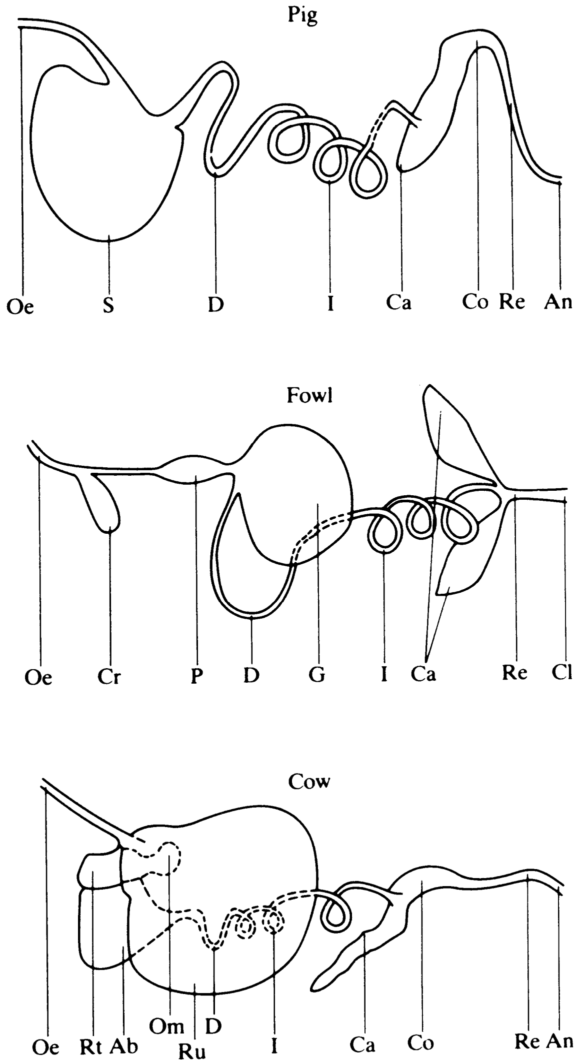


Figure 1. Diagrammatic representation of the digestive tracts of pigs, poultry and ruminants. An, anus; Ab, abomasums; Ca, caecum; Cl, cloaca; Co, colon; Cr, crop; D, duodenum; G, gizzard; I, ileum; Oe, oesophagus; Om, omasum; P, proventriculus; Re, rectum; Rt, reticulum; Ru, rumen; S, stomach. Reproduced from McDonald *et al.* (1988).

Poultry do not have a significant microbial population within the digestive tract and there is insignificant digestion of non-starch polysaccharide components in grain. Poultry have a gizzard where intense muscular contractions disrupt the integrity of cell walls and readily expose starch granules to enzymes in the small intestines. There is significant refluxing of digesta from the gizzard to the proventriculus where grain particles are continually mixed with gastric acids and enzymes as the size of the particles is reduced. There is also significant refluxing of digesta within the small intestines and from the colon to the ileum, which aids digestion and absorption from the short digestive tract (Duke, 1994). However, the high dry matter content of poultry digesta and the short transit time of digesta through the gut mean that non-starch polysaccharides, particularly long chain, increase digesta viscosity and reduce accessibility of enzymes to the starch granules.

Variation in available energy between grains and animal types

Variation in the energy value of grains must be considered in terms of both the available energy content or energy released and absorbed during digestion (MJ/kg) and total available energy intake (MJ/d), which is the product of both available energy content of the grain and the amount of grain eaten. Total available energy intake is highly correlated with animal performance, whereas the efficiency of feed use (kg feed:kg product) is determined more by available energy content of the grain.

Available energy content of cereal grains

Literature information

Examples of published variation in the available energy content of cereal grain species for poultry and pigs are shown in Table 3. The differences between values in AME for poultry of 3–6 MJ/kg DM for wheat, barley, triticale and sorghum would have a large impact on productivity, whereas the reported differences of 1.5–2 MJ/kg DM for maize and oats was less, but could still have important implications for commercial production. A similar difference between values in DE was observed for wheat and barley fed to pigs, but the difference for triticale and sorghum was less in pigs than reported for poultry. The results obtained from the literature do not cover the same grains fed to pigs and poultry, nor is there a comparison with ruminants. The range in available energy content of grains reported would include differences between laboratories in experimental techniques, which may exaggerate the range of values obtained.

Table 3. Variation in published values for the available energy content of cereal grains for poultry and pigs[a].

Cereal grain	Poultry AME (MJ/kg DM)	Pigs DE (MJ/kg DM)
Wheat	10.3-15.9	13.3-17.0
Barley	10.4-13.5	11.7-16.0
Triticale	8.6-15.2	14.8-16.0
Sorghum	13.5-17.7	15.8-17.4
Maize	15.5-17.0	-
Oats	10.5-12.4	-

[a]Constructed from Hughes and Choct (1999) and van Barneveld (1999).

Results from PGLP

Variation within grains and animal types

The range and mean values for available energy content within grain species for each animal type obtained from PGLP experiments when values were statistically corrected for all known sources of variation are shown in Table 4. Values for pigs and broilers are given on both a dry matter and as fed basis. Ileal DE and ileal:faecal DE ratio values are shown also for pigs and broilers.

The results presented in Table 4 indicate that, even when values are corrected for known experimental errors, there is considerable variation of from approximately 1 to over 4 MJ/kg DM in available energy content of individual cereal grain samples within grain species and animal types. The variation in available energy content of grains appeared to be greater in pigs and poultry than in ruminants for all grains except oats. However, only 3 oat samples, including a naked oat, were offered to poultry and none to pigs.

Table 4. Range, mean (in parenthesis) and number (n) of samples for available energy content of grains for each animal type examined in PGLP. Results are statistically corrected for known sources of variation. Available energy

content of grains is expressed as ME for ruminants, AME for poultry and DE for pigs.

Measurement	Wheat	Barley	Oats	Triticale	Sorghum
Sheep at maintenance (MJ/kg DM)	12.8-13.7 (13.3) *n=25*	11.5-13.9 (12.9) *n=32*	11.2-15.7 (12.7) *n=18*	12.3-13.4 (13.0) *N=9*	13.6-14.3 (13.9) *n=7*
Cattle *ad libitum* (MJ/kg DM)	12.2-13.1 (12.7) *n=8*	12.2-13.2 (12.5) *n=7*	10.8-13.4 (12.3) *n=6*	12.9-13.2 (13.1) *N=2*	10.2-13.1 (11.1) *n=7*
Pig faecal DE (MJ/kg DM)	14.2-16.9 (15.0) *n=33*	11.9-16.1 (14.4) *n=38*	-	12.3-16.5 (14.9) *N=8*	15.5-16.6 (16.2) *n=18*
Pig faecal DE (MJ/kg as fed)	12.4-15.0 (13.7) *n=33*	10.6-14.7 (12.8) *n=38*	-	11.0-15.1 (13.3) *N=8*	13.8-15.1 (14.5) *n=18*
Pig ileal DE (MJ/kg DM)	10.1-15.7 (13.1) *n=33*	6.7-14.0 (11.3) *n=23*	-	9.0-14.7 (12.6) *N=7*	10.2-15.3 (14.0) *n=4*
Pig ileal:faecal ratio	0.71-0.91 (0.85) *n=33*	0.58-0.87 (0.78) *n=38*	-	0.64-0.89 (0.82) *N=8*	0.81-0.91 (0.88) *n=18*
Broiler AME (MJ/kg DM)	12.4-15.6 (14.1) *n=36*	11.2-13.7 (12.5) *n=38*	12.6-14.6 (13.5) *n=3*	11.0-14.6 (13.9) *N=14*	15.2-16.5 (15.7) *n=18*
Broiler AME (MJ/kg as fed)	11.2-14.0 (12.7) *n=36*	9.9-12.3 (11.2) *n=38*	11.3-12.8 (12.1) *n=3*	9.7-13.0 (12.4) *N=14*	13.3-14.9 (13.9) *n=18*
Broiler ileal DE (MJ/kg DM)	12.9-15.7 (14.0) *n=33*	9.4-13.8 (11.8) *n=28*	11.4-13.0 (12.4) *n=3*	12.2-14.2 (13.5) *N=8*	14.8-16.1 (15.3) *n=18*
Broiler Ileal DE:AME ratio	0.90-1.10 (0.99) *n=33*	0.75-1.01 (0.93) *n=28*	0.89-0.97 (0.92) *n=3*	0.94-1.10 (0.99) *N=8*	0.94-1.02 (0.97) *n=18*
Layer AME (MJ/kg DM)	13.1-17.1 (14.5) *n=39*	11.0-14.8 (13.5) *n=34*	12.7-16.4 (14.0) *n=3*	11.6-14.4 (13.6) *N=8*	15.5-16.3 (15.8) *n=6*

The variation in available energy content was less for sorghum than the other grains for pigs, poultry and sheep, but higher for cattle when waxy sorghum samples were included. The range in values for ileal DE was greater than the range in faecal DE for pigs and the ratio of ileal DE to faecal DE also varied widely between grain samples. Sorghum grain had a higher proportional digestibility in the small intestines of pigs than the other cereal grains and showed least variation in the ileal DE:faecal DE ratio. However, with broilers, wheat and triticale were on average almost completely digested in the small intestines. For barley and oat grains, an average of 7-8% of digestion appeared to occur in the large intestine of broilers. The least variation in proportion of digestion occurring in the small intestines of broilers was observed with sorghum.

Variation across individual grain samples and animal types

Thirty nine individual grain samples were fed within PGLP to ruminants (sheep and cattle), pigs, broilers and layers. Although not all these grains were fed to cattle because of the high cost of these experiments, a regression relating digestibility of the grain in sheep fed at maintenance to cattle fed *ad libitum* (Figure 2) was used to estimate digestibility and thus the ME content of grains for cattle. The cattle *ad libitum* calculated values were used in the comparison with pigs and poultry because they more closely represent the use of cereal grains in the livestock industries than for grains fed to sheep at maintenance. Sorghum was not included in the regression equation because of its poor digestion in cattle relative to sheep, but several samples of sorghum were fed *ad libitum* to cattle as indicated in Table 4.

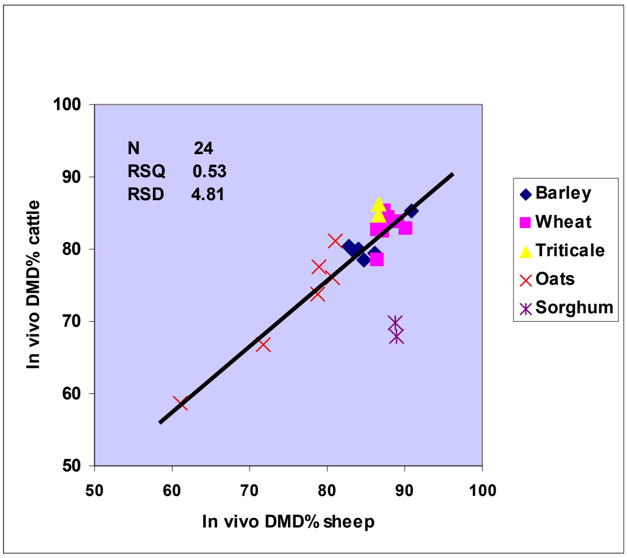
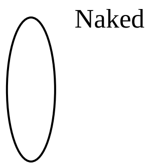
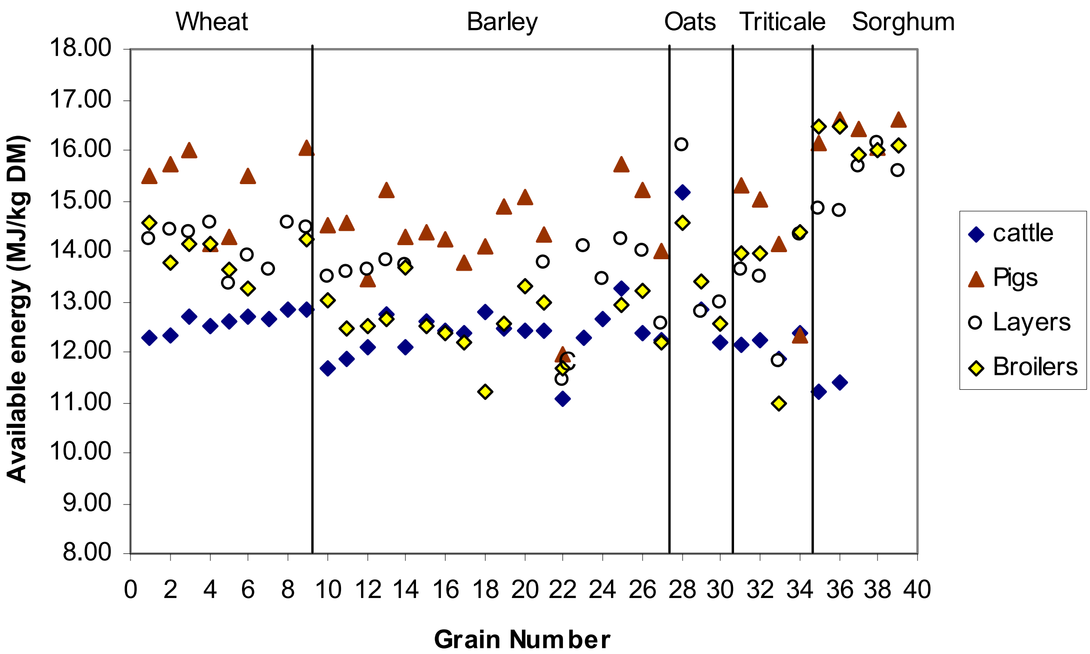


Figure 2. Relationship between dry matter digestibility (DMD%) for sheep at maintenance and steers *ad libitum* for 22 grains used in PGLP trials. The relationship, excluding sorghum: Cattle DMD = 3.375 + 0.911*Sheep DMD; R^2 = 0.90, RSD = 2.11

When the same grains were compared across animal types, there were large differences in available energy content across grain species, cultivars, individual grain samples and animal type (Figure 3). The main features to note in Figure 3, which compares the same grain samples across animal types, are:

- Grain species are digested with different efficiencies by the animal types. Barley tended to have the lowest available energy values for pigs and poultry, whereas sorghum had the highest values. However, sorghum had the lowest energy content of all grain species for cattle.
- For most wheat, barley and triticale samples, pigs tended to extract more energy from the grains than the other animal species, whereas cattle tended to extract the least.
- There was considerable variation in the available energy content within grain species for all animal types. The smallest within grain species variation was observed for cattle and the largest for broilers. However, the extent of the within grain variation depended on the grain species, with the variation being particularly small for pigs offered sorghum.





the 18 barley samples shown in Figure 3 when arranged in ascending order for cattle.

- The relative available energy content of grains for the different animal types was not constant between the grain samples. For example, wheat sample 1 had the lowest available energy content for cattle, the highest for broilers and a relatively high value for pigs and layers when all wheat samples were compared. In contrast, wheat sample 5 had intermediate energy content for cattle, but was low for pigs, broilers and layers. Wheat sample 6 was intermediate for cattle, high for pigs and low for poultry, whereas sample 9 had the highest values for both cattle and pigs and was also reasonably high for poultry. Similar variation between animal types can be seen within all grain species examined. The barley grains shown in Figure 3 have been rearranged in order of increasing energy content for cattle in Figure 4. Barley sample 1 in Figure 4 was relatively poorly digested by all animal types. The available energy content of sample 4 was low for cattle and pigs, and medium for broilers and layers, whereas sample 5 was low for cattle, high for poultry and medium for pigs. Sample 17 was high for cattle, low for pigs and very low for poultry, whereas sample 18 was high for cattle and pigs, low for broilers and medium for layers.

A waxy and a non-waxy isoline of sorghum bred by Bob Henzell at DPI&F Queensland along with a normal sorghum cultivar, Buster, were fed to all animal types. The results for AME for poultry and digestible energy for the other animal types are presented in Table 5.

Table 5. Available energy content of sorghum grains[a] (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
Individual sorghum samples					
Non-waxy isoline	15.1	10.1	16.2	16.5	14.8
Waxy isoline	14.7	13.7	16.6	16.5	14.8
Buster	14.5	10.5	15.5	16.3	16.3

[a]All grains were dry rolled prior to feeding to animals.

Table 6. Correlations between animal types in the available energy content (MJ/kg DM) of all grains fed to animals and for each grain species.

	Broilers	Layers	Pigs
All grains			
Layers	0.859	-	
Pigs	0.667	0.715	-
Cattle	0.393	0.706	0.533
Wheat			
Layers	0.762	-	
Pigs	0.188	0.404	-
Cattle	-0.284	-0.255	0.207
Barley			
Layers	0.766	-	
Pigs	0.562	0.873	-
Cattle	0.092	0.705	0.714
Oats			
Layers	0.889		
Pigs	-	-	
Cattle	0.997	0.967	
Triticale			
Layers	0.971	-	
Pigs	-0.091	-0.316	-
Cattle	0.919	0.954	-0.417
Sorghum			
Layers	-0.928	-	
Pigs	0.55	-0.285	-
Cattle	-0.771	0.810	-0.607

The energy content for cattle of non-waxy sorghum was only 61% of that for broiler chickens. The digestible energy content for cattle of a waxy-isoline was substantially greater than that of the normal isoline (13.7 MJ/kg DM compared with 10.1 MJ/kg DM), but was only 83% of the value for broiler chickens. This difference in energy content between waxy and non-waxy isolines of sorghum was not apparent for any other animal species examined. The available energy content of sorghum was higher than that for the other cereal grains for all animal types except cattle.

Correlations between animal types of the available energy content of grains are shown in Table 6 for all grains combined and for each grain species. The large number of low and negative correlations suggests that there are considerable differences between animal types in their capacity to digest individual grain samples, with some being relatively more digestible by ruminants, some by pigs and others by broilers or layers. Thus, many specific grain samples appear to have characteristics that make them more readily digestible by one animal type that another.

Variation in total available energy intake

Variation within grain species across animal types

Voluntary feed intake was measured with steers, broilers and layers during the periods digestibility of the grains was being measured. However, a separate set of experiments was conducted to measure voluntary feed intake with pigs soon after weaning. Details of the experiments are presented in the respective PGLP component Final Reports. There was no clear relationship between the available energy content of grains (MJ/kg) and voluntary intake (kg/d) for any of the four animal types (Figures 5-8). This lack of a strong relationship means that grains with high available energy content will not necessarily result in a high total intake of available energy or a high level of animal performance. The results suggest that different characteristics of the grains may affect digestibility from those that determine voluntary intake.

The mean and range of results obtained for diet intake and total available energy intake from each grain species fed to *ad libitum* to cattle, pigs, broilers and layers are presented in Table 7. In addition, the available energy intake index of each grain is included in the Table. The index was calculated by dividing total available energy intake for each grain sample offered across an animal type by the highest value and multiplying by 100. The intake index values therefore potentially ranged from 0-100+. The index was used because it provides an indication of the relative total energy availability between grains for each animal type and is likely to be more meaningful to people working within the animal industries.

The results presented in Table 7 show a considerable range in diet intake and in the intake of total available energy within each grain species for the different animal types. The range in grain DE intake was particularly high for young weaner pigs where values varied by greater than 2-fold for each grain species examined. The within grain range in total available energy intake was about 20-30% for broilers and from 30-60% for layers. The range in total available energy intake was least for cattle being only about 10% for all grains except oats, where the range was approximately 60%. The observed large range within a grain species in total energy available to each animal type confirms that different grain samples within a grain species should produce wide variations in animal performance.

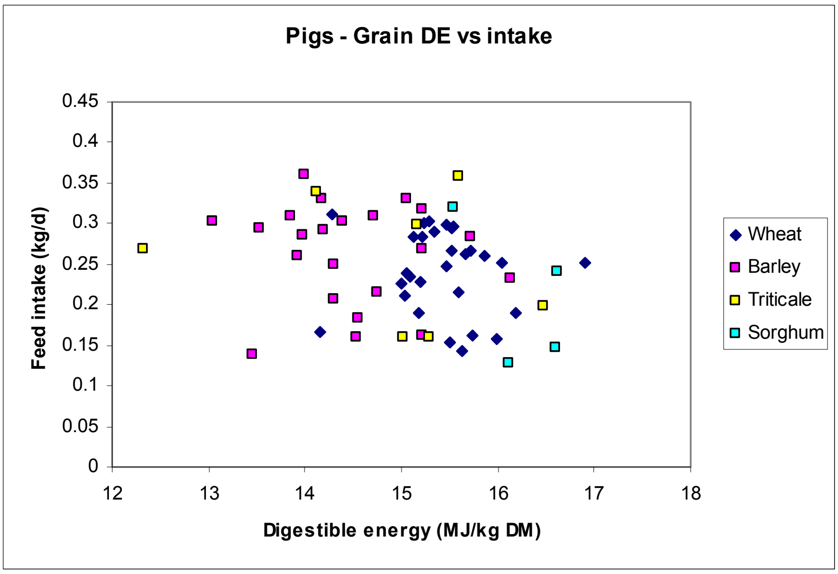


Figure 5. Relationship between the whole tract DE content of grains and voluntary intake of diets containing those grains for pigs.

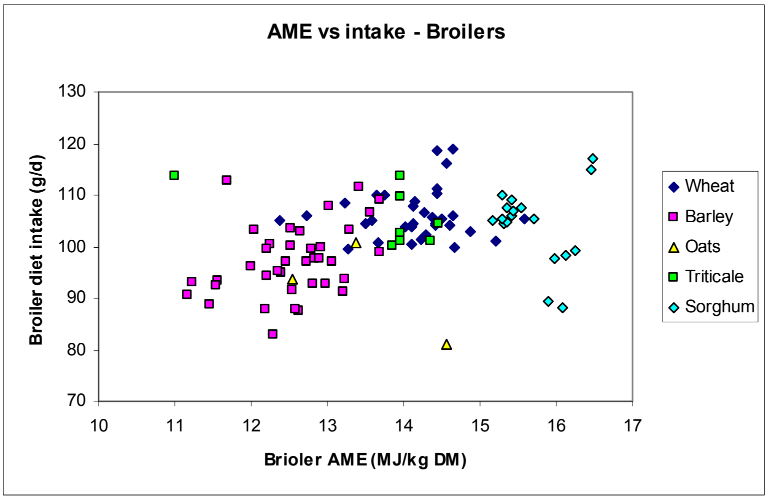


Figure 6. Relationship between the AME content of grains and voluntary intake of diets containing those grains for broilers.

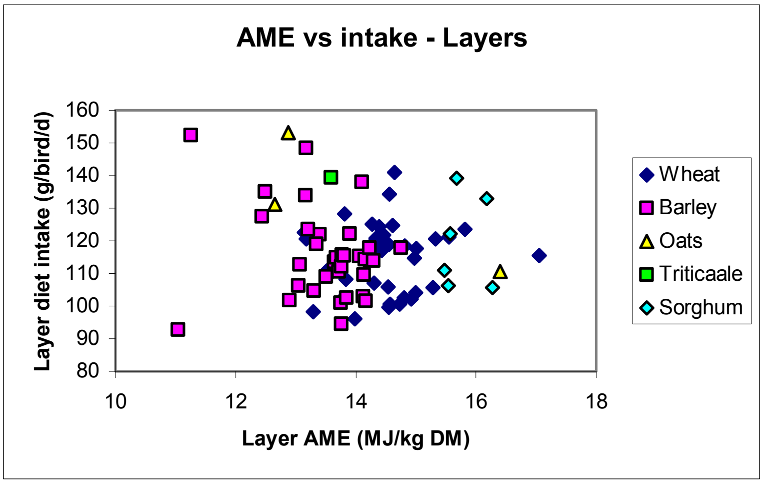


Figure 7. Relationship between the AME content of grains and voluntary intake of diets containing those grains for layers.

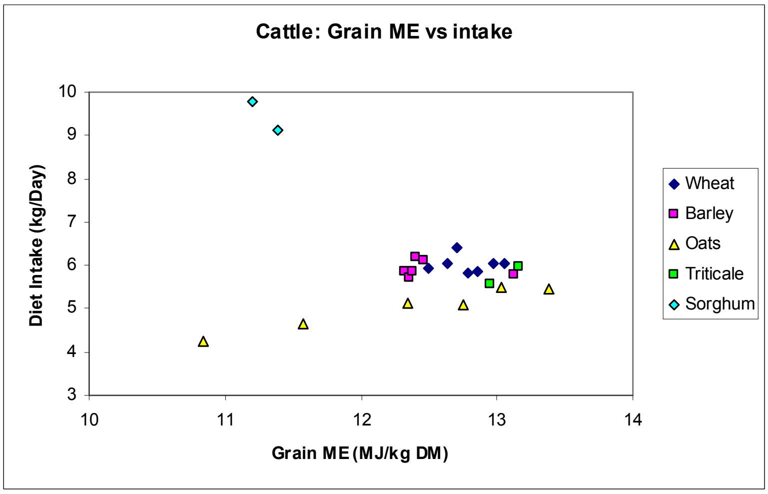


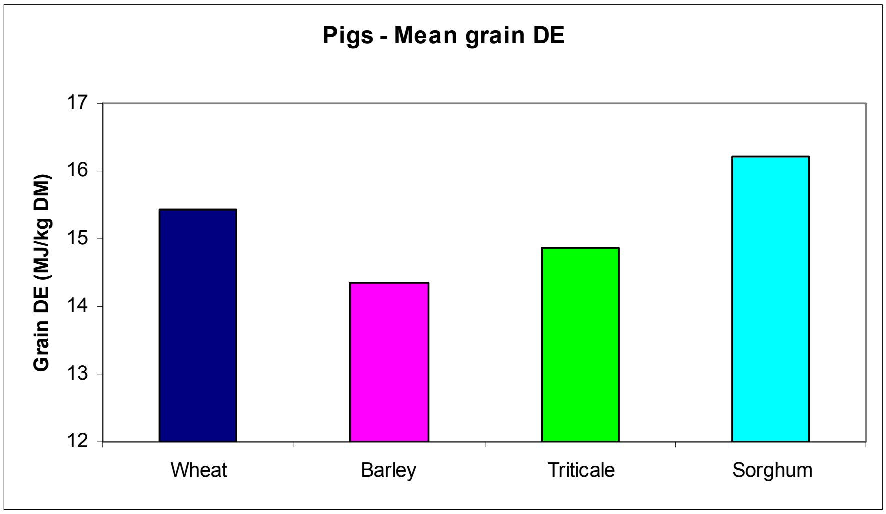
Figure 8. Relationship between the ME content of grains and voluntary intake of diets containing those grains for steers.

Table 7. Range, mean (in parenthesis) and number (n) of samples for diet intake, total available energy intake, and available energy intake index of grains for each animal type examined in PGLP.

Measurement	Wheat	Barley	Oats	Triticale	Sorghum
Cattle Diet intake (kg/d)	5.83-6.42 (6.03) *n=7*	5.73-6.18 (5.92) *n=6*	4.26-5.48 (5.01) *n=6*	5.56-5.98 (5.77) *n=2*	6.74-9.79 (8.19) *N=4*
Cattle Diet ME intake (MJ/d)	74.1-81.6 (76.6) *n=7*	71.4-75.6 (73.8) *n=6*	46.2-72.9 (61.7) *n=6*	72.0-78.7 (75.3) *n=2*	76.3-99.9 (88.8) *N=4*
Cattle ME intake index (0-100)	74.2-81.7 (75.8) *n=7*	71.5-75.7 (73.9) *n=6*	46.3-73.0 (62.1) *n=6*	72.1-78.8 (75.2) *n=2*	76.9-100 (89.0) *N=4*
Pig Diet intake (kg/d)	0.143- 0.312 (0.240) *n=29*	0.138- 0.412 (0.270) *n=23*		0.160- 0.359 (0.255) *n=7*	0.129- 0.320 (0.210) *N=4*
Pig Diet DE intake (MJ/d)	2.23-4.63 (3.72) *n=29*	1.86-4.98 (3.86) *n=23*		2.40-4.79 (3.76) *n=7*	2.08-4.77 (3.38) *N=4*
Pig Grain DE intake index (0-100)	39.9-82.7 (66.4) *n=29*	33.2-90.1 (69.0) *n=23*		43.0-100.0 (67.2) *n=7*	37.2-88.9 (60.4) *N=4*
Broiler Diet intake (g/d)	92.8-119.0 (105.5) *n=36*	82.9-112.7 (97.1) *n=38*	81.1-100.9 (91.9) *n=3*	98.3-113.8 (103.7) *N=14*	88.2-117.1 (104.3) *n=18*
Broiler Diet AME intake (MJ/d)	1.11-1.65 (1.47) *n=36*	1.03-1.49 (1.23) *n=38*	1.15-1.34 (1.23) *n=3*	1.32-1.56 (1.44) *N=14*	1.35-1.87 (1.57) *n=18*
Broiler Grain AME intake index (0-100)	60.2-79.9 (68.3) *n=36*	46.1-68.6 (56.4) *n=38*	53.8-61.9 (56.9) *n=3*	58.3-72.8 (66.3) *N=14*	64.9-88.4 (74.1) *n=18*
Layer Diet intake (g/d)	96.1-140.9 (114.5) *n=39*	92.7-152.4 (115.8) *n=34*	110.6- 153.1 (131.7) *n=3*	104.6- 153.5 (129.4) *n=8*	105.6- 139.2 (119.5) *N=6*
Layer Diet AME intake (MJ/d)	1.16-1.81 (1.46) *n=39*	0.94-1.74 (1.37) *n=34*	1.49-1.75 (1.66) *n=3*	1.25-1.76 (1.56) *n=8*	1.43-1.89 (1.64) *N=6*
Layer Grain AME intake index (0-100)	59.8-94.6 (76.0) *n=39*	46.9-89.6 (71.6) *n=34*	76.1-90.4 (83.2) *n=3*	64.4-92.0 (80.4) *n=8*	75.8-100 (86.5) *N=6*

Although the number of samples offered *ad libitum* to each type of animal varied between grain species and the range in values was large, the means presented in Figures 9-12 provide a guide to the relative digestibility and total available energy intake from the grain species examined for each animal type. The Figures show the mean values for available energy content, diet intake and total available energy intake for each grain species for pigs, broilers, layers and cattle, respectively.

a



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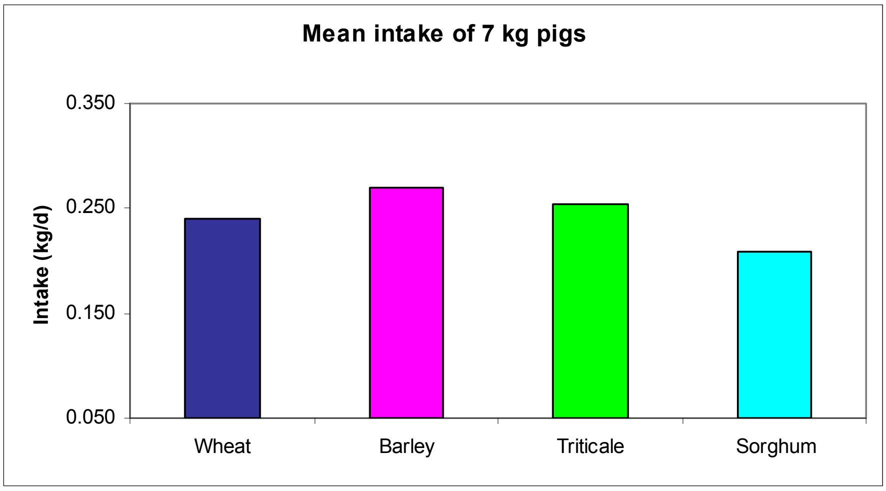

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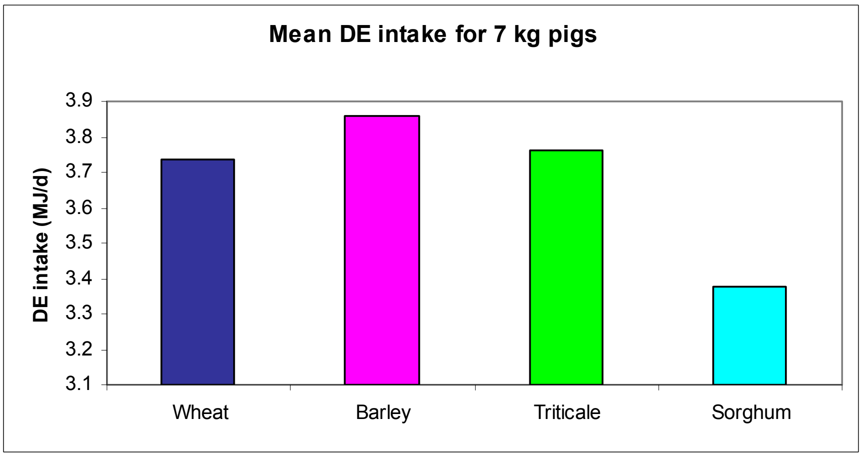
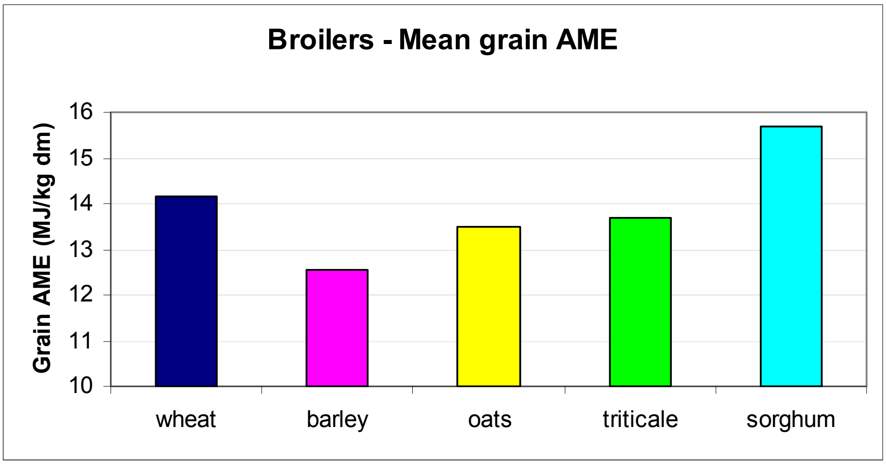


Figure 9. Mean values for grain DE content (MJ/kg), diet intake and total DE intake for diets containing wheat, barley, triticale or sorghum when offered to pigs.

a



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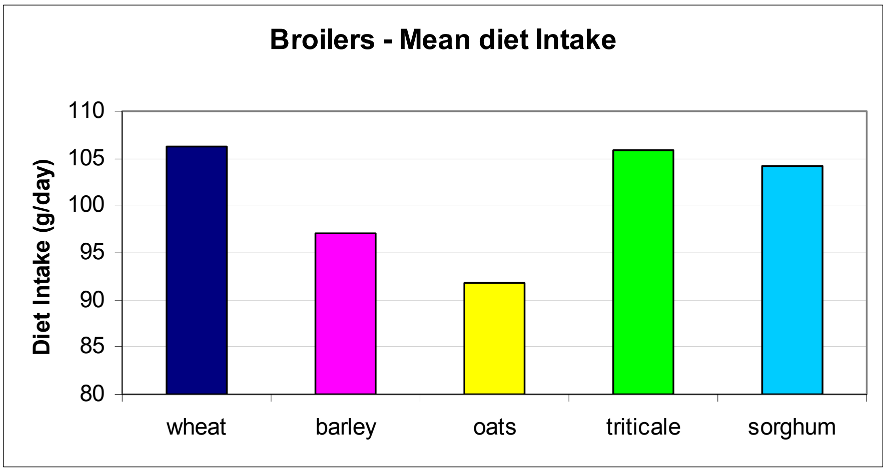

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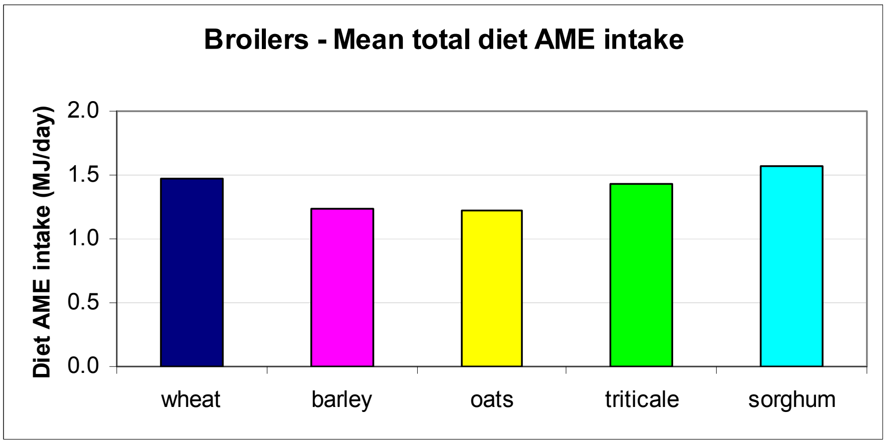

Figure 10. Mean values for grain AME content (MJ/kg), diet intake and total AME intake for diets containing wheat, barley, triticale or sorghum when offered to broilers.

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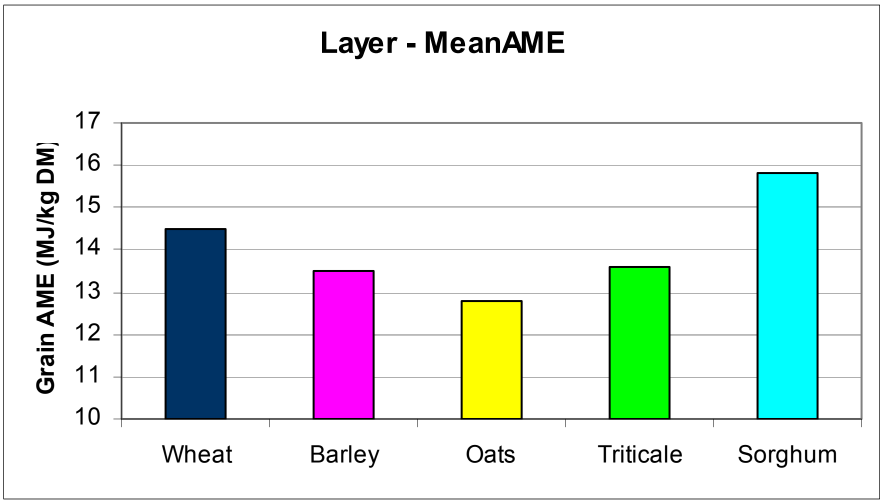

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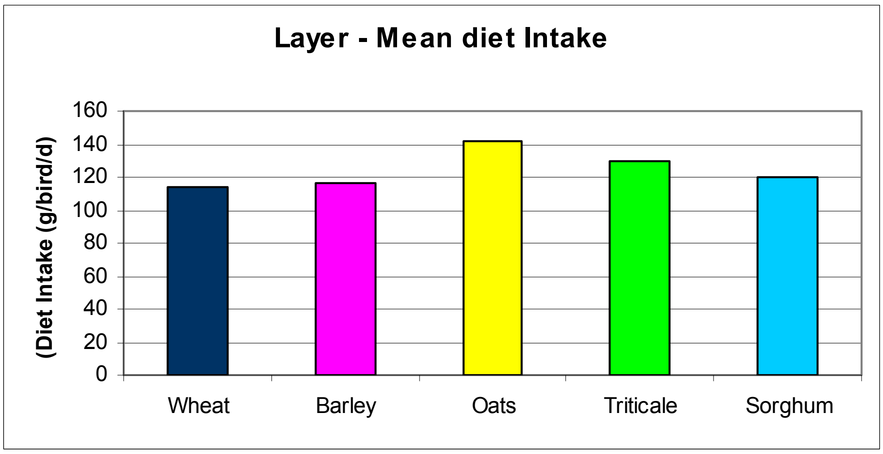

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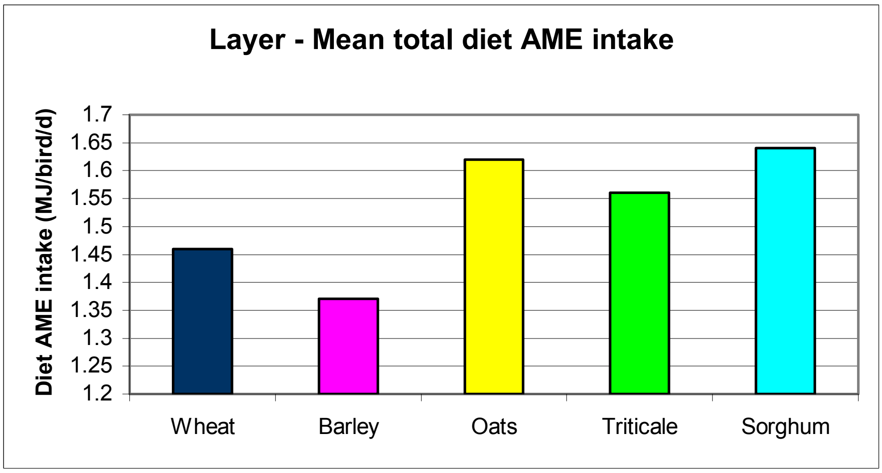

Figure 11. Mean values for grain AME content (MJ/kg), diet intake and total AME intake for diets containing wheat, barley, triticale or sorghum when offered to layers.

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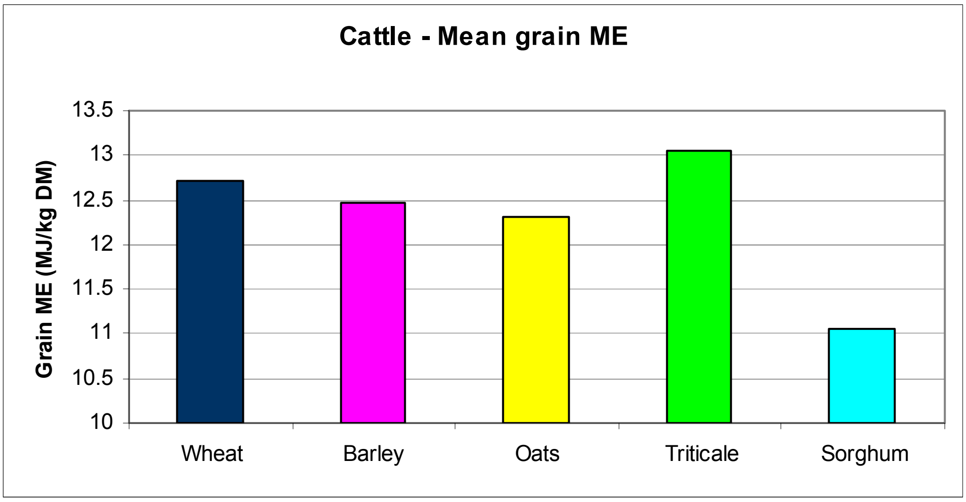

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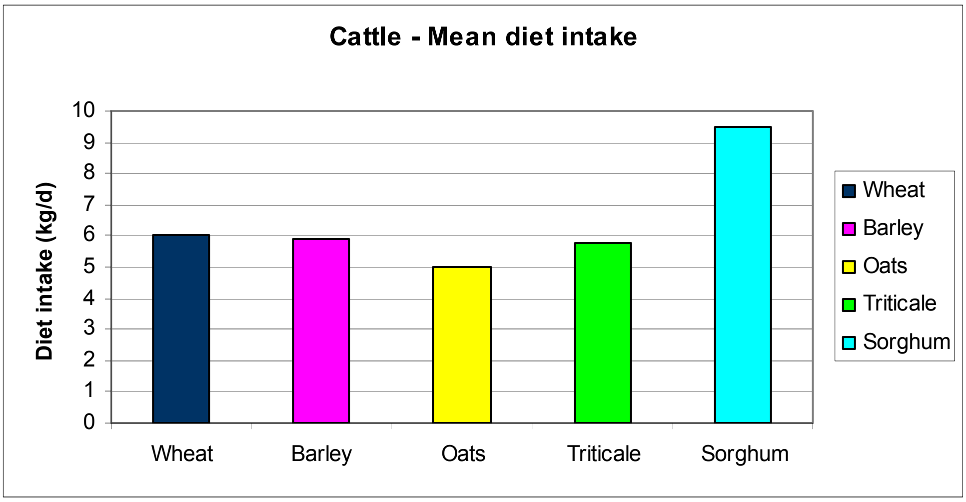

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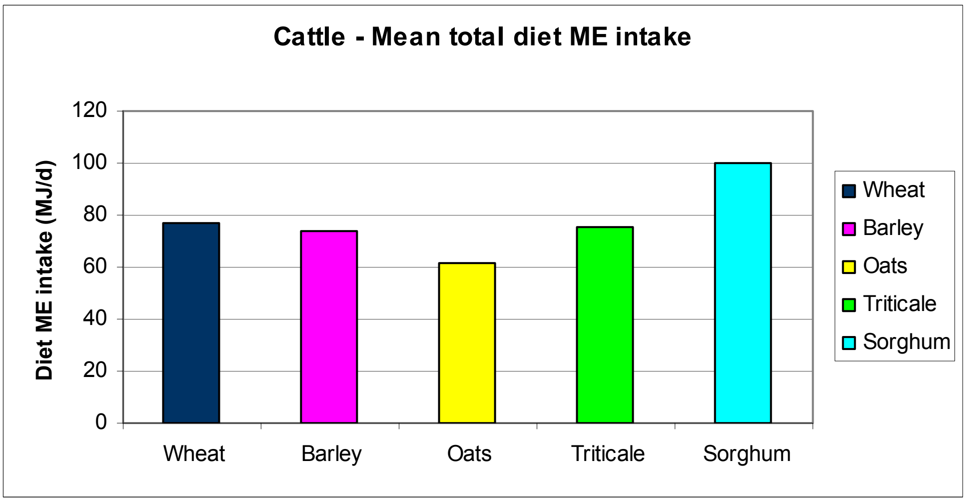


Figure 12. Mean values for grain ME content (MJ/kg), diet intake and total ME intake for diets containing wheat, barley, triticale or sorghum when offered to steers.

Figure 9 suggests that although sorghum has the highest DE content for pigs, intake of diets with sorghum was the lowest for all grains which resulted in total DE intake also being the lowest for sorghum compared with the other cereal grains examined. Alternatively, barley had the lowest DE content, but the highest diet intake and total DE intake. These results may suggest on average that the highest rate of growth may occur when pigs are fed barley and the lowest when they are fed sorghum. However, the low DE content of the barley could indicate that feed conversion efficiency (FCE) would be lower for barley than for some of the other grains. FCE depends on both actual feed used for growth relative to the amount needed for maintenance and on the DE content of the diet. Unfortunately, growth and feed efficiency experiments were not conducted with pigs within PGLP to test these suggestions.

Figures 10 and 11 suggest that sorghum has on average the highest AME content of all grains examined for both broilers and layers. Small differences in feed intake resulted in relatively little difference in total AME intake when broilers were offered sorghum, wheat or triticale. The mean intake of both barley and oats by broilers was substantially less than for the other grains, which resulted in these two grains providing less total AME intake than sorghum, wheat or triticale. With layers, sorghum provided the greatest total intake of available energy, followed by oats and triticale. Mean values for wheat and barley were inferior to the other grains for layers. There were considerable differences between layers and broilers in the relative mean intake of oat grains. Diets containing oat grain resulted in the highest intake for layers and the lowest for broilers when compared with the other cereal grains.

Figure 12 shows that the mean ME content for cattle from the grains offered was highest for triticale and reduced progressively by approximately 0.75 MJ/kg DM for wheat, barley and oats. As noted earlier, the ME content of sorghum for cattle was approximately 3 MJ/kg DM less than for the other grain species. Nevertheless, cattle consumed over 40% more of diets containing sorghum than the other grains when offered *ad libitum*. Consequently, cattle offered sorghum based diets consumed the greatest amount of total available energy than for diets containing the other grains. Mean total energy consumption was similar for wheat, triticale and barley and slightly lower for oats. These results suggest that cattle offered sorghum based diets may grow faster than for those offered other grains, but feed conversion efficiency would be considerably lower.

Although Figures 9-12 provide a comparison of the relative value of cereal grain species for productivity in different types of animals, the variation between individual grain samples within a grain species may often be more important than differences between grain species. Nevertheless, experiments measuring animal performance and efficiency of feed use are required to evaluate fully to suggestions made from the comparison of the mean results presented here. The impact of different grains on performance of animals is discussed in detail in section “Differences between grain and animal types in energy utilisation”.

Variation across individual grain samples and animal types

Total available energy intake index values for individual grains fed *ad libitum* to pigs, broilers, layers and cattle are shown in Figure 13. The index values were calculated within an animal type and are not directly comparable across animal types. However, the relativity of within grain values for the different animal types when compared across grains provides evidence that some grains are better at supplying available energy to one animal type than to others and vice versa. This difference in the suitability of individual grains for specific animal types is further confirmed when the index values are correlated across animal types (Table 8). There were not sufficient grains fed to all animal types to develop a full correlation matrix as shown by the missing values in Table 8. However, the large number of low and negative correlations, even between broilers and layers, suggest that the specific grain characteristics which determine intake of available energy differ for each of the animal types examined. Thus, individual grain samples can be chosen to provide greater rates of production for one animal type compared with another.

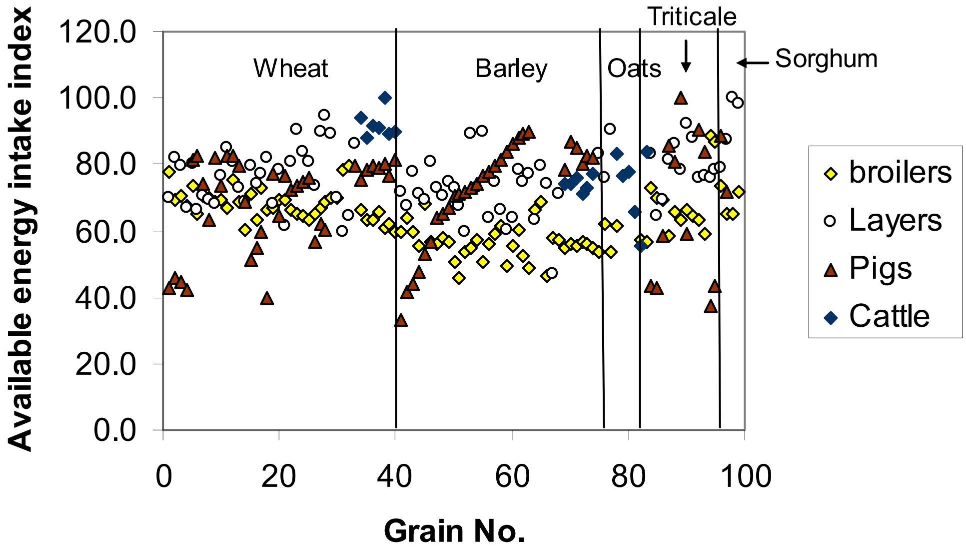


Figure 13. Total available energy intake index (0-100) of individual grain samples fed to animals *ad libitum.* Values are based on DE intake for pigs, AME intake for poultry and ME intake for cattle.

Table 8. Correlations between animal types in the available energy intake index (0-100) for all grains fed to animals and for each grain species.

	Broilers	Layers	Pigs
All grains			
Layers	0.024	-	
Pigs	-0.0374	0.012	-
Cattle	0.359	ID[a]	-0.023
Wheat			
Layers	-0.270	-	
Pigs	-0.148	-0.035	-
Cattle	-0.033	ID	0.116
Barley			
Layers	-0.076	-	
Pigs	-0.466	-0.018	-
Cattle	-0.706	ID	0.302
Triticale			
Layers	-0.332	-	
Pigs	-0.832	0.290	-
Cattle	ID	ID	ID
Sorghum			
Layers	-0.747	-	
Pigs	ID	ID	-
Cattle	ID	ID	ID

[a]Insufficient data

Variation in oat grains for ruminants

Large variation has been observed in the digestibility of oat grains when fed to sheep and cattle. The whole tract digestibility in sheep fed at maintenance for four cultivars of oats grown at the same location is shown in Table 9. Digestibility of the grain varied from 62.4 to 76.2 % and was associated closely with the lignin content of the grain.

Table 9. Digestibility of dry matter in the whole tract of sheep offered different cultivars of oat grain grown at the same site. The sheep were fed at maintenance.

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

Over 600 samples of oat grains from a wide variety of cultivars grown over several locations and years have been collected and analysed. Details of the experiments involved are described in the Final Report of Component 4. The 48 hr *in sacco* dry matter digestibility of whole grain samples ranged from 3.1 to 85.9 %. The lignin content of the hulls of 166 samples measured to date ranged from 1.1 to 21.7 %. There were significant genotype, environment and GxE interactions for both traits.

The relationship between statistically adjusted means for hull lignin content and *in sacco* whole grain DM digestibility is shown in Figure 14. Those oat grain cultiuvars with hulls containing more that about 5% lignin had relatively poor *in sacco* digestibility, whereas those cultivars with hull lignin content less than 5% could have either high or low digestibility.

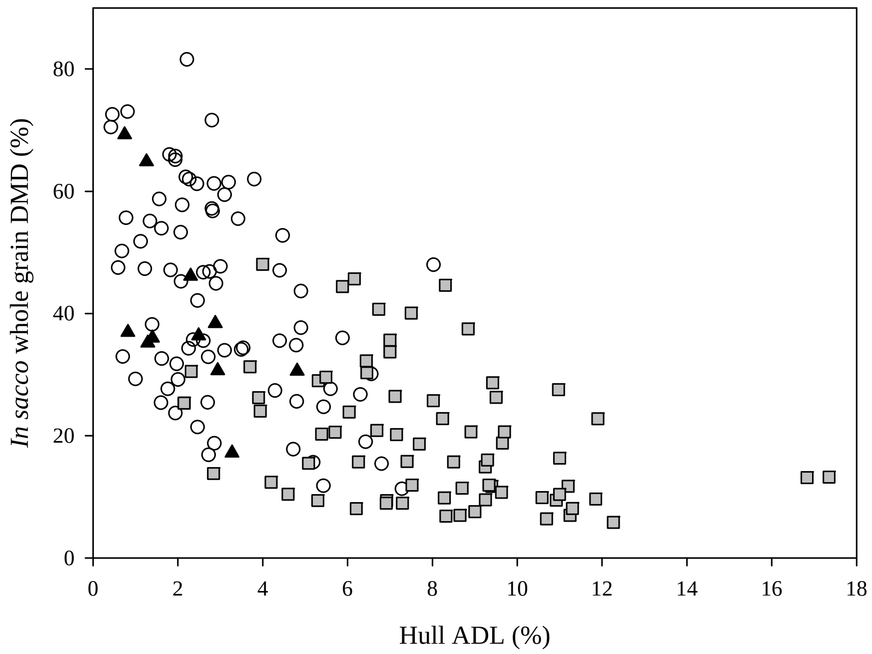


Figure 14. Relationship between *in sacco* whole grain DMD and hull lignin content in oats. Source breeding programs: ○ NSW, ▲ Tasmania and □ other (South Australia, Western Australia & North America). Data presented are adjusted G × E values from the REML analysis.

The *in sacco* digestibility, *in vivo* digestibility in cattle and cattle growth rate were determined using eight oat grain samples varying widely in lignin content as determined by the phloroglucinol colour score (high values represent high lignin content). Results presented in Table 10 show that there was an extremely wide variation between the samples in digestibility and in performance of the animals consuming the different oat grain samples. Those oat samples containing high lignin contents had lower digestibility and resulted in slower growth rates than oat grains with low lignin contents. However, there was little relationship between lignin content of the hull and digestibility of the oat grains for those grains containing less than 3 % hull lignin. In addition, the relationship between *in sacco* and *in vivo* digestibility was relatively poor (R^2 = 0.45). There was a stronger relationship between *in sacco* digestibility and growth rate (R^2 = 0.60).

Table 10. Lignin score, lignin content and digestibility and growth rate of cattle fed selected samples of oat grains.

Oat sample	Lignin score	Lignin (%)	Whole grain *in sacco* dry matter digestibility (%)	Dry matter digestibility in cattle (%)	Live weight gain of cattle (kg/day)
Echidna	5	10.7	6	60	0.41
Mortlock	4	9.25	14	67	0.88
Quoll	3	2.84	14	78	0.95
Eurabbie	2	1.22	47	73	1.00
MA 5237	2	1.11	37	82	1.10
Cooba (low)	1	1.30	24	75	1.03
Yiddah	1	2.15	38	78	1.27
Cooba (high)	1	1.34	55	80	1.27

Effects of weather damage on the available energy content of cereal grains

Frosted grains

Three frosted grains (Arapilies barley, Tahara triticale and Janz wheat) were fed to broilers, layers, pigs and sheep and a second wheat sample (Ouyen) fed also to sheep (Table 11). Frost reduced the available energy in all grain samples compared with the mean values from other samples of the same cultivars. However, there were substantial differences between the grains and animals in the magnitude of the effect. The broiler AME value was reduced in the frosted grain by only 0.1 MJ/kg DM for Janz wheat compared with 3.1 MJ/kg for Tahara triticale and 0.8 MJ/kg for Arapilies barley. The same order of differences was found between frosted and unfrosted grain for layers. However, with pigs and sheep, the greatest effect of frost damage was for Arapilies barley, followed by Tahara triticale and Janz wheat. The effect of frosting on digestibility of dry matter is sheep fed the sample of Ouyen wheat was small.

Frost appears to have an inconsistent effect on the total available energy intake index for pigs and poultry (Table 12). For the frosted Tahara triticale sample, which showed a consistent reduction in available energy content following digestion, total energy intake was also reduced. However, frost appeared to have little effect either the available energy content or energy intake of broilers for Arapilies barley, but had a larger impact on the intake of Janz wheat by layers. Alternatively, frost appeared to increase the total intake of available energy for broilers and pigs fed the sample of Janz wheat. The comparisons of the effects of frost exposed grain on both available energy content and total energy intake illustrate again that the effects across grain samples and animal types are not consistent.

Table 11. Effect of frost damage on the available energy content of cereal grains and chemical composition.

Grain	Broiler		Layer	Pig DE (MJ/kg DM)			Sheep DMD (%)	Crude protein (%)	Starch (%)	Amylose (% starch)	NDF (%)	Lignin (%)	Starch Ferment (%)	Enzyme Digest (%)
	AME (MJ/kg DM)	Viscosity (mPa.s)	AME (MJ/kg DM)	Ileal	Faecal	Ileal/ Faecal								
Barley Arapilies														
Unfrosted: 3801	12.5	39.6	12.8	11.6	14.5	0.80	85.9	8.2	56.1	34.7	16.6	1.1	45.2	39.3
Frosted: 3828	11.7	6.4	11.3	6.7	11.9	0.58	73.6	12.2	44.9	29.6	29.6	1.6	52.0	39.0
Triticale Tahara														
Unfrosted: 6704, 6806, 6901	14.1	37.9	14.0	11.0	14.1	0.79	84.4	11.5	58.7	32.5	13.4	0.9	42.3	57.0
Frosted: 6805	11.0	6.9	11.6	9.2	13.5	0.86	76.9	14.4	30.0	27.6	30.2	2.3	51.2	66.3
Wheat Janz														
Unfrosted: 1801, 1902, 1914	13.9	15.2	14.2	12.4	14.5	0.86	88.5	14.2	58.4	35.0	12.5	0.8	37.3	44.4
Frosted: 1809	13.8	13.7	13.7	11.1	14.1	0.79	84.5	16.4	47.1	33.3	21.4	1.4	47.3	44.2
Wheat Ouyen														
Unfrosted: 1804							85.6	9.4	63.4	37.7	11.5	0.6	40.3	40.9
Frosted: 1811							85.2	14.7	41.1	23.5	23.3	1.8	43.5	56.1

Frosting had a major effect on the chemical composition of the grains and the digestion characteristics of starch (Table 11). The starch content of the frosted grains was reduced substantially by approximately 10-30 % units and the contents of protein and fibrous compounds increased compared with unfrosted samples of the cultivars. Although the amount of starch in the frosted grain was reduced, the proportion of amylose in the starch was decreased substantially in all samples except the Janz wheat. This reduction in amylose in the frosted grains is consistent with the knowledge that amylopectins are deposited earlier than amylose during grain development.

The *in vitro* fermentation and enzyme digestion of the starch in frosted grain was increased compared with unfrosted grains, but the results were not consistent across the two wheat cultivars. With Janz wheat, the fermentation of starch was increased with frosting, whereas there was little difference in enzyme digestion. With the Ouyen cultivar, the effects of frosting on the respective *in vitro* assays was opposite with frosting increasing enzyme digestion more than fermentation of starch.

In addition, the viscosity of digesta in broiler chickens was reduced by approximately 6-fold in the frosted barley and triticale samples, but was changed little in the frosted Janz sample compared with unfrosted material. Although there is evidence that the viscosity of digesta in poultry can be reduced by the addition of fibre, the results presented may also indicate that viscosity of digesta is increased in grains with high amylose content. The increase in NDF was similar for each of the frosted grain samples fed to broilers, but digesta viscosity was reduced only in those grains where the proportion of amylose in the starch declined.

Table 12. Effect of frost damage on the total available energy intake index of cereal grains fed to broilers, layers and pigs.

Grain	Total available energy intake index (0-100)		
	Broilers	**Layers**	**Pigs**
Barley Arapilies			
Unfrosted: 3801	59.6	-	-
Frosted: 3828	60.2	-	-
Triticale Tahara			
Unfrosted: 6704, 6806, 6901	68.3	87.1	61.1
Frosted: 6805	58.3	81.4	58.6
Wheat Janz			
Unfrosted: 1801, 1902, 1914	64.7	84.5	67.6
Frosted: 1809	68.8	72.7	79.6

The method described above comparing frosted grain samples with non-frosted samples from the same cultivar is not truly scientifically sound because of the likely influence of unknown environmental factors on the quality of the non-frosted grains. Nevertheless, it was the only approach that could be adopted using PGLP results to provide some indication of the effects of frosting on the energy value of grains for animals. The impact of frost on grain quality is likely to be affected by the maturity stage of the grain when frosted and by the severity of the frost. Ideally, frost chambers should be used to control both the time of grain maturity and severity of the frost to produce a range of samples that could be used in animal experiments. A substantial amount of grain would need to be produced because the analyses conducted above indicate that the response obtained by each animal type is likely to vary.

High screenings grains

The effects of a high percentage of screenings on the availability of energy and chemical characteristics of cereal grains have been investigated using two methods. The first method involved establishing regression relationships between the percentage of screenings in a grain sample and either animal or laboratory measurements for different grain species. The second method involved screening single samples of a grain and comparing the effects of feeding to animals the grains that passed over a 2.2 mm screen with small grains that passed through a 2.2 mm screen.

Regression approach

For grains used in the regression analyses and fed to ruminants, the highest amount of grain passing through a 2.2 mm screen was 12 % for triticale, 21.3 % for wheat and 62.6 % for barley. The proportion of screenings was related to the chemical composition of the grains with a decrease in the amount of starch and an increase in the amount of protein and fibre as the percentage of screenings increased (Figure 15). An increase in the proportion of screenings also decreased the rate of dry matter disappearance within the rumen over a 6 hr period *in sacco* (Figure 16).

Despite these changes in the chemical composition and rate of dry matter disappearance in the rumen, there was only a minor association between screenings percentage and dry matter digestibility of the grains in sheep and cattle. When wheat and triticale were considered together, dry matter digestibility of the grains for sheep fed at maintenance fell by only 0.62% percentage units for every 10% increase in screenings less than 2.2 mm (Figure 17). Thus, for a wheat sample with 20% screenings, dry matter digestibility was predicted to fall by only 1.24% units or approximately 0.2 MJ/kg ME compared with grain containing no screenings. The negative effect of a 10% increase in screenings for wheat or triticale fed to cattle *ad libitum* was predicted to be 0.33 % which was approximately half the effect seen in sheep fed at maintenance. The effect on the energy value of wheat with 20% screenings was estimated to be only 0.1 MJ/kg ME for cattle fed *ad libitum* compared with a sample without small grains. Although there was a small effect of increasing screenings on the dry matter digestibility of wheat and triticale by sheep and cattle, there was no effect of increasing the screenings content of barley on dry matter digestibility in either animal species.

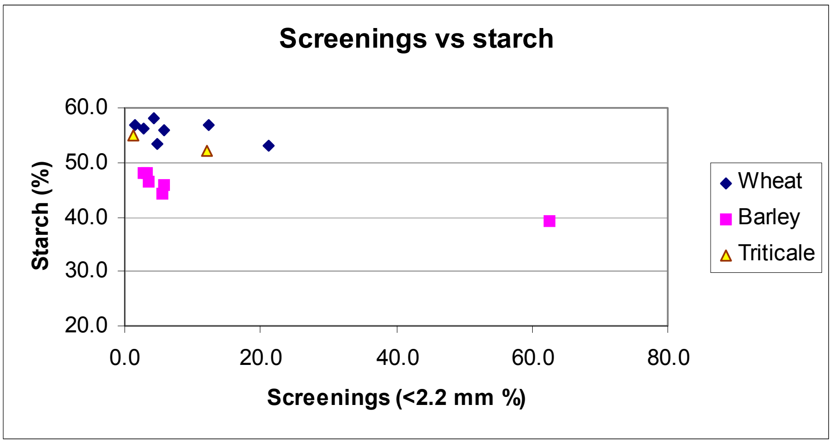
Despite the small decline in dry matter digestibility for sheep and cattle as the proportion of screenings in wheat, triticale and barley increased, there was no effect of increasing screenings on total ME intake for cattle consuming these grains (Figure 18).

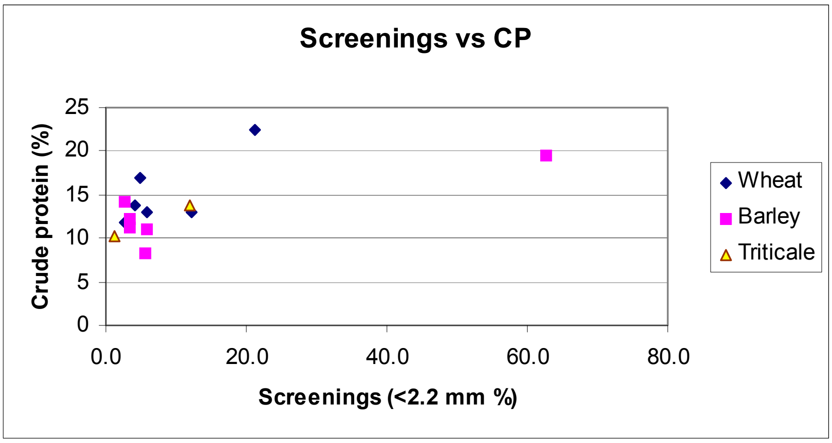
The regression approach has not yet been undertaken for investigating the effects of increasing screenings on the availability of energy for pigs or poultry. The proportion of screenings with grains less than 2.2 mm is currently being measured for all grains fed to pigs and poultry and the regression analyses will be conducted when the results are available.

Screening a normal sample into large and small grains

A small number of comparisons have been made with grains screened into large and small sizes. The comparisons have been with grains not passing through a 2.2 mm screen and small grains passing through a 2.2 mm screen obtained from the same initial grain sample. These comparisons were made with sheep, pigs, broilers and layers.

Samples of Chara wheat (1828) and of Schooner barley (3830) collected in 2002 were screened and either the greater than or less than 2.2 mm screenings fed to sheep at maintenance. With the Chara wheat, dry matter digestibility was 87.5% for the large grain sample and 86.7% for the grains passing the 2.2 mm screen. The observed drop of only 0.8% units was considerable less than the 6.2 % predicted from the regression equation established from the relationship in Figure 17. Dry matter digestibility values for the Schooner barley were 85.6 % for larger grains and 83.5 % for 100 % screenings. This difference between the large and screened barley grain samples was greater than predicted using the regression approach. Considering both approaches for estimating the effects of high screenings on the energy value of cereal grains for sheep and cattle, the analyses suggest that screenings reduce dry matter digestibility by no more than 0.2 % units for each 10% increase in screenings.





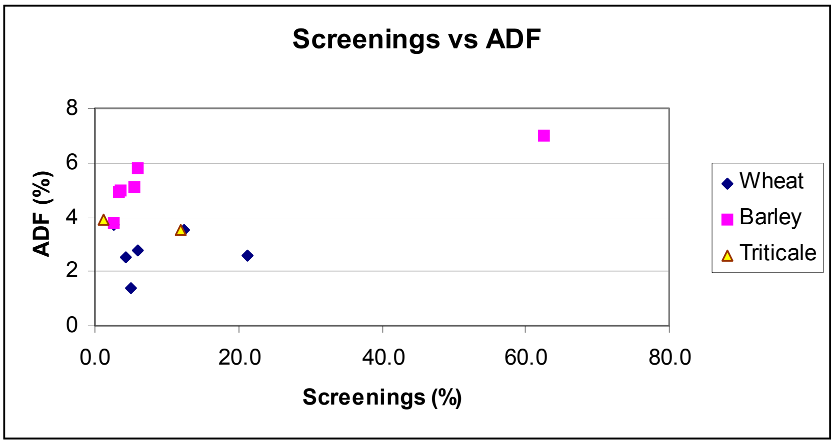


Figure 15. Relationships between chemical composition and the percentage screenings in grain samples.

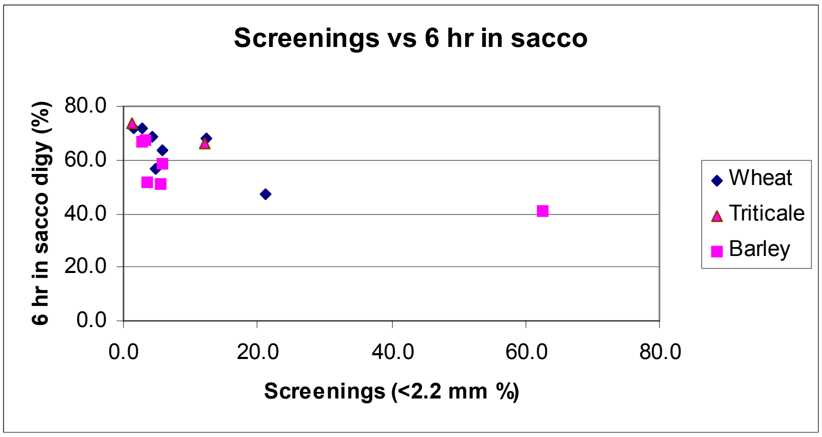


Figure 16. Relationships between 6 hour *in sacco* disappearance of dry matter and the percentage screenings in grain samples.

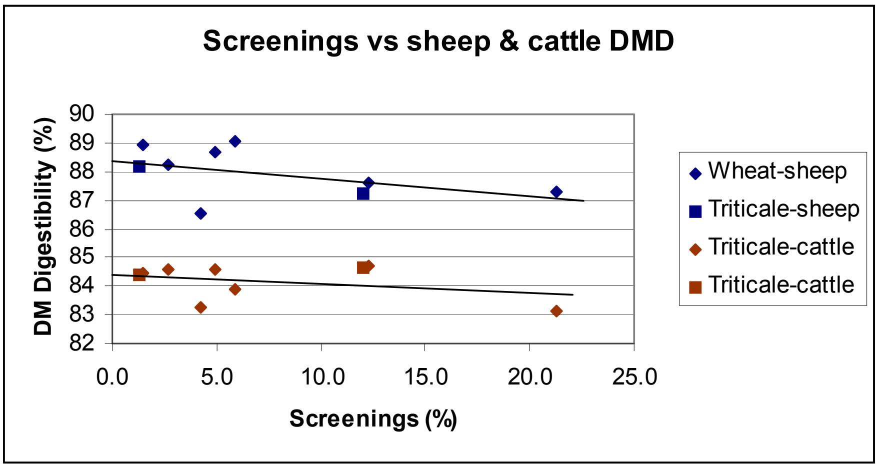


Figure 17. Relationship between dry matter digestibility (DMD) of wheat and triticale grains in sheep fed at maintenance and cattle fed *ad libitum* and percentage of grains passing a 2.2 mm screen (S).
Sheep DMD = 88.4 – 0.062*S: Cattle DMD = 84.4 – 0.033*S

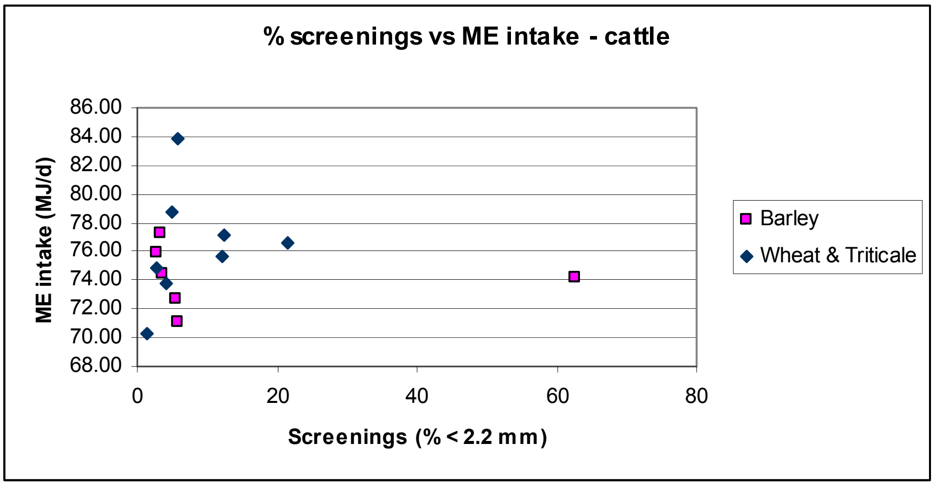


Figure 18. Relationship between total ME intake (MJ/d) for cattle and screenings content of wheat, triticale and barley.

The most comprehensive study of the effect of grain size was conducted with laying hens where large and small grains were obtained from five samples of wheat and four samples of barley. Although there was variation between grain samples, large grains were on average 65% heavier than grains passing the 2.2 mm screen for wheat and 20% heavier for barley (Figure 19). Despite the differences in grain weight, the effect of grain size on available energy content of the grains was variable (Figure 20). One wheat sample (1826) and one barley sample (3756) showed a significantly higher AME content for the larger grains. However, two of the five wheat samples and one of the four barley samples showed a higher (not significant P = 0.05) AME content for the small grain than for the large grain from the same sample. The average AME content of the small grains was 14.2 (MJ/kg DM) compared with 14.5 (MJ/kg DM) for the large grains in the wheat comparisons, and 13.2 (MJ/kg DM) compared with 14.0 (MJ/kg DM) in the barley comparisons.

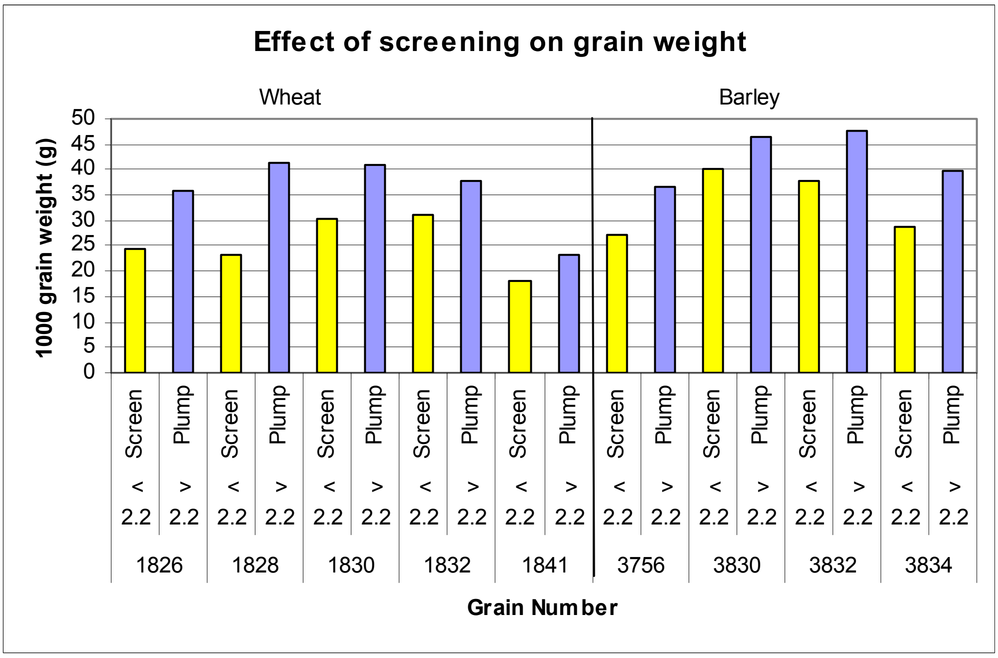


Table 19. The 1000 grain weight of grains from a common sample either passing through a 2.2 mm screen (screen) or not passing through the screen (plump) for wheat and barley samples fed to laying hens.

The small differences observed in AME content of wheat grains of different size were not reflected in total AME intake, where no significant differences were observed (Figure 21). Three of the five wheat samples showed higher AME intake for layers consuming the small grain than the large grain fraction. The mean AME intake was 1.38 (MJ/d) for the small grains compared with 1.35 (MJ/d) for the large grains across the five wheat samples. Small grains for barley sample 3756 resulted in a significantly lower AME intake than the large grains from the same sample (Figure 21). Although for the other three barley samples, AME intake was also less for the small than for the large grains, these differences were not significant. The mean AME intake across the four barley samples was 1.25 (MJ/d) for the small grains and 1.39 (MJ/d) for the large grains.

When all the wheat and barley samples used in the experiment were considered together, grain weight explained little of the variation in either AME content of the grain (R^2 = 0.07) or in AME intake (R^2 = 0.02) for laying hens (Figure 22). These results indicate that characteristics of grains other than size and weight are important for determining their energy value of the screened grains for laying hens.

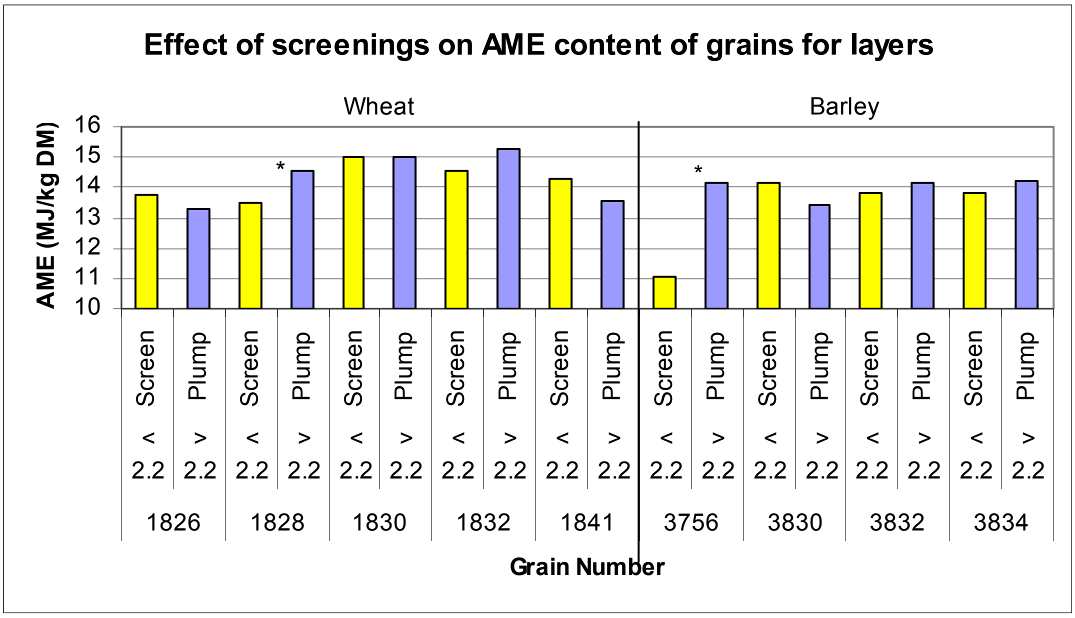


Figure 20. The AME content for layers of grains, from the same original sample, either passing through a 2.2 mm screen (screen, yellow) or not passing through the screen (plump, blue). * indicates significant differences (P<0.05) between the screen and plump grains from the same original sample.

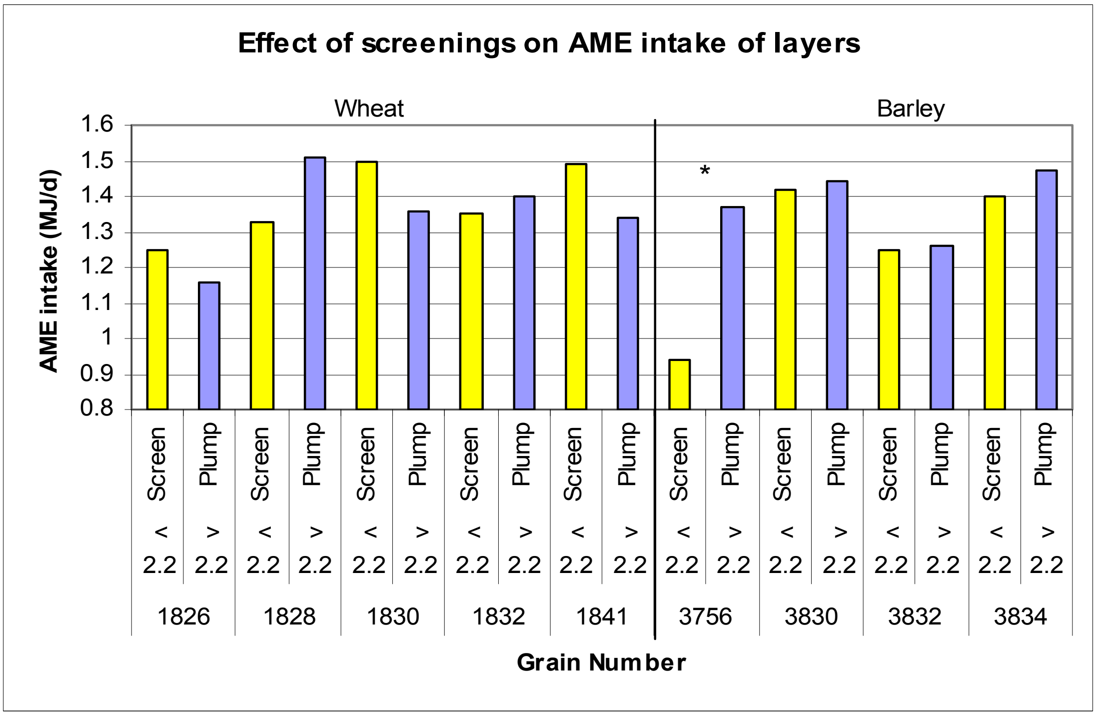
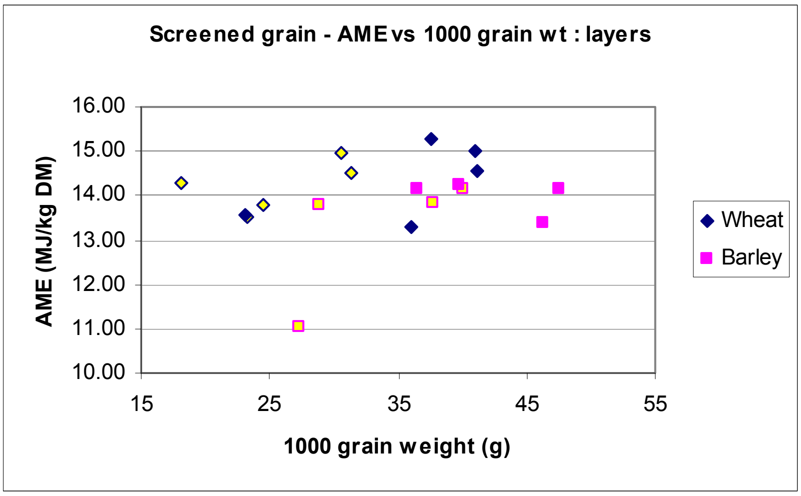


Figure 21. The AME intake for layers of grains, from the same original sample, either passing through a 2.2 mm screen (screen, yellow) or not passing through the screen (plump, blue). * indicates significant differences (P<0.05) between the screen and plump grains from the same original sample.

(a)



(b)

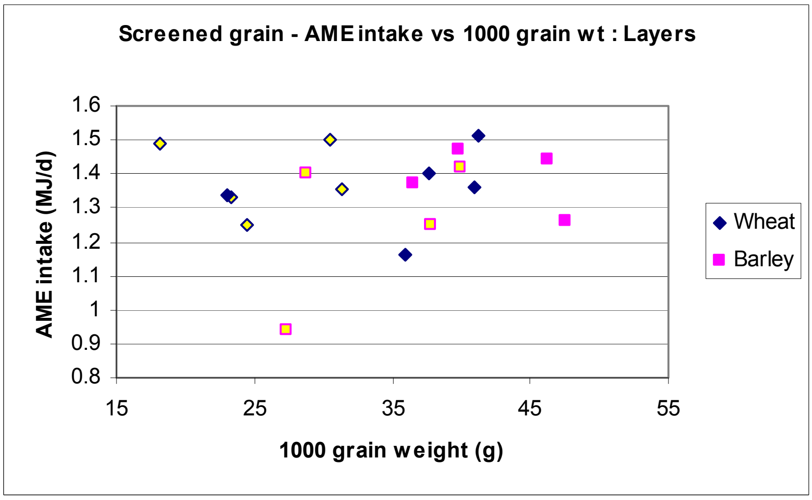
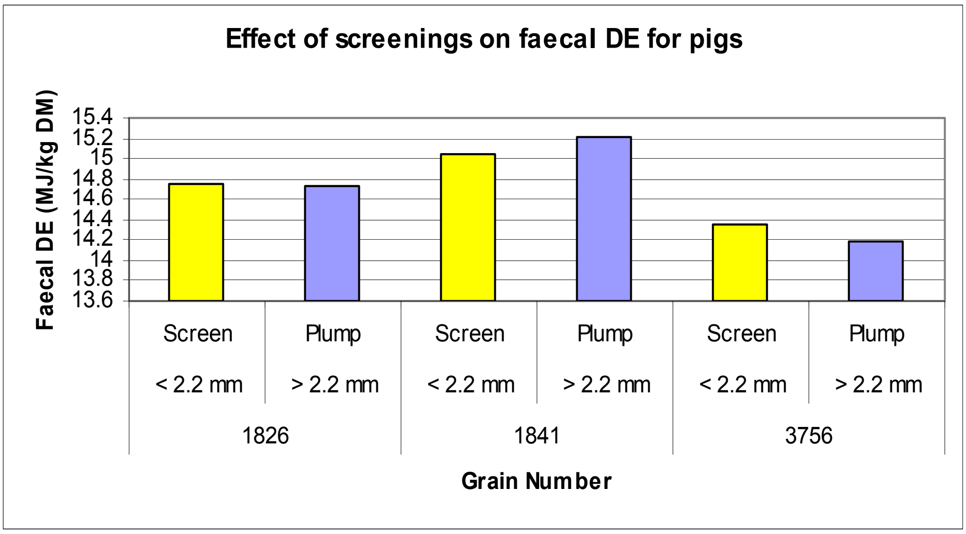
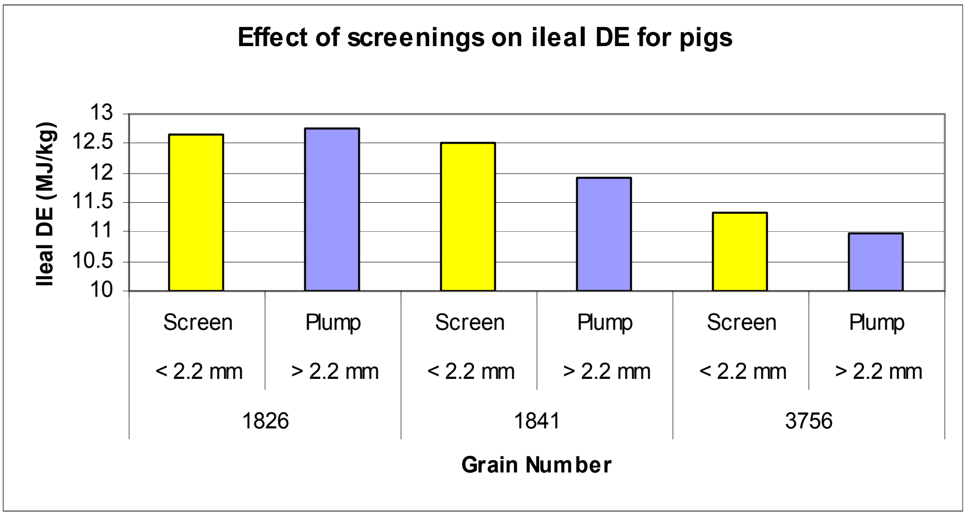


Figure 22. The relationship between 1000 grain weight and the AME content (a, R^2 = 0.07) and AME intake (b, R^2 = 0.02) of wheat and barley grains from the same original sample, either passing through a 2.2 mm screen (yellow) or not passing through the screen.

Three of the sets of screened grains offered to layers were also given to pigs and broiler chickens. The size of grains screened from a single sample did not significantly (P>0.05) affect faecal DE, ileal DE or the ileal:faecal DE ratio for pigs (Figure 23) nor the AME content, ileal DE or AME intake of the grains for broilers (Figure 24). Although these comparisons of grains differing in size with pigs and broilers were not as extensive as the comparisons with layers, the results suggest that grain size and weight *per se* appears to have little effect on its energy value for animals.





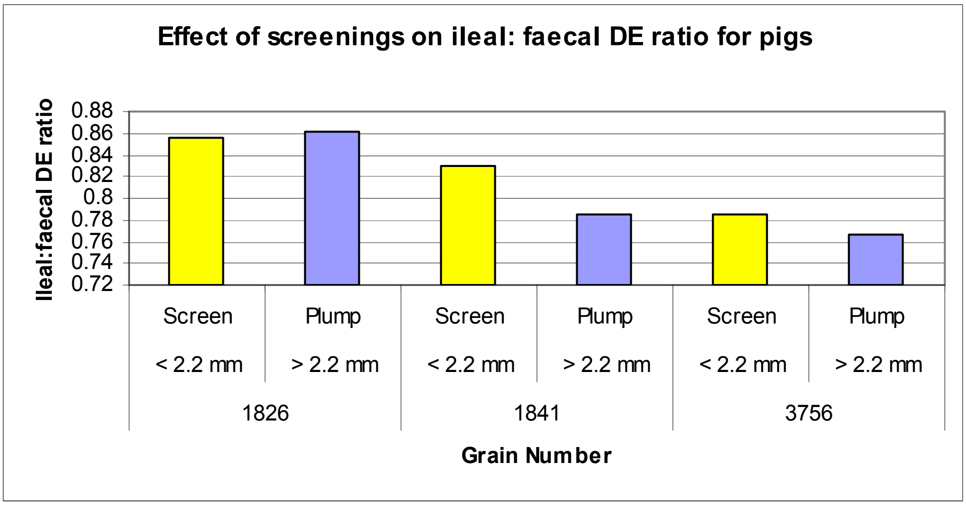


Figure 23. Faecal DE, ileal DE and ileal:faecal DE ratio for pigs of grains, from the same original sample, either passing through a 2.2 mm screen (screen, yellow) or not passing through the screen (plump, blue). No differences between screen and plump grains were significant at P=0.05.

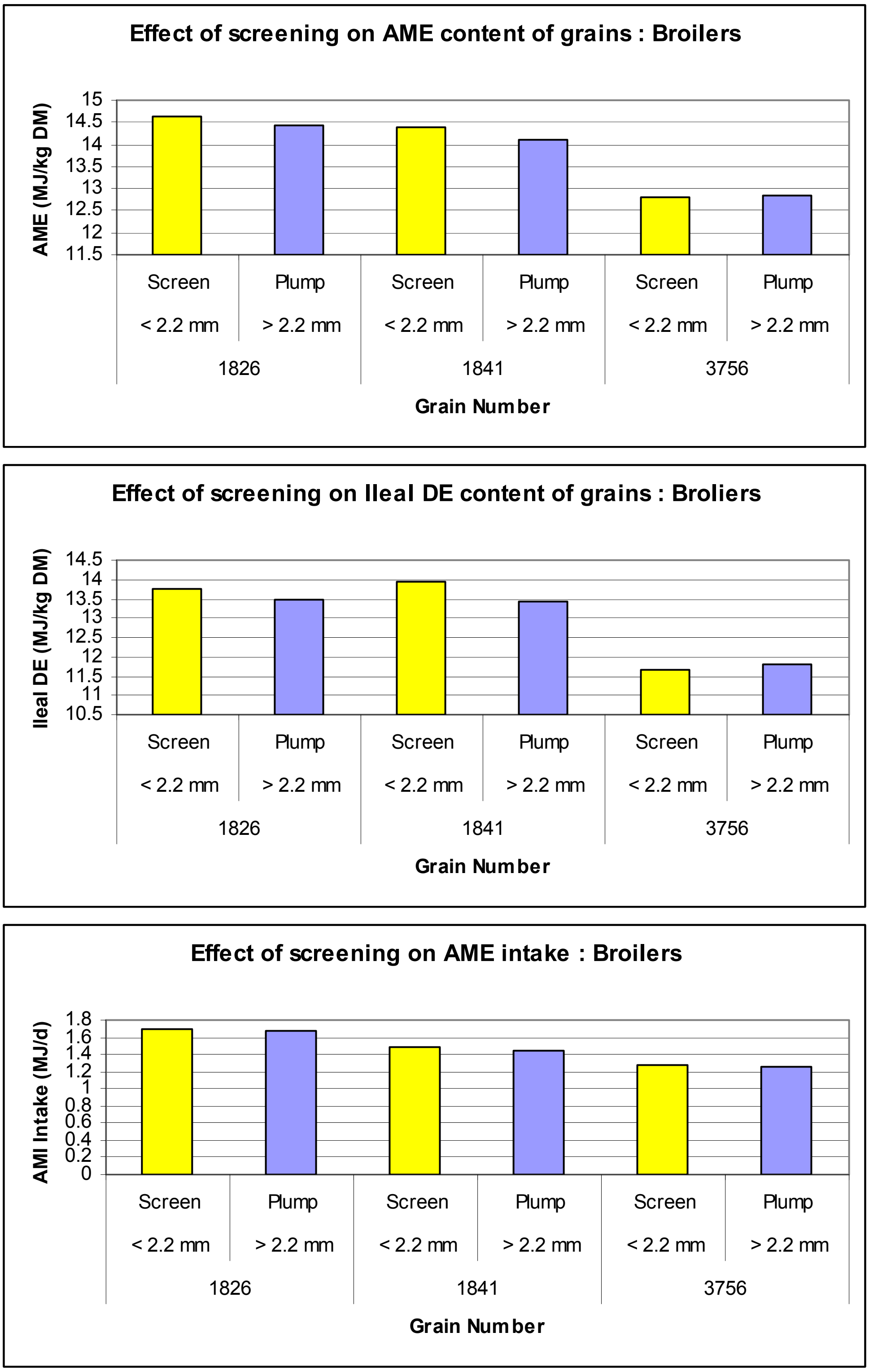


Figure 24. AME content, ileal DE and AME intake for broilers of grains, from the same original sample, either passing through a 2.2 mm screen (screen, yellow) or not passing through the screen (plump, blue). No differences between screen and plump grains were significant at P=0.05.

The effect of grain weight on the energy value of cereal grains for broilers, layers and pigs was examined further by evaluating the relationship between 1000 g weight and both available energy content (Figure 25) and total available energy intake (Figure 26) for all grains fed during PGLP. Similarly, the effect of 1000 grain weight on ME content of grains for cattle fed *ad libitum* was examined (Figure 25). The correlation coefficients for available energy content and total available energy intake for each animal type are given for all grains combined and for each grain species in Table 13.

These analyses confirm that overall there is little relationship between grain weight and its energy value for animals. There was a significant negative relationship between 1000 g weight and AME (MJ/kg DM) for broilers when all grains were included. However, the relationship was positive within wheat (NS), barley (NS) and triticale ($P<0.01$) samples, while negative within sorghum samples (NS). Although the relationship between 1000 g weight and AME content for layers was not significant across all grain species, there was a significant increase in AME with increasing grain weight within wheat ($P<0.01$), barley ($P<0.05$) and triticale ($P<0.01$), while the relationship was negative for sorghum (NS). Faecal DE in pigs tended to be positively related to grain weight with wheat (NS) and barley ($P<0.01$), but the overall relationship across all grains was negative. Similarly with ME of grains for cattle, there tended to be positive relationships with grain weight within each grain species, but these relationships were not significant.

Although there was a trend for the available energy content of grains within a cereal species, except sorghum, to increase with grain weight for each animal type, there was not a similar relationship between grain weight and total available energy intake. The only significant relationships for the total amount of energy consumed and grain weight were negative. When all grains were considered together, AME intake for broilers was negatively related to 1000 grain weight ($P<0.01$) and within barley samples offered to pigs, total DE intake declined significantly with grain weight ($P<0.01$).

Table 13. Correlation coefficients between 1000 grain weight (g) and available energy content or total available energy intake for all grains fed within PGLP.

Grain	Broilers	Layers	Pigs	Cattle
	Available energy content			
	(AME, MJ/kg DM)	**(AME, MJ/kg DM)**	**(Faecal DE, MJ/kg DM)**	**(ME, MJ/kg DM)**
All grains	-0.31^{**}	0.04	-0.19	0.17
Wheat	0.33	0.38^{**}	0.24	0.37
Barley	0.24	0.52^{*}	0.40^{**}	0.55
Oats	-	-	-	-0.11
Triticale	0.82^{**}	0.80^{**}	0.10	0.56
Sorghum	-0.36	-0.19	0.01	-
	Total available energy intake (MJ/d)			
All grains	-0.92^{**}	0.04	-0.22	-0.01
Wheat	0.13	0.17	0.22	-0.19
Barley	0.13	0.09	-0.45^{**}	0.64
Oats	-	-	-	-0.67
Triticale	0.70	0.23	0.33	-
Sorghum	0.08	0.12	-	-

Significance of correlation coefficients: * $P<0.05$, $^{**}P<0.01$

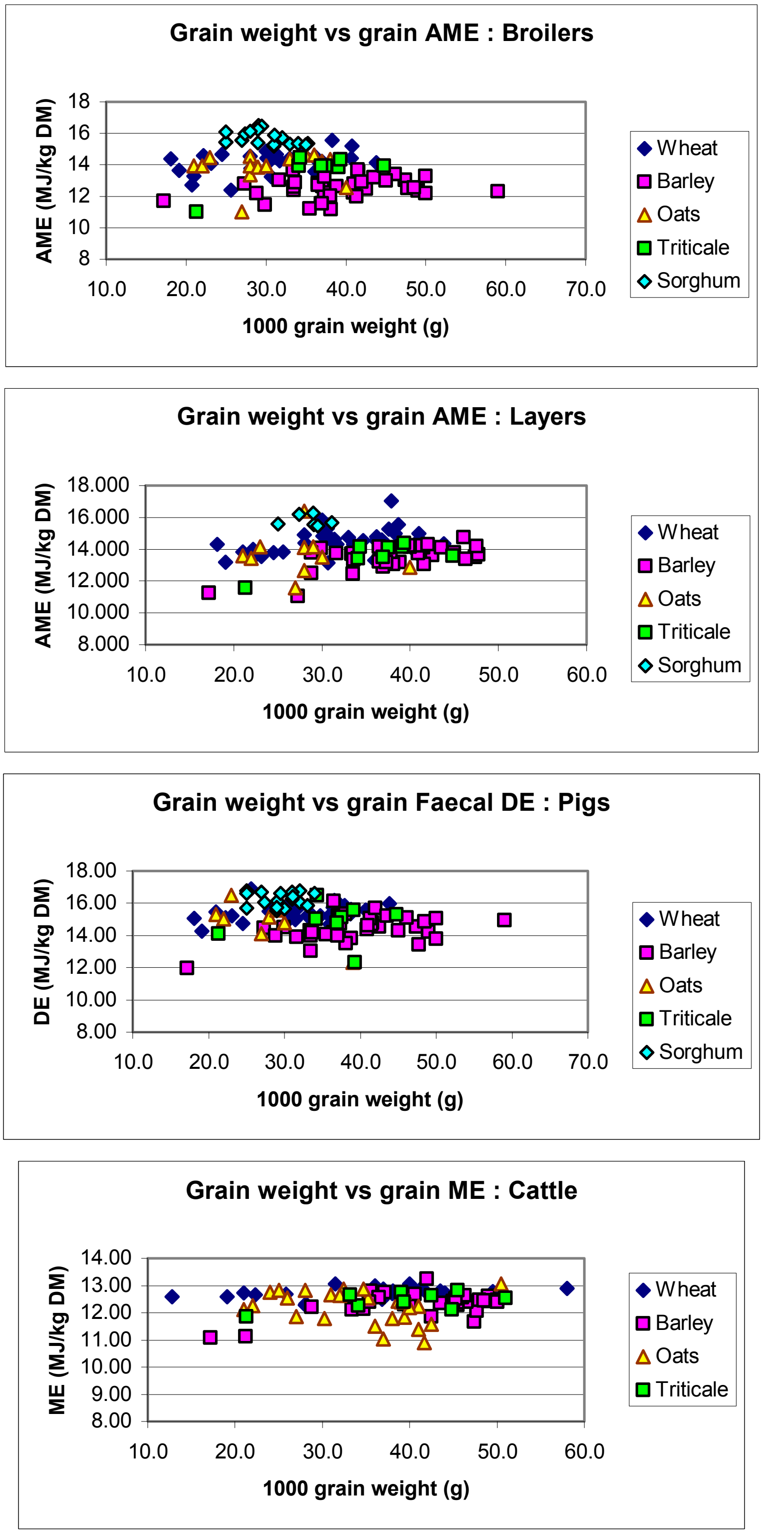
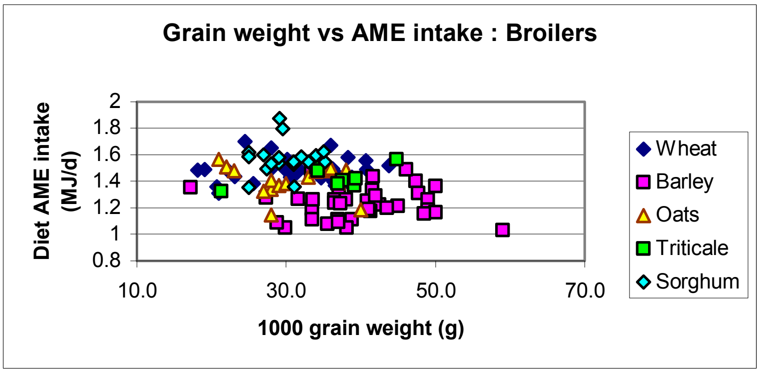
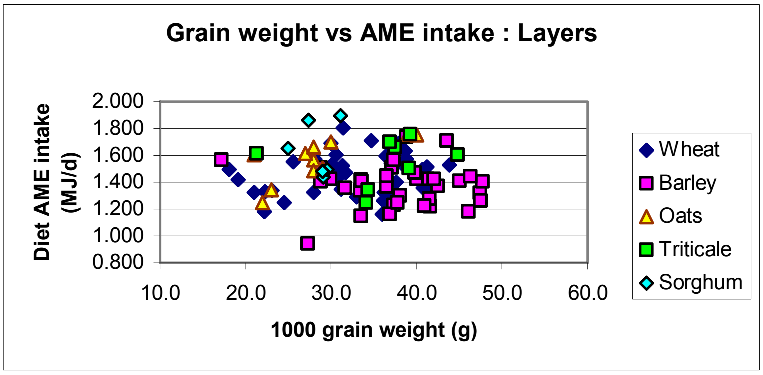


Figure 25. Relationships between 1000 grain weight and the available energy content of all grains fed to broilers, layers, pigs and ruminants within PGLP.





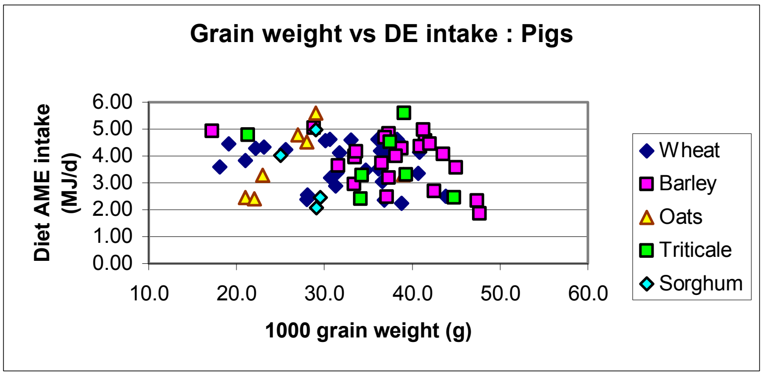


Figure 26. Relationships between 1000 grain weight and the available energy intake from diets containing grains fed to broilers, layers and pigs within PGLP.

In summary, the experiments conducted within PGLP suggest that grain samples with a high proportion of screenings have a small negative effect on the available energy content of grains for ruminants. Similarly, for pigs and poultry, small grain size tends to reduce the available energy content of grains within wheat, barley and triticale, but not within sorghum. However, grain size had no effect on total available energy intake of any animal type and therefore should have no negative effect on animal productivity. The lower available energy content of small grains would mean that efficiency of feed use would be reduced in animals consuming smaller grains despite rates of production not being less than in animals fed larger grains. The comparison between grains screened into large and small sizes from the same samples indicate that factors other than grain size contribute largely to differences in the available energy content and total available energy intake of animals.

Sprouted grains

Sprouted grains have obtained from farmers and produced within the Program through controlled germination. The effects of sprouting were determined by changes in *in vitro* digestion characteristics and animal performance measures.

Farmer sample

A sprouted sample of sorghum was collected from a farmer in Moree in 1999 and it had been significantly down-graded by GrainCo. Measurements for falling numbers values or α- amylase content for this sample were not made 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 14) suggest that the starch content and nutritional value of sorghum were unaffected by sprouting. The same grain was fed to sheep, pigs, broiler chickens and layers. The results for the available energy content and total available energy intake presented in Table 15 compared with the mean values obtained for all sorghum samples used within PGLP. The comparison suggests that the specific sample of sprouted sorghum was not substantially different from the other sorghum samples examined except the intake of AME was lowest recorded for sorghum samples offered to broilers.

Table 14. Effect of sprouting on the starch content and *in vitro* starch digestion of sorghum.

Grain	Total starch (%)	Starch fermentation (%)	Enzymic starch digestion (%)
Sprouted sorghum (7830)	69	44.5	28.0
Normal Sorghum (mean)	67	44.0	28.0

Table 15. Effect of a paddock sprouted sorghum on energy availability for sheep, pigs, broilers and layers compared with mean values for all sorghum samples fed in PGLP.

Sorghum source	Energy availability			
	Sheep			
	ME (MJ/kg DM)			
Sprouted (7830)	13.7			
Sorghum mean	13.9			
	Pigs			
	Faecal DE (MJ/kg DM)	**Ileal DE (MJ/kg DM)**	**Ileal:Faecal DE ratio**	**Faecal DE intake (MJ/d)**
Sprouted	16.6	13.7	0.83	4.02

(7830)				
Sorghum mean	16.2	14.0	0.88	3.38
	Broilers			
	AME (MJ/kg DM)	**Ileal DE (MJ/kg DM)**		**AME intake (MJ/d)**
Sprouted (7830)	16.1	15.6		1.35
Sorghum mean	15.7	15.3		1.57
	Layers			
	AME (MJ/kg DM)			**AME intake (MJ/d)**
Sprouted (7830)	15.6			1.65
Sorghum mean	15.8			1.64

Experimentally sprouted grains

Two cultivars each of wheat and barley and three cultivars of sorghum were germinated for periods from 16 to 48 hours and germination ceased by drying. Germination for these periods did not alter the starch content of the grains, but reduced significantly the Falling Numbers values (Table 16). The disappearance of starch using *in vitro* enzyme digestion tended to increase with germination, but the trend was significant only for barley ($P<0.001$). Germination did not affect the microbial fermentation of starch. However, the rate of starch digestion appeared to be increased with a significant increase in total acid and lactic acid production with all grain species ($P<0.005$). These results indicate that germination increases the accessibility of both rumen microbial and animal digestive enzymes to starch and increases the rate of starch digestion for all cereal species examined.

Table 16. *In Vitro* measurement of starch digestibility and fermentability in sprouted wheat, barley and sorghum cultivars.

Grain	Sprouting Time (h)	Starch (% as fed)	Falling Number	Starch Enzyme Digestibility (%)	Microbial Fermentability (%)	Lactate (mMol/l)
Wheat						
Oxley	0	54.3	403.7	44.6	34.5	5.9
Oxley	28	56.6	236.7	43.2	29.5	5.0
Oxley	38	54.8	120.0	44.3	32.3	5.5
Oxley	48	53.7	66.3	44.0	26.1	8.0
Currawong	0	51.8	237.0	53.5	28.5	8.6
Currawong	28	54.6	187.7	53.5	33.7	7.5
Currawong	38	53.6	98.3	54.4	37.5	9.5

Currawong	48	52.2	61.3	55.7	27.9	14.6
Barley						
Tantangara	0	43.5	406.7	39.9	52.0	3.2
Tantangara	36	45.5	76.0	41.1	53.6	4.0
Tantangara	48	45.3	62.0	45.2	51.0	6.3
Tantangara	60	44.0	62.0	51.9	53.3	9.2
Gilbert	0	44.7	415.0	46.7	52.3	4.2
Gilbert	16	44.7	428.7	44.0	49.2	5.3
Gilbert	24	44.9	254.7	45.9	52.0	6.2
Gilbert	48	46.0	62.0	50.5	51.9	15.7
Sorghum	**Extent germination**	**(% dm)**				**Total acid (mMol/l)**
Waxy isoline (7631)	None	65.7		51.1	18.0	8.1
Waxy isoline	Low	68.6		49.5	11.8	6.9
Waxy isoline	Medium	67.7		50.5	14.4	6.7
Waxy isoline	High	65.8		50.9	15.9	7.2
Non-waxy (7632)	None	70.1		28.2	11.9	5.9
Non-waxy	Low	69.7		28.5	15	4.5
Non-waxy	Medium	68.5		30.3	16.1	5.3
Non-waxy	High	69.3		28.7	14.1	5.8
Buster (7633)	None	69.7		32.4	16.6	5.9
Buster	Low	70.1		34.0	15.5	5.3
Buster	Medium	70.0		34.6	15.3	5.8
Buster	High	69.6		34.7	16.7	6.3

Effects of germination and ensiling of sorghum

The relative effects on starch digestion of germination, ensiling or both germination and ensiling sorghum grain also has been investigated. The results (Table 17) show that germination of sorghum increased the *in vitro* fermentation substantially, whereas ensiling for 21 days had relatively little effect. The greatest improvement in the fermentation and enzyme digestion of starch 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.

Table 17. The effects 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

Effects of germination on energy availability for poultry

Sufficient barley, sorghum, triticale and wheat for broiler chickens was germinated for either 20 hr or 48 hr. Germination significantly increased the AME content of the barley sample by over 1 MJ/kg DM (Figure 27). Germination did not alter the AME content for either the sorghum or triticale sample. Germination of wheat for 20 hr significantly reduced the AME content of wheat, but the energy value of wheat was recovered with 48 hr germination.

The effects of germination on total ME intake (Figure 28), growth rate (Figure 29) and feed conversion efficiency (Figure 30) suggest again there was a positive impact for the sample of barley, but not for either sorghum, triticale of wheat. The results show a reduced intake, growth rate and poorer feed efficiency for wheat germinated for 20 hours compared with either un-germinated wheat of wheat germinated for 48 hours. These results on the effects of germination on the energy value of cereal grains for broilers again indicate that there are likely to be different characteristics within the grain samples examined that result in an inconsistent response.

In summary, the experiments conducted within PGLP suggest that the energy content of sprouted grains for animals is not decreased and in some circumstances may be increased when compared with non-sprouted grain. The effects of germination were particularly favourable for a barley sample fed to broiler chickens and sorghum fed to cattle. Similar results had been found previously by Johnson and Taverner (1986) when sprouted wheat improved AME content for broilers and growth rate for young pigs. However, the effects of storage on the possible deterioration of sprouted grain or of mycotoxins that may develop needs to be examined.

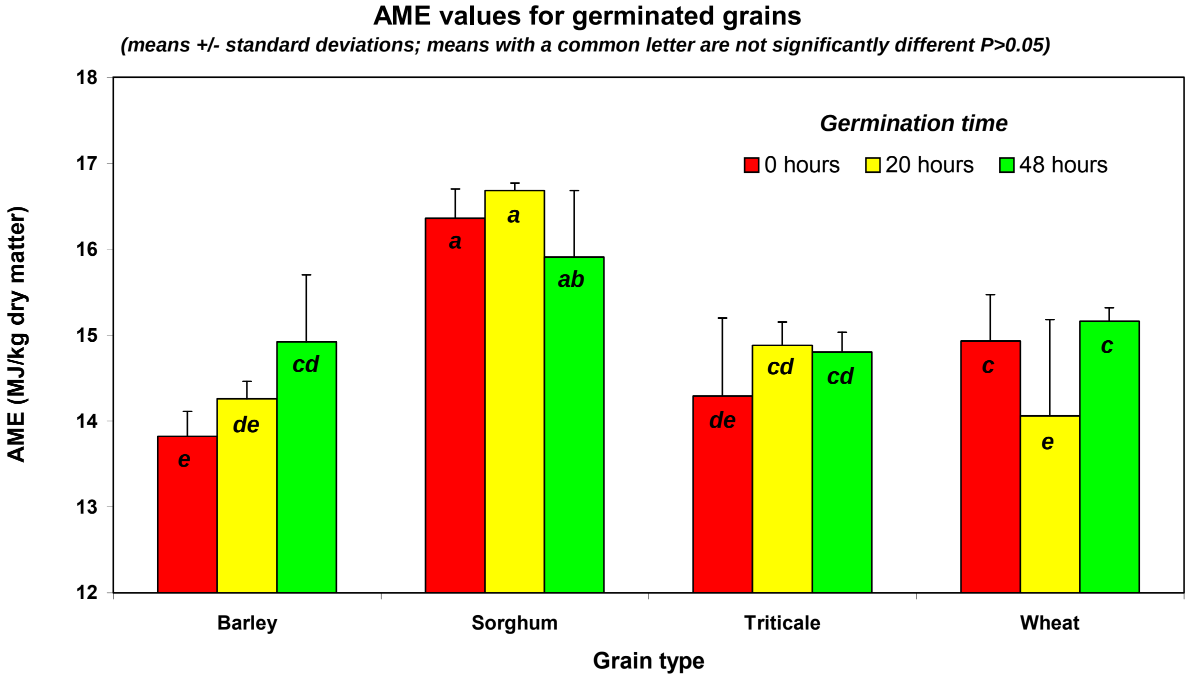


Figure 27. Effects of germination for 20 or 48 hours on the AME content of barley, sorghum, triticale and wheat samples for broiler chickens.

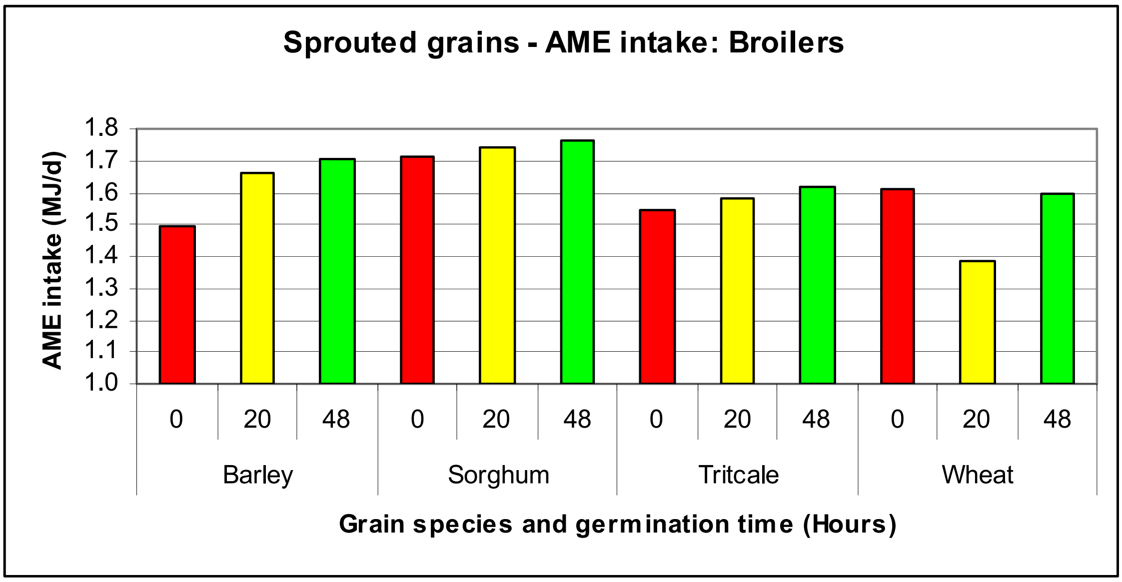


Figure 28. Effects of germination for 20 or 48 hours on the AME intake (MJ/d) of barley, sorghum, triticale and wheat samples fed to broiler chickens.

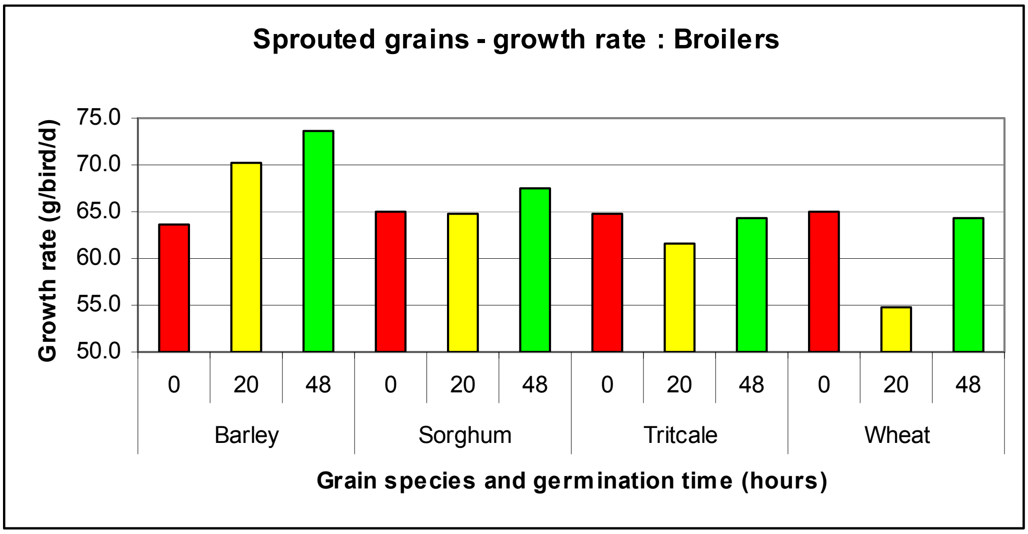


Figure 29. Effects of germination for 20 or 48 hours on growth rate (g/bird/day) of broiler chickens fed barley, sorghum, triticale and wheat samples.

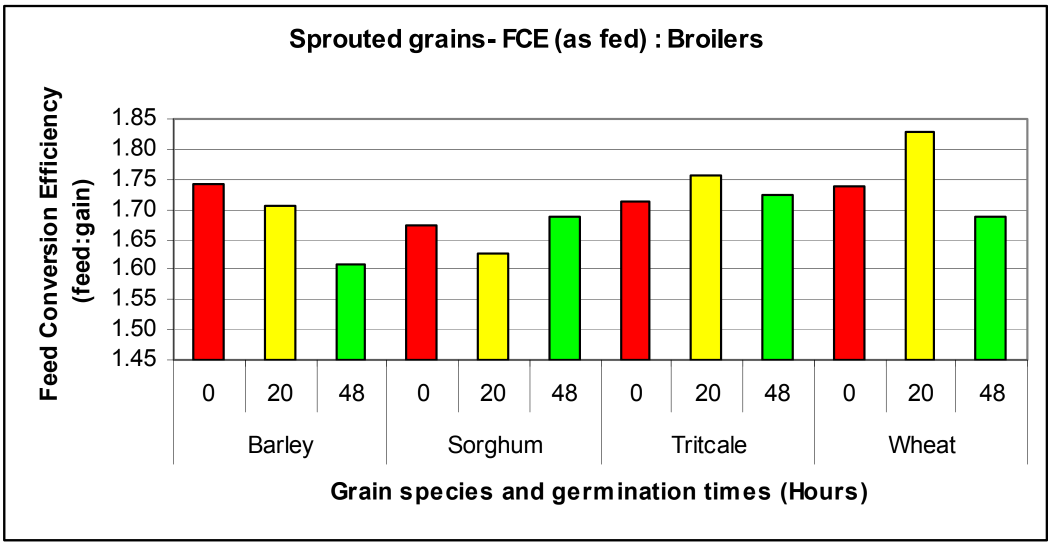


Figure 30. Effects of germination for 20 or 48 hours on the Feed Conversion Efficiency (g feed as fed: g gain) of barley, sorghum, triticale and wheat samples fed to broiler chickens.

Summary of variation

The examples presented above show clearly that, when considering the energy value of a cereal grain for animals, it is important to differentiate between the energy released during digestion (available energy content, MJ/kg) and total available energy consumed (available energy intake, MJ/d). The former is used traditionally in diet formulation to determine the ingredient mixture that produces a predetermined available energy concentration in a ration. The latter determines the amount of energy potentially available for production and the ultimate rate of animal performance. However, the two measures of energy value can interact to affect profitability. For grains with a high total available energy intake and low available energy content, productivity will be high, but feed conversion efficiency may be lower than for other grains with less total available energy intake but higher digestibility.

Profitability depends on the relative difference in monetary returns resulting from the faster rate of production compared with the cost of the additional feed used per unit of production and additional costs associated with effluent disposal.

The examples presented above show that there is considerable variation in both measures of the energy value between grain species, within grain species and between animal types. These differences are summarised below.

- Grain species appear to be digested with different efficiencies by each animal type examined, but the variation within grain species was frequently greater than the between species or animal type variation.

- The within grain species variation in available energy content differed also between animal types with the greatest variation occurring in broilers and the least in ruminants.

- The relative available energy content of individual grain samples varied widely between animal types with frequently some grain samples being more readily digested by one animal type compared with another and vice versa. A few grain samples were either poorly digested by all animal types such as the frosted Arapiles barley (3828) or highly digested by all animals such as the sample of Sunstate wheat (1901). However, in general individual grain samples had characteristics that made them relatively more suitable for digestion by one animal type than another.

- There was no relationship between the available energy content of grains (digestibility) and the intake of diets containing those grains for any of the animal types examined. This lack of a strong relationship between available energy content and intake suggests that different characteristics within grains influence digestion and intake. The latter is affected particularly by characteristics that influence rate of passage of digesta through the whole digestive tract, whereas the former is negatively affected by rate of passage.

- The total intake of available energy also varied widely between grain samples and animal types, indicating again that particular grain samples will provide more energy for productivity to one animal type than another.

- There was a large range in the digestibility of oat grain samples by sheep and cattle. The variation was associated with the lignin content of the hull with grains containing more than approximately 5.5% hull lignin always being relatively poorly digested. However, oat grains with less than 5.5% hull lignin showed digestibility values ranging from extremely low to extremely high. Knowledge of the characteristics of the grain that cause this large range in digestibility of low lignin oats is essential.

- Frost affected grains tended to have lower available energy content than unaffected grains, but the magnitude of the effect was inconsistent across frosted samples and animal types. Frosting of grains showed inconsistent effects on total energy intake across the animal types.

- The percentage of screenings (grains < 2.2 mm) within a grain sample and small grain size appeared to have a small negative effect on the available energy content of grains, but the extent of the decrease varied between grain samples and animal types. However, screenings percentage or grains size had no effect on the intake of available energy for any of the animal types examined.

- Germination of grain tended to increase the rate of starch digestion *in vitro*. This improvement is likely to be particularly important for feeding sorghum to cattle. Germination also significantly improved the AME content, AME intake and FCE for broilers of a sample of barley, but not samples of wheat, triticale or sorghum.

Potential reasons for difference between grains

Possible grain characteristics that may be responsible for the observed differences in available energy content and total available energy intake are examined. Correlations are first considered between individual grain characteristics and available energy content or available energy intake for all grains and, where there is sufficient information, within grain species for each animal type. Several specific examples are then given where the energy value of individual grains vary widely between animal types. Finally, general principles which may alter the available energy content and/or available energy intake of grains between and within animal types are discussed.

Correlations between grain characteristics and energy availability

Significant correlations between characteristics of grains and either the available energy content or total available energy intake are shown in Tables 18 – 21, respectively, for broilers, layers, pigs and cattle fed *ad libitum*. Not all significant correlations are shown because many characteristics are closely associated. The characteristics are divided into gross composition, anti-nutritional factors, cell wall components, physical characteristics and other variables of significance. In general, values are included only when they are significant to at least the $P<0.01$ level of probability. However, where the character may help with the explanation of reasons for differences between grains or when grain numbers are small, values with $P<0.05$ are included.

Broilers

AME content

Results presented in Table 18 suggest that correlations between the available energy content (AME, MJ/kg) of grains and grain characteristics are different for wheat, barley and triticale than for sorghum. For wheat, barley and triticale, AME was positively related to starch content, specific weight and starch granule area. It was negatively related to fibre, ash, phytic acid, oilgocassharide, condensed tannin, insoluble and soluble arabinoxylan, ß-glucans, total soluble non-starch polysaccharides, whole grain viscosity and hydration capacity. These correlations confirm the importance for providing digestible energy of high starch and low fibre content, which is reflected in a positive relationship with specific weight of the grains. There were also strong negative correlations with anti-nutritional factors, phytate, tannins and oligosaccharides, which either interfere with enzyme activity or are poorly digested by bird secreted enzymes. The negative effect of soluble cell wall constituents and whole grain viscosity are to be expected from knowledge of the impact of digesta viscosity on accessibility of amylases to starch granules. The negative correlation with hydration capacity is more difficult to explain. Hydration capacity was measured as the amount of water absorbed over 16 hours soaking in excess water and is likely to be associated with the total amount of NSP in the grain.

Various components of NSP in wheat, barley and triticale were shown to be related negatively to AME content of grains.

The AME content of sorghum fed to broilers was not correlated with either the starch or fibre content of the grain, because these vary little within sorghum samples. AME of sorghum was negatively associated with whole grain viscosity, but was positively related to the content of soluble mannose and ribose, hydration capacity, kernel hardness and kernel moisture content. The absence of correlations with cell wall constituents coincides with the thin and fragile nature of the endosperm cell walls in sorghum. The positive relationship with hydration capacity and grain moisture content suggest that grains with greater hydrophilic capacity are more quickly digested. In sorghum, which has relatively low NSP content, hydration capacity may reflect the proportion of floury to vitreous endosperm, with digestibility of the former being greater than the latter. The positive relationship with grain hardness may indicate that hard grains are more readily fractured into small particles within the gizzard than softer grains.

A more thorough statistical analysis of factors contributing to the variation in grain AME (MJ/kg DM) for broilers has been undertaken and is described in the attached file (28 PGLP broiler 2005). The analyses evaluated all the data across grain types and were divided into several 'runs' where the importance of individual chemical or physical components was considered. Each run included grain descriptors at a different 'levels' of complexity. For example, crude protein and crude fat were included along with other components in one 'high-level' run, whereas individual amino acids and fatty acids were considered in a lower level run. There were five runs, including runs for anti-nutritional factors and physical factors.

The analyses showed that the majority of the observed variation in the AME content of grains for broilers was explained by total starch, crude fibre and ash. Lower level components explaining most of the variations were total insoluble NSP, insoluble arabinoxylan, insoluble arabinose, in soluble cellulose, NDF, single kernel diameter, hydration capacity and whole grain time to peak viscosity. There were a number of interactions between grain components and grain type that contributed to significant variation in broiler AME values.

AME intake

Grain species also appears to effect the correlations between grain characteristics and AME intake, with those for wheat, barley and triticale differing from sorghum (Table 18). For wheat, barley and triticale, total AME intake tended to increase with starch content and to be reduced by tannins, oligosaccharides, cell wall constituents, whole grain viscosity and hydration capacity. These grain characteristics that affected total intake of AME were similar to those related AME content. Contrary to AME content of these grains, AME intake was related positively to the moisture content of the grain and tended to be positively related to the lignin content. However, for sorghum AME intake of broilers was strongly related to the fibre, oligosaccharide and cell wall components of the grain samples.

A more thorough statistical analysis of factors contributing to the variation in grain AME intake (MJ/day) for broilers across all grain types (attached file: 28 PGLP broiler 2005), showed that only the lignin, insoluble arabinoxylan, β-glucan and whole grain peak viscosity were statistically significant.

Layers

AME content

The correlations between grain characteristics and AME content of grains for layers shown in Table 19 are broadly similar to broilers, with positive correlations for starch content, specific weight and starch granule area and negative correlations for fibre, ash, oligosaccharides, tannins, cell wall components, whole grain viscosity and hydration capacity.

A more thorough statistical analysis of factors contributing to the variation in grain AME (MJ/kg DM) for layers across all grain types (attached file: PGLP Layers 2004 – all experiments (Sept 2005)), showed that only starch, specific weight, leucine, arabinose, ADF and hydration capacity were statistically significant. The effects of starch components, leucine and specific weight were positive, whereas the effects of arabinose, ADF and hydration capacity were negative. Total starch content of the grains and specific weight were highly correlated.

AME intake

The number of grain characteristics significantly correlated with total AME intake tended to be less in layers than in broilers. The significant correlations were again similar to broilers, except fibre and cell wall constituents were negatively related to intake in layers, but positively related in broilers fed sorghum.

A more thorough statistical analysis of factors contributing to the variation in grain AME intake (MJ/day) for layers across all grain types (attached file: Nielsen- 44 sn004), showed that only 1000 grain weight, single kernel diameter and insoluble xylose content were statistically significant. Single kernel diameter and 1000 grain weight were positively related and insoluble xylose was negatively related to AME intake.

Pigs

DE content

The DE content of grains for pigs was positively correlated with starch content and specific weight, but negatively correlated with fibre, ash, oligosaccharides, tannins, insoluble and insoluble cell wall constituents and hydration capacity (Table 20). Unlike correlations with AME in broilers, DE in pigs was not consistently related to whole grain viscosity. These correlations confirm again the importance for providing digestible energy of high starch and low fibre content, which is reflected in a positive relationship with specific weight of the grains. The correlations suggest also that cell walls have an important impact on the accessibility and digestibility of starch. However, viscosity *per se* appears to be of little importance to digestion in pigs.

A more thorough statistical analysis of factors contributing to the variation in grain faecal DE (MJ/kg DM) for pigs across all grain types (attached file: 44 sn004), showed that only insoluble xylose, lignin and specific weight were statistically significant. The effect on faecal DE was negative for insoluble xylose and lignin, but positive for specific weight. Approximately 70% of the variation in faecal DE across grain samples was explained by these three variables when differences between grain types were considered.

Ileal DE (MJ/kg DM) was found to be significantly related to insoluble xylose, hydration capacity and lignin. The effect of all three dietary components on ileal DE was negative. Approximately 74% of the variation in ileal DE across grain samples was explained by these three variables, which all had a negative impact.

DE intake

The grain characteristics correlated with DE intake in pigs were almost entirely different to those correlated with DE content (Table 20). DE intake was positively related to the fibre and insoluble arabinoxylan content of the grains as well as whole grain viscosity and surface area of starch granules. Intake was negatively related to the phytic acid content and, for barley, negatively related to soluble arabinoxylans and ß-glucans. There were insufficient sorghum samples fed to pigs in experiments measuring intake for correlations to be developed between DE intake and sorghum grain characteristics.

A more thorough statistical analysis of factors contributing to the variation in daily intake (kg/day) for pigs across all grain types (attached file: 46 RvB003), showed that only NDF and hydration capacity were statistically significant. The effect on intake was positive for both variables. Approximately 27% of the variation in intake across grain samples was explained by these three variables when differences between grain types were considered.

Cattle

ME content

The ME content of grains for cattle tended to be positively correlated with starch and negatively related to fibre, ash and tannin content of the grains (Table 21). The ME content of grains for cattle was also positively related to the acidosis index, suggesting that the more rapidly digested grains had higher total digestibility. Unlike poultry, the ME content of grains was positively correlated with whole grain viscosity.

ME intake

ME intake in cattle appeared to be closely correlated with grain characteristics that were related to digestibility or ME content except it was positively correlated with soluble cell wall components (Table 21). There was a slight negative relationship between ME intake and acidosis index for all grains excluding oats.

Comparison of the energy content of individual grain samples across animals

Several characteristics of four wheat and four barley samples (Figure 31) that showed differences in the relative available energy content between animal types are listed in Table 22 in an attempt to identify possible reasons for these observed differences.

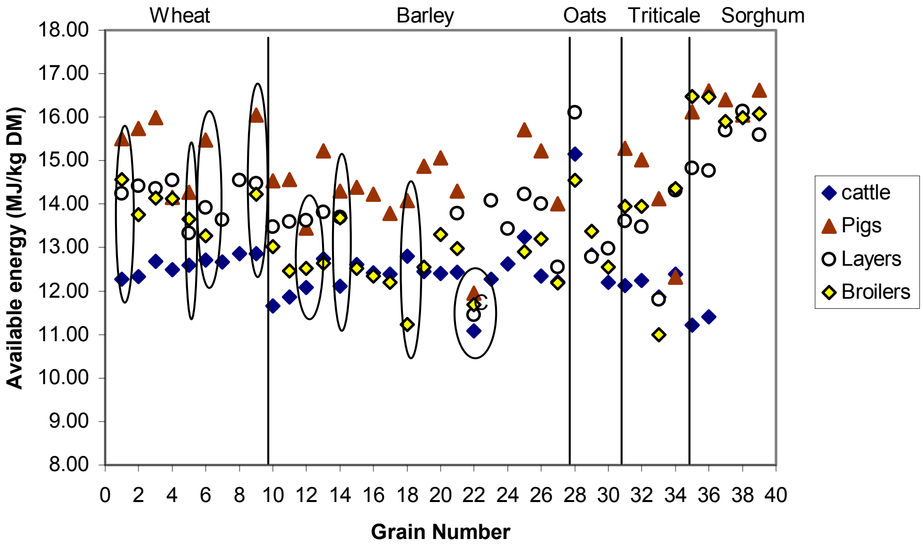


Figure 31. Four examples of wheat and four examples of barley where the relative available energy content of individual grain samples vary widely between animal types.

Grain 1, wheat 1718, Oxley; available energy content - low cattle, medium pigs, high broilers and layers: High starch and low fibre content, low insoluble arabinoxylan and relatively low ß-glucan, medium whole grain viscosity, low *in sacco* starch digestion and low total acid production. The low *in sacco* starch digestion may reflect the low available energy content for ruminants. The low cell wall components and medium whole grain peak viscosity should provide ready accessibility of enzymes to starch in poultry and pigs.

Table 18. Correlation coefficients between grain characteristics and both AME content (MJ/kg) and AME intake (MJ/d) for all cereal grains and individual grain species fed to broiler chickens.

	AME (MJ/kg DM)												
All grains	Starch 0.77	NDF -0.59	Ash -0.64	Oligo-saccharides -0.60	Condensed Tannins -0.47	Insoluble AX -0.51	ß-glucans -0.71	Total soluble NSP -0.69	Hydration Capacity -0.41	Specific weight 0.46	RVA WG Viscosity -0.32	Starch granule area 0.43	
Wheat	Starch 0.40	Ash -0.54	Phytic acid -0.45	Ribose sugar -0.45	Insoluble arabinose -0.35	Insoluble xylose -0.48	Total sol. NSP -0.39	Soluble fucose -0.47	Hydration capacity -0.37	Specific weight 0.37			
Barley	Fat -0.39	Protein 0.33	Oligo-saccharides -0.36	Condensed Tannins -0.44	Galactose free -0.46	Insoluble mannose -0.56	Soluble mannose -0.40	Soluble ribose -0.51	RVA-WG Viscosity -0.40				
Triticale	Starch 0.94	NDF -0.90	Lignin -0.93	Fat -0.91	Oligo-saccharides -0.81	Condensed Tannins -0.83	Insoluble AX -0.87	Total Insoluble NSP -0.96	Soluble AX -0.89	Total Soluble NSP -0.84	Hydration Capacity -0.91	Specific weight 0.92	1000 grain weight 0.82
Sorghum	Protein 0.47	Amylose -0.60	Soluble mannose 0.75	Soluble Ribose 0.56	Hydration Capacity 0.62	RVA WG Viscosity -0.47	Single kernel hardness 0.62	Single kernel moisture 0.57					
	AME Intake (MJ/d)												
All grains	Starch 0.71	NDF -0.56	Ash -0.61	Oligo-saccharides -0.60	Condensed Tannins -0.47	Galactose free -0.64	Insoluble AX -0.61	ß-glucans -0.72	Total sol. NSP -0.69	Hydration Capacity -0.31	Specific weight 0.43	Grain moisture 0.47	
Wheat	Starch 0.46	Lignin 0.49	Ash -0.35	Free mannose 0.45	Free ribose -0.41								
Barley	Protein 0.40	Oligo-saccharides -0.48	Condensed Tannins -0.51	Galactose free -0.63	Soluble ribose -0.44	RVA-WG Viscosity -0.59							

Triticale	Starch 075	NDF -0.90	Fat -0.87	Total tannin -0.76	Linoleic acid 0.85	Oleic acid -0.74	Free ribose -0.76	Insoluble AX -0.92	Soluble AX -0.94	Galactose soluble -0.88	Hydration Capacity -0.84		
Sorghum	NDF 0.68	Oligo- saccharides 0.57	Free glucose 0.57	Free ribose -0.67	Total free sugars 0.52	Insoluble cellulose 0.52	Soluble AX 0.53	ß- glucans 0.81					

Table 19. Correlation coefficients between grain characteristics and both AME content (MJ/kg) and AME intake (MJ/d) for all cereal grains and individual grain species fed to laying hens.

	AME (MJ/kg DM)												
All grains	Starch 0.61	NDF -0.49	Ash -0.54	Oligo- saccharides -0.38	Total Tannins -0.32	Insoluble arabinose -0.50	Insoluble galactose -0.49	ß- glucans -0.44	Soluble mannose -0.50	Total soluble NSP -0.46	Hydration Capacity -0.50	Specific weight 0.59	Starch granule area 0.40
Wheat	Insoluble arabinose -0.36	Hydration capacity -0.37	1000 grain weight 0.38										
Barley	ADF -0.57	Total Tannins -0.42	Insoluble AX -0.47	Insoluble arabinose -0.55	Insoluble galactose -0.52	Insoluble ribose -0.48	Hydration Capacity -0.46	Specific weight 0.48	1000 g weight 0.52				
Triticale	Starch 0.83	NDF -0.74	Ash -0.82	Fat -0.72	Oligo- saccharides -0.72	Condensed Tannins -0.85	Total sugars -0.91	Total Insoluble NSP -0.83	Soluble AX -0.73	Total Soluble NSP -0.82	Hydration Capacity -0.84	Specific weight 0.85	1000 grain weight 0.80
Sorghum	Insoluble cellulose -0.88	Soluble AX -0.82											
	AME Intake (MJ/d)												
All grains	Condensed Tannins -0.34	Mannose free -0.38	Soluble fructose 0.31	Soluble ribose -0.35									

Wheat	Enz. Dig. Starch 0.54	Lignin 0.47	Free mannose 0.47	Free ribose -0.45	Soluble rhamnose -0.42								
Barley	Total Tannins 0.56	Soluble ribose -0.42	Insoluble Ribose 0.42										
Triticale	Resistant Starch -0.81	Free mannose -0.79	WG Viscosity -0.76										
Sorghum	NDF -0.84	Free mannose -0.95	Free xylose 0.86	Insoluble galactose 0.81	Insoluble rhamnose 0.85	Insoluble ribose 0.91	Soluble AX -0.89	soluble glucose 0.94	WG Viscosity -0.85				

Table 20. Correlation coefficients between grain characteristics and both DE content (MJ/kg) and DE intake (MJ/d) for all cereal grains and individual grain species fed to pigs.

	Faecal DE (MJ/kg DM)											
All grains	Starch 0.65	NDF -0.62	Ash -0.54	Oligo-saccharides -0.47	Condensed Tannins -0.44	Insoluble AX -0.59	Free galactose -0.48	ß-glucans -0.52	Soluble mannose -0.50	Total soluble NSP -0.52	Hydration Capacity -0.42	Specific weight 0.52
Wheat	Lignin -0.39	Insoluble galactose -0.35	Gross energy -0.41									
Barley	ADF -0.74	Ash -0.40	Insoluble AX -0.42	Insoluble galactose -0.51	Insoluble xylose -0.49	Total insoluble -0.43	Hydration Capacity -0.40	Specific weight 0.66	1000 g weight 0.40			
Triticale	Free rhamnose -0.83	RVA-WG Viscosity -0.78										
Sorghum	Gross energy 0.69	Grain moisture -0.64	RVA-WG Peak time 0.70									

	DE Intake (MJ/d)												
All grains	ADF 0.37	NDF 0.49	Lignin 0.50	Phytic Acid -0.50	Condensed Tannins 0.44	Insoluble AX 0.51	Insoluble cellulose -0.71	Soluble mannose 0.39	Soluble Rhamnose 0.51	RVA-WG viscosity 0.36	Starch granule surface area 0.64		
Wheat	ß-glucans 0.4												
Barley	NDF 0.44	Lignin 0.49	Phytic acid -0.60	Condensed Tannins 0.70	Insoluble cellulose -0.88	Soluble AX -0.83	ß-glucans -0.63	1000 g weight -0.45	RVA-WG viscosity 0.44				
Triticale	Insoluble mannose 0.83	Soluble fucose 0.76	Soluble rhamnose 0.92	Soluble ribose 0.83									

Table 21. Correlation coefficients between grain characteristics and both ME content (MJ/kg) and ME intake (MJ/d) for all cereal grains and individual grain species fed to cattle.

	ME (MJ/kg DM)												
All grains	Starch 0.42	ADF -0.58	NDF -0.47	Fat -0.35	Ash -0.45	Condensed Tannins -0.44	Insoluble NSP -0.35	ß-glucans -0.30	Hydration Capacity -0.33	Specific weight 0.63	RVA WG viscosity 0.24	Single Kernel Diameter 0.46	Single kernel hardness 0.39
Wheat	NDF 0.48	Protei- 0.42	Ash -0.65	Phytic acid -0.57	Insoluble cellulose -0.67	Soluble AX 0.54	Acidosis Index 0.57						
Barley	ADF -0.74	Fat 0.56	Total tannin -0.59	Insoluble Galactose -0.71	Insoluble ribose -0.54	Hydration Capacity -0.71	Specific weight 0.83	1000 g weight 0.55	RVA WG Viscosity 0.64	Single Kernel Diameter 0.59	Single kernel hardness 0.51	Acidosis Index 0.53	

Oats	ADF -0.57	NDF -0.62	Lignin -0.69	Insoluble Arabinoxylan 0.63	Insoluble galactose 0.60								
Triticale	Crude fibre -0.75	Protein -0.77	Ash -0.75	Total tannin -0.69	Soluble fucose -0.81	Acidosis Index 0.80							
	ME Intake (MJ/d)												
All grains	Starch 0.77	ADF -0.82	NDF -0.58	Fat -0.81	Total Tannins 0.49	Insoluble AX -0.75	Insoluble cellulose -0.79	Soluble AX 0.53	Soluble ribose -0.54	Soluble Xylose 0.52	Specific weight 0.70		
Wheat	Insoluble Cellulose -0.76												
Barley	Insoluble AX -0.82	Insoluble Rhamnose -0.83	Soluble AX 0.83	Soluble Xylose 0.86									
Oats	NDF -0.83	Lignin -0.87	Soluble Galactose 0.86	Soluble xylose 0.89	Soluble Ribose -0.84	RVA Starch Viscosity -0.83							

Grain 5, wheat 1809, Janz frost affected; available energy content – medium cattle, low pigs, broilers and layers: Small grains, low starch and high fibre content, high insoluble arabinoxylan and ß-glucan, low whole grain viscosity. Low starch and high cell wall content reduces energy for digestion by pigs and poultry. Although NDF is high, it is presumably reasonably digested by rumen bacteria.

Grain 6, wheat 1810, Janz; available energy content – medium cattle, medium-high pigs, low poultry: Small normal grain, medium-low starch and medium-high fibre content, high insoluble arabinoxylan, medium ß-glucan and medium high whole grain viscosity, relatively hard grain with medium high *in sacco* starch digestion. Medium available energy content would be expected for all animals because of the relatively low starch and high fibre content. The ileal:faecal DE ratio for pigs was 0.82, which is below the mean value, suggesting a significant digestion of fibre in the hind gut. The low AME for poultry may be due to the relatively high cell wall content and grain viscosity, but there may be an interaction with small grain size exacerbating the influence of cell wall compounds.

Grain 9, wheat 1901, Sunstate; available energy content – high all animal types: Large grain with high starch and low-medium fibre content, medium-low insoluble arabinoxylan, high ß-glucan, high whole grain viscosity, hard grain and high *in sacco* starch digestion. The high grain viscosity is not reflected in low available energy content for poultry. Grain size may be an important factor. High starch fermentation is reflected in high energy availability for cattle.

Grain 12, barley 3723, Psaknon; available energy content – medium low all animal types: Large grain, high starch but high fibre content, medium insoluble arabinoxylan, high ß-glucan and medium whole grain viscosity. The medium arabinoxylan and high ß-glucan concentrations suggests that the grain, although large, had high cell wall contents, which may be responsible for the low available energy content, particularly for pigs. The high fibre content would be expected to reduce the available energy for ruminants.

Grain 14, barley 3727, Gilbert sprouted; available energy content – medium low cattle, medium pigs, very high broilers, medium high layers: medium low starch, low fibre, low insoluble arabinoxylan, medium low ß-glucan, extremely low whole grain viscosity. Low viscosity may explain high available energy content for broilers and layers.

Grain 18, barley 3808, Grimmett; available energy content – high cattle, medium pigs, very low broilers: high starch, medium fibre, high medium insoluble arabinoxylan, medium ß-glucan, very high whole grain viscosity. High viscosity corresponds with very low available energy content for broilers, whereas high starch and medium fibre provides high energy availability for cattle.

Grain 22, barley 2838, Arapiles frosted; available energy content – very low for all animals: small grain, low starch, high fibre, high insoluble arabinoxylans, low ß-glucan and low medium whole grain viscosity. Low starch and high fibre reduces available energy content for all animal types.

Summary of reasons for differences between grains and animal types

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. The differences between animal species in the availability of enzymes and the role of microbial fermentation in digestion of non-starch polysaccharides components of the endosperm cell wall is of major importance for explaining differences in energy availability between ruminant and non-ruminant species. In addition, there appear to be some differences between animal species in the concentration or effectiveness of secreted enzymes for digesting specific components of cereal grains. For example, Simon Bird showed that digesta

Table 22. Characteristics of individual grain samples that had different relative available energy content between broilers, layers, pigs and cattle.

Grain No. Fig. 31	PGLP Grain No.	Cultivar & condition	Broiler AME (MJ/kg)	Layer AME (MJ/kg)	Pig DE (MJ/kg)	Cattle ME (MJ/kg)	Starch (%)	NDF (%)	Insoluble AX (%)	ß-glucan (%)	1000 grain wt (g)	RVA – WG viscosity	Kernel hardness	*In sacco* 24h starch (%)
Wheat														
1	1718	Oxley	14.6	14.2	15.5	12.2	67.9	9.0	2.9	0.68	28.0	68	45	80
5	1809	Janz – frosted	13.6	13.3	14.3	12.7	52.0	23.6	8.9	0.91	19.1	44	48	85
6	1810	Janz	13.3	13.9	15.5	12.7	62.5	16.0	7.2	0.69	21.0	75	76	88
9	1901	Sunstate	14.2	14.5	16.0	12.9	68.0	12.2	5.2	1.04	37.0	129	86	93
Barley														
12	3723	Psaknon	12.5	13.6	13.5	12.6	56.3	29.8	5.1	5.7	47.4	59	55	86
14	3727	Gilbert - sprouted	13.7	13.7	14.2	12.7	52.9	16.9	3.8	4.5	33.4	10	47	90
18	3803	Grimmett	11.2	-	14.1	12.8	55.0	21.3	7.7	5.1	35.5	150	58	84
22	3828	Arapiles - frosted	11.7	11.5	12.0	11.1	49.7	32.8	9.4	1.8	17.2	39	22	83

collected from the duodenum of broilers digested starch from barley 4-fold faster and starch from sorghum 16-fold faster than digesta collected from cattle when determined *in vitro*.

Enzyme accessibility 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 enclosed within the protein matrix of 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. Frequently, there is a negative association between rate of passage of digesta through the digestive tract and digestibility of grain components. However, the opposite is generally true for feed intake where an increase in rate of passage of digesta is associated with an increase in feed intake. Following is a brief outline of the main factors thought to contribute to differences in the available energy content and total available energy intake of cereal grains for livestock.

Gross chemical composition of the grain

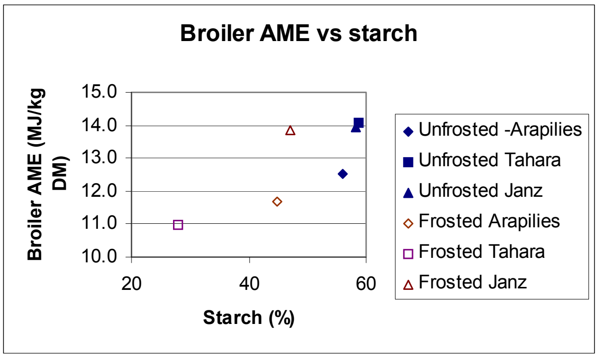
The amount of energy available to an animal from a grain during digestion depends largely on the relative proportions of each chemical constituent because of differences in either the extent of digestion or in the energy content of the constituent. There is a general positive relationship with starch content and negative relationship with fibre content of cereal grains and energy availability for all animal types. Although the negative influence of fibre components is less for ruminants than pigs and less for pigs than poultry because of the role of microorgainsms in digestion, increasing fibre and lignin content of grains also reduces the availability of energy from grains for ruminants. A clear negative relationship has been described between the lignin content of oat grains and digestibility in sheep and cattle.

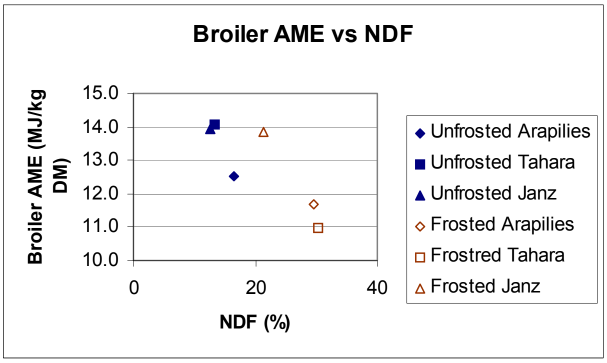
The negative effect of frost on the available energy content of grains for poultry, pigs and sheep can be explained largely by the decrease in starch and increase in fibre content of the frost affected grain (Figure 32). The importance of microbial action in the hindgut of pigs is illustrated in Figure 33 with different relationships between the NDF content of grains and either ileal DE or faecal DE. An increase in the NDF component of a grain had a greater negative effect on ileal than on faecal DE because of significant digestion of fibrous components of the grain in the hindgut of the pig.

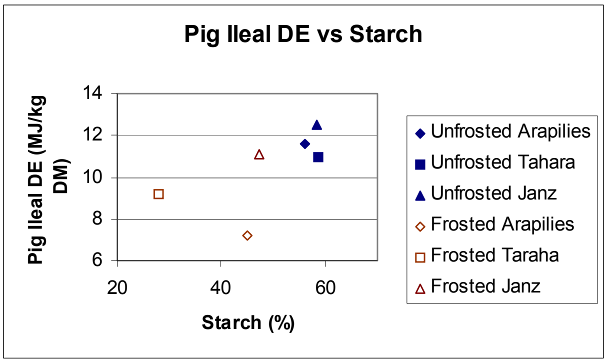
Despite the relatively close relationship between the starch and fibre contents of frosted grains and their energy availability for animals, the relationships are not perfect and other factors are clearly important. For example, the AME content of frosted Janz wheat for broiler chickens remained high despite a substantial fall in starch and increase in fibre content (Figure 32). The effect of frost on energy availability in pigs and sheep offered the Arapilies barley sample was greater than expected from the changes in starch and fibre content. On the contrary, the digestibility of frosted Ouyen wheat by sheep was observed to change little from the unfrosted sample although there was a substantial reduction in starch and increase in fibre content of the frosted grain. The stage of grain development when the frost event occurred is likely to contribute to these variable observations.

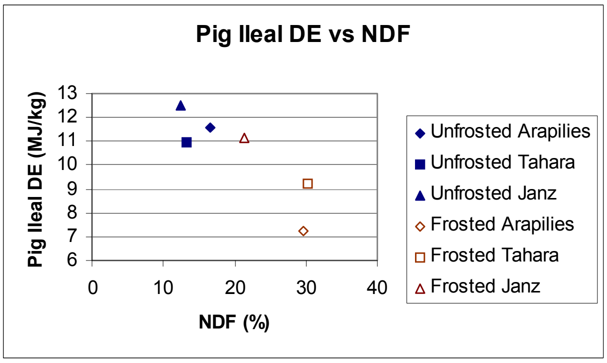
Although an increase in the fibre content of grains was negatively correlated with available energy content (MJ/kg) for all animal types examined, feed intake was positively related to fibre components (NDF and/or lignin) for some grain species offered to broilers, layers and pigs but not cattle where increasing fibre resulted in a depression in intake (Tables 18-21). These associations can be explained by stimulation of the rate of passage of digesta through the gut of mono-gastric animals as the fibre content increased, whereas with ruminants where rumen capacity is limiting intake, an increase in the fibre content of feed will reduce intake.

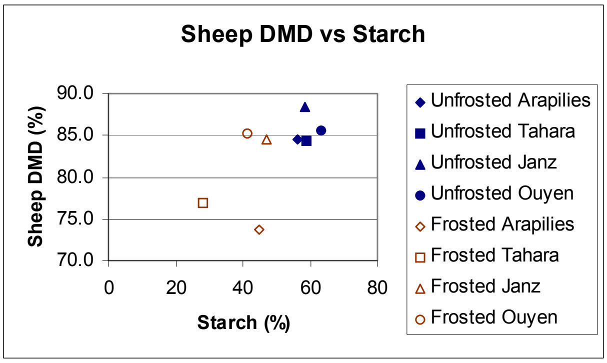
The high available energy content of the naked oat sample for laying hens shown in Figure 3 is due to the high proportion of lipid and its higher energy content than other grain components. However, the energy available to broiler chickens from the same oat sample was 1.6 MJ/kg DM lower than for layers, because of a lower concentration of lipase enzymes and lower efficiency of digestion of the lipid in the younger birds.











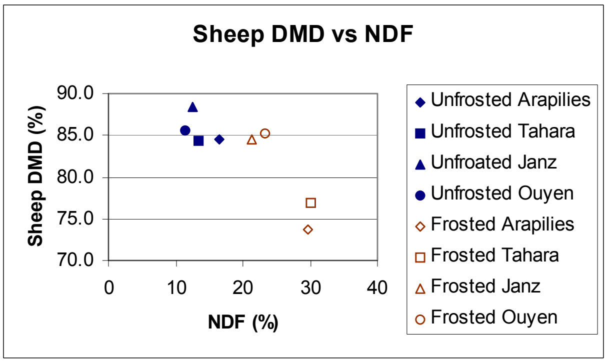


Figure 32. Relationships between broiler AME (MJ/kg DM), pig ileal DE (MJ/kg DM) and sheep dry matter digestibility (DMD, %) and the starch (%) and neutral detergent fibre (NDF, %) content of frosted and unfrosted sampes of barley (Aparilies), triticale (Tahara) and wheat (Janz) cultivars.

Although gross chemical composition of a grain and the digestive system are major determinants of available energy content of cereal grains for animals, other factors contribute to the variation observed between grain samples and animal types. Much of the variation that cannot be explained by chemical composition and digestive system relates to physical barriers limiting enzyme contact with chemical components of the grain.

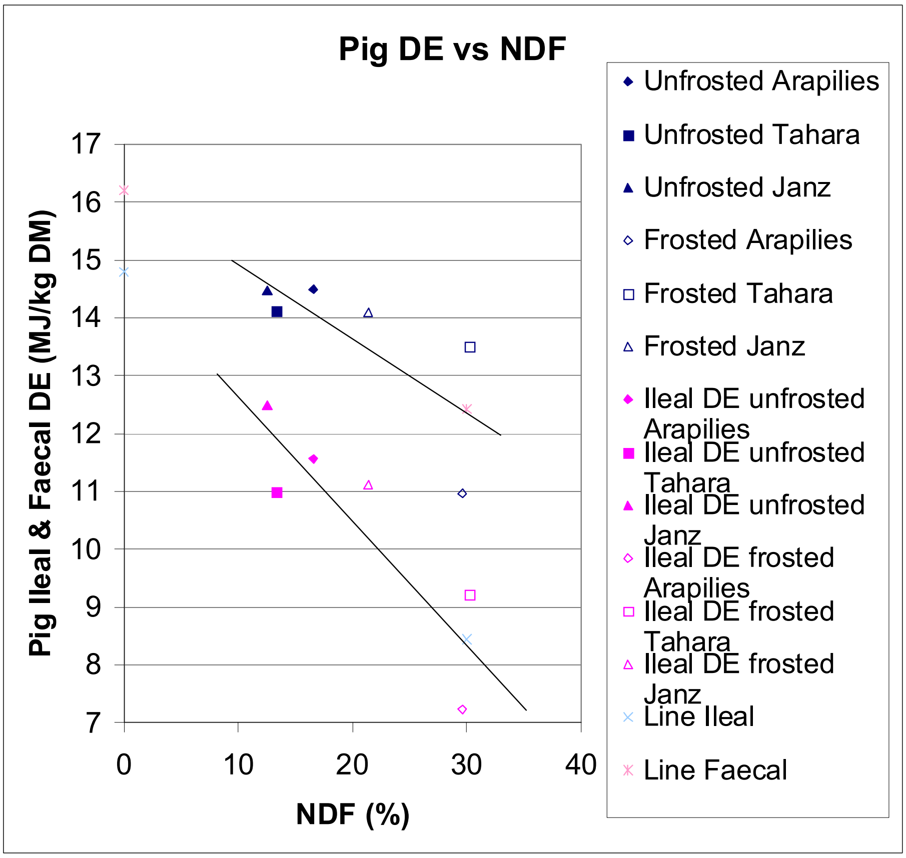
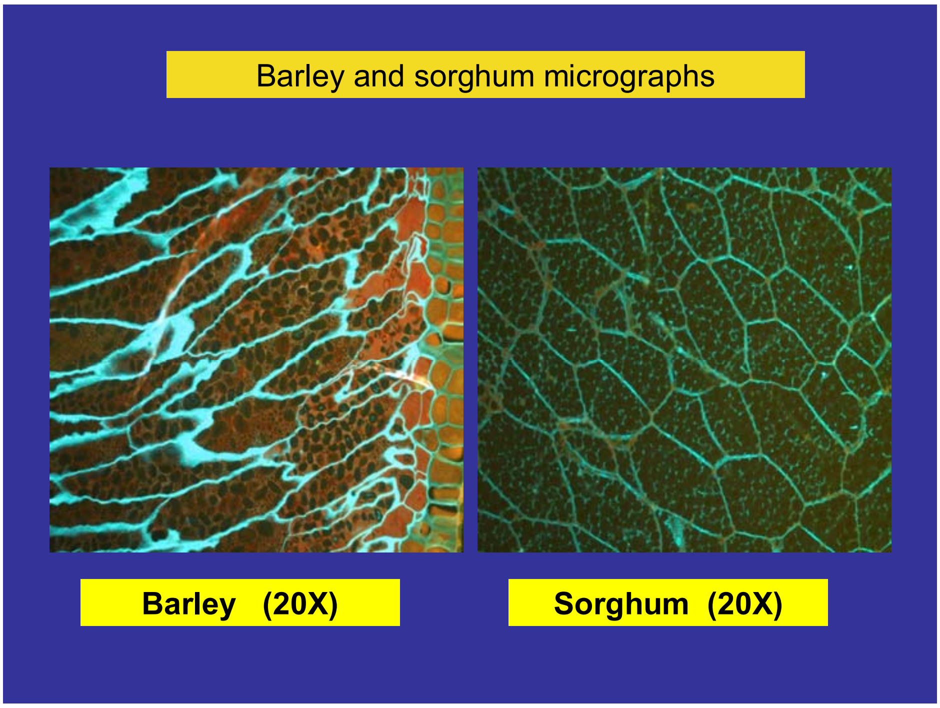


Figure 33. Relationships between ileal and faecal DE in pigs and the neutral detergent fibre (NDF) content of frosted and unfrosted samples of barley (Aparilies), triticale (Tahara) and wheat (Janz) cultivars. Ileal DE (MJ/kg DM) = 14.79 – 0.21*NDF (%); Faecal DE (MJ/kg DM) = 16.20 – 0.13*NDF (%)

Endosperm cell wall composition, thickness and integrity

Endosperm cell walls are composed of a cellulose skeleton impregnated with soluble and insoluble arabinoxylans and β-glucans. There are marked differences between cereal species in the thickness of endosperm cell walls (Figure 34). The walls are particularly thick in barley and thin in sorghum, rice and oat grains. Cell walls in wheat and triticale tend to have intermediate thickness. There is evidence that endosperm cell wall thickness and integrity is affected both by genetic and environmental factors.

Endosperm cell walls have little effect on the overall accessibility of starch from cereal grains for ruminants because they are degraded readily by rumen microorganisms. However, thick cell walls take longer to break down than thin walls and slow the rate of starch digestion within the rumen, alter the rate of acid production and may affect the susceptibility of animals to acidosis. Grinding cereal grains can disrupt the integrity of endosperm cell walls.



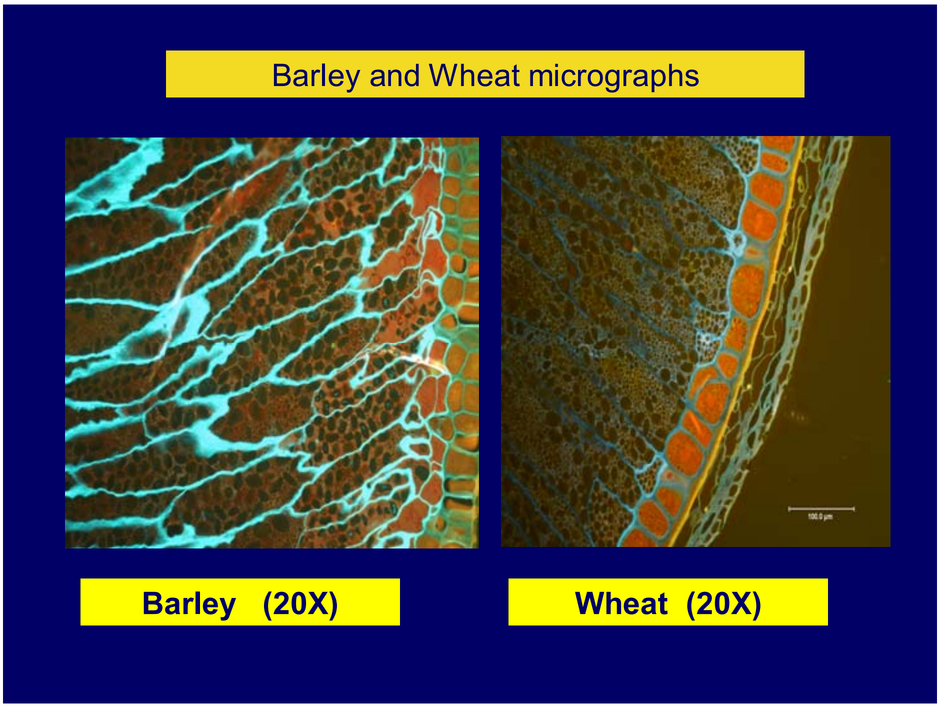
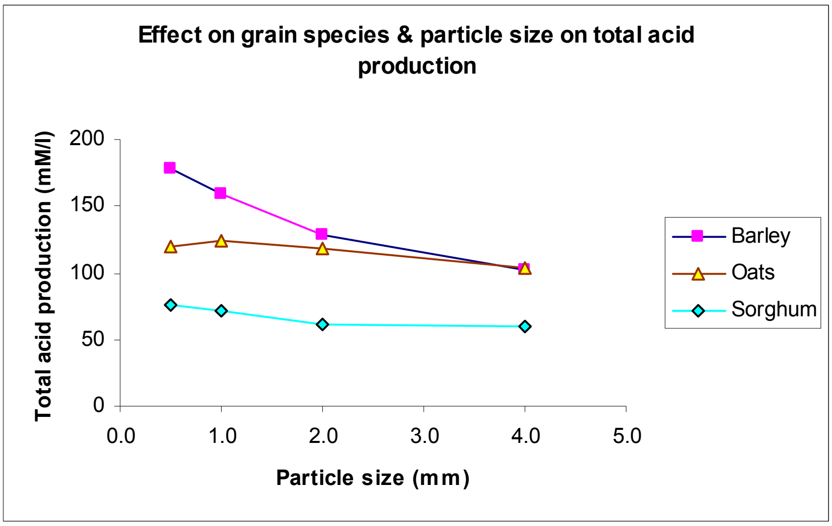


Figure 34. Light micrographs of the endosperm of barley, sorghum & wheat showing differences in cell wall characteristics.

Simon Bird has shown that reducing particle size by grinding barley grain through screens from 4.0 mm to 0.5 mm causes a greater than 2-fold increase in the rate of total acid production, a 15-fold increase in lactic acid production and a substantial increase in starch fermentation *in vitro* (Figure 35). However, a similar reduction in particle size for sorghum and oat grains had little effect on either acid production or starch fermentation because endosperm cell walls in these grains form little barrier between amylolytic enzymes and starch.



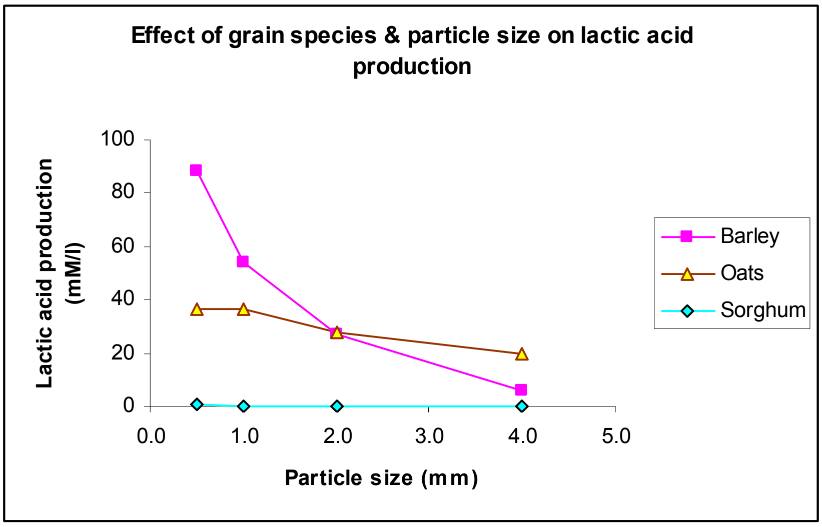


Figure 35. Effect of particle size on the *in vitro* fermentation of barley, oats and sorghum grain expressed as total acid or lactic acid production.

Contrary to ruminants, endosperm cell walls can have a marked effect on the energy value of cereal grains for non-ruminant animals. Cell walls reduce 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 to the digestion of starch 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 which exposes the starch to amylolytic enzymes (Wondra *et al.* 1995). Fine grinding does not increase the availability of energy from cereal grains for poultry because the endosperm cells are ruptured during normal movement through the digestive tract (Wiseman 2000). Although there is little scientific proof, it is logical to presume that cereal grains with large endosperm cells will require less processing for pigs than grains with small cells because more starch would be made available through the disruption of the same number of cell walls.

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 comprising largely arabinoxylans, xylans and β-glucans. A linear decline has been observed by Choct and Annison (1990) in broiler AME values from 17.5 $MJkg^{-1}$ DM for rice to 11 MJ/kg DM for rye with increasing non-starch polysaccharide content of the grain. Soluble non-starch polysaccharide compounds are thought to increase the viscosity of digesta, reduce the diffusion of digestive enzymes through the digesta and reduce the rate of substrate digestion.

Chain length of soluble non-starch polysaccharide polymers appears to be more important for reducing AME of wheat for broilers than is the total content of soluble non-starch polysaccharides, because of the greater increase in digesta viscosity, which reduces the digestion of starch, amino acids and fatty acids. The addition of long chain pentosans to a sorghum-based diet fed to broiler chickens significantly reduces the availability of energy. However, as shown in Table 23, if the pentosans are first hydrolysed to pentoses using arabinoxylanases and glucanases, viscosity of the digesta declines and the availability of energy is restored (Choct and Annison, 1992).

Table 23. Effect of non-starch polysaccharide chain length on the apparent metabolisable energy content (AME), digestibility and digesta viscosity for a diet fed to broiler chickens. Choct and Annison (1992).

Diet	AME (MJ/kg DM)	Digestibility to end of small intestines (%)			Relative digesta viscosity[a]
		Starch	Protein	C18:0 fatty acid	
Control[b]	16.13	98	69	71	1.2
Pentosan[c]	14.53	92	63	41	3.0
Pentoses[d]	16.23	98	72	71	1.3

[a]Relative digesta viscosity determined by time taken for an aliquot of digesta supernatant to flow through a viscometer relative to distilled water.
[b]Control diet: 0.68 sorghum, 0.17 soybean meal,0.076 meat and bone meal,0.04 soybean oil plus amino acids, minerals and vitamins.
[c]Pentosan diet: control diet in which 0.035 (0.854 pure arabinoxylan) replaced sorghum.
[d]Pentose diet: control diet in which 0.015 arabinose and 0.015 xylose replaced sorghum.

Enzymes that degrade soluble non-starch polysaccharide compounds are now regularly added to diets for poultry to reduce the viscosity of digesta and increase the access of enzymes to dietary substrates within the small intestines. The addition of non-starch polysaccharide degrading enzymes to the sample of the naked barley cultivar, Merlin (3725), increased the AME value from 12.6 to 14.6 MJ/kg DM. The observed increase in the AME content of cereal grains following several months of storage after harvest is believed to be due to a reduction in the chain length of soluble non-starch polysaccharides within the grain through the activity of endogenous enzymes.

Soluble non-starch polysaccharides have 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. The fast transit time of digesta in poultry decreases the time digestive enzymes and grain components are in contact compared with pigs. There is some evidence that viscosity of grains may affect digestion in young weaned pigs.

Protein matrix surrounding starch granules

Starch granules in the endosperm of cereal grains are inserted 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 individual starch granules. Figure 36 shows the protein matrix surrounding each of the starch granules of a sorghum grain when some starch granules were dislodged following soaking prior to preparation for microscopic examination.

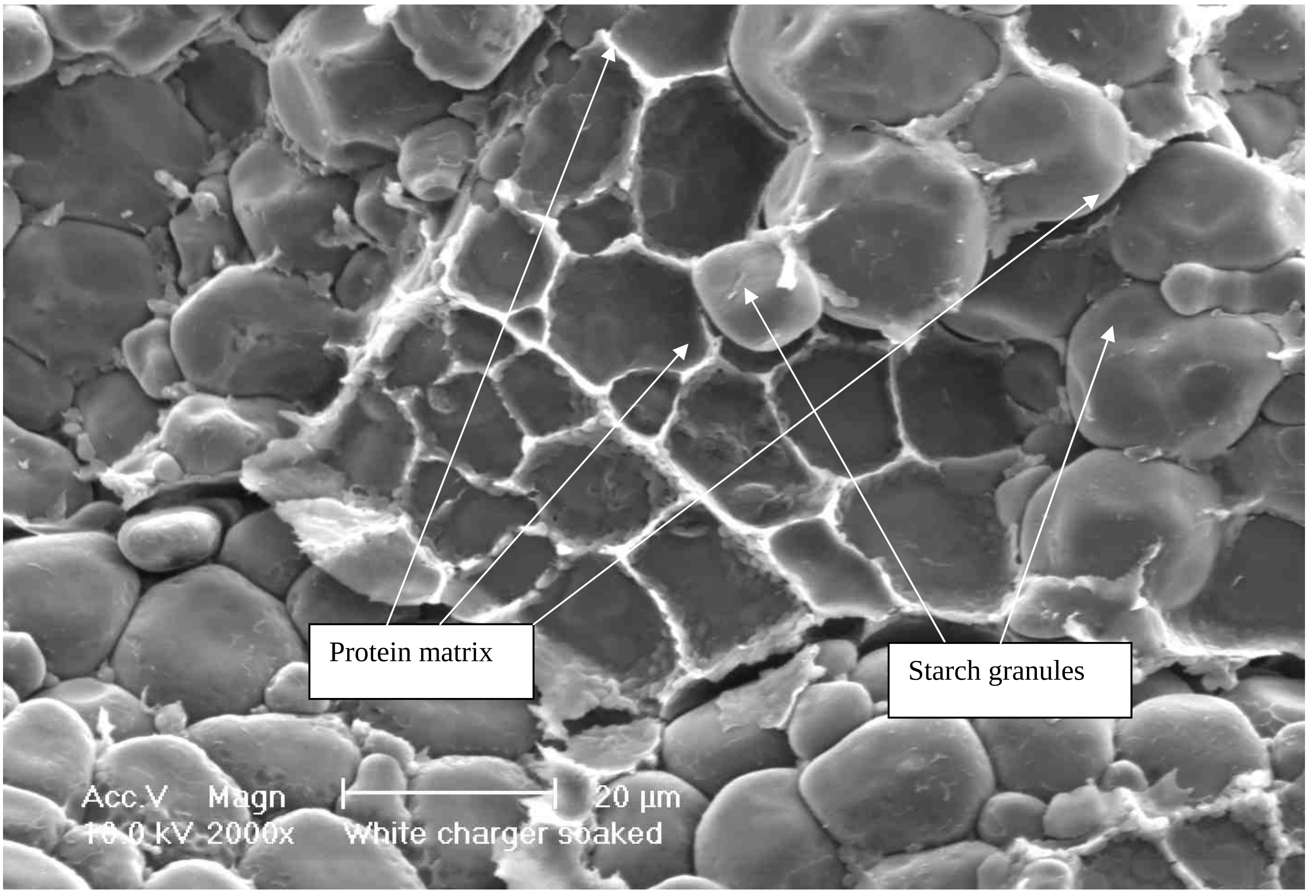


Figure 36. An electron micrograph of sorghum endosperm showing the protein matrix which encapsulates starch granules.

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 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 cleavage by some enzymes. There is 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 encapsulated by the protein matrix. Waxy sorghum grains appear to have less protein matrix with a lower proportion of γ-kafirins than normal cultivars (Sullins and Rooney 1975). The marked difference in digestion of sorghum starch by cattle compared with sheep, pigs and poultry is most probably due to differences in the capacity of proteases from the different animal species to degrade the high disulphide bond proteins in the matrix surrounding the starch granules. As described above, there are also differences between animal species in the concentration of proteolytic enzymes within the small intestines, which favours the degradation of the matrix proteins by poultry and pigs.

The degree of starch granule encapsulation, amino acid composition of the protein matrix, nature of proteases and the presence of anti-nutritional factors like tannins and trypsin inhibitors will affect the digestion of starch in sorghum. Many earlier cultivars of sorghum were high in condensed tannins, which bound to digestive enzymes. Simon Bird found that the degradability of protein using a pancreatin protease from 44 archived sorghum cultivars ranged from 22.7 % to 41.7 %. The fermentability of starch from the same samples ranged from 46.8 to 73.1 %, but there was little correlation between degradability of protein and starch fermentation (Figure 37). Silano (1977) found that the digestibility of protein from several sorghum cultivars with similar protein content varied from 30 to 70%. 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 (Elmalik *et al*. 1986). These results and observations by Oria *et al*. (2000) of a mutant sorghum (P721N) suggest that the completeness of the encapsulation of starch granules by the protein matrix and the number of disulphide bonds may vary between sorghum cultivars.

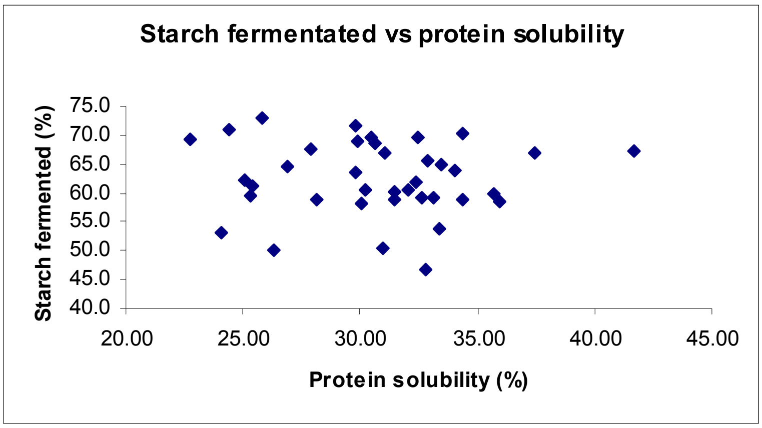


Figure 37. Relationship between *in vitro* protein solubility with bovine pancreatin and *in vitro* starch fermentation in rumen fluid for 44 cultivars of sorghum selected from genetic archives. Results from Simon Bird.

There is evidence that the presence of the protein matrix may affect the extent of starch digestion in maize and barley grains when incubated with mixed micro-organisms from the rumen of cattle (McAllister *et al.* 1993). Incubation of ground barley as well as maize with proteases has been shown to increase significantly the digestion of starch. 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. Simon Bird examined the degradability of protein by pancreatin in 15 cultivars of barley and found the values to range from 71.3 % for a sample of Lindwall to 86.9 % for a sample of Nigrindinum.

Composition of starch

Cereal starch is composed primarily of amylose and amylopectin. The tight helical structure of the long chains of glucose in the amylose molecule makes it less accessible to amylases than amylopectin with its branched α-(1-6) linkages. The α-(1-6) glucose branches provide a more open structure to the starch molecule, which increases the accessibility to amylolytic enzymes. Grains that contain starches with low proportions of amylose are translucent in appearance and are termed waxy grains.

Starches with high proportions of amylopectin have lower gelatinisation temperatures than high amylose starches. The rate of digestion of isolated starch from waxy sorghum is faster than for a non-waxy isoline and is compared with the digestion of starch from wheat and maize in Table 24. These results confirm that the rate of digestion of isolated starch is increased as the amylose content declines. The difference in digestion of isolated starch was confirmed from *in vitro* fermentation and enzyme digestion studies which showed grains with low amylose content have faster rates of starch disappearance than grains with high amylose (Table 25). Waxy sorghum with lower starch gelatinisation temperatures also produces harder more durable stock pellets than non-waxy isolines (Table 26).

Table 24. 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] (mg digested)	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 of 1 g starch.
Results from Tony Blakeney

Information from the literature confirms a positive effect of low amylose grains on animal performance. For example, an experiment with pigs by Pettersson and Lindberg (1997) showed 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). Recently, Kim *et al* (2005) fed the waxy Janz and normal Janz wheat collected within PGLP to pigs immediately post weaning and measured starch digestion, energy availability and animal performance. Although the ratio of amylose:amylopectin was 0.03 for the waxy wheat compared with 0.42 for the non-waxy wheat, digestibility of starch was significantly higher for the non-waxy, high amylose sample (Table 27). There was no significant difference in the performance of pigs fed the two types of wheat. The waxy wheat contained less starch, more non-starch polysaccharides and had a higher extract viscosity than the non-waxy wheat. Addition of a glucanase-xylanase enzyme to the diet substantially increased the DE content of waxy, but not the non-waxy wheat (Figure 38).

Table 25. Effect of amylose proportion of starch on *in vitro* fermentation and enzyme digestion of starch in various grain species.

Grain		Amylose (% DM)	*Invitro* starch degradation (%)	
			Fermentability	Enzyme digestion
Sorghum	Waxy isoline	5	29	33
	Non-waxy isoline	31	27	56
Barley	HB340	4-9		82
	Namoi	23-38		37
Wheat	Waxy Janz	8	49	77
	Non-waxy Janz	33	41	45
Maize	33A63	0		55
	3335	30		35
	704A	57		21

Table 26. Influence of sorghum cultivar on particle size following a standard grinding, pellet durability and pellet hardness.

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

The positive effect of enzymes suggests that the higher cell wall component of the waxy Janz increased digesta viscosity in the young pig and reduced the digestion of starch. The adverse effect of high viscosity apparently overrode the positive effect of the potentially greater digestion of the low amylose starch. The experiment illustrates the importance of understanding the interactions between the factors that influence energy availability. There are other examples of such interactions. The higher intrinsic rate of digestion of starch from waxy sorghum contributes to its higher rate of digestion in cattle, but the lower γ-kafirin content of the protein matrix is also an important factor for increasing the availability of energy in waxy sorghum for cattle.

Table 27. Composition and extract viscosity of waxy and non-waxy cultivars of Janz wheat, and apparent digestibility of starch over 21 days in pigs immediately post weaning. Results from an experiment by Kim et al. (2005).

Characteristic	Janz wheat	
	Waxy	Non-waxy
Chemical composition (%)		
Starch (%)	59.1	65.7
Amylose:amylopectin	0.03	0.42
Total NSP	8.72	7.08
Soluble NSP	2.68	2.34
In vitro extract viscosity (cp)	12.0	7.2
In vivo apparent starch digestion (%)	97.7[b]	98.6[a]

[a,b] P <0.06

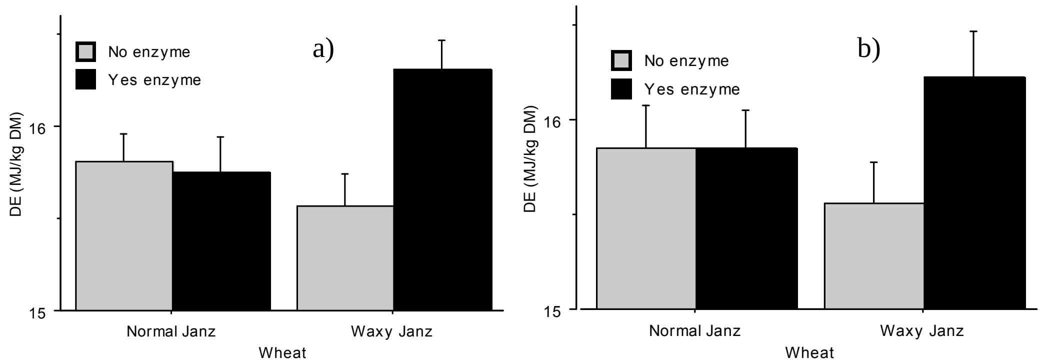


Figure 38. DE content of normal or waxy Janz wheat with and without enzymes in diets fed to pigs post weaning: a) 7 days post-weaning b) at 21 days post-weaning. From Kim et al. (2005).

Starch granule size and surface area

The size of starch granules in cereal grains varies widely from large A granules to small B granules. The surface area of the granules increases per unit weight of starch as the granule size decreases and exposes a greater surface area for attachment of enzymes. The rate of digestion of cereal grains with a larger proportion of small granules should be greater than for grains with a higher proportion of large granules, provided the small granules are not encapsulated within a protein matrix. Simon Bird (Supplemental Report) isolated and iodine stained starch granules from 24 wheat, 15 barley and 6 triticale samples selected from grains fed to sheep, pigs, layers and broilers. Light microscopy and an image analysis software packaged were used to separate and count A granules with a surface area > 100 μm^2 or B granules with a surface area < 100 μm^2. In addition, total granule surface area/1000 granules, /g starch and /g grain were also calculated. There were several significant correlations between *in vivo* and *in sacco* measurements and total granule surface area. Those characteristics showing a significant positive correlation with starch granule surface area/g grain are shown in Table 28. Zarrinkalam (2002) who used a similar technique to Bird for isolating starch granules from 7 wheat samples fed to pigs in the first phase of PGLP confirmed that a greater proportion of starch is digested in the small intestine of pigs when the average size (area) of individual starch granules is small (Figure 39).

Table 28. Measured variable significantly correlated with total starch granule surface area for 24 wheat, 15 barley and 6 triticale samples offered to different animal types of examined *in sacco* in the rumen of cattle.

Measured variable	Correlation coefficient	Significance (P<)
Broiler AME (MJ/kg DM)	0.43	0.05
Broiler ileal DE (MJ/kg DM)	0.55	0.01
Layer AME (MJ/kg DM)	0.37	0.05
Pig ileal DE (MJ/kg DM)	0.42	0.05
Pig ileal:faecal DE	0.40	0.05
Sheep DMD (%)	0.40	0.05
Cattle DMD (%)	0.63	0.01
24 h *in sacco* DMD (%)	0.40	0.05
6 hr *in sacco* starch dig (%)	0.44	0.05
Acidosis index	0.34	0.05

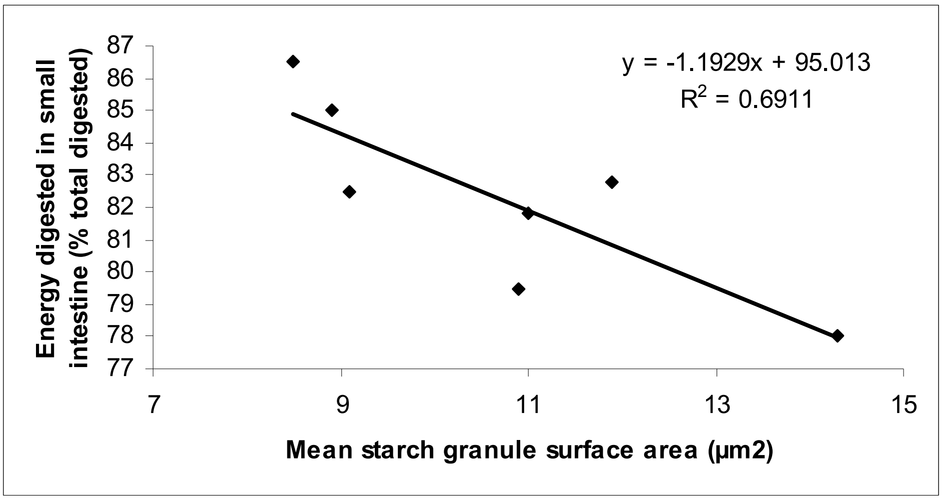


Figure 39. Relationship between proportion of energy digested in the small intestine of wheat samples and the mean surface area on starch granules extracted from the sample. (Derived from the work of M-R Zarrinkalam, 2002).

Hydration capacity and grain hardness

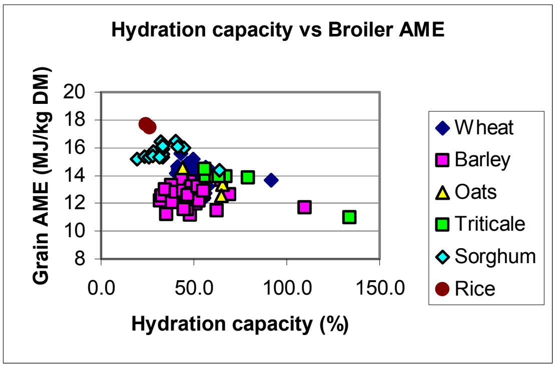
Scott (2002) has suggested that an increase in the time taken for a grain to become hydrated within the digestive tract would increase the time needed for digestion, slow the rate of passage of digesta and thereby reduce feed intake and performance of broiler chickens. Consequently, a strong positive relationship would be expected between hydration capacity of a grain and its AME content and total AME intake in broilers. Support for this hypothesis was provided by Scott (2003) when wheat samples, presoaked prior to feeding to broilers, resulted in a significant increase in feed intake and growth rate. However, the AME content of the grain was reduced slightly presumably because the increase in rate of digesta passage reduced the time for digestion.

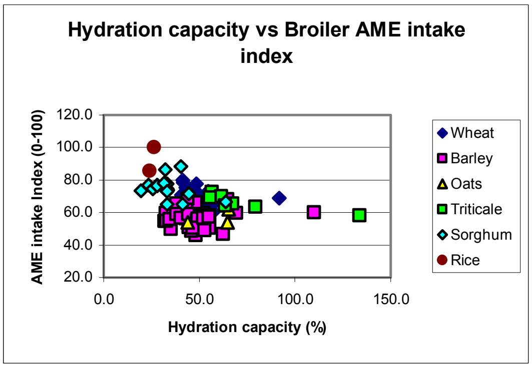
Correlations between various measures of the energy value of grains to animals and grain hydration capacity obtained within PGLP are shown in Table 29 and in Figure 40.

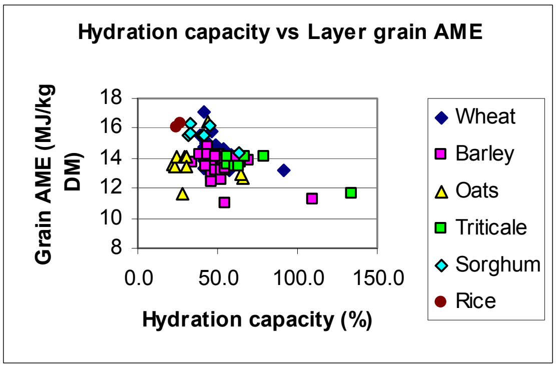
Table 29. Correlations between hydration capacity (%) of cereal grains and various measures of the energy value for different animal types.

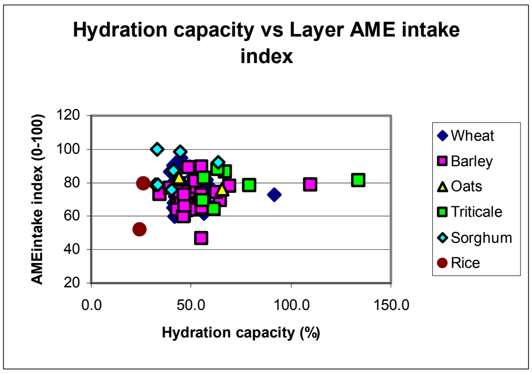
Measured animal variable	Grain species	Correlation coefficient	Significance (P<)
Broiler AME (MJ/kg DM)	All grains	-0.41	0.01
	Wheat	-0.37	0.05
	Barley	-0.11	NS
	Triticale	-0.92	0.01
	Sorghum	0.67	0.01
Broiler AME intake index	All grains	-0.31	0.01
	Wheat	-0.26	NS
	Barley	0.09	NS
	Triticale	-0.84	0.01
	Sorghum	-0.08	NS
Layer AME (MJ/kg DM)	All grains	-0.50	0.01
	Wheat	-0.37	0.05
	Barley	-0.46	0.01
	Triticale	-0.84	0.01
	Sorghum	0.18	NS
Layer AME intake index	All grains	0.08	NS
	Wheat	-0.24	NS
	Barley	0.16	NS
	Triticale	0.10	NS
	Sorghum	0.26	NS
Pig faecal DE (MJ/kg DM)	All grains	-0.42	0.01
	Wheat	-0.29	NS
	Barley	-0.40	0.05
	Triticale	-0.25	NS
	Sorghum	-0.23	NS
Pig DE intake index	All grains	0.17	NS
	Wheat	-0.13	NS
	Barley	0.10	NS
	Triticale	0.29	NS
	Sorghum	-	-
Cattle ME (MJ/kg DM)	All grains	-0.33	0.01
	Wheat	0.31	NS
	Barley	-0.71	0.01

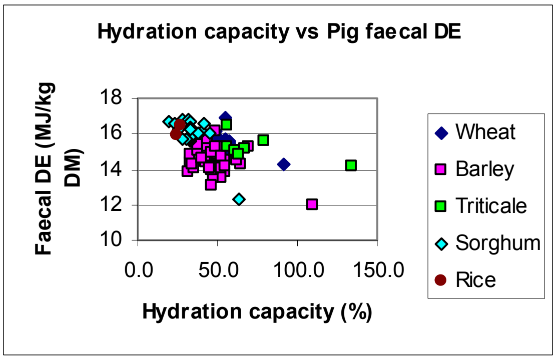
	Oats	0.30	NS
	Triticale	-0.79	0.05
	Sorghum	-	-
Cattle ME intake (kg/d)	All grains	-0.37	NS
	Wheat	-0.07	NS
	Barley	-0.05	NS
	Oats	-0.61	NS
	Triticale	-	-
	Sorghum	-	-

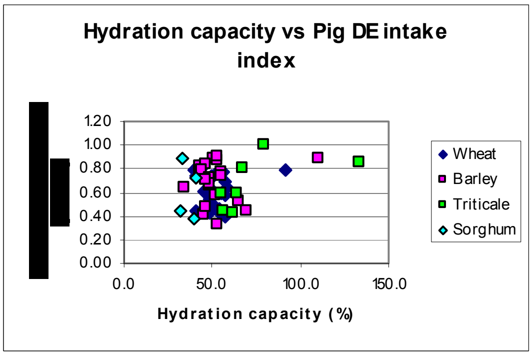












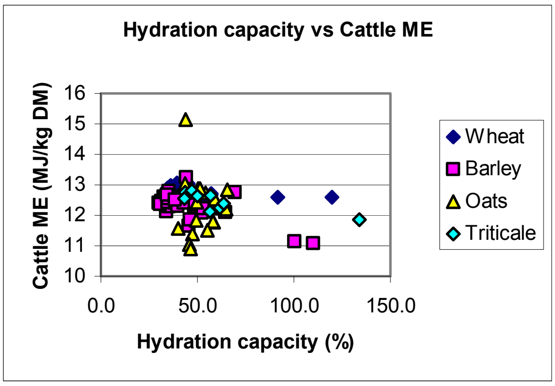


Figure 40. Relationships between grain hydration capacity and available energy content or total available energy intake index for broilers, layers, pigs and cattle.

Hydration capacity was determined by soaking 100 pre-weighed grains in excess distilled water at 18-24˚C for 16 h and expressing the increase in grain weight as a percentage of the initial weight. Contrary to the hypothesis proposed by Scott (2002), there was a strong negative correlation between hydration capacity and grain available energy content (MJ/kg DM) for most grain species and animal types examined. Also, there was little relationship between hydration capacity and the available energy intake index for each animal type. The only significant correlations were negative for the all grains and triticale samples in broilers.

These results suggest that hydration capacity as measured did not mimic the pre-soaking of grain prior to feeding used by Scott (2003) who found a significant increase in feed intake following soaking. There was a strong negative correlation between hydration capacity and the starch content of grains examined in PGLP (Figure 41). This observation suggests that hydration capacity is reflecting differences in the gross chemical composition of the grains and explains the negative relationship observed between hydration capacity and the available energy content of grains for each animal type.

Adjustment for gross chemical composition

During PGLP a spreadsheet model was developed to predict the potential energy available from the digestion of grains by broilers from knowledge of the gross chemical composition of a grain and extent of digestion of each component. Initially it was assumed that other factors that may influence digestion such as digesta viscosity did not influence the extent of digestion or reduce the actual energy available below the potential calculated. Thus, a comparison between predicted and observed AME values can be used to identify the major grain characteristics causing actual AME to be below the value expected from knowledge of its chemical composition.

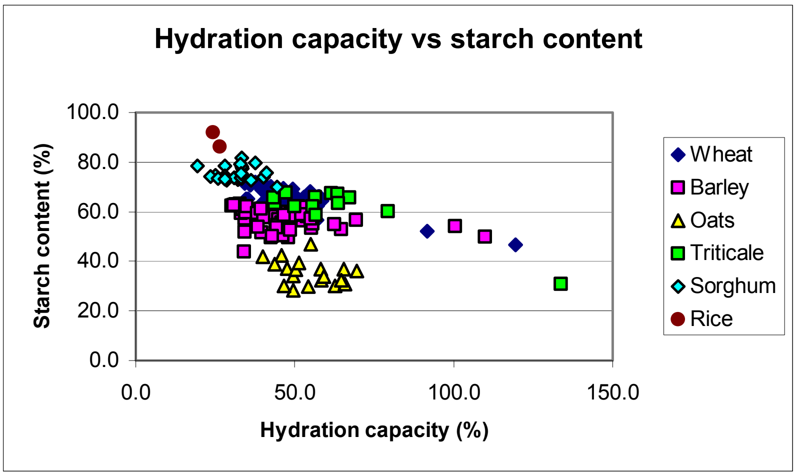


Figure 41. Relationship between hydration capacity and starch content of cereal grains fed to animals in PGLP.

Broiler AME was predicted from the proportion of the following chemical components and, shown in parentheses respectively, the gross energy (MJ/kg) and assumed digestibility (fraction) of each component; ash (0,0), lignin (15.0, 0), cellulose (16.0, 0), insoluble arabinoxylans (16.0, 0.05), soluble arabinoxylans (16.0, 0.25), β-glucans (16.0, 0.25), other polysaccharides (16.0, 0.25), oligosaccharides (16.0, 0.10), glucose (15.7, 1.0), starch (17.4, 0.98), crude protein (23.2, 0.90), lipid (39.3, 0.90), phytic acid (18.0, 0.10) and tannins (18.0, 0.10). The digestibility of protein and lipid was reduced below 1.0 to allow for endogenous gut losses. The gross composition was adjusted to sum to unity and predicted AME was corrected for grain water content and compared with observed values in Figure 42.

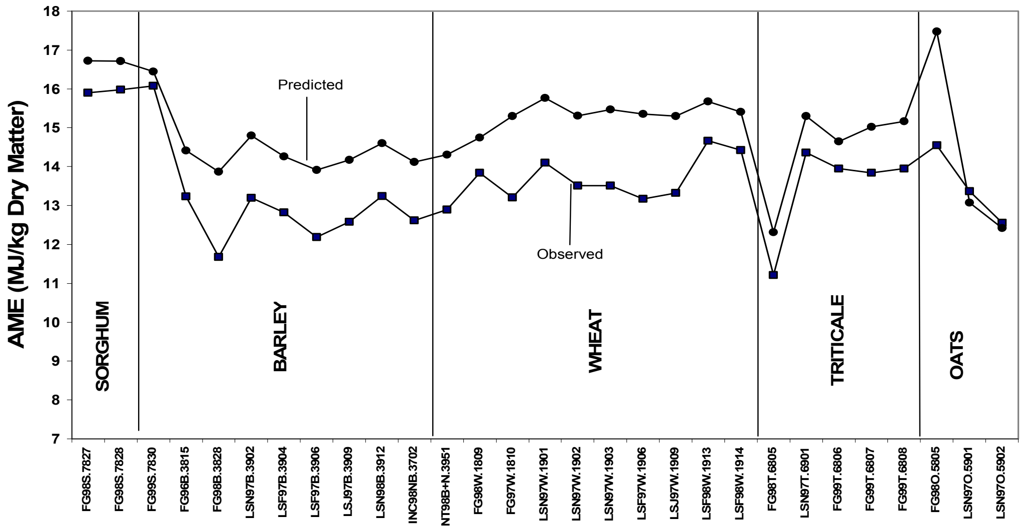


Figure 42. Spreadsheet model predicted broiler AME based on gross chemical composition and standard digestibility values compared with observed AME.

The pattern of changes in predicted AME followed closely the observed pattern confirming that much of the variation in available energy between grains can be explained by gross chemical composition. The most accurate predictions were for normal oat grain. The predicted values were substantially higher than the observed values for barley and wheat. Although the accuracy of the assumed endogenous energy losses can be questioned, it is probable that other characteristics of the grain affect the digestion of nutrients.

Because the model described takes account of gross chemical composition, the difference between predicted and observed AME values can be used to test the importance of other grain characteristics that may reduce digestion (Black 2001). The relationship between the difference in predicted and observed AME and hydration capacity presented in Figure 43 (R^2 = -0.02) suggests that hydration capacity *per se* has little direct effect on the AME content of grains for broilers. However, the relationship between the difference in predicted and observed AME and single kernel hardness (Figure 43) with an R^2 = 0.72 when sorghum, the naked oat sample and frosted barley sample are excluded, suggests that grain hardness may be a major factor affecting broiler AME once the effects of gross chemical composition are removed. Hard grains take up moisture more slowly than soft grains (Kent and Evers, 1994) suggesting that the rate of hydration has a greater effect on penetration of enzymes into the grain and extent of digestion as it passes rapidly through the digestive tract of broilers than the extend of hydration measured after prolonged soaking.

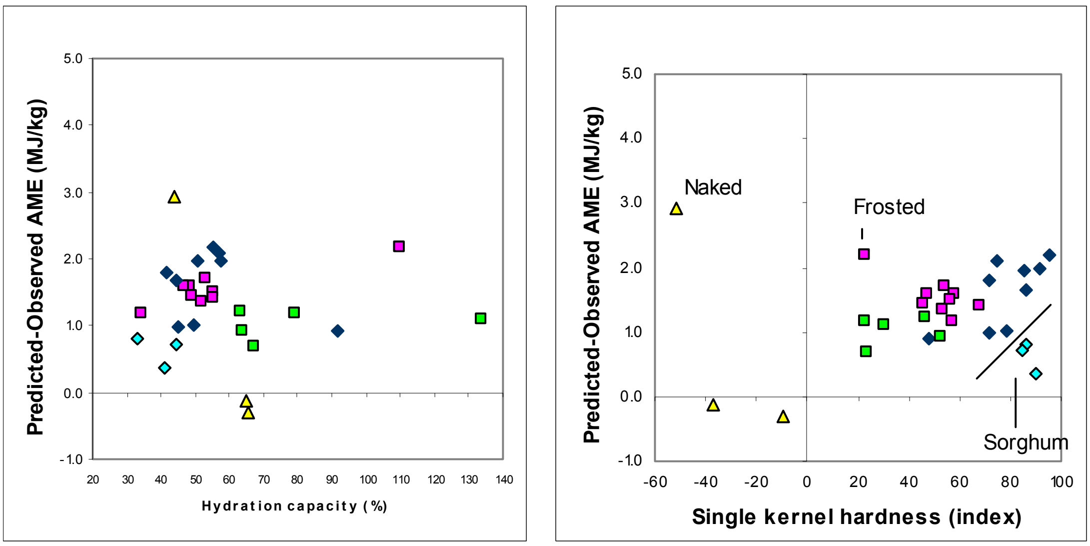


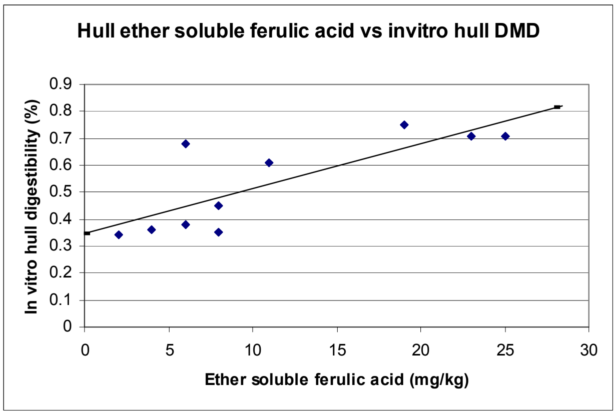
Figure 43. Relationships between predicted – observed AME for broilers and grain hydration capacity (left) and single kernel hardness (right).

Digestibility of oat grains

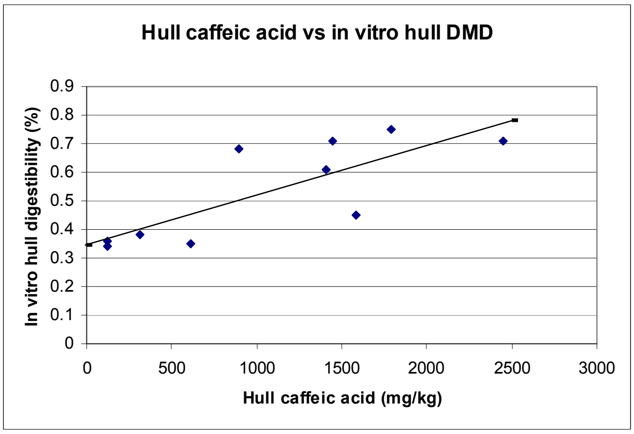
Digestibility of whole oat grains either *in sacco* or *in vivo* in cattle tends to be low for samples with a hull lignin content of greater than about 5 %. Lignin binds covalently to plant cell wall polysaccharides and proteins rendering them less accessible to digestive enzymes and reducing their digestibility. However, digestibility of oat grains with hull lignin contents of less than 5 % show little association with hull lignin content, particularly when digestibility is affected by environmental factors. There was also no association between digestibility and ash content of the hulls.

Possible reasons for differences in digestibility of oat grains with low hull lignin content are the type and amounts of phenolic acids, the nature of the chemical bonds between phenolic acids, polysaccharides and lignin or the arabinose to xylose ratio. The phenolic acid bonds can be either ester or ether linkages. Although ester linkages are more easily broken than the ether links, ester-ether linkages of ferulic acid are particularly resistant to microbial breakdown and the number of these linkages could alter digestibility of the hulls (Iiyama *et al*. 1990; 1994).

Alan Kaiser examined the chemical composition of eight oat grain samples containing less than 5 % lignin in hulls and selected for a wide range in whole grain *in sacco* and hull *in vitro* digestibility. The results showed that both the ether soluble ferulic acid and soluble caffeic acid content of the hull were moderately associated with digestibility (Figure 44). In addition, hull digestibility was related closely to the arabinose:xylose ratio in the hull, with digestibility increasing rapidly for samples with a ratio of greater than 0.14 (Figure 45). Further analysis of the possible role of the arabinose:xylose ratio was examined using NIR calibrations to predict whole grain values for several hundred oat grain samples for which *in vitro* hull and *in sacco* digestibility of whole oat grains were measured. The results presented in Figure 46 show a general positive relationship between aribinose:xylose ratio and both hull OMD and *in sacco* DMD, but there is no indication of a critical value associated with a rapid change in digestibility.



$Y = 0.0168 X + 0.35$, $R^2 = 0.63$



$$Y = 0.000175 X + 0.35, \quad R^2 = 0.63$$

Figure 44. Relationships between phenolic acid content of oat grain hulls and hull *in vitro* digestibility for hulls containing less than 5% lignin.

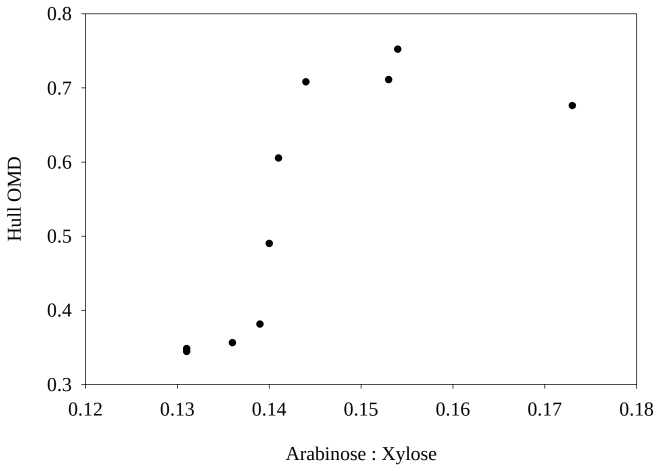
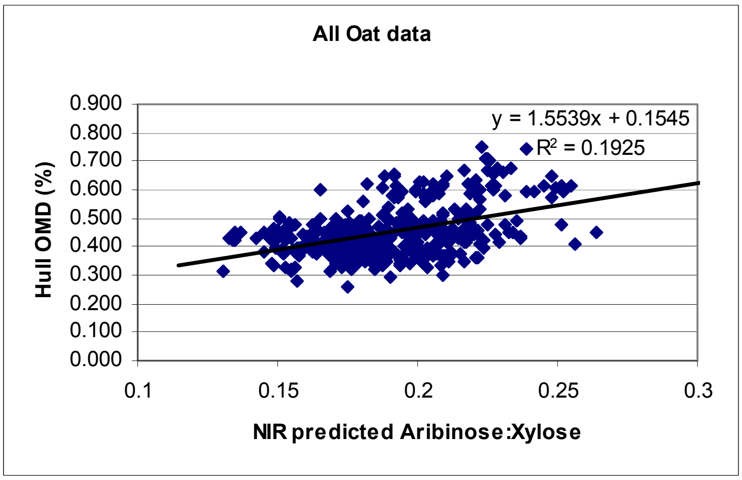


Figure 45. Relationship between hull organic matter digestibility (OMD) and total arabinose;xylose ratio for eight low lignin oat samples.



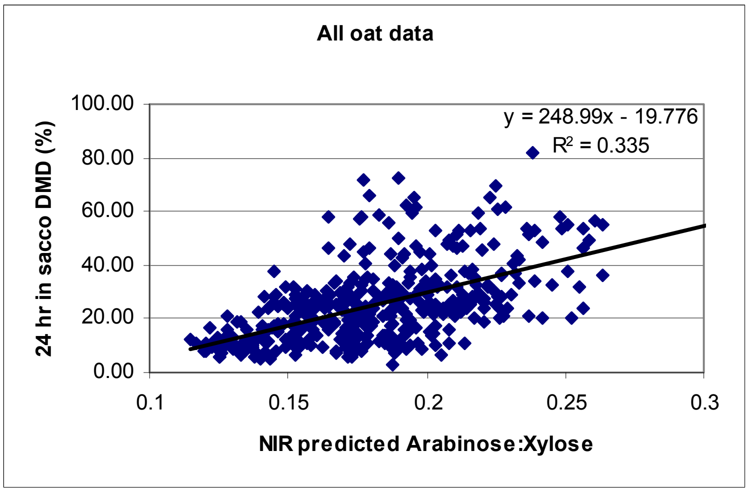


Figure 46. Relationship between NIR predicted total arabinose:xylose ratio and hull organic matter digestibility (OMD, top) and 48 hr *in sacco* dry matter digestibility (DMD, bottom).

Although several specific phenolic acids and the arabinose:xylose ratio show positive relationships with oat grain digestibility, the currently available evidence suggest that oat grain digestibility, particularly with oat grains with low hull lignin content, is likely to be determined by a yet to be quantified interaction between several factors. Further analysis of the PGLP data may identify these interactions. Although an understanding of the reasons for differences in oat grain digestibility is desirable, the NIR calibration to predict *in sacco* digestibility of whole oats has reasonable accuracy for samples with either more than or less than 5 % lignin in hulls.

Grain test weight and energy availability

Grain test weight or bulk density expressed as kg/hl is currently used along with screenings percentage by the animal and the livestock feed manufacturing industries as a primary method for estimating the likely energy value of grains for animals. The National Agricultural Commodities Marketing Association (NACMA) list the minimum test weight standards for each grain type with the assumption that grains with higher test weights have greater capacity to deliver energy to livestock. Current NACMA minimum test weight and screenings specifications are given in Table 30 for common cereal grains and grades.

Table 30. Current NACMA standards for cereal grain grading.

Grain type	Minimum Test weight (kg/hl)	Maximum screenings (%)
Wheat		
ASW1	74	5
AGP1	68	10
Feed 1	68	15
Barley	62.5	15
Oats	48	20
Triticale	65	10
Sorghum 1	71	11

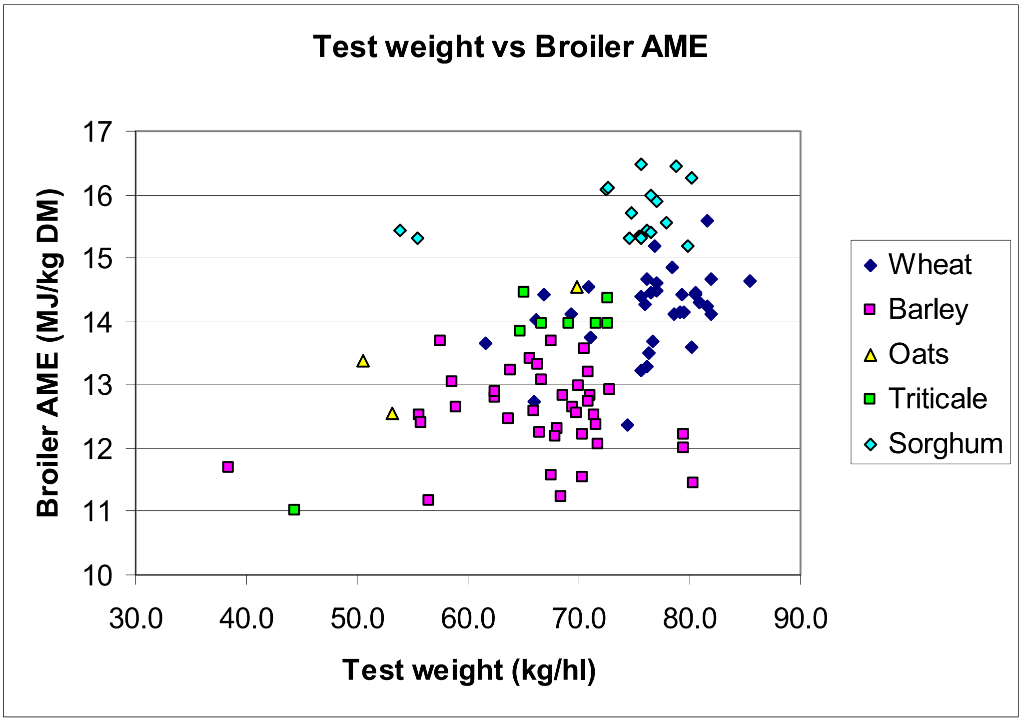
Correlations between various measures of the energy value of grains to animals and test weight obtained within PGLP are shown in Table 31. Although most available energy content variables showed a positive relationship with test weight when all grains were considered together, the within grain relationships were generally poor and interpretation could be misleading. The relationships showing individual grain values are illustrated for broilers, layers, pigs and cattle in Figures 47-50, respectively. For example, the AME content of wheat for broilers was positively correlated to test weight ($P<0.05$), but the AME values for samples above the NACMA test weight minimum of 68 kg/hl ranged from 12.4 to 15.6 (MJ/kg DM) compared with values from 12.7 to 14.4 (MJ/kg DM) for grain samples with test weights below the NACMA standards. These results suggest that the minimum standard is of little irrelevance for wheat fed to broilers. Nevertheless, for triticale samples fed to broilers and layers, the grain with the lowest test weight also had the lowest AME content. The highly significant positive relationship ($P<0.01$) between AME content and test weight was due entirely to the low test weight grain (44.4 kg/hl). The AME content of triticale samples with test weights above 64.8 (kg/hl) was not related to test weight. These results for triticale suggest that the NACMA minimum standard of 65 (kg/hl) for triticale fits closely with PGLP observations. This was not the case with barley fed to layers, where the grain with the lowest AME value had the lowest test weight, but there was little further effect on AME content of grains once test weight reached 55 kg/hl, compared with the NACMA minimum of 62.5 kg/hl.

There was only one significant (positive) relationship between test weight and total available energy intake for the all grain and animal types examined and this relationship was across grain species. The lack of significant within grain relationships suggests that productive energy intake and therefore animal performance is not influenced by the test weight of cereal grains.

Table 31. Correlations between test weight (kg/hl) of cereal grains and various measures of the energy value for different animal types.

Measured animal variable	Grain species	Correlation coefficient	Significance (P<)
Broiler AME (MJ/kg DM)	All grains	0.46	0.01
	Wheat	0.39	0.05
	Barley	-0.30	NS
	Triticale	0.92	0.01

	Sorghum	0.27	NS
Broiler AME intake index	All grains	0.43	0.01
	Wheat	0.18	NS
	Barley	-0.21	NS
	Triticale	0.67	NS
	Sorghum	0.67	NS
Layer AME (MJ/kg DM)	All grains	0.59	0.01
	Wheat	0.22	NS
	Barley	0.48	0.01
	Triticale	0.84	0.01
	Sorghum	0.25	NS
Layer AME intake index	All grains	0.07	NS
	Wheat	0.14	NS
	Barley	0.01	NS
	Triticale	0.23	NS
	Sorghum	-0.22	NS
Pig faecal DE (MJ/kg DM)	All grains	0.52	0.01
	Wheat	0.15	NS
	Barley	0.66	0.01
	Triticale	0.00	NS
	Sorghum	0.44	NS
Pig DE intake index	All grains	0.05	NS
	Wheat	0.01	NS
	Barley	0.24	NS
	Triticale	-0.47	NS
	Sorghum	-	-
Cattle ME (MJ/kg DM)	All grains	0.63	0.01
	Wheat	0.38	NS
	Barley	0.83	0.01
	Oats	0.19	NS
	Triticale	0.61	NS
	Sorghum	-	-
Cattle ME intake (kg/d)	All grains	0.05	NS
	Wheat	0.01	NS
	Barley	0.24	NS
	Oats	-	-
	Triticale	-0.47	NS
	Sorghum	-	-



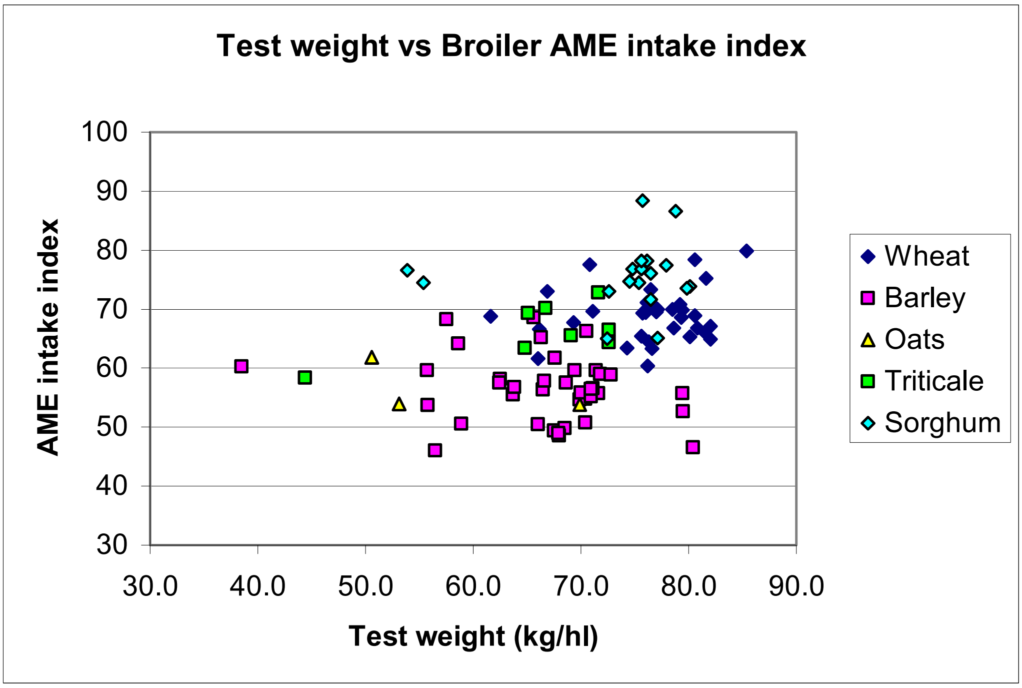
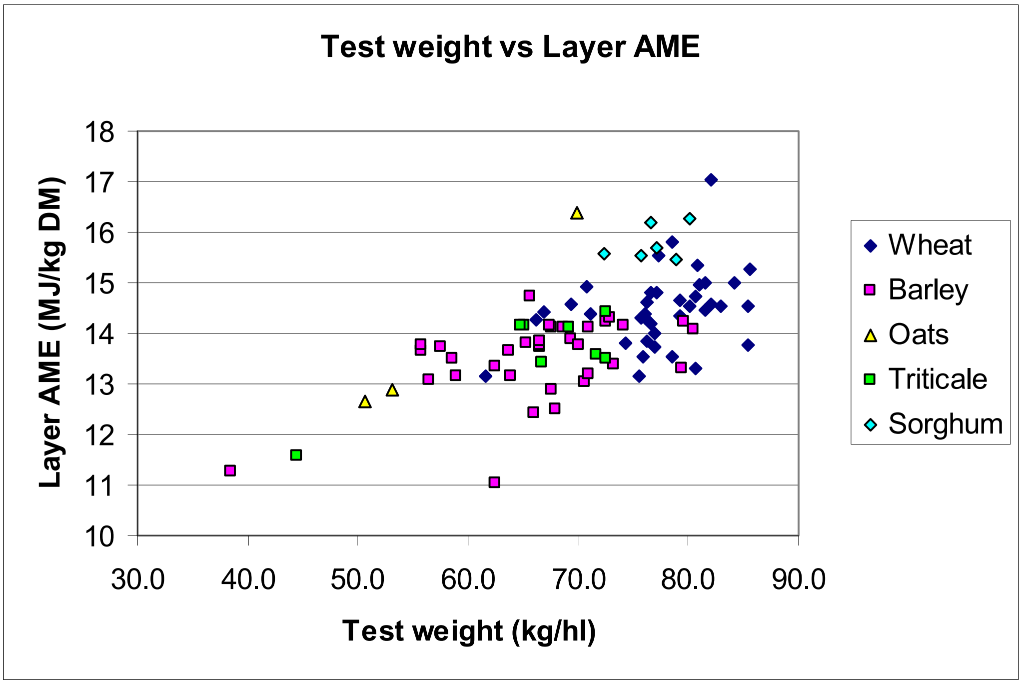


Figure 47. Relationships between test weight and AME or AME intake index for broilers consuming different cereal grain species.



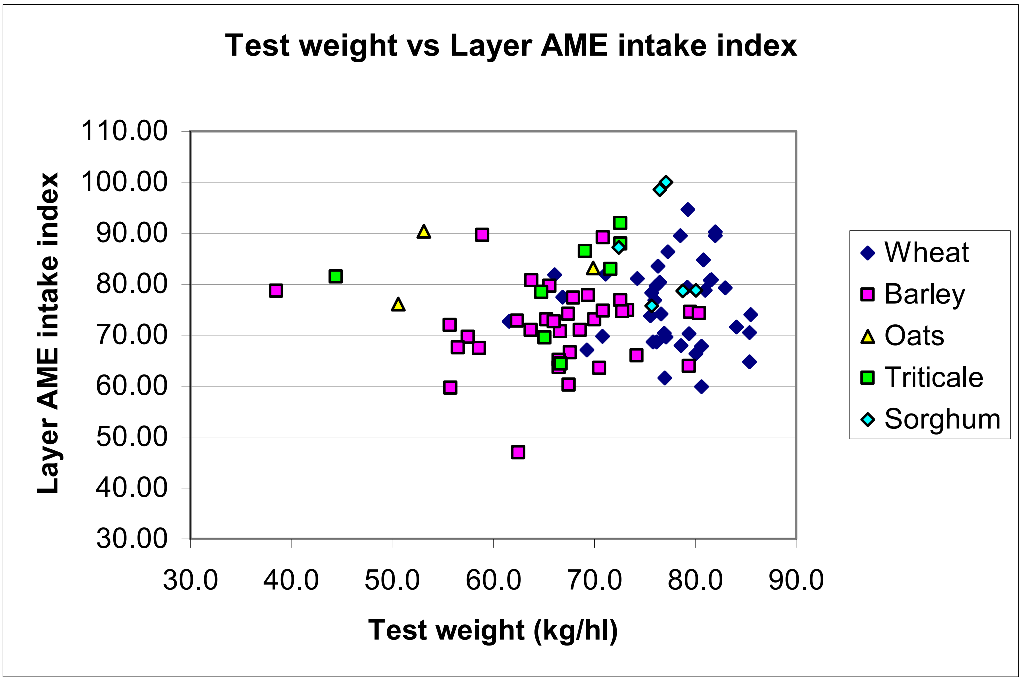
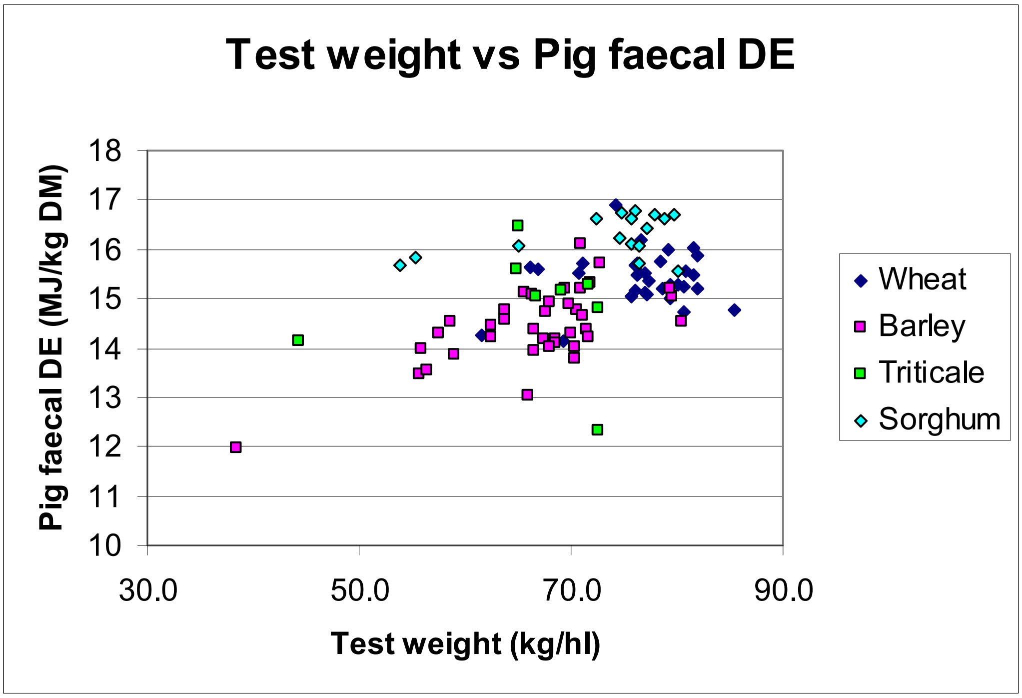


Figure 48. Relationships between test weight and AME or AME intake index for layers consuming different cereal grain species.



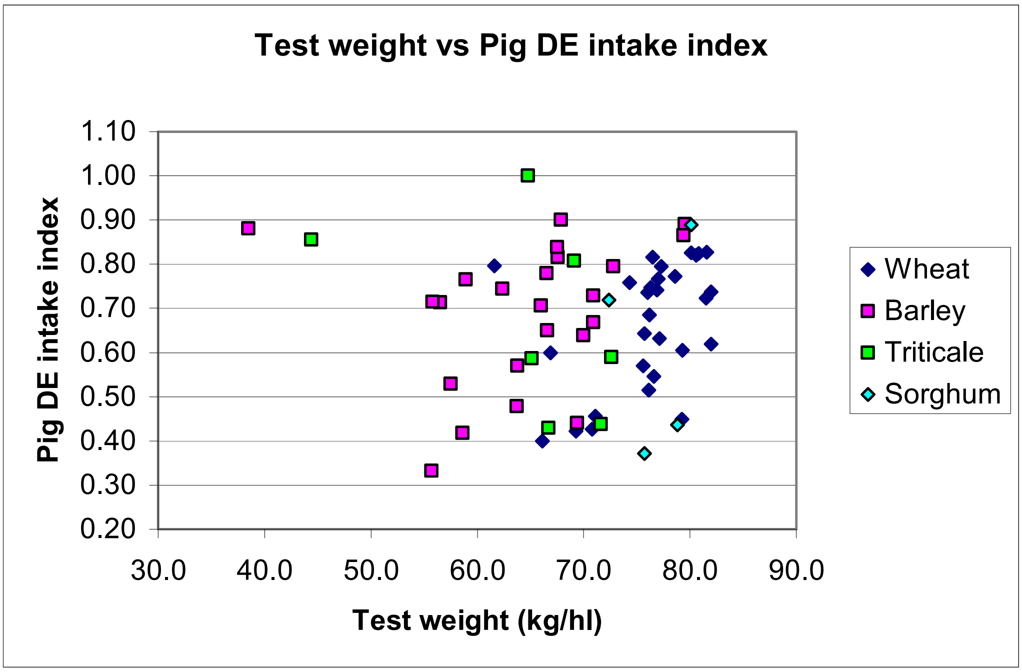
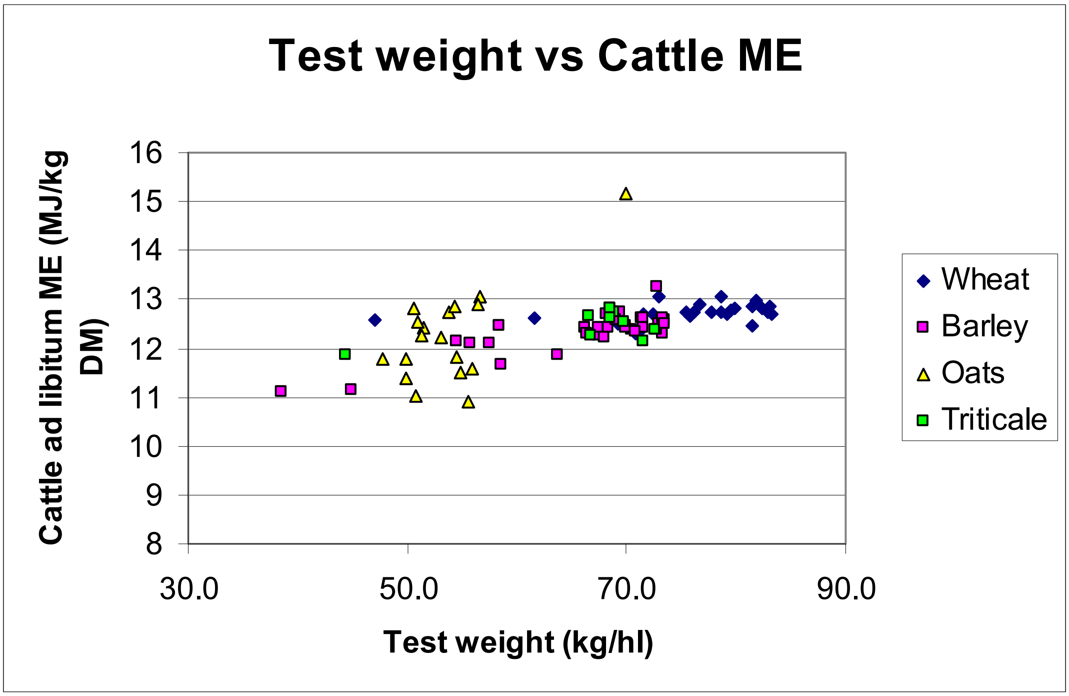


Figure 49. Relationships between test weight and faecal DE or faecal DE intake index for pigs consuming different cereal grain species.



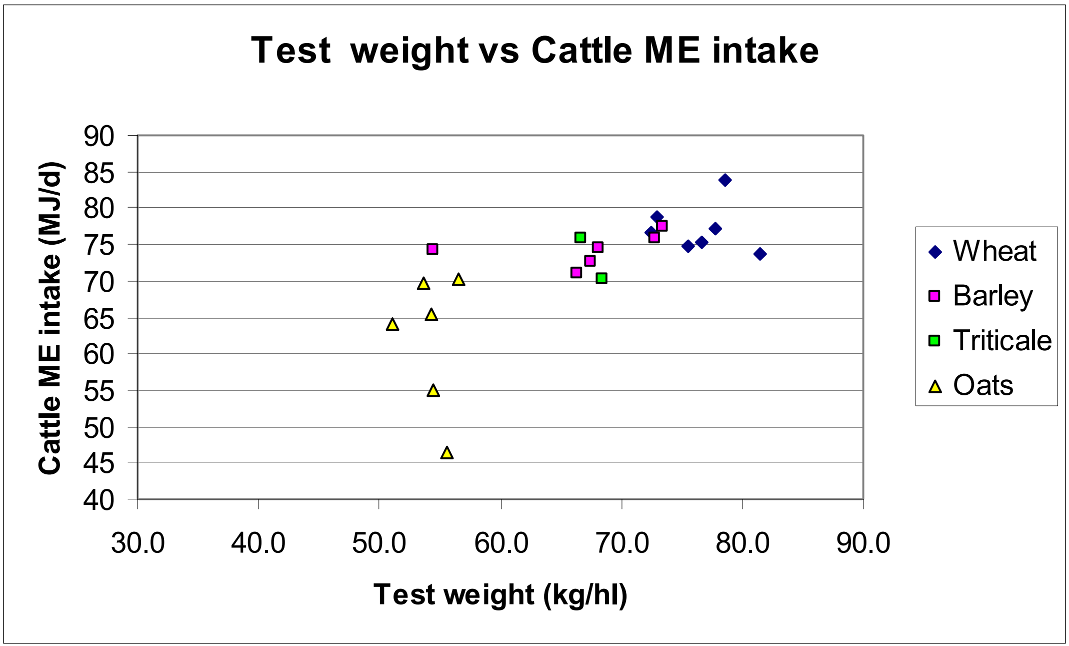


Figure 50. Relationship between test weight and ME or ME intake index for cattle consuming different cereal grain species.

In summary, the information presented suggests that test weight is not a good indicator of the potential energy value of a cereal grain for animals and that accurate NIR calibrations developed for predicting the available energy content and total available energy intake would be of greater benefit for determining the likely animal productivity obtained from individual batches of grains.

Assessing the 'hotness' of cereal grains for ruminants

Acidosis is an important nutritional problem for feedlot cattle and dairy cows caused by feeding high amounts of some cereal grains. Ruminal lactic acidosis is a clinical disorder of cattle that can result in rumenitis, metabolic acidosis, lameness, hepatic abscesses, pneumonia and death. Sub-clinical acidosis in dairy cattle, particularly those grazing pasture and given access to grain based concentrates for a short time, results in a decreased intake of pasture and can have a substantial impact of productivity (Bramley *et al*. 2005). Acidosis is difficult to measure in cattle and sub-acute acidosis is an insidious problem in both feedlot and dairy cattle. Bramley *et al.* (2005) identified that approximately 10% of dairy cows from a sample of 800 animals had ruminal conditions that were associated with grain induced acidosis, which resulted in lower milk fat content and higher risk of lameness. Acidosis is often well managed in feedlot cattle, but can reduce the intake and productivity of individual animals through ulceration of the rumen and lameness.

The susceptibility of cattle to rumen acidosis varies with grain species and also with particular parcels of grain from one species. The likelihood that a grain will cause acidosis depends on the rate of production of volatile fatty acids in the rumen, particularly the concentration of lactic acid, and the buffering capacity of rumen contents. Although the method of feeding grain can have a significant influence on the chances of acidosis occurring, characteristics of the grain are also important. Consequently, an attempt was made from the results obtained within PGLP to develop a method for predicting the relative 'hotness' of individual cereal grain samples. Subsequently, a NIR calibration was developed to predict the acidosis index value for any grain sample.

The acidosis index was calculated from a combination of *in sacco* and *in vitro* analyses and from several components of grain chemical composition. The results from all the grains fed to ruminants and for which *in sacco* and *in vitro* analyses had been made, were used to develop the index as follows.

Acidosis Index = ((6 hr *in sacco* starch disappearance * starch content)
*((total *in vitro* acid production + 2*in vitro lactic acid production)/total acid production)) – (41*NDF content)

The logic behind the algorithm was that the 6 hr *in sacco* disappearance of starch (fraction of total starch) from rolled grain normally fed to ruminants multiplied by the starch content provides an indication of the total rate of starch digestion. The figure was adjusted for the relative release of lactate compared with total acid production and reduced by the fibre content of the grain stimulating saliva flow and pH buffering. The parameters were derived from simulations with Barry Nagorcka's AusBeef model and the paper by Defoor *et al.* (2002).

The final index was adjusted to have a value potentially between 0 and 100+ by dividing all values by the largest value and multiplying by 100. Figure 51 shows the Acidosis Index for the grains fed to ruminants and demonstrates considerable variation both between and within cereal grain species. Details of the NIR calibration for predicting Acidosis Index are given in the section outlining the development and accuracy of all PGLP NIR calibrations. The calibration has moderate accuracy and should be valuable for identifying the relative 'hotness' of any particular grain sample. A study is currently being undertaken by Ian Lean from Bovine Research Australia to evaluate the accuracy of the calibration. Twenty grains across wheat, barley, triticale, oats and sorghum have been selected from the 2005-06 harvest using the NIR calibration to obtain grains vary widely in predicted acidosis index. An acute challenge of up to 4kg of each grain will be given to cattle and rumen pH, lactic acid concentration and other measures of rumen function made. These results will be used to rank the 'hotness' of grains relative to the NIR predictions. The algorithm used to predict acidosis index may be adjusted following the experiment and a new NIR calibration developed. The results from the experiment will provide good evidence of the acidosis index score that is likely to be associated with reductions in productivity of cattle and where management of the syndrome needs more or less attention.

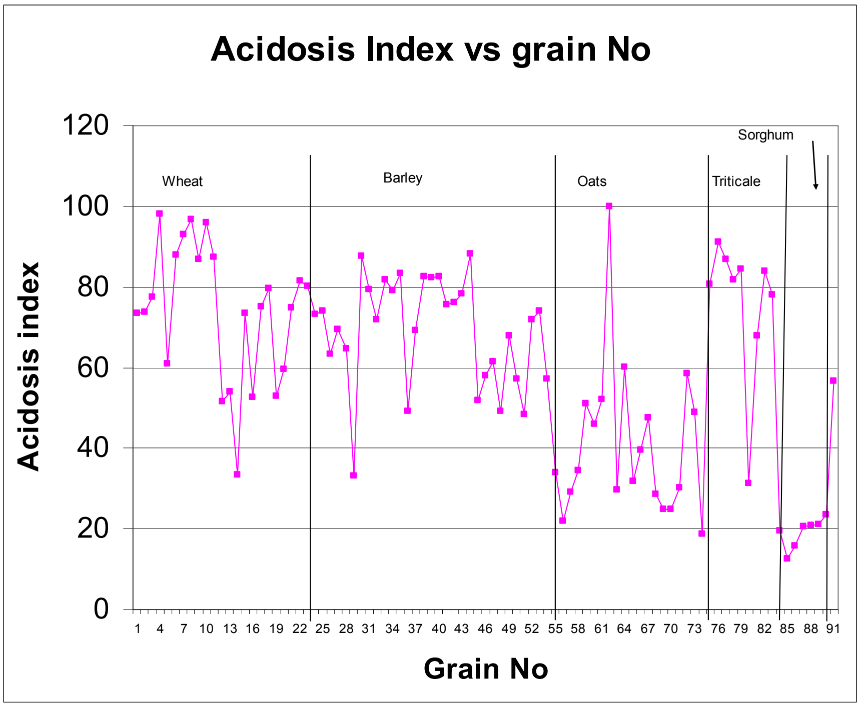


Figure 51. Calculated acidosis index for all grains fed to ruminants within PGLP and for which *in sacco* and *in vitro* starch digestibility values were obtained.

Differences between grain and animal types in energy utilization

The effect of grain cereal species on the growth rate and feed conversion efficiency for broiler chickens could be evaluated because body weight and feed intake were measured in all experiments during the measurement of AME. Growth rate and feed conversion were also measured in several of the experiments in which feed intake was measured in weaner pigs, but the diets were deficient in protein and resulted in lower growth rates than normal. Results from the broiler experiments have been used to evaluate the effects of cereal grain species on the efficiency of energy utilization. A comparison in the site of digestion between broiler chickens and pigs is made also for individual samples of wheat and sorghum.

Comparison of cereal grain species for performance of broilers

There was a poor relationship between the AME content of grain (MJ/kg) and either growth rate of broilers or the efficiency of feed use (FCR, feed:gain) both within and between grain species (Figure 52). However, there were stronger relationships between total daily AME intake (MJ/d) and either growth rate or FCR (Figure 53). These relationships were particularly strong ($P<0.01$) within grain species. Nevertheless, it is apparent that for the same daily intake of available energy of approximately 1.5 MJ/d (1.46-1.61 MJ/d), growth rate of chickens offered wheat based diets was 20% (61.5 vs 51.0 g/d) higher than for those offered sorghum based diets. Similarly, 17% less feed was consumed for each unit of body weight gain for the chickens offered wheat than sorghum based diets (FCR 1.55 vs 1.85).

The observations suggesting that energy available from sorghum is used less efficiently by broiler chickens than the energy from wheat are supported by an experiment conducted in industry by R. MacAlpine (Table 32). Despite diets having similar AME content, replacing sorghum for wheat in diets significantly reduced the efficiency of feed energy use. Further support showing that sorghum based diets are used less efficiently and produce significantly slower growth rates in young broiler chicks has been produced recently by Perez-Maldonada *et al* (2006).

Table 32. Effect of wheat and sorghum based diets on efficiency of feed (FCR, feed:gain) and energy use by broiler chicks from 0-35 days of age (R. MacAlpine, unpublished).

Grain base for diet	Diet AME (MJ/kg)	FCR	MJ AME/kg gain
Wheat	12.55 [a]	1.58[a]	19.8 [a]
Wheat: sorghum (50:50)	12.69 [a]	1.59[a]	20.2 [a]
Sorghum	12.82 [a]	1.63 [a]	20.9 [b]

[a,b] Values with different letters differ significantly ($P<0.05$)

There are several possible explanations for the poorer use of available energy from sorghum than from wheat for chicken growth including:

- A deficiency in essential amino acids available for growth due to the lower protein content and digestibility of sorghum proteins containing a high content of disulphide bonds.
- A deficiency of amino acids due to the high tannin and polyphenol content and/or the high phytic acid content of sorghum binding dietary and enzyme proteins and released amino acids thus reducing the digestion of protein and availability of amino acids for growth.
- A deficiency in amino acids due to the inadequate hydrolysis of protein and absorption of peptide chains that are too long and/or of incorrect amino acid structure to be incorporated directly into body proteins.
- A deficiency in some other essential nutrient required for protein synthesis and growth.
- A lack of synchronisation in the timing of the release of amino acids and of energy from starch digestion that results in the catabolism of amino acids rather than their incorporation into body protein.
- A difference between the grain sources in the timing of the release of glucose from starch digestion and its effects on insulin stimulation of protein synthesis.

Results from all grains shown in the Figure 53b with a daily dietary AME intake between 1.46 and 1.61 MJ were analysed to evaluate several of the suggested possible explanations causing the range in efficiency of feed use (FCR) within each grain species and between wheat and sorghum, when total available energy intake was similar. There was a strong positive relationship (R^2 = 0.73) between the efficiency of feed use and the crude protein content of the grain in diets as shown by the decline in FCR (Figure 54). This result suggests that the protein content of the diets may have limited growth rate of the chickens. However, a protein deficiency *per se* would seem unlikely for chickens from 22-29 days of age because the total protein contents of the diets ranged from approximately 23-34% DM. Analysis of the amino acid content of sorghum and wheat proteins shows that sorghum protein contains less arginine, cystine, methionine, lysine and tryptophan than wheat protein. There was a particularly strong relationship between FCR and the daily intake of arginine from grain for both sorghum and wheat up to an intake of approximately 0.9 g/d (Figure 55), suggesting that arginine may have been first limiting amino acid for broiler performance with the sorghum and some wheat based diets used in the experiments (Black *et al.* 2005). Although the diets used in the PGLP experiments were cold pelleted before being offered to broilers, there is strong evidence showing that the digestion of animo acids in sorghum is depressed further following heat treatments (Duodu *et al.*2002).

The analyses presented suggest that a protein inadequacy, and particularly arginine as the first limiting amino acid, in the diets with a constant grain and casein content and the lower digestibility of sorghum proteins may have been responsible for the differences in the efficiency of use of available energy from sorghum relative to wheat based diets when the daily intake of AME was similar. If the low content and digestibility of sorghum protein are the main reasons for the poor utilisation of available energy by broiler chickens, there should be differences between cultivars and chicken growth rates should respond to additional dietary amino acids. However, this conclusion is not supported by recent observations from R. MacAlpine (unpublished) who found that the inclusion of 10% additional amino acids in the form of soybean meal and synthetic lysine and methionine to sorghum diets formulated to have adequate protein did not significantly improve FCR in broiler chickens. One possible explanation for the lack of response to additional amino acids may be the presence of anti-nutritional factors such as tannins or phytic acid. However, neither tannins nor phytic acid were found to be the likely reasons for reduced efficiency of use of sorghum by chickens in the PGLP results described above (Black *et al.* 2005).

The most plausible explanation for the poor utilisation of energy available from sorghum may be an asynchrony in the absorption of energy providing nutrients and amino acids for protein synthesis. The major source of protein in the experiments was casein which is rapidly digested, whereas the major source of energy was from cereal starch. There is likely to be considerable differences between sorghum and wheat in the timing of starch digestion. Once the endosperm cell walls of the grains are fractured by the action of the gizzard, starch granules from wheat are readily accessible to amylolytic enzymes. The rate of digestion of wheat starch would then be influenced by factors such as size of the granules, content of resistant starch and viscosity of the digesta. However, the starch granules from sorghum are completely surrounded by a protein matrix which must be disrupted before the starch can be digested. Thus, it is hypothesised that the amino acids from casein in the sorghum based diet are largely absorbed and catabolised before energy was available for protein synthesis from the hydrolysis of starch. This concept of asynchrony may help explain the observations by R MacAlpine that adding amino acids did not improve the efficiency of utilisation of sorghum based diets because the amino acids would have been more rapidly absorbed than glucose from starch. However, the concept does not fit well with the observation that the efficiency of feed use by chickens offered the wheat based diets continued to improve as the protein content of the grain increased, unless the amino acids from casein were so rapidly absorbed relative to the digestion of wheat starch that the more slowly digested wheat protein provided the majority of the amino acids used for growth. The latter idea could explain why chickens continued to improve in performance as protein content of wheat diets increased to over 30% DM.

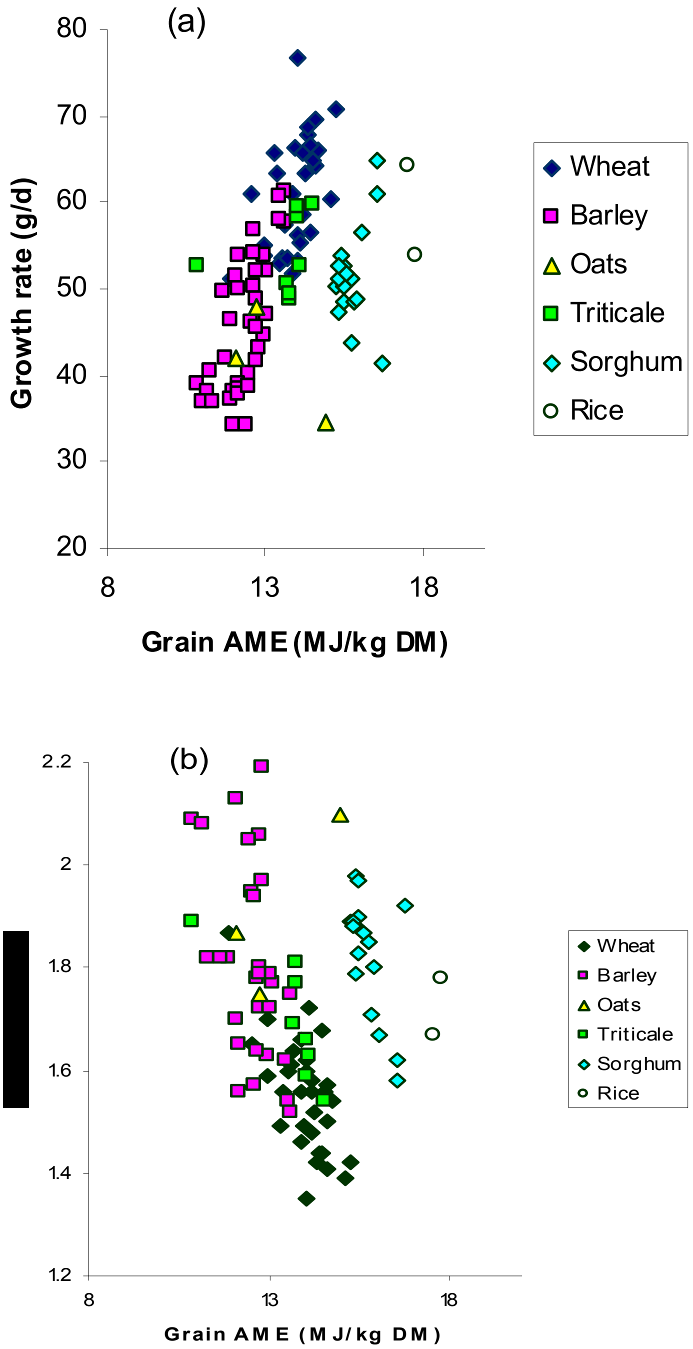


Figure 52. Relationship between grain AME content and (a) growth rate and (b) feed conversion ratio (FCR) for broiler chickens given different cereal grains.

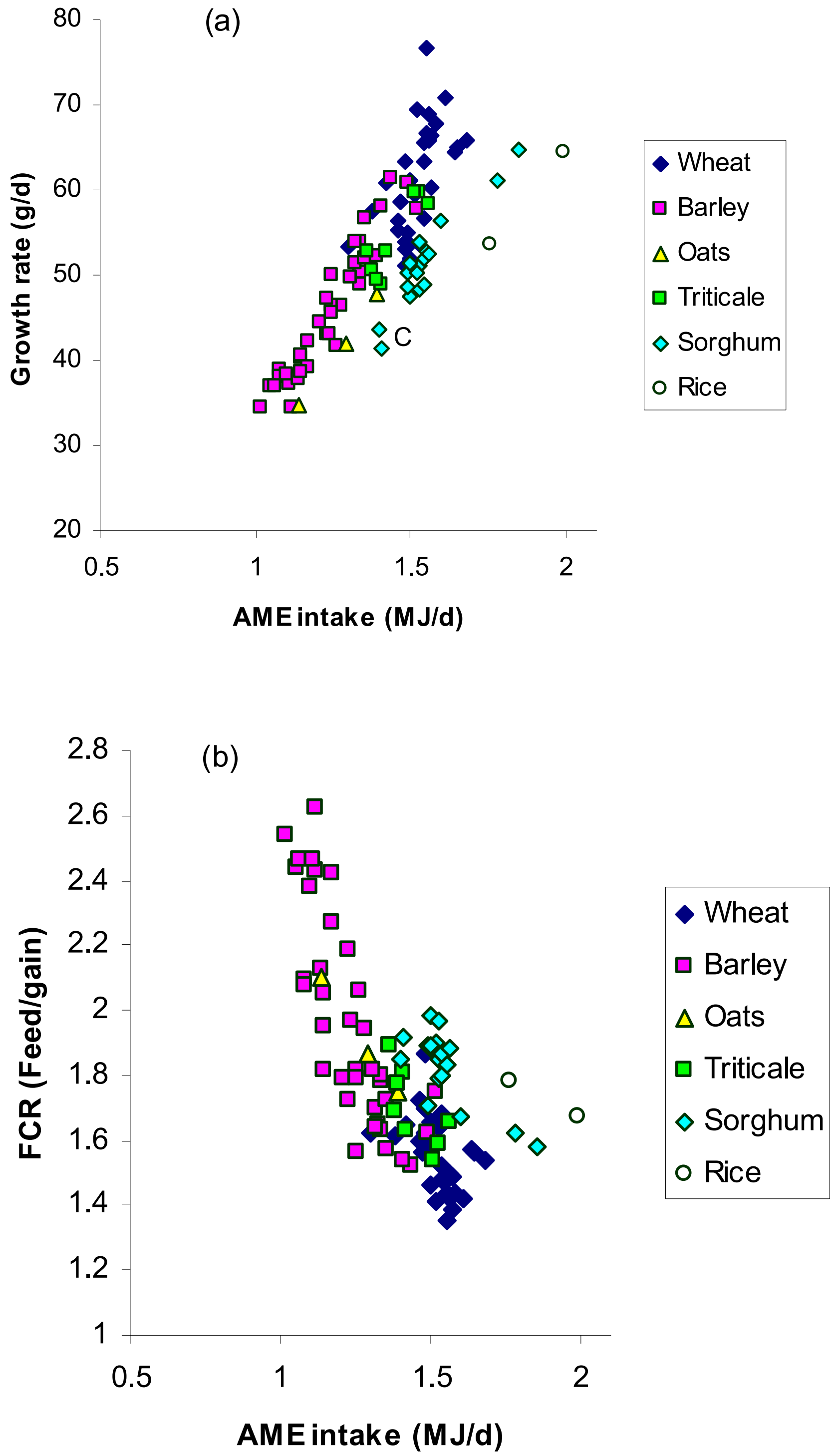


Figure 53. Relationship between AME intake and (a) growth rate and (b) feed conversion ratio (FCR) for broiler chickens given different cereal grains.

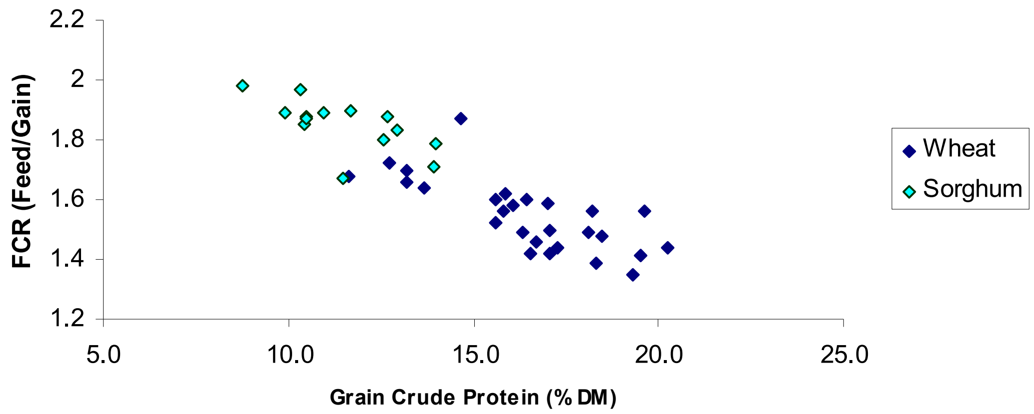


Figure 54. Relationship between feed conversion efficiency (FCR) and grain protein content for broiler chickens fed wheat or sorghum based diets.

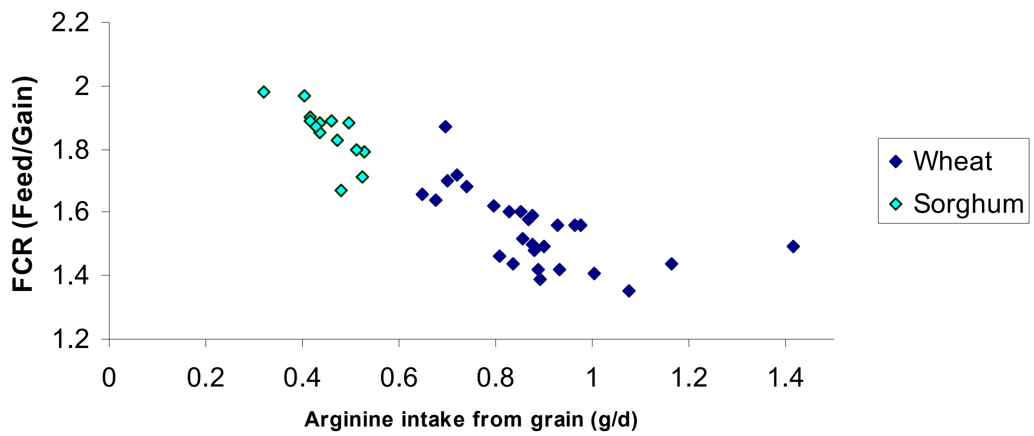


Figure 55. Relationship between feed conversion efficiency (FCR) and total arginine intake from grains for broiler chickens fed wheat or sorghum based diets.

The results presented from several sources show that energy from sorghum based diets is used less efficiently for growth of broiler chickens than energy from wheat based diets. The most probable reason for the inferior performance of birds consuming sorghum is an asynchrony in the timing of release during digestion and absorption of amino acids and starch derived glucose for growth. The slow rate of digestion of sulphide-bond rich kafirin proteins in the protein matrix of sorghum is the most likely cause of the asynchrony. Thus, there is an opportunity to first test the hypothesis by examining the progress of digestion of protein and starch as digesta moves through the digestive tract of chickens. Then, if the hypothesis is verified, improve the rate of digestion of sorghum matrix proteins by either plant breeding or grain processing techniques including application of protease enzymes targeting high sulphide-bond proteins.

Comparison between pigs & poultry in site of digestion: opportunities for improving the value of sorghum for pigs

Examination of the relative digestion of energy in the small and large intestines for individual grains by pigs and poultry provides evidence there is an opportunity to increase the energy value of sorghum for pigs. Table 33 shows that the energy released during digestion in the small intestines (ileal DE, MJ/kg) is similar for pigs and broilers consuming a diet based on a sample of Janz wheat (1810) or Tahara triticale (6806). Little further energy is digested by broilers as the digesta moves through the large intestine as indicated by the high ileal DE:AME ratios. However, with pigs consuming the same grains, from approximately 1.5 to 2.5 extra MJ/kg of energy from the grains was digested in the large intestines. Microbes with their capacity to digest cell wall and grain hull components in the large intestines provide the additional energy for pigs consuming grains similar to wheat, triticale and barley, whereas there is limited microbial activity in the hind-gut of broilers.

Examination of the results for sorghum (Table 33) shows a different pattern in the site of digestion between pigs and poultry. The total energy made available from digestion of sorghum sample (7827) was similar for pigs and broilers. Little digestion of sorghum occurred in the large intestines of broilers, which was similar to the wheat and triticale samples. However, approximately 2.5 MJ/kg less energy was digested in small intestines of pigs, but this was derived through microbial fermentation in the large intestines. The majority of the energy derived from microbial fermentation should be capable of being digested in the small intestines of pigs because sorghum has a small cell wall and hull content relative to barley, wheat and triticale. Approximately 20%, or 0.5 MJ/kg, additional energy would be available for metabolism in pigs if sorghum digestion in the small intestines was similar to broilers. Further discussion of the differences in site of digestion between pigs and broilers is given by van Barneveld *et al.* (2001).

The most likely reason for the poor digestion of sorghum in the small intestines of pigs compared with broilers would seem to be a lower digestion of the high sulphide-bond kafirin proteins by pigs than poultry and perhaps a reduced digestion of starch because of entrapment in the protein matrix envelopes. The comparison of site of digestion for sorghum between pigs and poultry indicates that the energy value of sorghum for pigs could be enhanced by improving the digestion of the high-sulphur kafirins through plant breeding or processing techniques, including the use of appropriate protease enzymes.

Table 33. Comparison of the site of digestion of individual wheat, triticale and sorghum samples by pigs and broilers.

	Wheat (1810)		**Triticale (6806)**		**Sorghum (7827)**	
	Pig	**Broiler**	**Pig**	**Broiler**	**Pig**	**Broiler**
Ileal DE (MJ/kg)[a]	12.7	13.1	13.4	13.5	13.9	16.1
Faecal AME-DE (MJ/kg DM)[b]	15.5	13.3	15.2	13.9	16.4	15.9
Ileal:faecal ratio[c]	0.82	0.99	0.88	0.97	0.85	1.01

[a] Ileal digestible energy represents energy digested in the small intestines
[b] Faecal DE in pigs and AME in broilers represents total energy digested
[c] Ileal:faecal ratio represents the proportion of total digestion occurring in the small intestines

Comparison between wheat types for supplying energy to cattle
Anecdotal discussion among dairy farmers and some dairy consultants suggest that red feed wheat grown in Tasmania is of lower value for lactating dairy cattle than traditional hard wheat varieties from the mainland. One sample of the red feed wheat, Tennant, was obtained from a grower in Tasmania and used in the cattle *ad libitum* experiment. Results from PGLP have been used to investigate the effect of grain hardness and type of wheat on available energy content, available energy intake, acidosis index and performance of growing cattle.

The ME content of wheat for cattle was estimated on 25 wheat samples from 20 cultivars or breeders lines. Acidosis index was determined for 22 of these grains. The wheat samples included soft red, soft white, hard white and waxy endosperm grains classified as bread, feed and noodle types (Table 34). Seven of the wheat samples were included in an experiment with young, 335 kg steers where feed intake and growth rate were determined. The rations offered to cattle contained 70% grain and 30% forage.

Table 34. Wheat samples examined for their energy value for cattle in PGLP.

Cultivar name & condition	Description	Single kernel hardness index	Relative hardness
Oxley	hard white wheat	45	intermediate
VK058	breeders line - hard white	72	Hard
Currawong	white feed wheat	72	Hard
Currawong (rain damaged)	white feed wheat	50	intermediate
Waxy Janz[a]	hard waxy wheat (mixed red & white)	74	Hard
Currawong	white feed wheat	68	intermediate
Declic	red feed wheat	69	intermediate
Kelallac	hard white APW wheat	66	intermediate
Ouyen	hard white wheat	81	Hard
Rosella	soft white noodle wheat	27	Soft
Swift	hard white bread wheat	67	intermediate
Triller	soft white biscuit wheat	34	Soft
Janz (frosted)	prime hard white bread wheat	48	intermediate
Janz	prime hard white bread wheat	75	Hard
Ouyen (frosted)	hard white wheat	61	intermediate
More	red feed wheat	48	intermediate
Chara (<2.2mm)	hard white bread wheat	89	Hard
Chara (>2.2mm)	hard white bread wheat	56	intermediate
Sunlin[a]	prime hard white bread wheat	75	Hard
Dollarbird[a]	hard white bread wheat	74	Hard
Apollo[a]	hybrid - hard white bread wheat	70	Hard
QAL2000[a]	soft white biscuit wheat	33	Soft
Brennan[a]	high yielding white feed wheat	37	Soft
Tennant[a]	red feed wheat	10	v. soft
Sunstate	prime hard white bread wheat	86	Hard

[a] Grains used in the cattle feeding experiment.

ME content of grains for cattle

The ME content for cattle of the wheat samples examined in PGLP is shown in Figure 56. The value for the Tennant sample was 12.9 MJ/kg DM compared with the average of 12.7 MJ/kg DM for all the wheat samples examined. Values for the other red feed wheat cultivars, Declic and More, were 12.9 and 12.7 MJ/kg DM, respectively. Grains with the highest ME contents were a sample of the soft biscuit wheat, QAL2000 (13.07 MJ/kg), and a sample of waxy Janz (13.05 MJ/kg). Waxy grains have a high proportion of amylopectin compared to amylose in the starch. Starches containing high proportions of amylopectin are digested more efficiently than high amylose starches because branching of the glucose molecules increases the accessibility of digestive enzymes to the starch molecules. The samples of the hard white bread wheats, Oxley (12.18 MJ/kg DM) and VK058 (12.33 MJ/kg DM), had the lowest ME contents for cattle.

The results presented suggest that the energy content of red feed wheats for cattle is slightly above average and higher than most of the hard white bread wheats.

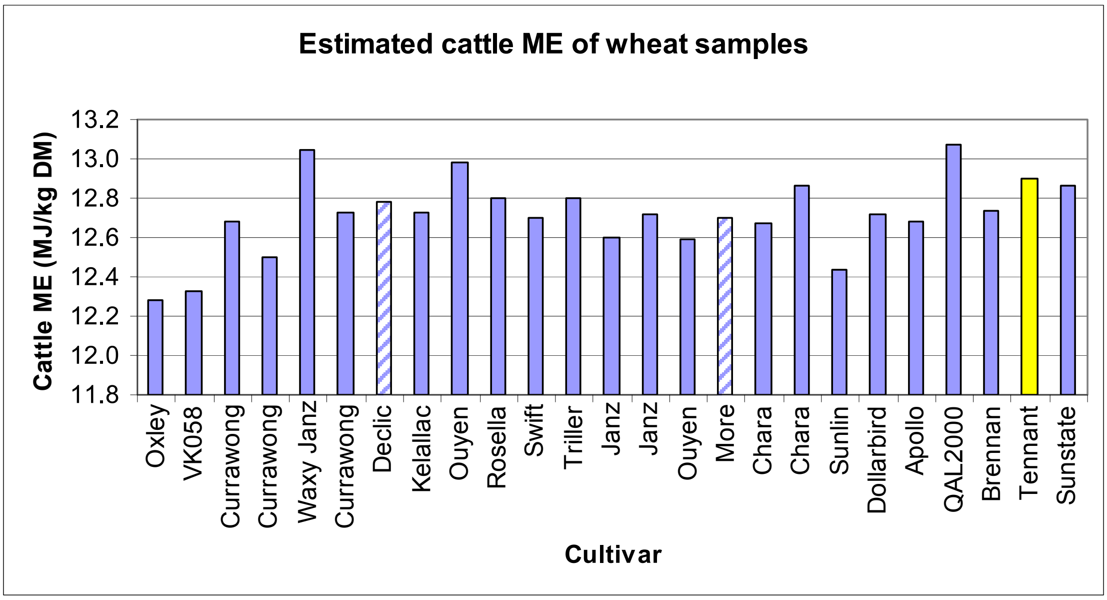


Figure 56. Estimated ME content values for cattle of wheat samples examined in PGLP. The Tasmanian sample of the cultivar Tennant is shown in yellow and the other two red wheats examined, Declic and More, are hatched.

Acidosis Index

The relative ability of a grain to cause lactic acidosis in cattle was estimated for all grains through an acidosis index. The index can have a value from 0-100+, with high values indicating a greater capacity of the grain to cause acidosis. The index value below which the grain may be regarded as 'safe' for feeding high amounts to cattle is not known. However, an experiment is in progress to provide information that should allow a safe index threshold value to be established for cattle.

The acidosis index value for 22 wheat samples is shown in Figure 57. The index value for the Tennant sample was 82 compared with an average for all wheat samples of 72. Corresponding values for the other two red wheat samples, Declic and More, were 93 and 74, respectively. The highest acidosis index values were for the relatively large grained white wheat, Kelallac (97), and the soft noodle wheat, Rosella (96). The lowest values were for low starch and high fibre content frosted or pinched samples, Ouyen-frosted (33), Janz-frosted (52), Chara-pinched (53). The sample of the hybrid hard wheat, Apollo, with relatively small grain size also had a low acidosis index of 53.

The results suggest that the susceptibility of cattle to acidosis is likely to be increased by the feeding of soft feed wheats including the red wheats, compared with standard hard bread wheats.

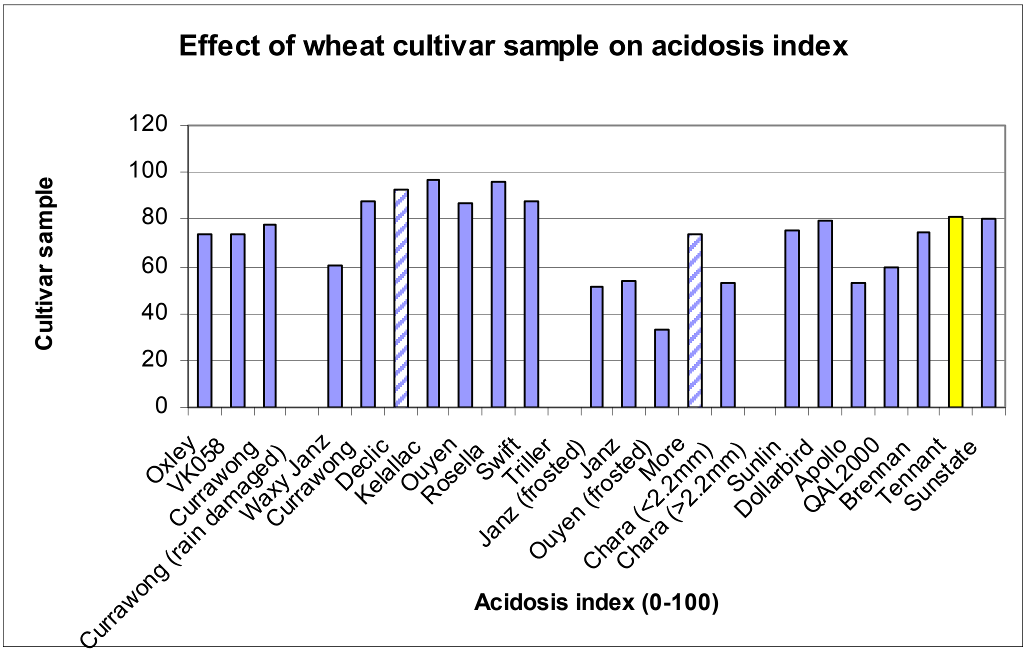


Figure 57. Calculated acidosis index values of wheat samples examined in PGLP. The Tasmanian sample of the cultivar Tennant is shown in yellow and the other two red wheats examined, Declic and More, are hatched.

Protein content

The protein content of the 25 wheat samples is shown in Figure 58. The sample of Tennant had a protein content of 11.2 % DM compared with an average of 15.0% DM for all the wheat samples examined. The protein contents of the other red wheats, Declic and More, were 13.4 and 13.5 % DM, respectively. Samples with the highest protein content were the small grain size white bread wheat variety, Apollo (21.9 % DM), rain-damaged Currawong (19.6 % DM), Chara-pinched (19.2 % DM), and the hard white Oxley (18.3 % DM). The lowest values were for the noodle wheat, Rosella (9.6 % DM), a sample of Ouyen (10.5 % DM) and Tennant.

The results show that the soft red wheats have a below average protein content with the sample of Tennant being near the lowest examined.

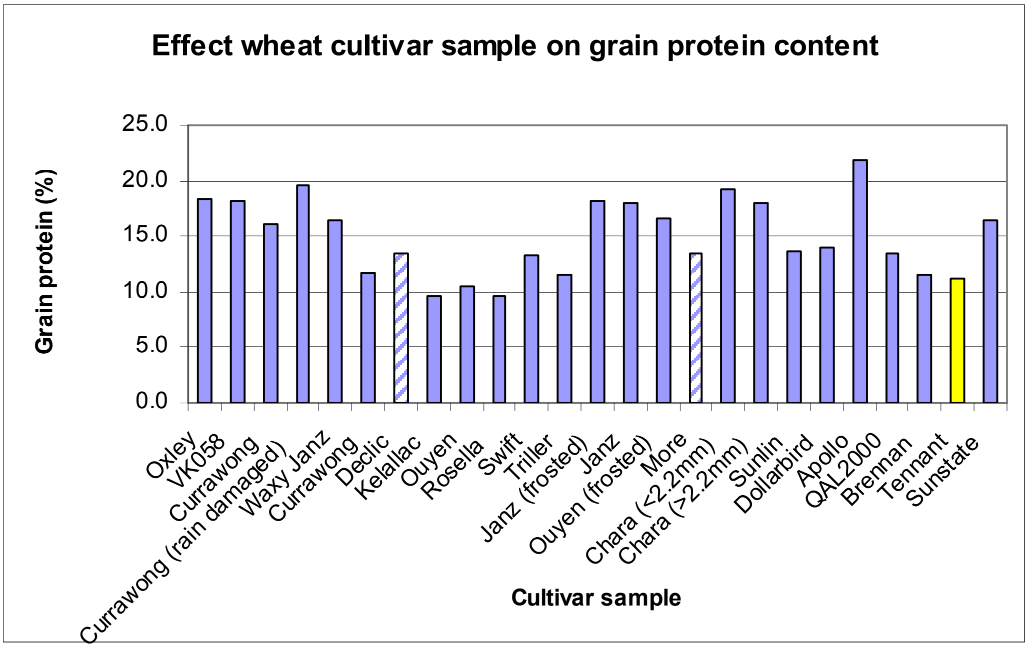


Figure 58. Protein values for the wheat samples examined in PGLP. The Tasmanian sample of the cultivar Tennant is shown in yellow and the other two red wheats examined, Declic and More, are hatched.

Diet and total ME intake

Productivity of cattle is determined largely by the total intake of energy that can be used in metabolic reactions within the animal. The total intake of ME or productive energy (MJ/day) is determined by energy released during digestion of the grain as it passes through the digestive tract or its ME content (MJ/kg) and the amount of diet consumed (kg/day). The voluntary intake by cattle fed diets containing one of seven wheat samples is shown in Figure 59. Cattle fed the diet containing Tennant consumed 7.61 kg DM/day compared with the average of 7.71 kg DM/day for the seven wheat samples examined. The highest intake occurred for the diet containing the soft biscuit wheat, QAL2000 (8.49 kg DM/day), and the lowest was 7.41 kg DM/day for the soft white feed wheat, Brennan. These results suggest that the intake of feed wheats by cattle is similar to the hard white bread wheats, but less than the soft white biscuit wheat examined.

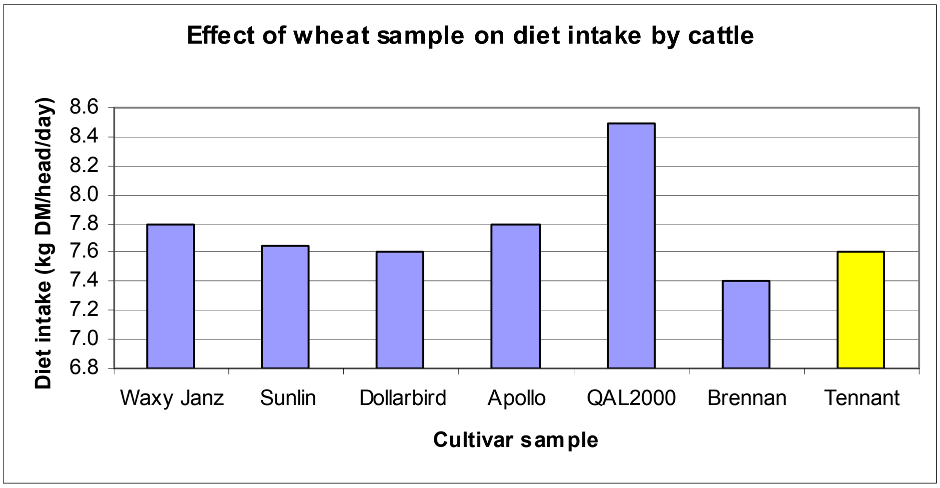


Figure 59. Voluntary intake by cattle of diets containing samples from different wheat cultivars

The total intake of metabolisable energy for production, which accounts for both digestibility and intake, shows that cattle offered a diet containing Tennant consumed 98.2 MJ/day compared with the average of 99.4 (MJ/day) for all wheat samples (Figure 60). The highest intake of productive energy was from QAL2000 (111.0 MJ/day) and the lowest from the sample of Brennan (94.4 MJ/day). The differences observed for total ME intake were reflected in growth rate of the cattle (Figure 61). These results suggest that performance of cattle consuming the sample of Tennant was close to the average of all the wheat samples examined (1.23 vs 1.24 kg/day). The greatest performance was from diets containing the sample of QAL2000 and the lowest from diet containing the white feed wheat, Brennan. The sample of QAL2000 showed the highest yield of energy during digestion, a relatively low acidosis index and a high intake. These results suggest that the relatively high acidosis index of the soft feed grains may have a negative effect on their intake by cattle despite having high digestibility and ME values.

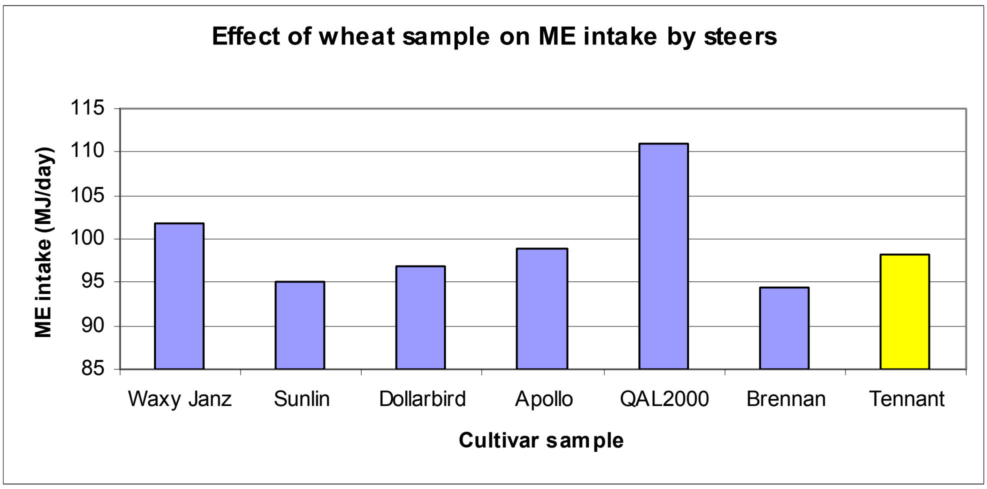


Figure 60. Total intake of ME by cattle offered diets containing samples from different wheat cultivars.

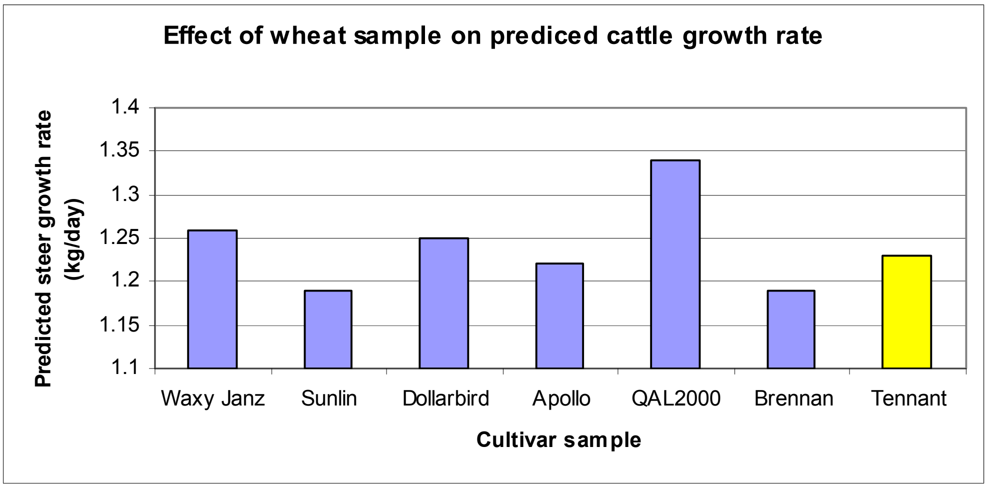


Figure 61. Growth rate cattle offered diets containing samples from different wheat cultivars.

Discussion and Conclusions

Many of the observations made within PGLP have shown that there are strong genotype by environment interactions affecting the physical and chemical characteristics of cereal grains and that results obtained for particular measurements are often more dependent on the specific grain sample used than on the cultivar or grain type description. Hence, broad extrapolation of the results presented above to all samples of the cultivar of Tennant, must be treated with caution because only one sample of Tennant has been examined.

The results suggest that the digestible energy (ME) content of red feed wheats is in general higher than for the hard white bread wheats, but the chances of causing ruminal acidosis are greater. The intake of diets containing 70% grain tended to be similar for the red feed wheats and the hard white bread wheats, but lower than for the soft white biscuit wheats. Hence, the productive energy available to cattle and performance was similar between the red feed wheats and the hard white bread wheats. Soft biscuit wheats appeared to give the greatest performance in cattle because of their high digestibility, low acidosis index and high feed intake. The feed wheats contained less protein than the hard white bread wheats and this would need to be taken into account when formulating diets for high producing cattle.

The results presented, suggesting little difference in performance of cattle fed red feed wheats and hard white bread wheats, mean that they should generally be interchangeable for maintaining cattle productivity provided account is taken of differences in protein content when formulating rations. Hence, the superior yield of the red wheats in the Tasmanian environment should provide a greater return to grain growers planting these cultivars compared with the conventional Australian hard bread wheats.

Improving through processing the energy value of grains for animals

Several experiments were conducted within PGLP to investigate processing methods that may improve the energy value of cereal grains for different types of livestock. The processing techniques investigated were targeted towards specific grain species for each animal type because of the grain type x animal type interactions determining the available energy value of individual grains. The greatest effort was put into developing processing techniques for improving the available energy content of sorghum for cattle because of the clear evidence that up to 3 MJ/kg of additional energy could be obtained if the integrity of the protein matrix surrounding the starch granules could be disrupted. This research was of high priority for the feedlot industry because there were few steam-flaking units in Australia when PGLP was established and the high capital cost of these units. In addition, several experiments were undertaken to determine the suitability for cattle of treating whole grain from several species with urea or enzymes to improve energy availability and reduce the costs of traditional processing.

A small number of experiments were conducted investigating methods for breaking the integrity of cell walls in wheat, barley and triticale fed to pigs and poultry. Several experiments were conducted also investigating the effects of using enzymes to hydrolyse long-chain non-starch polysaccharides in cell walls for grains fed to broilers and pigs.

Processing methods to improve the energy value of sorghum for cattle

The primary goals in processing cereal grains for ruminants are to increase total energy digestion throughout the digestive tract, while ensuring that as much starch as possible is digested in the small intestines rather than being fermented in the rumen or hind gut. The high cost of cattle experiments dictated that *in vitro* laboratory procedures had to be used for the initial screen of the effectiveness of potential processing techniques. *In vitro* methods were developed to mimic the rate of fermentation of starch in the rumen and digestion in the small intestines of cattle.

Suitability of in vitro assays for screening grains and processing methods

The *in vitro* system (Bird *et al*., 1999) 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 of xylanases. Figure 62 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.

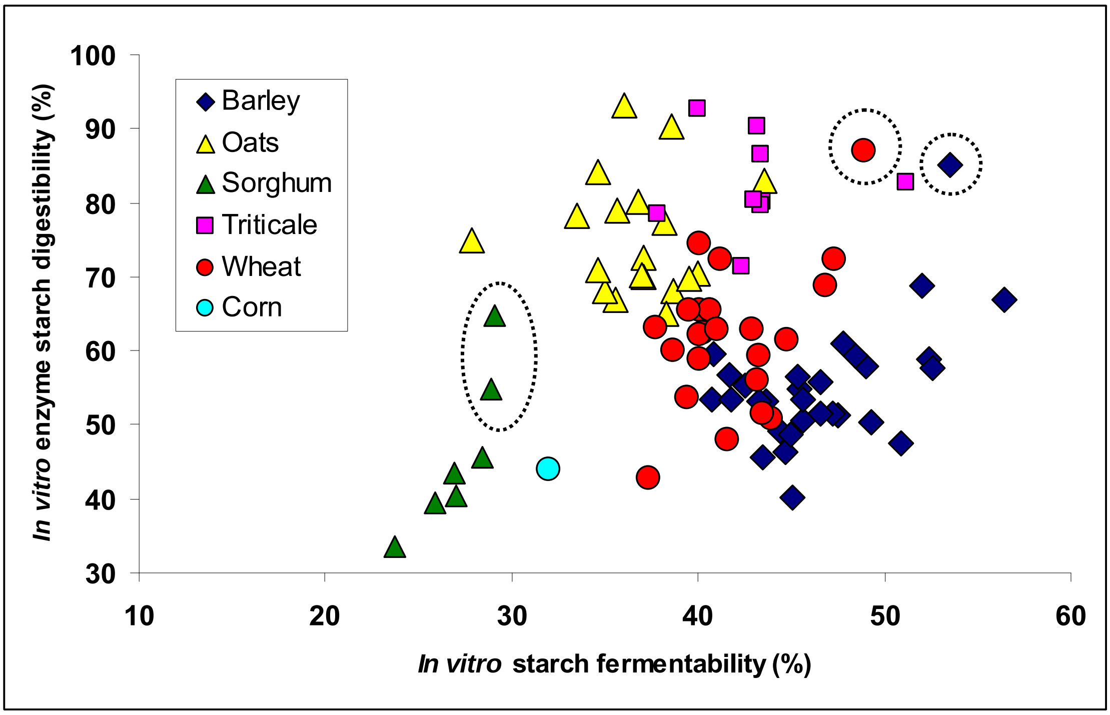


Figure 62. Relationship between starch digested in the *in vitro* system representing intestinal digestion and the *in vitro* system representing rumen fermentation for all cereal grains fed to animals. Waxy cultivars are circled.

There were substantial differences between the fermentation of individual samples for all the grain species examined. Waxy grain samples consistently had higher rates of both fermentation and enzymic digestion than non-waxy cultivars when compared within grain species. Oat grain starch was more highly fermented than sorghum starch, but less than wheat, tritical or barley starch. However, similar to starch in the triticale samples, oat starch was relatively poorly fermented by rumen microorganisms, but highly digested by the intestinal simulation system. 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 protein, fat or lactose synthesis. The most striking observation from Figure 62 is the extremely low digestibility of starch from non-waxy sorghum in the system representing intestinal digestion. The *in vitro* system contained enzymes that should have digested starch. The results represent closely digestion of sorghum by cattle, but not by pigs and poultry.

Comparison of in vitro assays 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 63 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.

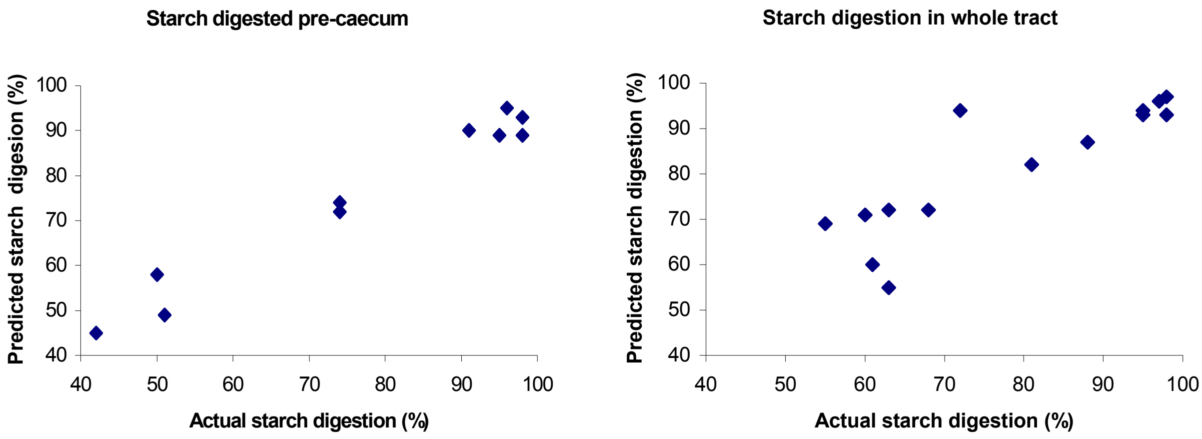


Figure 63. The relationship between starch digestion predicted from *in vitro* measurements and values observed in cattle fed a range of grains processed by various techniques.

The strong relationships provide evidence that 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 energy value for cattle. The suitability of the *in vitro* assays for screening alternative processing methods is further supported by the experiment conducted to investigate the effect of processing waxy and non-waxy isolines of sorghum. There were five treatments in a 90 day cattle feeding experiment; non-waxy sorghum dry rolled, steam-flaked or extruded and waxy sorghum dry rolled or steam-flaked. Feed conversion ratio (feed:gain) in the cattle was significantly related to both *in vitro* assays for starch fermentation (R^2 = 0.89) and enzyme starch digestion (R^2 = 0.89) as shown in Figure 64.

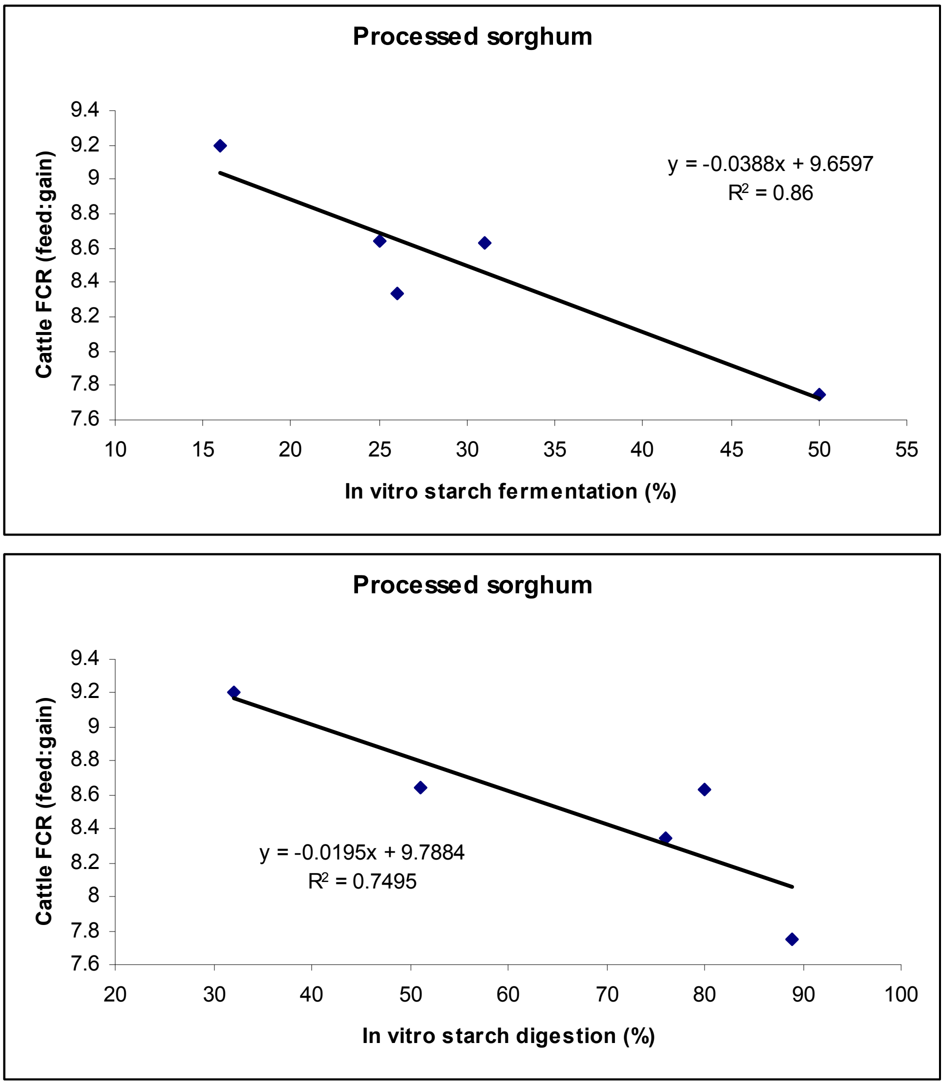


Figure 64. Relationships between feed conversion ratio (FCR) of cattle fed either waxy or non-waxy sorghum isolines following different processing and *in vitro* starch fermentation or enzyme digestion.

Comparison of processing methods for sorghum

A number of different processing methods were examined for improving the digestibility of sorghum grains for cattle. The processes evaluated were either being used by the animal industries or designed to increase the digestion of starch by disrupting the protein matrix surrounding the starch granules. The main processes examined were targeted to physically damage the protein matrix, rupture it through expansion of starch during gelatinisation, digest it with added chemicals, digest it with endogenous enzymes released during germination or use a combination of mechanisms. The treatments of sorghum grain included grinding through various screen sizes, cooking in water, extraction of protein using tert-butanol and dithriothreitol, ensiling with urea for 5 months, reconstitution (steeping in water to approximately 30% moisture), reconstitution and anaerobic ensiling (to mimic a harvestor), germination, germination followed by ensiling, steam-flaking, steam-pelleting, extrusion at >125˚C and greater than atmospheric pressure, and microwaving. Full descriptions of the treatments are given in the reports by Simon Bird and Alan Kaiser for phases one and two of PGLP.

The *in vitro* enzyme digestion of starch is shown in Table 35 for each of the processing methods investigated and compared with unprocessed normal and waxy sorghum samples. The observed range in enzyme starch digestion is shown when more than one sample of sorghum was examined in a process. The same sample was used for the steeping, germination and anaerobic ensiling processes.

Table 35. Effects of different processing methods on the *in vitro* enzyme digestion of sorghum starch.

Treatment	*In vitro* enzyme digestion of starch (% starch)
Unprocessed normal sorghum	23-43
Unprocessed waxy sorghum	42-56
Fine grinding (1mm screen)	42
Protein extraction (58% protein removed)	49
Urea ensiling (5 months)	43
Steeping (24 hr to 30% moisture)	27
Steeping and 21 day anaerobic ensiling	27
Germination (5 days)	35
Germination (5days) + anaerobic ensiling (16 days)	43
Steam flaking	70-84
Grinding and steam pelleting	54-64
Extrusion	89-94
Microwaving	70-82
Cooking (5-10 mins > 85˚C)	90

The results suggest that only those processes that involve some degree of starch gelatinisation (steam-flaking, steam-pelleting, extrusion, microwaving or cooking) show major improvements in the digestion of starch in sorghum. Variability in the extent of starch digestion between samples undergoing the same process appears to be greater in those processes where the proportion of gelatinisation varies (steam-flaking, steam-pelleting and microwaving) between batches, but was more constant during extrusion. Sorghum grain is particularly difficult to obtain uniform gelatinisation over time during the steam-pelleting process because of its high gelatinisation temperature and often high moisture content which means that the increase in temperature that can occur with the application of steam is limited before the moisture content of the mixture pre-pelleting exceeds the maximum allowed of 17-18%. Moisture content above this maximum is often associated with jamming of the pellet press.

Samples from pelleted, extruded and microwave treatments, examined with an electron microscope, showed substantial disruption of the starch-protein matrix structure. The pelleted sample showed substantial breaking of the protein matrix, but individual starch granules were still clearly visible (Figure 65). Extrusion appeared to completely destroy the starch granule-protein matrix structure into a largely amorphous material (Figure 66), whereas microwaving appeared to blow the starch granules from the protein matrix leaving the skeleton of the matrix intact (Figure 67).

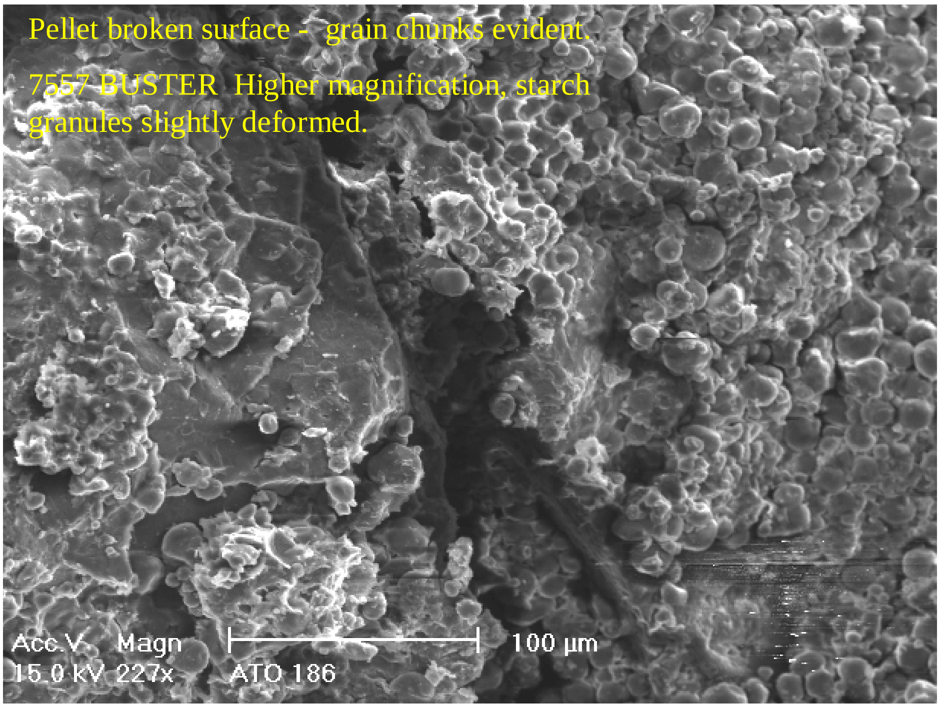


Figure 65. Electron micrograph of a pellet made from sorghum showing slightly deformed, but still intact starch granules partially dislodged from the encapsulating protein matrix.

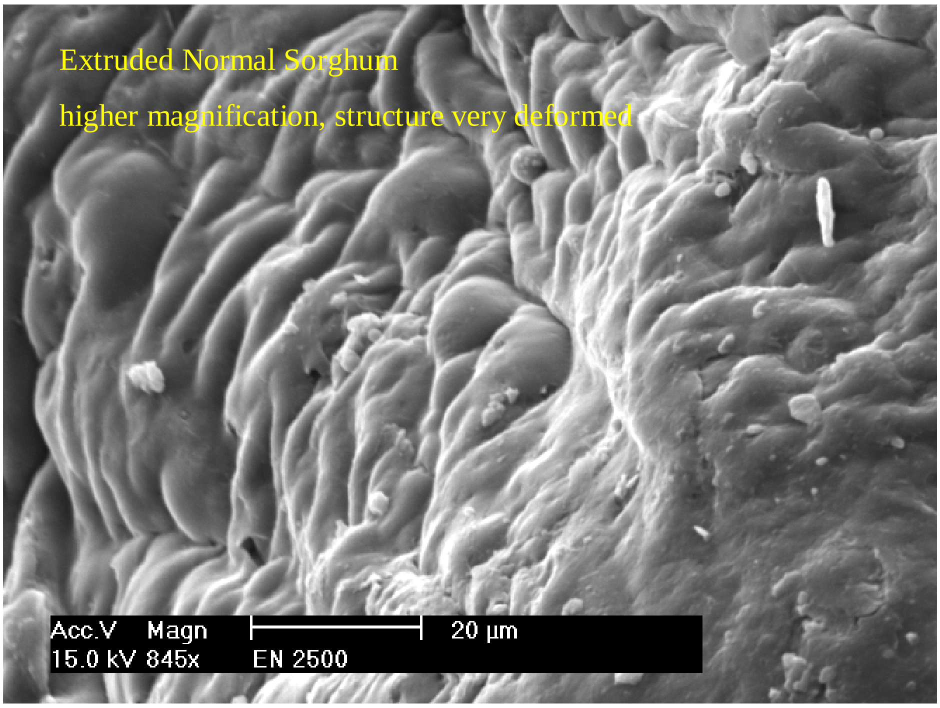


Figure 66. An electron micrograph of extruded sorghum showing almost complete destruction of the microstructure of the starch granules and protein matrix.

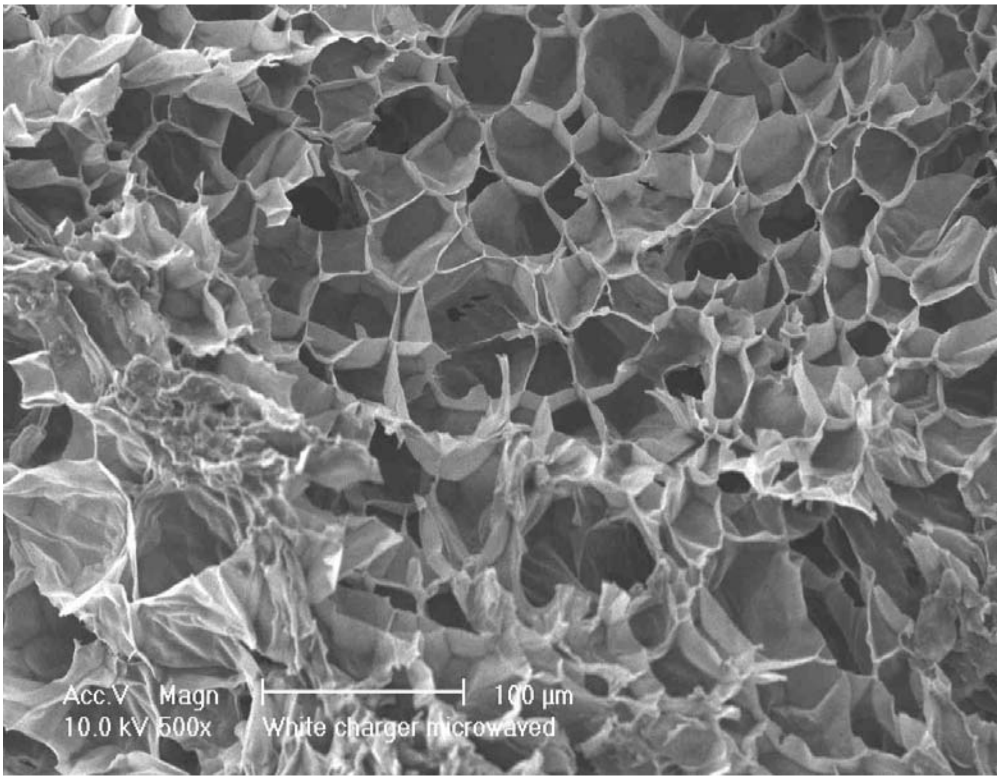


Figure 67. An electron micrograph of sorghum following microwaving showing the 'popping' open of the protein matrix and disappearance of the starch granules.

The physical disruption of the protein matrix by fine grinding or its partial removal using reducing chemicals caused significant, but only moderate, improvement in starch digestion compared with the processes that resulted in gelatinisation. Although germination significantly improved ($P<0.05$) *in vitro* starch digestion relative to the unprocessed control (Balogun *et al.* 2000), the improvement was less than that observed with grinding and protein extraction. Anaerobic ensiling of sorghum for 21 days did not significantly improve starch digestion relative to the control. However, 16 days anaerobic ensiling following 5 days germination resulted in a synergism with significantly more starch being digested than with germination alone. The variable results reported from the use of harvestors may be due to differences in the extent of germination of grain before the anaerobic ensiling is initiated.

In summary, the experiments using *in vitro* assays to investigate the suitability of different processing techniques for improving the digestion of sorghum by cattle suggest that almost total disruption of all protein matrix envelopes surrounding starch granules is required for near complete starch digestion. Such a high consistency of protein matrix disruption appears to be achievable only through gelatinisation of the starch within the envelopes. However, the relative high gelatinisation temperature and often limited capacity to add steam resulted in substantial variation between batches in the digestibility of steam-pelleted or steam-flaked material. More consistent high digestibility was obtained with extrusion and microwaving where higher grain hydration could be achieved. However, the practicality of microwaving large amounts of grain for feedlot cattle is questionable.

Urea and enzyme treatment of whole grain for ruminants

A series of experiments was conducted to determine the feasibility of treating whole grains with urea or fibrolytic enzymes (cellulase and xylanase) to reduce the cost of processing grains for feedlot cattle and minimising the risk of rumen acidosis. Urea is converted to ammonia under moist conditions with ureases present in the grains. Work conducted previously has shown that medium concentrations of ammonia can substantially improve the digestibility of whole grains when fed to cattle. The effects of amount of urea, grain hydration level and addition of urease were investigated. Details of the experiments and results are provided in the Final Report by Alan Kaiser.

Whole wheat, barley and sorghum grains were used in the experiments. Fibrolytic enzymes were found to be ineffective for increasing the digestibility of dry matter for any of the grain species when held *in sacco* in the rumen of cattle for 48 hours. However, the results with treatment of urea and subsequent anaerobic ensiling of whole grains showed more promise. Although urea treatment and ensiling was found to increase the *in sacco* dry matter digestibility of whole barley from 8 to 34% and of unprocessed sorghum from 13 to 53%, the digestibility achieved was too low to be of practical value. On the contrary, when the moisture content of whole wheat grain was raised to 30% with the addition of 3% urea and anaerobic storage for 10 days, 48 hour *in sacco* dry matter digestibility increased from around 25% to greater than 83%.

The results from the urea treatment of whole wheat grain were comparable with *in sacco* digestibility values obtained for samples of dry rolled wheat, suggesting that the process may be cheaper and more effective in reducing the risk of acidosis than the conventional processing of grain. Evaluation of the urea treatment of whole wheat grain in cattle production trials was not conducted within PGLP, but this low capital method of processing wheat may be useful for small feedlot and dairy cow operations. Further evaluation of the process appears warranted.

Evaluation of sorghum processing methods for cattle production

Examination of the effectiveness of various processing techniques for improving the *in vitro* digestion of starch in sorghum (Table 35) suggested that only microwaving or extrusion would provide rates of production and feed use efficiencies comparable with steam-flaking which is now used by many of the larger feedlots in Australia. An attempt was made through the University of Woolongong to produce 1 tonne of microwaved sorghum that could be used in a cattle feeding study. Unfortunately, the exit temperature of the grain from the processing unit achieved only 130˚C and not the 150˚C shown previously in laboratory tests to be required for high rates of starch digestion. A higher exit temperature may have been achievable, but at the cost of a reduced grain throughput. The study at Woolongong cast doubt on the economic viability of microwaving sorghum for commercial use by feedlots. Full details of the microwaving experiments are provided in the Final Report by Simon Bird.

Consequently, an experiment was conducted at Wagga Wagga by Alan Kaiser (see Final Report) to compare the effects of extruded sorghum with steam-flaked sorghum on cattle production. Normal and waxy-isolines of sorghum were used in the experiment to determine the likely value of the waxy sorghum for cattle feedlot production. The two isolines differing only in the genes for waxy characters were grown specifically for the study at Biloela. There were five dietary treatments in the experiment:

(a) Normal sorghum – dry rolled
(b) Normal sorghum – steam flaked
(c) Normal sorghum – extruded
(d) Waxy sorghum – dry rolled
(e) Waxy sorghum – steam flaked

The diets contained 73% sorghum, 7% cottonseed meal and 20% oaten silage and a mineral supplement. The grains were introduced over a 21 days and the final diets fed for 82 days. Eight Angus steers, initially 258 kg live weight, were allocated to each treatment. Steers were housed in individual pens and fed to appetite. Intake, live weight gain and feed conversion efficiency were measured throughout the experiment and digestibility of the diets determined. The experiment coincided with a particularly hot summer, with heatwaves in early January and February affecting intake and performance of the cattle.

Digestibility by cattle of organic matter and starch in diets containing dry rolled sorghum was low (Table 36). However, the digestibility of dry rolled waxy sorghum was significantly higher than for the non-waxy isoline. Steam-flaking significantly increased the digestibility of organic matter and starch for both isolines, but there was no difference between the waxy and non-waxy grains. Extrusion significantly improved digestibility over that obtained for steam-flaking in the normal isoline.

Feed intake was negatively related to digestibility for all treatments such that the daily intake of digestible dry matter was not significantly affected by grain processing method

(Table 36). Consequently, cattle growth rate was not influenced by the processing method. However, feed conversion efficiency reflected digestibility with was highest in cattle offered the extruded diet and lowest in cattle consuming the dry rolled normal sorghum diet. Although an additional 1.5 kg of the diet containing dry rolled normal sorghum was required for each kg of live weight gain compared with the extruded sorghum treatment, these differences in efficiency of feed use were not significant. The differential effect of the heat stress on individual animals resulted in higher than usual variation within animal groups and under more normal environmental conditions these mean differences in efficiency would be significant.

Table 36. Effects of sorghum processing techniques and waxy starch characteristics on the digestibility of diets and cattle performance.

Measurement	Non-waxy isoline			Waxy isoline	
	DR	SF	Ex	DR	Ex
OM digestibility (%)	59.5[a]	71.7[c]	76.8[d]	65.1[b]	73.0[c]
Starch digestibility (%)	67.1[a]	91.3[c]	94.6[d]	73.9[b]	91.9[c]
Starch in faeces (% DM)	44.4[a]	14.8[c]	12.3[c]	37.1[b]	15.4[c]
DM intake (g/kg lwt/d)	32.5[a]	25.9[c]	24.1[d]	30.4[b]	26.5[c]
Digestible DM intake (kg/d)	5.55	5.25	5.24	5.42	5.38
Live weight gain (kg/d)	1.08	0.97	0.96	1.06	0.92
FCE (feed:gain)	9.20	8.34	7.75	8.64	8.63

DR - dry rolled, SF - steam-flaked, Ex - extruded, OM - organic matter, DM - dry matter
[a b c d] Values with different superscripts are significantly different ($P<0.05$)

In summary, the cattle production study suggested that for feedlot or other cattle production systems using sorghum that cannot be heat-processed, a greater efficiency of feed use will occur by feeding dry rolled waxy than non-waxy sorghum lines. However, substantial improvements in the efficiency of sorghum use by cattle results from steam-flaking or extruding the grain before feeding. Waxy lines provide no additional advantage when steam-flaked compared with the normal lines. Extrusion significantly improved the digestibility of starch in normal sorghum compared with steam-flaking and may be a viable alternative technology for the cattle industry.

Assessing the effectiveness of grain processing for cattle

The effectiveness of grain processing can vary widely in commercial plants used in the feedlot and livestock feed manufacturing industries depending on the chemical and physical characteristics of the grains being processed, the type of processing method and the settings used for the processing equipment. Three methods developed within the PGLP can be used to determine the effectiveness of grain processing.

***In vitro* fermentation assay**

The first method involves the *in vitro* fermentation assay developed by Simon Bird. This laboratory assay established at the University of New England was used to show that the effectiveness of processing of grains in commercial feedlots can vary by almost 100%. The effectiveness of steam-flaking sorghum grains was shown to depend greatly on the adjustments made to the processing equipment and on the particular grain sample processed. Similarly the assay showed that the fermentation of starch from pelleted sorghum produced by Ridley Agriproducts could vary from approximately 30% to 55% depending on the sample and conditions of pelleting. Unfortunately, with the end of the University of New England's involvement in PGLP, this laboratory assay is no longer available to the industry.

AusBeef simulation model

The second method developed within PGLP to assess the effectiveness of processing grains for cattle was the AusBeef model developed by Barry Nagorcka and described in detail in his Final Report. The AusBeef model is based on mathematical representation of the underlying mechanisms of rumen function and nutrient utilisation. The model has the capacity to predict the consequences on animal productivity and feedlot enterprise profitability of grains with different degrees of processing effectiveness. However, total acid production derived from the University of New England *in vitro* fermentation system is an essential input to the model. Although a reasonably robust NIR calibration was developed for unprocessed grains, there were insufficient grains with varying effectiveness of processing to attempt to develop a separate calibration for processed grains.

NIR measurement of starch in faeces

The third method to assess the effectiveness of processing grains fed to cattle developed in PGLP is a NIR calibration for determining the proportion of starch in the faeces of cattle. Over 300 samples of faeces from cattle used in the digestibility studies in PGLP were dried, coarsely ground and scanned using a Foss 6500 NIR instrument. The samples were then subjected to ball-milling to ensure that all starch from within grains in the faeces was released and the starch content analysed. The faeces were from cattle given the range of cereal grains examined in PGLP when offered at either maintenance or *ad libitum* levels of feeding. The amount of starch in the faeces ranged from less than 0.1% to 48.7% DM. The NIR calibration developed has an extremely high accuracy with a $R^2 > 0.99$ and an ability to identify at the 95% confidence limit, 0.92% differences in faecal starch content. This NIR calibration could be particularly valuable for assessing the effectiveness of grain processing in commercial feedlots or dairy farms in Australia which process grains on site.

Processing methods to improve the energy value of cereals for pigs & poultry

A small number of experiments only were undertaken within PGLP to examine processing methods for increasing the energy value of grains for pigs and poultry. It was argued above that the digestibility of cereal grains with relatively thick endosperm cell walls (wheat, barley and triticale) could be improved in pigs by disrupting the integrity of these walls to increase access of amylolytic enzymes to starch in the small intestines and in poultry by decreasing the viscosity of digesta through reducing the chain length of cell wall arabinoxylans and ß-glucans. Previous studies with pigs have shown that the digestible energy content of cereal grains can be increased significantly by breaking endosperm cell walls through fine grinding and use of roller mills (Wondra *et al.* 1995; Oryschak *et al*. 2002). An experiment was conducted within PGLP to investigate the effect of either ground grain or whole grain extrusion on the site of digestion of energy in pigs, broilers and layers. Grains with thick endosperm cell walls (wheat and barley) were compared with grains having less endosperm cell wall material (sorghum and rice). In addition, several experiments were undertaken where diets offered to broilers and layers were treated with xylanases and/or glucanases to reduce the length of the cell wall polymers. Again comparisons were made where the enzymes were added to grains with relatively thick cell walls and sorghum with relatively thin cell walls.

Effect of extrusion on energy availability for pigs and poultry

Four samples of wheat and two each of barley, sorghum and rice were dry rolled and cold pelleted, ground and extruded or extruded as whole grain after soaking to contain approximately 16% moisture. The latter process closely resembles the technique known as expansion in the feed manufacturing industries. The grains were incorporated into diets and offered to pigs, broilers and layers. Ileal and faecal digestible energy were measured in pigs. Ileal digestible energy, AME, feed intake, growth rate and feed conversion efficiency were measured in broilers and AME and feed intake in layers. Details of the experiments are given in the Final Report by Robert van Barneveld and also in van Barneveld *et al.* 2005.

Effect of extrusion on energy availability in pigs

Extrusion increased significantly the ileal (Figure 68) and faecal (Figure 69) digestible energy content of three of the four wheat samples examined. The proportion of total digestion occurring in the small intestines was also significantly increased in two of the wheat samples (Figure 70). Whole grain extrusion produced consistently higher release of digestible energy than ground grain extrusion for all the wheat samples examined.

Extrusion had a markedly different effect on the barley samples than on the wheat samples examined. Whole grain extrusion significantly reduced both ileal and faecal digestible content of one barley sample (3782), with faecal DE content falling from 14.8 to 13.4 MJ/kg DM. Ground grain extrusion had little consistent effect on energy digestion for the same sample. Neither type of extrusion had consistent effects on either ileal or faecal DE content of the other barley sample. Extrusion had no consistent effect on the ileal or faecal digestible energy content of the sorghum or rice samples examined.

In summary, extrusion and particularly whole grain extrusion tended to increase the available energy content of wheat samples for pigs. However, whole grain extrusion substantially reduced the energy content of one barley sample while having little effect on the other sample. Extrusion had little consistent effect on the energy content of either sorghum or rice as would be expected in grains with thin and fragile cell endosperm cell walls.

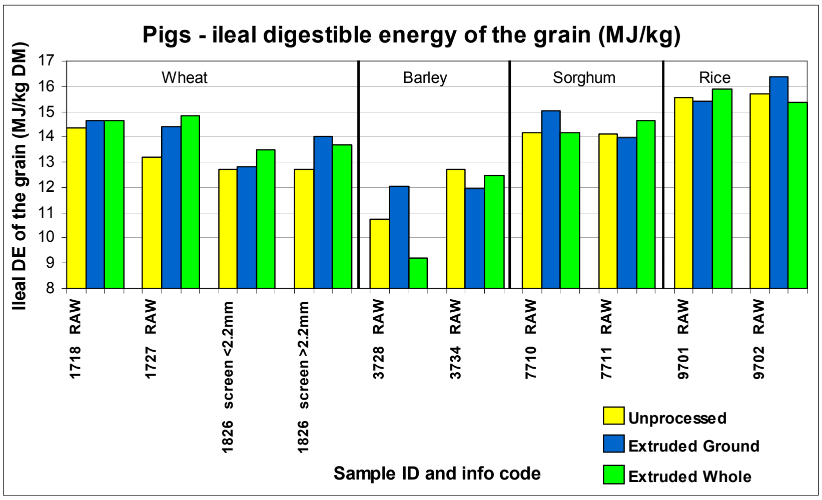


Figure 68. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on ileal digestible energy content of grains (MJ/kg DM) for pigs.

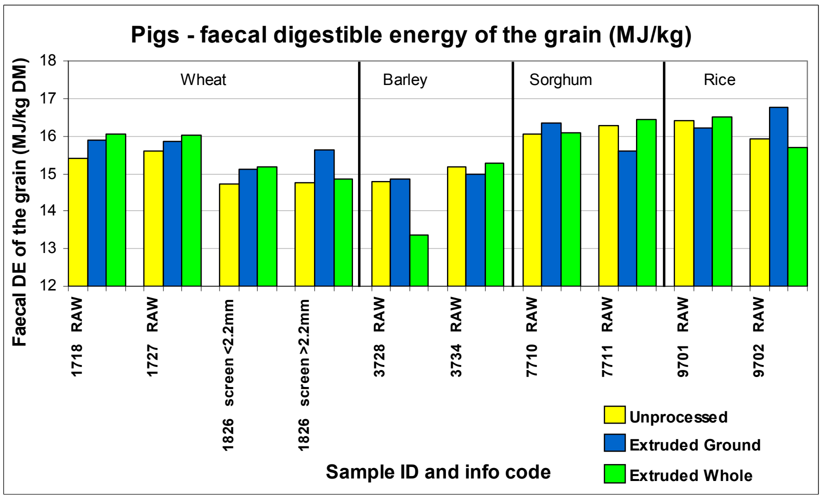


Figure 69. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on faecal digestible energy content of grains (MJ/kg DM) for pigs.

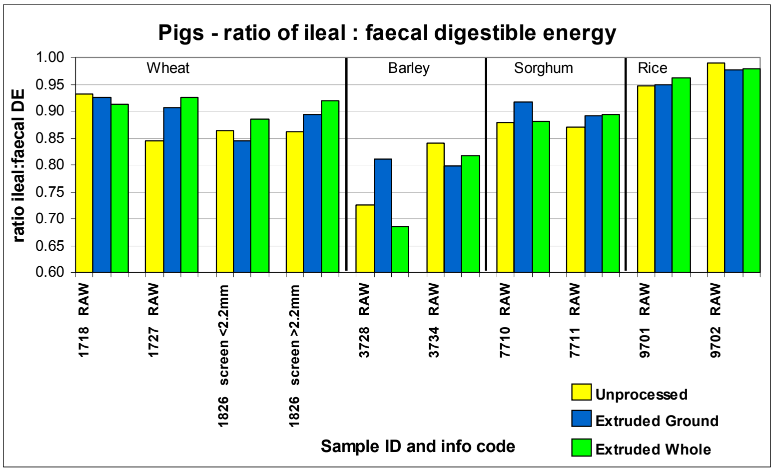


Figure 70. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on the ileal:faecal digestible energy content ratio of grains for pigs.

Effect of extrusion on energy availability for broiler chickens

Significant interactions were observed between grain type, sex, experiment and processing method in the broiler experiment. In addition, no significant differences were observed between the 1826 plump and screened samples and this data was subsequently combined. The predicted values were assigned a rank based on individual pairwise least significant differences and as a consequence no overall standard error or difference is provided. However, average values across sex and experiment are given in Figures 71-74 for the effects of grain species, individual grain sample and processing on AME of the grain (MJ/kg DM), grain AME intake (MJ/day), growth rate and feed conversion ratio (feed:gain). These Figures illustrate broadly the effects of processing on the energy availability from different grains and performance of broilers.

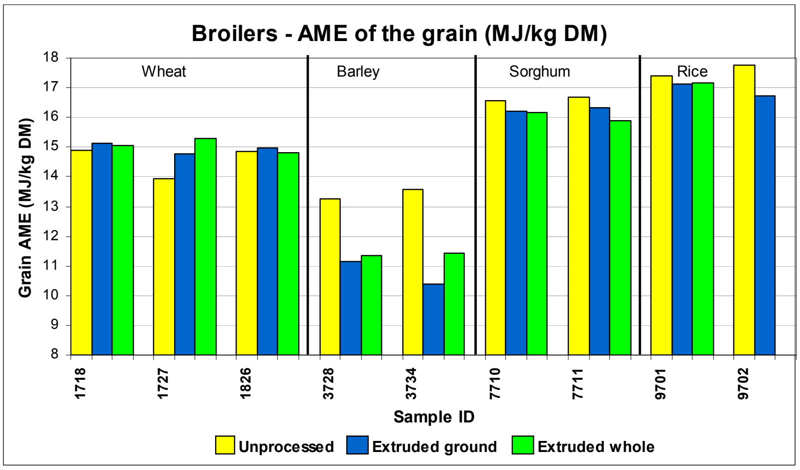


Figure 71. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on the AME content of grains for broilers.

Processing induced variable AME responses in the wheat samples. These varied between significant improvements with both extrusion and expansion in some experiments, to no response or a significant decrease in others. Barley AME values generally declined significantly with ground and whole grain extrusion, however, the effects were less marked with whole grain extrusion. Both barley samples responded similarly to processing. The AME content of sorghum and rice was either not influenced by processing method or a significant negative response was observed with one rice sample.

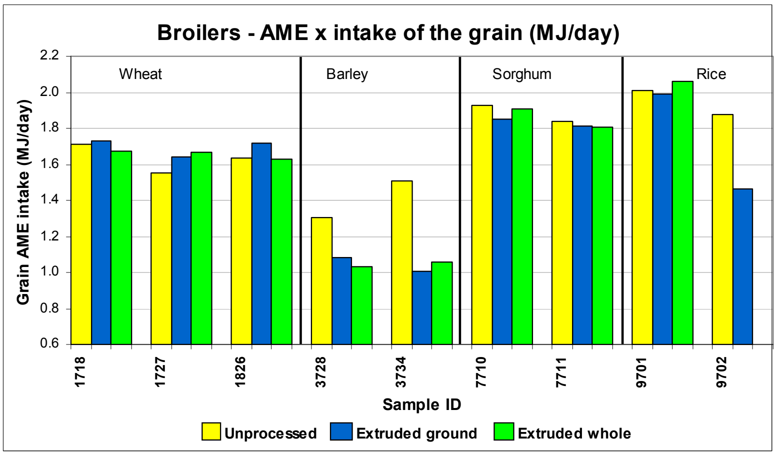


Figure 72. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on the AME intake of grains for broilers.

Whole grain extrusion significantly increased grain AME intake for wheat sample (1727) over the control, whereas ground grain extrusion significantly increased AME intake for sample 1826 over both the control and whole grain extrusion. Both forms of extrusion significantly reduced AME intake for both the samples of barley. There was no significant effect of processing on the AME intake of sorghum or one rice sample, but extrusion significantly depressed AME intake for the other sample of rice (9702).

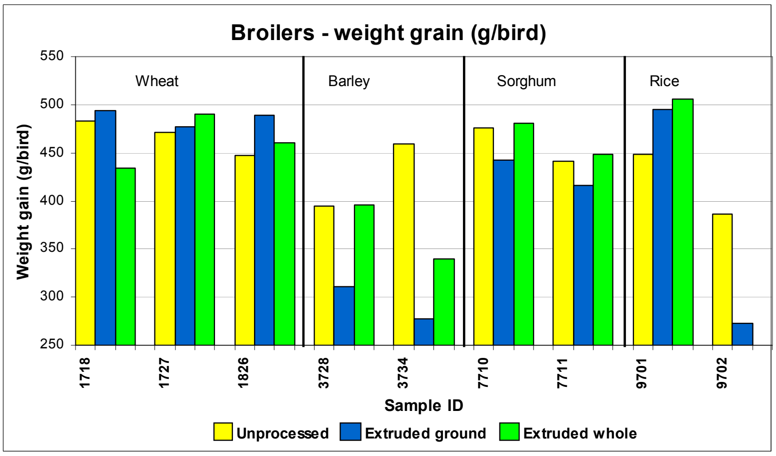


Figure 73. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on growth rate of broilers consuming different grains.

Whole grain extrusion significantly depressed weight gain of broilers offered wheat sample 1718. Both ground grain and whole grain extrusion significantly decreased weight gain for broilers fed barley sample 3734, whereas ground grain extrusion resulted in a lower weight gain for barley 3728. There was no significant effect of processing on weight gain of broilers offered sorghum or one rice sample, but extrusion significantly depressed weight gain for the other sample of rice (9702).

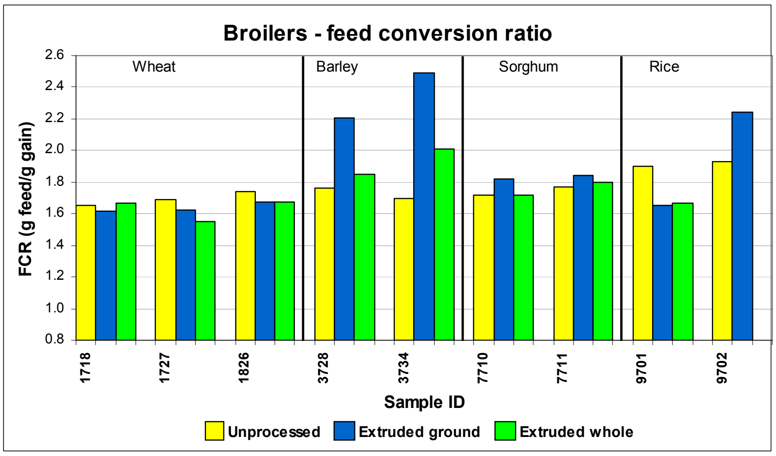


Figure 74. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on feed conversion ratio (feed:gain) of broilers consuming different grains.

Whole grain extrusion significantly improved feed conversion efficiency (lower FCR) compared to the control for wheat samples 1727 and 1828. There was no significant effect of processing on FCR for wheat 1718. Ground grain extrusion reduced significantly the efficiency of feed conversion by broilers offered the two barley samples. Feed conversion efficiency was also poorer for whole grain extruded barley sample 3734 compared with the unprocessed grain. There was no significant effect of processing on feed conversion efficiency of broilers offered sorghum or one rice sample, but extrusion significantly depressed the efficiency of feed use for the other sample of rice (9702).

Effect of extrusion on energy availability for layers

Significant interactions were observed between grain type, experiment and processing method. The predicted values were assigned a rank based on individual pairwise least significant differences and as a consequence no overall standard error or difference is provided. However, average values across sex and experiment are given in Figures 75 and 76 for the effects of grain species, individual grain sample and processing on AME of the grain (MJ/kg DM) and grain AME intake (MJ/day) by layers. These Figures illustrate broadly the effects of processing on the energy availability from different grains for laying hens.

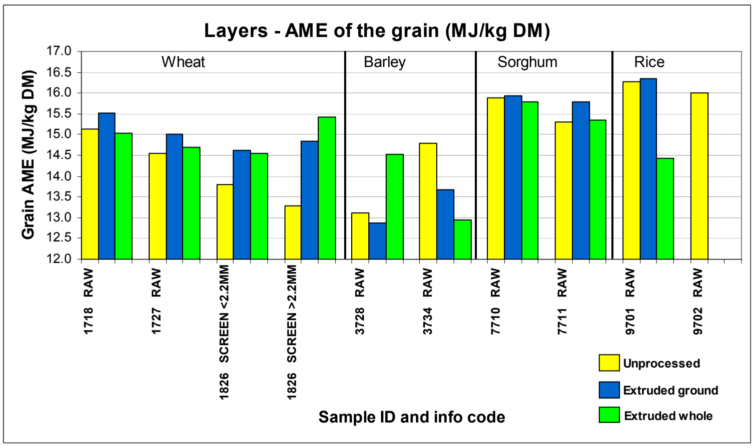


Figure 75. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on the AME content of grains for layers.

Extrusion significantly increased the AME content of both the large and small grain samples from wheat 1826, but did not affect the AME content of the other wheat samples. Whole grain extrusion significantly increased AME for barley sample 1328, but both ground grain and whole grain extrusion decreased AME for barley 3734. Processing did not significantly affect AME for the sorghum samples examined, but whole grain extrusion significantly depressed AME for rice sample 9701.

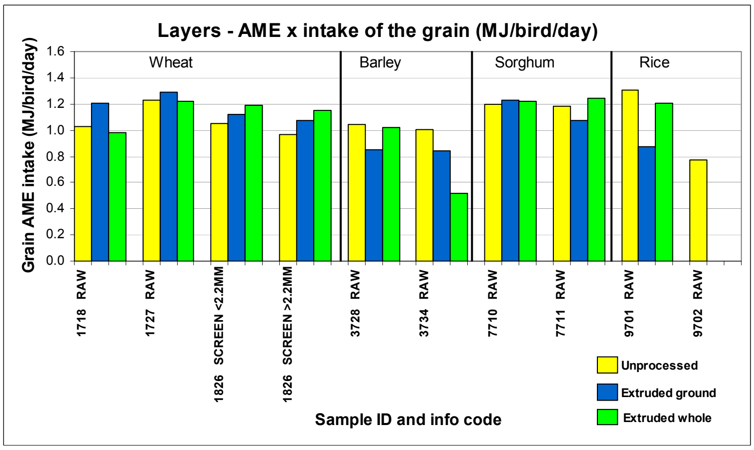


Figure 76. Effect of dry rolling and cold pelleting (unprocessed), extrusion of ground or extrusion of whole grains on the AME intake of grains by layers.

Whole grain extrusion significantly reduced the intake of AME by layers fed barley 3734 and ground grain extrusion reduced AME intake for rice 7710. There were no other significant effects of processing grains on their energy value for layers.

Summary of effects of processing on cereal grains for pigs and poultry

Pigs chew feed poorly and extrusion, through its disruption of the endosperm cell walls, was expected to substantially increase the energy value in pigs of the thick cell-walled grains, wheat and barley, but have little effect on the thin cell-walled grains, sorghum and rice. However, because cell walls are largely ruptured through the action of the gizzard in poultry, extrusion was anticipated to have little effect on energy availability from either thick-walled or thin-walled grains in broilers or layers. These hypotheses were not fully supported by the extrusion experiments. In general, there was a positive effect on energy availability from extruding wheat and one barley sample for pigs. In addition, there was little effect of extrusion on the energy value of sorghum and rice for pigs. However, extrusion had a highly negative effect on energy availability of one barley sample for pigs. Furthermore, instead of extrusion having little effect on the energy value of grains for poultry, it had a highly negative effect for both samples of barley and one sample of rice for broilers and a smaller negative effect for layers.

These variable results suggest that factors other than disruption of the endosperm cell walls are important in determining the outcome of various grain processing techniques. In particular, heat and moisture can result in the retrogradation of starch within cereal grains and a reduction in starch digestibility (Berry, 1988). The degree of retrogradation depends on the amylose content and chemical and crystalline structure of the starch molecules (Evers and Stevens, 1985), but interactions between the starch, cell wall components and endosperm proteins are likely also to influence the digestibility of processed grain by different animal types. The results from the extrusion experiments suggest that further work is required to understand how the chemical and physical characteristics of individual grain samples are changed during processing and the subsequent effects on digestibility of starch and protein by different animals.

A major project for the new Pork CRC will be examine the interactions between processing techniques and grain characteristics on the chemical constituents of the processed grain and on digestion of grain components. The raw grains, prepared diets (including processed grains), ileal and faecal material from a wide range of grain samples will be examined using microscopy, differential scanning calorimetry, solid-state Nuclear Magnetic Resonance, X-ray diffusion, particle sizing, Rapid Visco Analysis (RVA), *in vitro* digestion and other techniques to identify the physical and chemical changes that have occurred in relation to the extent of digestion as grains pass through the digestive tract of pigs. The results will be used to develop hypotheses about the reasons for differences in digestion and likely responses to various types of processing. A range of existing and novel processing techniques will be investigated with the aim of understanding how individual grain characteristics can best to exploit through specific processing techniques to increase consistently the energy value of grains for pigs.

Effect of addition of enzymes to cereal grains for poultry and pigs

Effect of the addition of enzymes to cereal grains for broilers

Three experiments with broiler chickens examined the effects of inclusion of xylanase and glucanase enzymes to reduce the length of cell wall polymers. One experiment investigated the effect of adding enzymes to 10 samples of sorghum, which has thin and fragile cell walls, whereas the other two experiments investigated the effect of adding enzymes to wheat, barley and triticale samples with thicker endosperm cell walls. Full details of the experiments are provided in the Final Report by Robert van Barneveld.

The addition of enzymes to sorghum grain samples had no significant effect on ileal DE, AME, AME intake, growth rate or feed conversion efficiency. These results were expected because of the low endosperm cell wall content of sorghum and low viscosity of the grain. However, Scott (2006) showed recently that addition of xylanase and phytase to sorghum diets significantly decreased the AME content from 13.6 to 12.6 MJ/kg, but did not affect feed intake.

The addition of enzymes to a Tantangara barley sample (3815) increased significantly AME from 12.7 to 14.0 MJ/kg DM, diet intake from 93 to 137 g/d as fed and growth rate of broilers from 60 to 104 g/d. In another experiment, enzymes increased the AME content for broilers of a sample of the waxy-naked barley cultivar, Merlin (3725), from 12.6 to 14.6 MJ/kg DM. A summary of the effect of adding xylanase and glucanase enzymes to different grain types from several experiments conducted in PGLP is given in Table 37.

Table 37. Effect of addition of xylanase and glucanase enzymes to various grain samples on grain AME and diet AME intake for broilers.

Grain description	Enzyme	AME (MJ/kg DM)	Significance of enzyme	Diet AME intake (MJ/d)	Significance of enzyme
Wheat: Currawong 1721	Yes	14.73	P<0.05	1.54	NS
	No	14.12		1.52	
Triticale: Abacus 6706	Yes	14.52	NS	1.58	NS
	No	13.95		1.51	
Barley: Tantangara 3815	Yes	14.02	P<0.05	1.38	P<0.05
	No	12.73		0.84	
Barley: Gilbert 3719	Yes	13.56	P<0.05	1.48	P<0.05
	No	12.46		1.22	
Barley: Naked Merlin 3725	Yes	14.61	P<0.05		
	No	12.60			

These results are consistent with those obtained previously by Scott (2005; 2006) who showed that the addition of enzymes to wheat and triticale diets increased AME, feed intake and performance of broiler chickens. The addition of xylanase and glucanase enzymes to wheat, triticale and barley diets fed to poultry has consistently reduced the viscosity of digesta and improved access of amylases and lipases to dietary ingredients. Although the addition of enzymes increases feed intake of broilers offered wheat and triticale based diets, Scott (2005; 2006) found that the between grain variation in feed intake was not reduced.

Predicting the response of broilers to the addition of enzymes

The results obtained by Tom Scott using grains provided by PGLP and examining the effects of added enzymes on AME, feed intake and performance of broilers fed a range of grain types can be used to investigate the accuracy of algorithms for predicting the likely response from adding xylanase and phytase enzymes to diets containing any grain sample because of the extensive chemical and physical measurements made on all grains. A summary of the response in diet AME (MJ/kg DM) and diet AME intake (MJ/day) for each grain sample examined is given in Table 38.

Table 38. Effect of treating grains with enzymes on AME and AME intake for broilers. Results are from Tom Scott using PGLP grains.

Grain	Grain No.	Enzyme	Diet AME (MJ/kg DM)	Enzyme effect on Diet AME (MJ/kg DM)	Diet AME intake (MJ/d)	Enzyme effect on Diet AME intake (MJ/d)
Wheat						
Lawson	1724	E+	12.58	-1.01	0.465	-0.071
		E-	13.59		0.536	
Currawong	1725	E+	12.99	1.04	0.479	0.055
		E-	11.95		0.424	
Oxley	1727	E+	14.12	0.10	0.590	0.059
		E-	14.02		0.532	
QAL 2000	1728	E+	12.43	-0.05	0.478	0.038
		E-	12.48		0.440	
VK058	1731	E+	13.69	0.08	0.525	0.054
		E-	13.61		0.471	
Janz	1735	E+	13.91	1.88	0.569	0.094
		E-	12.02		0.475	
Fielder	1736	E+	12.62	2.17	0.519	0.111
		E-	10.45		0.408	
Glenlea	1737	E+	12.64	0.20	0.503	0.037
		E-	12.44		0.467	
Kewel	1738	E+	12.71	-0.63	0.538	0.057
		E-	13.35		0.482	
Oslo	1740	E+	12.12	-0.18	0.474	0.016
		E-	12.31		0.459	
Owens	1741	E+	12.95	1.26	0.497	0.054
		E-	11.69		0.444	
QAL 2000	1742	E+	12.82	-0.12	0.509	0.069
		E-	12.94		0.440	
Spear	1743	E+	12.13	-1.69	0.442	-0.109
		E-	13.83		0.551	
Spillman	1744	E+	12.63	0.91	0.503	0.057
		E-	11.72		0.447	
Vulcan	1746	E+	13.56	1.28	0.517	0.064
		E-	12.28		0.453	
Wanser	2002	E+	10.37	-2.26	0.380	-0.076
		E-	12.64		0.456	
Waxy Janz	1748	E+	13.29	0.27	0.488	0.063
		E-	13.02		0.425	

Wollaroi	1749	E+	13.88	0.75	0.565	0.083
		E-	13.13		0.482	
Barbee	1750	E+	12.12	0.28	0.472	0.024
		E-	11.85		0.448	
Kewel	1751	E+	12.38	1.91	0.513	0.134
		E-	10.48		0.378	
Vulcan	1752	E+	12.17	-0.77	0.466	0.044
		E-	12.94		0.422	
Janz (frosted)	1809	E+	13.56	-1.32	0.589	-0.043
		E+	12.55	-1.86	0.543	-0.042
Janz (frosted)	1809	E-	14.88		0.631	
		E-	14.40		0.586	
Janz	1815	E+	14.27	0.64	0.564	0.078
		E-	13.63		0.485	
Waxy wheat	1817	E+	12.14	0.29	0.508	0.121
		E-	11.86		0.387	
2001-02 (sprouted)	1822	E+	13.15	-0.15	0.500	0.066
		E-	13.29		0.434	
Lorikeet (1st)	1830	E+	12.69	-0.33	0.505	0.102
		E+	14.72	1.20	0.585	0.122
Lorikeet (1st)	1830	E-	13.02		0.404	
		E-	13.53		0.463	
H45	1832	E+	13.16	3.54	0.545	0.192
		E-	9.62		0.354	
Sunlin	1834	E+	13.82	1.13	0.547	0.145
		E-	12.69		0.403	
Ellison	1834	E+	12.40	1.00	0.559	0.139
		E-	11.40		0.420	
H45	1841	E+	12.85	1.96	0.493	0.083
		E-	10.89		0.410	
Dollarbird	1843	E+	12.20	2.12	0.493	0.164
		E-	10.08		0.328	
QAL 2000	1846	E+	12.13	0.26	0.486	-0.005
		E-	11.88		0.491	
Brennan	1850	E+	13.32	0.58	0.516	0.044
		E-	12.74		0.473	
Tennant	1852	E+	15.28	1.51	0.568	0.066
		E-	13.77		0.502	
Triticale						
Prime 322	6081	E+	13.25	0.66	0.468	-0.004
		E-	12.59		0.473	
Abacus	6708	E+	13.87	0.70	0.515	0.074
		E-	13.17		0.440	
Maiden	6709	E+	13.41	-0.39	0.493	0.001
		E-	13.80		0.493	
Muir	6711	E+	12.96	-0.43	0.513	0.020
		E-	13.40		0.493	
Madonna	6713	E+	14.25	0.59	0.585	0.100

		E-	13.66		0.485	
Treat	6809	E+	13.71	-0.31	0.512	0.052
		E-	14.02		0.460	
Abacus	6811	E+	14.38	0.94	0.595	0.128
		E-	13.44		0.467	
Abacus	6814	E+	14.57	2.29	0.473	0.077
		E-	12.28		0.396	
Sorghum						
Buster	7712	E+	13.88	-0.36	0.520	0.015
		E-	14.24		0.505	
Waxy Sorghum	7835	E+	12.58	-2.05	0.454	-0.081
		E+	12.68	-1.99	0.498	-0.032
Waxy Sorghum	7835	E-	14.63		0.535	
		E-	14.67		0.529	
Normal Sorghum	7836	E+	14.47	-0.45	0.503	-0.049
		E+	14.60	-0.58	0.537	-0.065
Normal Sorghum	7836	E-	14.92		0.552	
		E-	15.18		0.602	

The results presented in Table 38 show a wide range in AME and AME intake for grains treated with enzymes. The response in AME for enzyme treated wheat samples ranged from -2.26 to +3.54 (MJ/kg DM). The AME response to enzymes for triticale ranged from -0.43 to +2.29 MJ/kg DM and for sorghum from -2.05 to -0.36 MJ/kg DM. Similarly, the response in AME intake varied widely from -0.109 to 0.139 MJ/day for wheat, -0.004 to 0.128 MJ/day for triticale and -0.081 to 0.015 MJ/day for sorghum. Duplicate measurements were made on three grain samples, Janz-frosted, Lorikeet wheat and waxy sorghum. These duplicates show that there was considerable experimental variation between measurements. Figure 77 shows that the responses to enzymes for individual grains in diet AME and diet AME intake were similar.

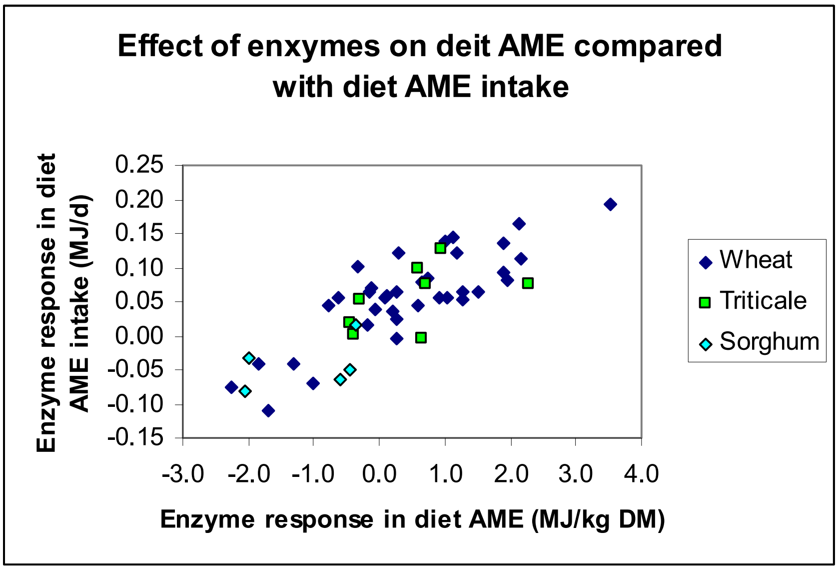


Figure 77. Response in diet AME and diet AME intake of individual grain samples to the application of xylanase and glucanase enzymes.

Possible reasons for variation between grains in the response of birds to enzyme addition to diets were investigated by correlating measured chemical and physical characteristics of grains with the responses in diet AME and AME intake. Full chemical analyses were made on only 21 of the 34 wheat samples, 3 of the 8 triticale samples and 3 of the 5 sorghum samples examined. The most significant correlations are shown in Table 39, except for those characteristics which form part of a subset such as total individual fatty acids and crude fat.

Table 39. Correlation coefficients between the effect of enzyme treatment on diet AME and AME intake for broilers and grain characteristics.

Grain Characteristics (% DM)	Correlation coefficients		Statistical significance (P<)	
	Diet AME (MJ/kg DM)	Diet AME intake (MJ/d)	Diet AME (MJ/kg DM)	Diet AME intake (MJ/d)
Soluble arabinoxylans	0.53	0.55	0.01	0.01
ß-glucans	0.60	0.55	0.01	0.01
Soluble arabinose	0.55	0.57	0.01	0.01
Soluble xylose	0.51	0.54	0.01	0.01
Total soluble NSP	0.47	0.48	0.05	0.05
Soluble fucose	-0.44	-0.39	0.05	0.05
Soluble galactose	0.45	0.44	0.05	0.05
Alanine	-0.53	-0.59	0.01	0.01
Leucine	-0.43	-0.48	0.05	0.05
ADF	-0.59	-0.64	0.01	0.01
Crude fat	-0.61	-0.65	0.01	0.01
Gross energy	-0.58	-0.58	0.01	0.01

(MJ/kg)

The correlations suggest that the response to enzymes is positively related to soluble cell wall contents of the grain as would be expected because these long chain polymers are known to increase digesta viscosity and are hydrolysed by the enzymes. The response was also positively related to soluble galactose, but the concentrations of galactose were generally low. The response to enzymes was negatively related to ADF content of the grain which corresponds with earlier methods used to increase the AME content of low AME wheat samples through the addition of oat hulls to allow physical disruption of viscous digesta and improved penetration by enzymes. The response to enzymes was also negatively related to the lipid content of the grains. It is likely that higher lipid concentrations produce a hydrophobic effect and reduce the ability of the hydrophilic enzymes to attach to the soluble cell wall substrates. The negative correlation between response to enzymes and gross energy is likely to be due to the higher lipid concentrations being strongly associated with gross energy. The negative correlations between response to enzymes and soluble fucose, alanine and leucine are likely to be due to digesta viscosity. The relationships between the effect of enzymes on diet AME and ß-glucan, soluble arabinose, soluble xylose, ADF and crude fat content of grains are shown in Figures 78-82.

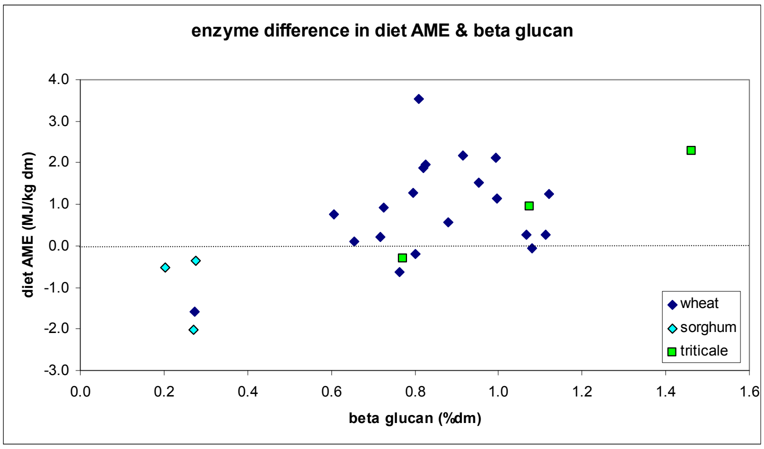


Figure 78. Relationship between ß-glucan content of grains and their response in diet AME to addition of enzymes.

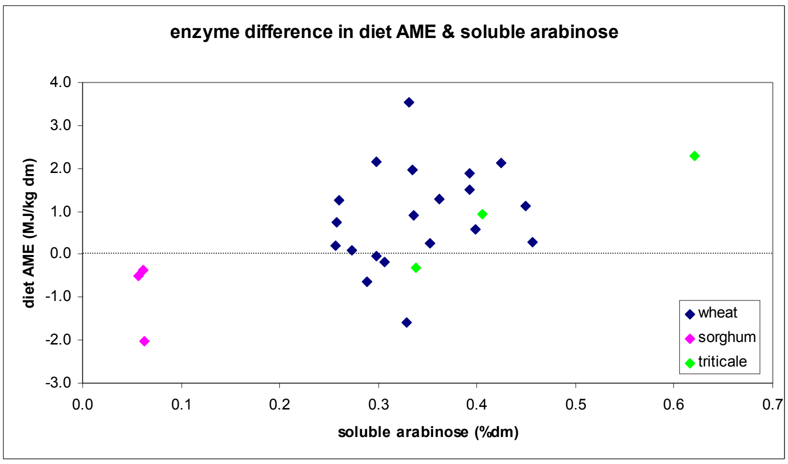


Figure 79. Relationship between soluble arabinose content of grains and their response in diet AME to addition of enzymes.

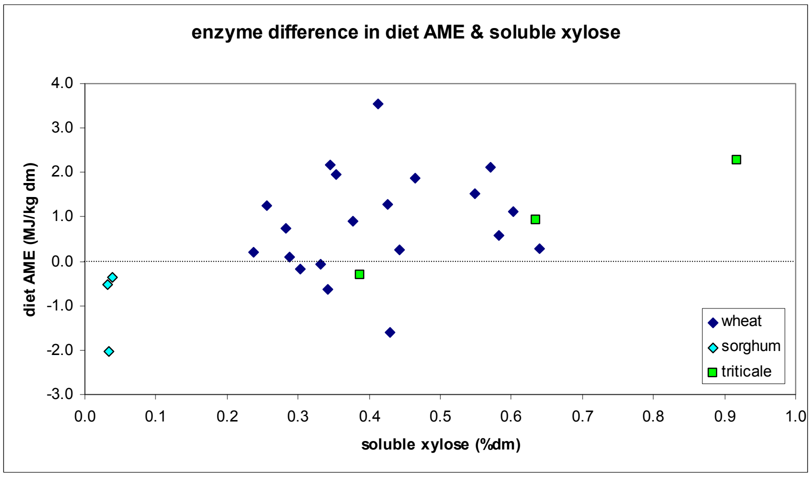


Figure 80. Relationship between soluble xylose content of grains and their response in diet AME to addition of enzymes.

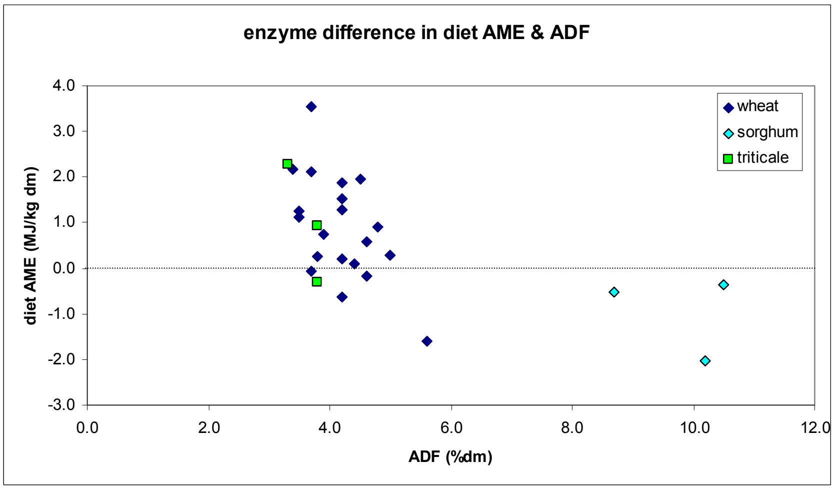


Figure 81. Relationship between ADF content of grains and their response in diet AME to addition of enzymes.

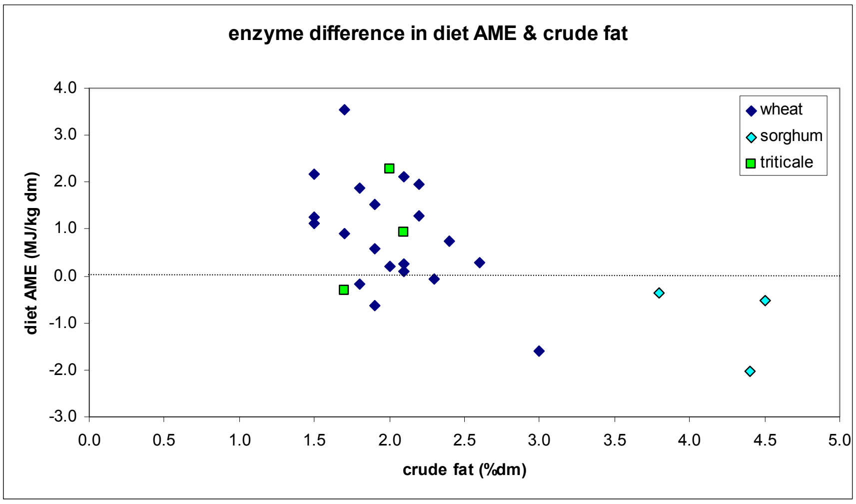


Figure 82. Relationship between crude fat content of grains and their response in diet AME to addition of enzymes.

A more complete statistical analysis of the grain variables related to the response in available energy to enzymes for broilers has been completed (see attached file: 40 Proof of concept trial covariate analysis). Tannins were included in this analysis, but individual amino acids and sugars with negligible concentrations, such as soluble galactose and fucose, excluded. Variables with a significant probability ($P<0.05$) of being associated with the enzyme response in diet AME content (MJ/kg) are shown in Table 40 along with crude fat which had a P value of 0.055 as well as corresponding values for AME intake (MJ/day).

Table 40. Variables that were significantly related to the response in AME content of a diet and AME intake by broilers to enzymes.

Grain characteristics	AME (MJ/kg)		AME intake (MJ/day)	
	Probability P=	Slope	Probability P=	Slope
Total tannin	0.010	-16.01	0.010	-0.84
Oleic acid	0.022	-3.27	0.009	-0.19
Stearic acid	0.028	-44.37	0.016	-0.25
Cell wall[1]	0.036	1.21	0.052	0.06
Hydration capacity	0.040	-0.04	0.034	-0.002
β-glucan	0.045	1.722	0.125	0.07
Crude fat	0.055	-0.88	0.123	-0.04

[1]β-glucan + soluble arabinoxylan

When oleic and stearic acids were replaced by crude fat and β-glucan replaced by cell wall content, the equation with the best statistical fit for predicting the enzyme response in both AME and AME intake for diets containing different grains included total tannin, cell wall and crude fat. There was a significant effect of grain species for the relationships for AME ($P=0.014$) and AME intake ($P=0.004$), respectively.

The equations for predicting the response to enzymes in the AME (MJ/kg) of a diet containing different grain samples for broilers were for different grain types:

Sorghum response $= 6.11 - 11.62 \times$ Tannin (P=0.046) $- 0.827 \times$ Crude Fat (P=0.020) $+ 0.948 \times$ Cell wall (P=0.018)

Triticale response $= 3.30 - 11.62 \times$ Tannin (P=0.046) $- 0.827 \times$ Crude Fat (P=0.020) $+ 0.948 \times$ Cell wall (P=0.018)

Wheat response $= 3.31 - 11.62 \times$ Tannin (P=0.046) $- 0.827 \times$ Crude Fat (P=0.020) $+ 0.948 \times$ Cell wall (P=0.018)

The predicted response in AME of the diet using the above equations is compared with the measured response in Figure 83. The equations predict the general response well accounting for 63% of the observed variation (R^2=0.63). The response for the wheat sample H45 was not well predicted, but this inaccuracy did not substantially affect the overall accuracy of the prediction.

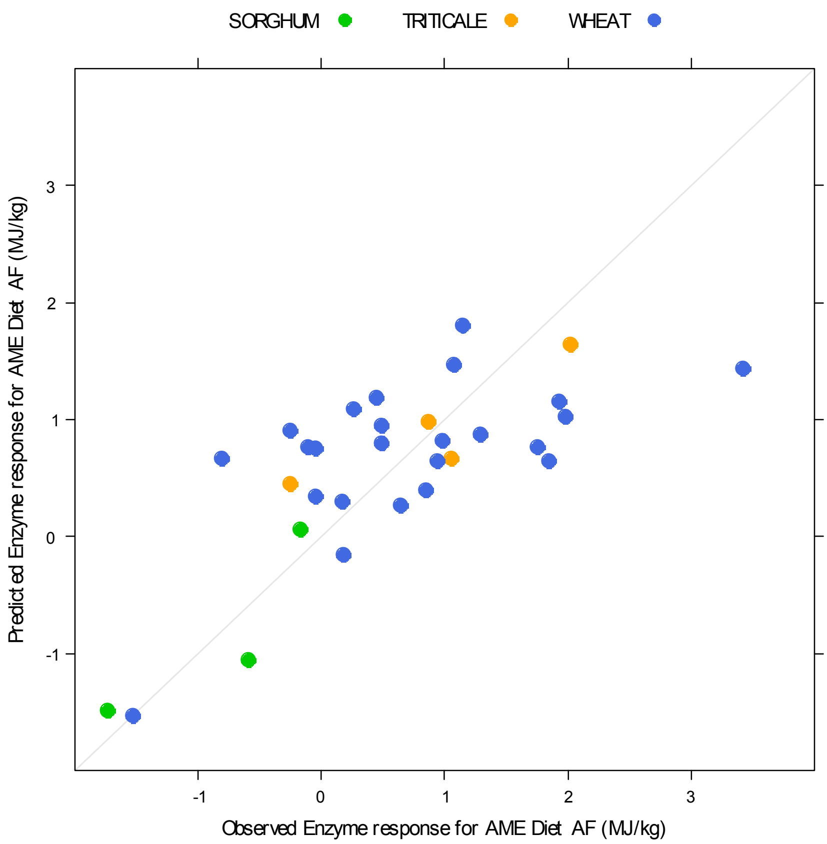


Figure 83. A comparison of the observed response in diet AME to enzymes and the predicted response using the above equations. (R^2=0.63).

The similar equations for predicting the response to enzymes in the AME intake (MJ/day) of a diet containing different grain samples for broilers were for different grain types:

Sorghum response $= 0.348 - 0.621 \times$ Tannin (P=0.043) $- 0.044 \times$ Crude Fat (P=0.019) $+ 0.045 \times$ Cell wall (P=0.028)

Triticale response $= 0.221 - 0.621 \times$ Tannin(P=0.043) $- 0.044 \times$ Crude Fat (P=0.019) $+ 0.045 \times$ Cell wall (P=0.028)

Wheat response $= 0.218 - 0.621 \times$ Tannin (P=0.043) $- 0.044 \times$ Crude Fat (P=0.019) $+ 0.045 \times$ Cell wall (P=0.028)

The predicted response in AME intake of the diet using the above equations is compared with the measured response in Figure 84. The equations predict the general response well accounting for 68% of the observed variation (R^2=0.68). Again the response for the wheat sample H45 was not well predicted, but this inaccuracy did not substantially affect the overall accuracy of the prediction.

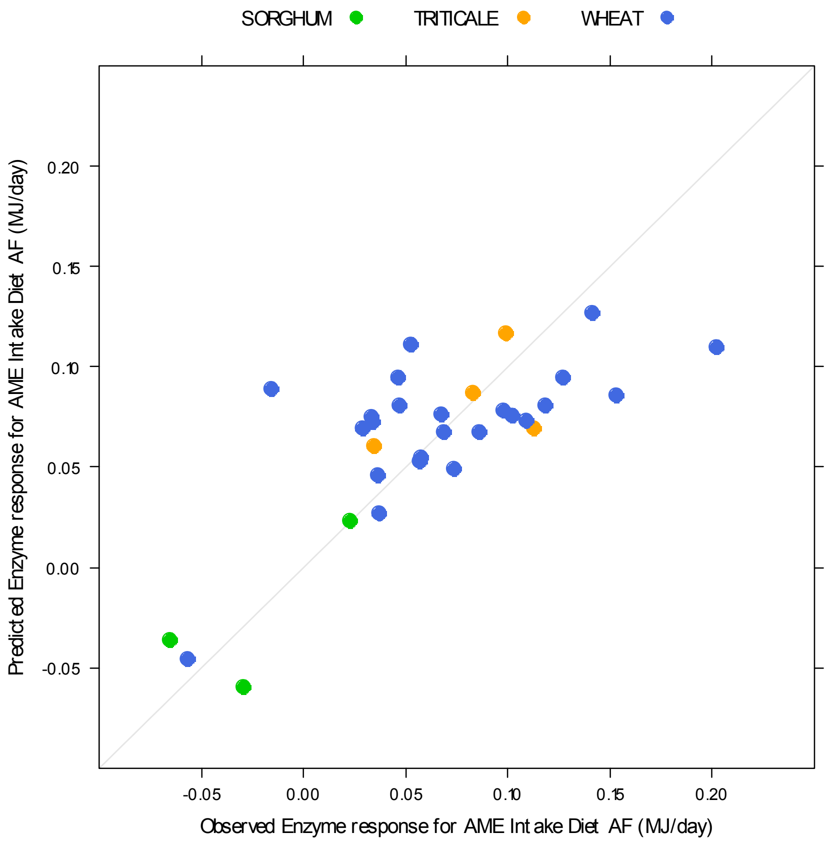


Figure 84. A comparison of the observed response in diet AME intake to enzymes and the predicted response using the above equations. (R^2=0.68).

An important observation from the experiment was that the addition of enzymes reduced feed intake (g/day) of the broilers in only 3 of the diets containing different grains compared with a reduction in AME content (MJ/kg) for 20 of the diets. Thus, the addition of enzymes appeared to have a greater effect on intake than digestibility of diets for broilers. The same statistical approach was used to determine the grain variables that accounted significantly for the variation in feed intake in response to the addition of enzymes. Only grain oligosaccharide (P=0.019, slope=13.28) and NDF (P=0.003, slope=-0.24) content of the grain were found to be significantly related to the feed intake response to enzymes. The equations for predicting the response in intake to enzymes were for each grain type:

Sorghum response $= 5.050 - 0.287 \times$ Englyst NDF (P=0.006) $+ 6.241 \times$ Oligosaccharides (P=0.008)

Triticale response $= 7.347 - 0.287 \times$ Englyst NDF (P=0.006) $+ 6.241 \times$ Oligosaccharides (P=0.008)

Wheat response $= 6.564 - 0.287 \times$ Englyst NDF (P=0.006) $+ 6.241 \times$ Oligosaccharides (P=0.008)

The predicted response in feed intake (g/day) of the diet using the above equations is compared with the measured response in Figure 85. The equations predict the general response well accounting for 55% of the observed variation (R^2=0.55).

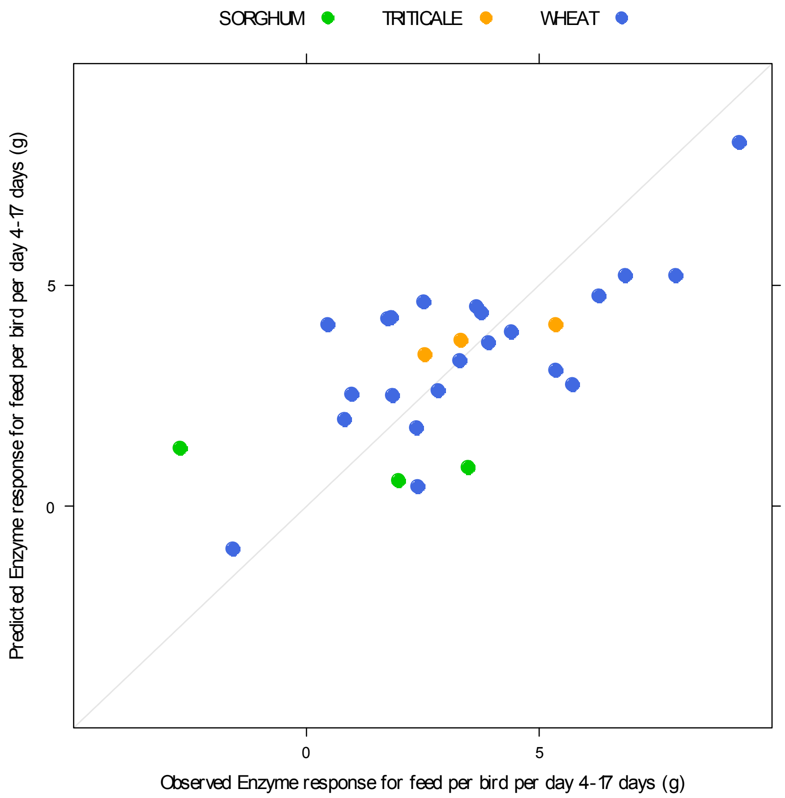


Figure 85. A comparison of the observed response in feed intake to enzymes and the predicted response using the above equations. (R^2=0.55).

In summary, xylanase and phytase enzyme additions to broiler diets result in a wide range of responses in AME and AME intake from negative to highly positive. The magnitude of the responses was shown to be positively related to the soluble cell wall constituents, arabinoxylan and ß-glucan and negatively related to the tannin and crude fat content of the grain. Multiple regression equations were developed to predict the magnitude of the response to enzymes from various chemical components of the grains. These equations accounted for over 60% of the variation observed in diets containing triticale, sorghum and wheat and should be useful as a method for predicting the likely response of broilers to enzyme additions. An important observation was that the addition of enzymes reduced the AME content in 20 of the 49 diets that included wheat, triticale or sorghum, but reduced intake in only three diets. Thus the major positive effect of enzymes on broiler productivity may be through an increase in intake rather than digestibility. AME intake was reduced in 10 of the diets. These analyses indicate that effective equations for predicting the response to enzymes in AME and AME intake for broilers from specified chemical components of cereal grains can be developed. However, a larger experiment including up to 100 cereal grains with widely different characteristics would be needed to validate and enhance the equations before they could be used with confidence by industry.

Effect of the addition of enzymes to cereal grains for pigs

One experiment investigating the effects on ileal DE and faecal DE of addition of xylanases and glucanases to the diets of pig receiving different cereal grains was conducted. The experiment investigated the digestibility of 21 grains including wheat (9), barley (7), triticale (3) and sorghum (2) with the effect of enzymes being evaluated for one sample each of wheat, barley, triticale and sorghum. The addition of enzymes to the diet significantly increased the faecal DE for the barley and sorghum sample, significantly degreased faecal DE for the triticale sample and did not significantly affect faecal DE for the wheat sample (Table 40a). The direction of the responses for each grain was similar for ileal DE, but only the negative response for triticale was significant. Enzymes had no significant effect on the ratio of ileal:faecal DE.

Table 40a. Effect of xylanase and glucanase enzymes on the response in digestibility of one sample of wheat, barley, triticale and sorghum in pigs.

Grain	Faecal DE (MJ/kg DM)		Ileal DE (MJ/kg DM)		Ileal:Faecal DE	
	No[1]	**Yes[1]**	**No[1]**	**Yes[1]**	**No[1]**	**Yes[1]**
Wheat 1721	16.08	16.15	14.22	14.75	0.889	0.920
Barley 3719	14.54	15.00*	11.48	11.89	0.793	0.797
Triticale 6706	15.91	14.39*	14.12	11.83*	0.890	0.826
Sorghum 7710	16.13	16.59*	13.94	14.42	0.871	0.874

[1] Enzyme not added or added * Effect of enzymes significant ($P<0.05$)

The effect of xylanase and glucanase enzymes on digestibility of cereal grains is known to be less in pigs than in poultry because of the higher dry matter content and viscosity of digesta in poultry and the shorter transit time of digesta through the intestines. The significant positive effect of enzymes on DE from barley would be expected because of the thick cell walls found in most samples of barley. However, the positive effect of enzymes on digestibility of sorghum is more difficult to explain because of thin cell walls and generally low NSP content of sorghum. Similarly, the large negative effect of enzymes on digestibility of the triticale sample is difficult to explain. There were insufficient numbers of grains to which enzymes were added in this experiment to draw sound conclusions about their effects on digestibility in pigs.

Summary of achievement of contracted outcomes for PGLP2

The following section outlines progress made towards delivery of the eleven outcomes contracted by GRDC in agreements with the research providers for PGLP2. Opportunities for further analysis of the PGLP results and significant opportunities for additional investment are mentioned also in this section, although the major deliverables from the program are outlined separately in a later section of the report. Results relating to many of the contracted outcomes have been discussed in detail in this report and a brief summary is given here for those outcomes, whereas others such as development of NIR calibrations are now discussed in detail.

The eleven contracted outcomes for PGLP2 were:

1. Near infra-red spectrometry (NIR) and other methods for measuring rapidly voluntary feed intake and energy availability of grains for sheep, cattle, pigs, broiler chickens and laying hens.
2. Rapid methods for predicting the response in nutritional value of individual grains to various mechanical, physical and enzymic processing techniques.
3. Measurement of the nutritional value of sprouted grains (and other weather damaged grains).
4. Selection criteria and breeding objectives for plant breeders aimed at improving the nutritional value of grains for specific forms of livestock production.
5. A ruminant model for predicting the growth and body composition of feedlot cattle offered specific grains with specific processing techniques.
6. A process for improving the pelletability and nutritional value of compound feeds based on cereal grains.
7. An extremely comprehensive database on the chemical, physical and morphological characteristics of cereal grains.
8. Recommendations to grain growers on specific cultivars to be grown for each form of animal production.
9. Potential increase in marketing opportunities, including export, for feed grains based on specification and rapid measurement.
10. Information on grain characteristics affecting their value for humans and rapid methods for measuring these characteristics.
11. A process for rational trading of grains for livestock based on rapid measurement of factors known to influence nutritional value for each form of animal production.

Near infra-red spectrometry (NIR) and other methods for measuring rapidly voluntary feed intake and energy availability of grains for sheep, cattle, pigs, broiler chickens and laying hens

Summary of NIR calibrations developed

Near infra red spectrophotometry (NIR) calibrations were developed from a large number of results generated within the Premium Grains for Livestock Program. The calibrations were developed using a Foss 6500 instrument. The full list of variables for which NIR calibrations were attempted is shown in Tables 41-44. All calibrations were established using scans from whole and milled grains and all results were presented on a dry matter and 'as fed' basis.

Following is a glossary of terms used in Tables 41-44 to assist in determining the value of the calibrations.

Term	Meaning
Experimental observations	Number of experimental observations included in initial calibration
Used in NIR	Number of observations used in final calibration – excluding outliers
Mean	Mean of experimental observations
SD	Standard Deviation of experimental observations
R^2	Fraction of the variance accounted for by the NIR calibration when all accepted observations are included in the relationship
SEC	Standard error of the calibration – when all accepted observations are included in the relationship
1-VR	1-Variance Ration – Fraction of variance accounted for in NIR prediction when some observations are used for 'cross validation' of the calibration as determined by the NIR software
SECV	Standard error of cross validation – Standard error of the calibration when some observations are used for 'cross validation' of the calibration as determined by the NIR software
RPD	Ratio of Prediction to Deviation = SD/SECV an indication of the value of the calibration RPD < 1.5: calibration unsatisfactory RPD = 1.5 – 2.0: calibration can distinguish between high & low values (H-L) RPD = 2.0-2.5: calibration approximately quantitative RPD = 2.5-3.0: calibration predictions good RPD = > 3.0: calibration predictions excellent
95% accuracy value	NIR predicted values will be within the 95% accuracy value for 95% of samples measured from the same population

The calibrations thought to be of most value to the grains and livestock industries and their essential calibration statistics are given in the Table 45. In general there was little difference in the accuracy of calibrations when the whole grain or milled samples were scanned or whether the energy values were expressed on a dry matter or as-fed basis. Thus, the scanning of whole grain is recommended for use of the calibrations in the grains and livestock industries. Because there was little difference in the accuracy of the calibrations between results expressed on a dry matter or as-fed basis, graphs showing observed and NIR predicted values are given for dry matter only.

Table 41. NIR calibrations for whole grain with values expressed on a dry matter basis.

Animal Type	Experimental variable (units)	Experimental Observations	Observations Used in NIR	Mean	SD	NIR calibration statistics R^2	SEC	1-VR	SECV	RPD	Value of calibration	95%a
Ruminants												
Sheep	Dry matter digestibility of cereal grain at maintenance (%)	103	103		6.4			0.89	2.16	3.0	Excellent	4.32
	Metabolisable Energy content of cereal grain at maintenance (MJ/kg dm)	103	103	13.2	0.8	0.88		0.79	0.28	2.9	Good	0.56
Cattle												
	Metabolisable Energy content of cereal grain *ad libitum* (MJ/kg dm)	103	94	12	0.75	0.88		0.80	0.26	2.9	Good	0.52
	Faecal starch (% dm) ground faeces	311	311		9.6			0.99	0.92	10.4	Excellent	1.84
Sheep, cattle, horses												
Oar grains												
	48 hr whole grain *in sacco* dry matter digestibility (%)	389	389		13.7			0.87	4.92	2.8	Good	9.84
	Hull *in vitro* dry matter digestibility (%)	395	395		0.08			0.39	0.06	1.3	Unsatisfactory	0.12
	Hull NDF (%)	211	211		5.7			0.43	4.33	1.3	Unsatisfactory	8.66
	Hull ADF (%)	232	232		3.6			0.66	2.08	1.7	H-L	4.16
	Hull ADL (%)	227	227		3.3			0.83	1.39	2.4	Quantitative	2.78
	Hull Acid insoluble ash (%)	166	166		0.48			0.67	0.28	1.7	H-L	0.56
	Test weight (kg/hl)	290	290		5.6			0.87	2.02	2.8	Good	4.04
	Thousand grain weight (g)	337	337		5.1			0.75	2.57	2.0	Quantitative	5.14
	Hull (% of whole grain)	346	346		7.1			0.86	2.69	2.6	Good	5.38
Monogastrics												
Pigs												
	Grain Faecal digestible energy (MJ/kg DM)	97	90	15.1	0.81	0.86	0.30	0.81	0.35	2.3	Quantitative	0.70
	Grain Ileal digestible energy (MJ/kg DM)	97	91	12.7	1.44	0.85	0.59	0.75	0.71	2.0	Quantitative	1.43
	Ratio Ileal:Faecal digestible energy	97	93	0.83	0.06	0.69	0.03	0.59	0.03	1.6	H-L	0.07
	Faecal DE intake index (0-100+)	63	60	66.5	15.7	0.65	9.29	0.52	10.9	1.5	H-L	21.8
Broilers												
	Apparent Metabolisable Energy (AME) of grain (MJ/kg dm)	109	103	13.87	1.24	0.83	0.51	0.80	0.56	2.2	Quantitative	1.12
	Diet intake (g dm/bird/day)	109	103	101.66	6.78	0.63	4.11	0.47	4.93	1.4	Unsatisfactory	9.85
	Grain intake (g dm/bird/day)	109	103	78.69	5.10	0.62	3.14	0.44	3.82	1.3	Unsatisfactory	7.64
	Diet AME intake (MJ/bird/day)	109	103	1.39	0.16	0.90	0.05	0.75	0.08	2.1	Quantitative	0.15

Grain AME intake (MJ/day)	109	102	1.09	0.15	0.89	0.05	0.78	0.07	2.1	Quantitative	0.14
Ileal Digestible Energy (DE, MJ/kg dm)	90	84	13.72	1.35	0.80	0.61	0.75	0.68	2.0	Quantitative	1.36
AME intake index (0-100+)	109	102	64.97	9.04	0.89	2.99	0.78	4.28	2.1	Quantitative	8.55
Layers											
Apparent Metabolisable Energy (AME) of grain (MJ/kg dm)	92	86	14.04	0.86	0.69	0.48	0.58	0.56	1.5	H-L	1.11
Diet intake (g dm/bird/day)	92	89	117.36	13.62	0.66	7.98	0.54	9.24	1.5	H-L	18.49
Grain intake (g dm/bird/day)	92	89	90.37	10.49	0.66	6.15	0.55	7.12	1.5	H-L	14.23
Diet AME intake (MJ/bird/day)	92	89	1.46	0.17	0.55	0.11	0.46	0.12	1.4	Unsatisfactory	0.24
Grain AME intake (MJ/day)	92	89	1.28	0.15	0.53	0.10	0.45	0.11	1.3	Unsatisfactory	0.22
AME intake index (0-100+)	92	89	76.00	8.84	0.53	6.08	0.43	6.59	1.3	Unsatisfactory	13.18
Chemical/physical properties											
amino acids											
Alanine (g/100g protein)	187	177	4.74	1.99	0.97	0.37	0.95	0.46	4.3	Excellent	0.92
Arginine (g/100g protein)	187	176	5.33	1.38	0.94	0.35	0.92	0.38	3.6	Excellent	0.76
Aspartic Acid (g/100g protein)	187	175	6.18	1.37	0.88	0.47	0.84	0.55	2.5	Good	1.10
Cystine (g/100g protein)	187	180	2.08	0.40	0.78	0.19	0.74	0.21	2.0	Quantitative	0.42
Glutamic Acid (g/100g protein)	187	178	25.77	5.22	0.80	2.36	0.68	2.94	1.8	H-L	5.88
Glycine (g/100g protein)	187	176	3.90	0.50	0.81	0.22	0.73	0.26	1.9	H-L	0.52
Histidine (g/100g protein)	187	173	2.65	0.17	0.21	0.15	0.14	0.16	1.1	Unsatisfactory	0.32
Isoleucine (g/100g protein)	187	176	3.63	0.27	0.69	0.15	0.47	0.20	1.4	Unsatisfactory	0.40
Leucine (g/100g protein)	187	176	7.66	2.35	0.97	0.44	0.95	0.50	4.8	Excellent	1.00
Lysine (g/100g protein)	187	178	3.11	0.75	0.92	0.22	0.89	0.25	3.0	Excellent	0.50
Methionine (g/100g protein)	187	178	1.63	0.26	0.62	0.16	0.57	0.17	1.5	H-L	0.34
Phenylalanine (g/100g protein)	187	176	4.87	0.46	0.77	0.22	0.65	0.27	1.7	H-L	0.54
Proline (g/100g protein)	187	179	9.17	2.45	0.86	0.92	0.82	1.02	2.4	Quantitative	2.04
Serine (g/100g protein)	187	174	4.93	0.36	0.71	0.20	0.66	0.21	1.7	H-L	0.42
Threonine (g/100g protein)	187	179	3.30	0.32	0.81	0.14	0.70	0.17	1.8	H-L	0.34
Tryptophan (g/100g protein)	187	176	1.04	0.21	0.38	0.16	0.31	0.17	1.2	Unsatisfactory	0.34
Tyrosine (g/100g protein)	187	174	3.30	0.44	0.89	0.15	0.82	0.18	2.4	Quantitative	0.36
Valine (g/100g protein)	187	175	4.87	0.45	0.73	0.23	0.62	0.28	1.6	H-L	0.56
Fatty acids											
Linoleic Acid (%DM)	186	174	51.61	7.92	0.93	2.05	0.92	2.27	3.4	Excellent	4.54

Oleic Acid (%DM)	186	175	22.19	10.24	0.95	2.39	0.92	2.81	3.7	Excellent	5.62
Palmitic Acid (%DM)	186	177	17.40	2.92	0.84	1.15	0.80	1.30	2.2	Quantitative	2.60
Stearic Acid (%DM)	185	177	1.52	0.47	0.58	0.31	0.51	0.33	1.4	Unsatisfactory	0.66
N0n-starch polysaccharidss											
Arabinoxylan (%DM)	187	179	6.17	3.49	0.89	1.15	0.87	1.24	2.8	Good	2.48
Arabinose (%DM)	187	178	2.51	0.76	0.80	0.34	0.77	0.36	2.1	Quantitative	0.72
Galactose (%DM)	187	175	0.29	0.17	0.29	0.15	0.27	0.15	1.2	Unsatisfactory	0.30
Xylose (%DM)	187	178	4.58	3.38	0.94	0.84	0.92	0.96	3.6	Excellent	1.92
Total Insoluble NSP (%DM)	187	178	11.05	6.02	0.93	1.65	0.91	1.82	3.3	Excellent	3.64
Beta Glucan (%DM)	177	166	1.73	1.71	0.95	0.40	0.90	0.53	3.2	Excellent	1.06
Total Soluble NSP (%DM)	187	179	1.90	1.47	0.91	0.43	0.86	0.55	2.7	Good	1.10
Proximates											
Moisture (%)	187	179	10.42	1.00	0.67	0.58	0.56	0.67	1.5	H-L	1.34
Crude Fat (%DM)	184	172	2.83	1.42	0.95	0.31	0.93	0.37	3.8	Excellent	0.74
Crude Protein (%DM)	187	177	14.40	4.26	0.97	0.77	0.94	1.01	4.2	Excellent	2.02
Acid Detergent Fibre (%DM)	187	176	6.12	3.96	0.96	0.75	0.96	0.83	4.8	Excellent	1.66
Englyst Neutral Detergent Fibre (%DM)	187	176	18.73	6.93	0.84	2.77	0.80	3.13	2.2	Quantitative	6.26
Starch											
Enzyme-digestible Starch (%DM)	186	179	51.75	12.58	0.96	2.59	0.94	3.00	4.2	Excellent	6.00
Resistant Starch (%DM)	175	168	1.85	1.30	0.22	1.15	0.19	1.17	1.1	Unsatisfactory	2.34
Total Starch (%DM)	186	180	59.72	14.39	0.95	3.11	0.94	3.49	4.2	Excellent	6.98
Other											
Amylose (%DM)	183	171	33.10	3.39	0.71	1.83	0.51	2.38	1.4	Unsatisfactory	4.76
Oligosaccharides (%DM)	187	181	0.49	0.75	0.96	0.16	0.92	0.21	3.7	Excellent	0.42
Gross Energy (MJ/kg DM)	187	175	16.87	0.47	0.91	0.14	0.87	0.17	2.9	Good	0.34
Hydration Capacity (% increase in grain weight following 16 hr emersion in water)	187	180	48.72	20.04	0.92	5.52	0.89	6.68	3.0	Excellent	13.36

Table 42. NIR calibrations for milled grain with values expressed on a dry matter basis.

		Experimental	Observations			NIR calibration statistics						
Animal Type	Experimental variable	Observations	Used in NIR	Mean	SD	R^2	SEC	1-VR	SECV	RPD	Value of calibration	95%accuracy Value
Ruminants												
Sheep	Dry matter digestibility of cereal grain at maintenance (%)	103	103		6.4			0.91	1.9	3.4	Excellent	3.8
	Metabolisable Energy content of cereal grain at maintenance(MJ/kg dm)	103	103	13.2	0.8	0.94	0.2	0.89	0.27	3.0	Excellent	0.54
Cattle												
	Metabolisable Energy content of cereal grain *ad libitum* (MJ/kg dm)	103	94	12	0.75	0.92	0.21	0.89	0.25	3.0	Excellent	0.5
Sheep & cattle	Acidosis index		87		22.7			0.8	10.24	2.2	Quantitative	20.5
UNE in vitro assays												
	Enzyme digestible starch (% starch)		84		10.7			0.44	8.02	1.3	Unsatisfactory	16.0
	Enzyme digestible starch from 6 hr *in sacco* residue (% starch)		86		13			0.52	9	1.4	Unsatisfactory	18
	6hr *in sacco* dry matter digestibility (%)		86		12.4			0.79	5.65	2.2	Quantitative	11.3
	24hr *in sacco* dry matter digestibility (%)		85		11.1			0.82	4.71	2.4	Quantitative	9.4
	6hr *in sacco* starch digestibility (% starch) with sorghum		84		14.9			0.79	6.84	2.2	Quantitative	13.7
	6hr *in sacco* starch digestibility (% starch) without sorghum		76		6.4			0.39	5.05	1.3	Unsatisfactory	10.1
	24hr in sacco starch digestibility (% starch) with sorghum		85		11.7			0.75	5.77	2.0	Quantitative	11.5
	24hr in sacco starch digestibility (% starch) without sorghum		79		5.6			0.38	4.45	1.3	Unsatisfactory	8.9
	Starch lost from in sacco bagsd in water(% starch)		88		12.4			0.16	11.3	1.1	Unsatisfactory	22.6
	Starch lost durung 5 hr *in vitro* fermentation (% starch)		83		6.2			0.8	2.78	2.2	Quantitative	5.6
	Total acid produiction 5 hr in vitro fermentation (mM)		86		3.2			0.92	0.89	3.6	Excellent	1.78
	Lactic acid produiction 5 hr in vitro fermentation (mM)		86		1.2			0.72	0.63	1.9	H-L	1.26
Monogastrics												
Pigs												
	Grain Faecal digestible energy (MJ/kg as fed)	98	92	15.2	0.84	0.85	0.33	0.79	0.38	2.2	Quantitative	0.76
	Grain Ileal digestible energy (MJ/kg as fed)	98	92	12.6	1.44	0.76	0.70	0.73	0.75	1.9	H-L	1.50
	Ratio Ileal:Faecal digestible energy	98	95	0.83	0.06	0.65	0.03	0.59	0.04	1.5	H-L	0.07

Faecal DE intake index (0-100+)	63	61	67.3	15.8	0.81	6.95	0.58	10.3	1.5	H-L	20.6
Broilers											
Apparent Metabolisable Energy (AME) of grain (MJ/kg dm)	109	103	13.8	1.31	0.93	0.35	0.85	0.51	2.6	Good	1.02
Diet intake (g dm/bird/day)	109	102	101.7	6.58	0.55	4.40	0.47	4.80	1.4	Unsatisfactory	9.59
Grain intake (g dm/day)	109	103	78.7	4.95	0.57	3.23	0.48	3.56	1.4	Unsatisfactory	7.12
Diet AME intake (MJ/bird/day)	109	104	1.39	0.16	0.78	0.07	0.75	0.08	2.0	Quantitative	0.15
Grain AME intake (MJ dm/day)	109	102	1.09	0.14	0.83	0.06	0.80	0.06	2.4	Quantitative	0.12
Ileal Digestible Energy (DE, MJ/kg dm)	109	84	13.6	1.45	0.83	3.52	0.70	0.79	1.8	H-L	1.57
AME intake index dm (0-100+)	109	102	64.7	8.46	0.93	0.39	0.80	3.73	2.3	Quantitative	7.5
AME combined Canadian/PGLP results	290	280	13.9	1.24	0.91		0.87	0.45	2.8	Good	0.9
Layers											
Apparent Metabolisable Energy (AME) of grain (MJ/kg dm)	92	85	14.1	0.831	0.687	0.465	0.598	0.527	1.6	H-L	1.05
Diet intake (g dm/bird/day)	92	88	117.0	13.148	0.599	8.323	0.479	9.472	1.4	Unsatisfactory	18.9
Grain intake (g dm/bird/day)	92	88	90.1	10.124	0.599	6.408	0.479	7.293	1.4	Unsatisfactory	14.5
Diet AME intake (MJ/bird/day)	92	89	1.46	0.166	0.51	0.116	0.301	0.139	1.2	Unsatisfactory	0.27
Grain AME intake (MJ/day)	92	89	1.28	0.149	0.416	0.114	0.265	0.128	1.2	Unsatisfactory	0.26
AME intake index (0-100+)	92	89	76.0	8.84	0.416	6.755	0.265	7.585	1.2	Unsatisfactory	15.2
Chemical/physical properties											
amino acids											
Alanine (g/100g protein)	188	180	4.81	2.05	0.97	0.36	0.95	0.44	4.8	Excellent	0.88
Arginine (g/100g protein)	188	177	5.30	1.33	0.94	0.33	0.93	0.36	3.7	Excellent	0.72
Aspartic Acid (g/100g protein)	188	182	6.34	1.60	0.95	0.36	0.93	0.43	3.7	Excellent	0.86
Cystine (g/100g protein)	188	184	2.06	0.41	0.81	0.18	0.76	0.20	2.0	Quantitative	0.40
Glutamic Acid (g/100g protein)	188	180	25.62	5.39	0.90	1.71	0.84	2.16	2.5	Good	4.32
Glycine (g/100g protein)	188	182	3.95	0.53	0.90	0.17	0.84	0.21	2.5	Good	0.42
Histidine (g/100g protein)	188	174	2.66	0.18	0.21	0.16	0.12	0.17	1.1	Unsatisfactory	0.34
Isoleucine (g/100g protein)	188	180	3.63	0.29	0.61	0.18	0.47	0.21	1.4	Unsatisfactory	0.42
Leucine (g/100g protein)	188	181	7.81	2.56	0.96	0.54	0.94	0.62	4.2	Excellent	1.24
Lysine (g/100g protein)	188	183	3.11	0.80	0.94	0.20	0.91	0.24	3.4	Excellent	0.48

	Methionine (g/100g protein)	188	180	1.63	0.25	0.66	0.15	0.55	0.17	1.5	H-L	0.34
	Phenylalanine (g/100g protein)	188	178	4.87	0.44	0.80	0.20	0.70	0.24	1.9	H-L	0.48
	Proline (g/100g protein)	188	179	9.17	2.37	0.94	0.61	0.91	0.71	3.3	Excellent	1.42
	Serine (g/100g protein)	188	182	4.91	0.39	0.74	0.20	0.69	0.22	1.8	H-L	0.44
	Threonine (g/100g protein)	188	182	3.31	0.32	0.82	0.14	0.69	0.18	1.8	H-L	0.36
	Tryptophan (g/100g protein)	188	180	1.04	0.21	0.40	0.16	0.28	0.17	1.2	Unsatisfactory	0.34
	Tyrosine (g/100g protein)	188	178	3.31	0.42	0.84	0.17	0.80	0.19	2.2	Quantitative	0.38
	Valine (g/100g protein)	188	175	4.88	0.43	0.78	0.20	0.66	0.25	1.7	H-L	0.50
Fatty acids												
	Linoleic Acid (%DM)	187	174	51.44	8.40	0.97	1.47	0.94	2.09	4.0	Excellent	4.18
	Oleic Acid (%DM)	187	178	22.35	10.41	0.97	1.71	0.96	2.17	4.8	Excellent	4.34
	Palmitic Acid (%DM)	187	183	17.41	3.09	0.88	1.05	0.85	1.18	2.6	Good	2.36
	Stearic Acid (%DM)	186	177	1.53	0.46	0.58	0.30	0.54	0.31	1.5	H-L	0.62
N0n-starch polysaccharidss												
	Arabinoxylan (%DM)	188	182	6.10	3.47	0.94	0.88	0.87	1.25	2.8	Good	2.50
	Arabinose (%DM)	188	181	2.50	0.75	0.81	0.32	0.76	0.36	2.0	Quantitative	0.72
	Galactose (%DM)	188	181	0.30	0.17	0.75	0.09	0.63	0.11	1.6	H-L	0.22
	Xylose (%DM)	188	181	4.56	3.46	0.95	0.75	0.90	1.08	3.2	Excellent	2.16
	Total Insoluble NSP (%DM)	188	176	10.65	5.75	0.94	1.46	0.90	1.78	3.2	Excellent	3.56
	Beta Glucan (%DM)	178	171	1.79	1.75	0.97	0.32	0.93	0.47	3.7	Excellent	0.94
	Total Soluble NSP (%DM)	188	181	1.91	1.47	0.88	0.50	0.85	0.57	2.6	Good	1.14
Proximates												
	Moisture (%)	188	184	10.38	1.05	0.63	0.64	0.56	0.69	1.5	H-L	1.38
	Crude Fat (%DM)	185	178	2.88	1.68	0.99	0.18	0.98	0.23	7.1	Excellent	0.46
	Crude Protein (%DM)	188	180	14.48	4.55	0.99	0.44	0.99	0.53	8.3	Excellent	1.06
	Acid Detergent Fibre (%DM)	188	177	6.16	3.80	0.96	0.74	0.95	0.87	4.3	Excellent	1.74
	Englyst Neutral Detergent Fibre (%DM)	187	180	18.81	7.09	0.89	2.36	0.85	2.74	2.6	Good	5.48
Starch												
	Enzyme-digestible Starch (%DM)	187	180	51.79	11.98	0.97	2.11	0.95	2.69	4.5	Excellent	5.38

	Resistant Starch (%DM)	176	168	1.82	1.27	0.23	1.12	0.20	1.15	1.1	Unsatisfactory	2.29
	Total Starch (%DM)	187	180	60.36	14.16	0.98	2.16	0.96	2.89	5.0	Excellent	5.78
Other												
	Amylose (%DM)	184	171	33.21	2.98	0.57	1.96	0.40	2.33	1.3	Unsatisfactory	4.66
	Oligosaccharides (%DM)	188	181	0.53	0.81	0.96	0.15	0.95	0.18	4.5	Excellent	0.36
	Gross Energy (MJ/kg DM)	188	183	16.88	0.53	0.94	0.13	0.93	0.14	3.8	Excellent	0.28
	Hydration Capacity	187	182	48.20	19.51	0.93	5.30	0.89	6.44	3.0	Excellent	12.9

Table 43. NIR calibrations for whole grain with values expressed on an as-fed basis.

		Experimental	Observations			NIR calibration statistics						
Animal Type	Experimental variable (units)	Observations	Used in NIR	Mean	SD	R^2	SEC	1-VR	SECV	RPD	Value of calibration	95%accuracy Value
Monogastrics												
Pigs												
	Grain Faecal digestible energy (MJ/kg as fed)	97	91	13.5	0.79	0.84	0.32	0.77	0.38	2.1	Quantitative	0.75
	Grain Ileal digestible energy (MJ/kg as fed)	97	91	11.3	1.32	0.84	0.52	0.74	0.68	2.0	Quantitative	1.35
	Ratio Ileal:Faecal digestible energy	97	93	0.83	0.06	0.69	0.03	0.59	0.03	1.6	H-L	0.07
	Faecal DE intake index (0-100+)	63	60	66.5	15.7	0.65	9.29	0.52	10.9	1.5	H-L	21.8
Broilers												
	AME of grain (MJ/kg as fed)	109	104	12.4	1.07	0.88	0.37	0.75	0.54	2.0	Good	1.07
	Diet intake (g/bird/day as fed)	109	101	114.3	7.42	0.71	4.02	0.48	5.35	1.4	Unsatisfactory	10.7
	Grain intake (g/bird/day as fed)	109	100	88.3	5.55	0.66	3.24	0.51	3.91	1.4	Unsatisfactory	7.8
	Diet AME intake (MJ/bird/day)	109	103	1.39	0.16	0.90	0.05	0.75	0.08	2.1	Quantitative	0.15
	Grain AME intake (MJ/day)	109	102	1.09	0.15	0.89	0.05	0.78	0.07	2.1	Quantitative	0.14
	Ileal Digestible Energy (MJ/kg as fed)	90	84	13.7	1.35	0.80	0.61	0.75	0.68	2.0	Quantitative	1.36
	AME intake index (0-100+)	109	102	65.0	9.04	0.89	2.99	0.78	4.28	2.1	Quantitative	8.6
Layers												
	AME of grain (MJ/kg as fed)	92	84	12.7	0.75	0.56	0.50	0.48	0.54	1.4	Unsatisfactory	1.09
	Diet intake (g/bird/day as fed)	92	89	130.8	14.88	0.66	8.72	0.55	10.07	1.5	Good	20.1
	Grain intake (g/bird/day as fed)	92	89	100.7	11.46	0.66	6.72	0.55	7.75	1.5	Good	15.5
	Diet AME intake (MJ/bird/day as fed)	92	89	1.46	0.17	0.55	0.11	0.46	0.12	1.4	Unsatisfactory	0.24
	Grain AME intake (MJ/day)	92	89	1.28	0.15	0.53	0.10	0.45	0.11	1.3	Unsatisfactory	0.22
	AME intake index (0-100+)	92	89	76.0	8.84	0.53	6.08	0.43	6.59	1.3	Unsatisfactory	13.2
Chemical/physical properties												

amino acids												
	Alanine (% as received)	142	134	0.58	0.22	0.92	0.06	0.89	0.07	3.0	Excellent	0.15
	Arginine (% as received)	142	132	0.62	0.16	0.95	0.04	0.90	0.05	3.2	Excellent	0.10
	Aspartic Acid (% as received)	142	131	0.72	0.12	0.85	0.05	0.76	0.06	2.1	Good	0.12
	Cystine (% as received)	142	133	0.26	0.07	0.91	0.02	0.89	0.02	3.0	Excellent	0.05
	Glutamic Acid (% as received)	142	131	3.45	1.19	0.95	0.28	0.91	0.35	3.4	Excellent	0.71
	Glycine (% as received)	142	132	0.48	0.12	0.97	0.02	0.94	0.03	4.1	Excellent	0.06
	Histidine (% as received)	142	135	0.34	0.08	0.90	0.03	0.85	0.03	2.6	Good	0.06
	Isoleucine (% as received)	142	135	0.46	0.11	0.92	0.03	0.89	0.04	3.0	Excellent	0.07
	Leucine (% as received)	142	132	0.97	0.29	0.96	0.06	0.94	0.07	4.0	Excellent	0.15
	Lysine (% as received)	142	132	0.37	0.10	0.94	0.02	0.91	0.03	3.3	Excellent	0.06
	Methionine (% as received)	142	133	0.22	0.05	0.88	0.02	0.82	0.02	2.4	Quantitative	0.04
	Phenylalanine (% as received)	142	134	0.62	0.16	0.92	0.05	0.88	0.06	2.9	Good	0.11
	Proline (% as received)	142	133	1.28	0.43	0.93	0.11	0.89	0.14	3.0	Excellent	0.28
	Serine (% as received)	142	136	0.62	0.15	0.94	0.04	0.90	0.05	3.2	Excellent	0.09
	Threonine (% as received)	142	133	0.41	0.08	0.92	0.02	0.87	0.03	2.8	Good	0.05
	Tryptophan (% as received)	93	90	0.13	0.04	0.79	0.02	0.71	0.02	1.9	H-L	0.04
	Tyrosine (% as received)	142	132	0.41	0.09	0.93	0.02	0.89	0.03	3.0	Excellent	0.06
	Valine (% as received)	142	135	0.62	0.14	0.90	0.04	0.85	0.05	2.6	Good	0.11
Fatty acids												
	Linoleic Acid (% total fat)	186	174	51.606	7.92	0.93	2.05	0.92	2.27	3.4	Excellent	4.54
	Oleic Acid (% total fat)	186	175	22.187	10.24	0.95	2.39	0.92	2.81	3.7	Excellent	5.62
	Palmitic Acid (% total fat)	186	177	17.404	2.92	0.84	1.15	0.80	1.30	2.2	Quantitative	2.60
	Stearic Acid (% total fat)	186	177	1.518	0.47	0.58	0.31	0.51	0.33	1.4	Unsatisfactory	0.66
Non-starch polysaccharidss												
	Arabinoxylan - insol (% as received)	142	134	4.6048	1.75	0.91	0.54	0.83	0.71	2.5	Good	1.43
	Arabinose - insol. (% as received)	142	133	2.199	0.57	0.85	0.22	0.75	0.28	2.0	Quantitative	0.57
	Galactose - insol. (% as received)	142	131	0.2125	0.05	0.59	0.03	0.47	0.04	1.4	Unsatisfactory	0.07
	Xylose - insol. (% as received)	142	134	3.2789	1.37	0.94	0.34	0.86	0.50	2.7	Good	1.01
	Total Insoluble NSP (% as received)	142	130	8.0455	2.38	0.90	0.75	0.84	0.94	2.5	Good	1.89

	Beta Glucan (% as received)	142	130	1.4265	1.53	0.97	0.28	0.90	0.48	3.1	Excellent	0.97
	Total Soluble NSP (% as received)	142	129	1.6343	1.31	0.94	0.31	0.88	0.46	2.9	Good	0.91
*	Total_free_sugar (% as received)	142	134	1.7438	0.62	0.78	0.29	0.72	0.33	1.9	H-L	0.66
*	Cellulose (% as received)	142	131	2.9693	1.22	0.79	0.56	0.62	0.75	1.6	H-L	1.49
Proximates												
	Moisture (%)	186	179	10.42	1.00	0.67	0.58	0.56	0.67	1.5	H-L	1.34
	Moisture (%)	139	133	10.50	0.96	0.74	0.49	0.55	0.64	1.5	H-L	1.29
	Crude Fat (% as received)	139	131	2.12	0.60	0.96	0.12	0.92	0.17	3.5	Excellent	0.35
	Crude Protein (% as received)	139	134	12.75	3.03	0.95	0.69	0.91	0.90	3.4	Excellent	1.80
*	Acid Detergent Fibre (% as received)											
*	Englyst Neutral Detergent Fibre (% as received)											
*	Crude_Fibre	139	130	3.26	1.18	0.95	0.28	0.90	0.37	3.2	Excellent	0.74
Starch												
	Enzyme-digestible Starch (% as received)		179	51.75	12.58	0.96	2.59	0.94	3.00	4.2	Excellent	6.0
	Enzyme-digestible Starch (% as received)	141	134	55.27	6.29	0.91	1.93	0.83	2.59	2.4	Quantitative	5.2
	Resistant Starch (% as received)		168	1.85	1.30	0.22	1.15	0.19	1.17	1.1	Unsatisfactory	2.3
	Resistant Starch (% as received)	141	125	2.02	1.22	0.15	1.13	0.13	1.14	1.1	Unsatisfactory	2.3
	Total Starch (% as received)	141	133	57.43	6.41	0.91	1.91	0.83	2.61	2.5	Good	5.2
Other												
	Amylose (% as received)	142	133	28.60	2.65	0.36	2.11	0.29	2.22	1.2	Unsatisfactory	4.4
	Oligosaccharides (% as received)	142	135	0.38	0.20	0.70	0.11	0.59	0.13	1.6	Excellent	0.25
*	Tannin_total (% as received)	142	130	0.19	0.09	0.91	0.03	0.72	0.05	1.9	H-L	0.10
	Gross Energy (MJ/kg as received)	187	175	16.87	0.47	0.91	0.14	0.87	0.17	2.9	Good	0.34
	Gross Energy (MJ/kg as received)	142	133	16.71	0.23	0.65	0.14	0.60	0.15	1.6	H-L	0.30
	Hydration Capacity (% increase in	187	180	48.72	20.04	0.92	5.52	0.89	6.68	3.0	Excellent	13.4

	grain weight following 16 hr emersion in water)

*	This measurement was only used in the monogastric (as fed) calibrations and has no equivalent ruminant (dry matter) calibration
*	This measurement was only used in the ruminant (dm) calibrations and has no equivalent monogastric (as fed) calibration

Table 44. NIR calibrations for milled grain with values expressed on an as-fed basis.

		Experimental	Observations			NIR calibration statistics						
Animal Type	**Experimental variable**	**Observations**	**Used in NIR**	**Mean**	**SD**	**R^2**	**SEC**	**1-VR**	**SECV**	**RPD**	**Value of calibration**	**95%accuracy Value**
Monogastrics												
Pigs												
	Grain Faecal digestible energy (MJ/kg as fed)	98	92	13.5	0.80	0.85	0.31	0.80	0.36	2.2	Quantitative	0.72
	Grain Ileal digestible energy (MJ/kg as fed)	98	92	11.2	1.31	0.79	0.60	0.74	0.67	2.0	Quantitative	1.33
	Ratio Ileal:Faecal digestible energy	98	95	0.83	0.06	0.65	0.03	0.59	0.04	1.5	H-L	0.07
	Faecal DE intake index (0-100+)	63	61	67.3	15.8	0.81	6.95	0.58	10.3	1.5	H-L	20.6
Broilers												
	AME of grain (MJ/kg)	109	104	12.4	1.14	0.94	0.28	0.82	0.48	2.4	Quantitative	0.96
	Diet intake (g/bird/day)	109	101	114.1	7.47	0.62	4.58	0.56	4.96	1.5	H-L	9.93
	Grain intake (g/day)	109	100	88.5	5.47	0.62	3.36	0.55	3.66	1.5	H-L	7.32
	Diet AME intake (MJ/bird/day)	109	104	1.39	0.16	0.78	0.07	0.75	0.08	2.0	Quantitative	0.15
	Grain AME intake (MJ dm/day)	109	102	1.09	0.14	0.83	0.06	0.80	0.06	2.4	Quantitative	0.12
	Ileal Digestible Energy (DE, MJ/kg as fed)	109	84	13.6	1.45	0.83	3.52	0.70	0.79	1.8	H-L	1.57
	AME intake index dm (0-100+)	109	102	64.7	8.46	0.93	0.39	0.80	3.73	2.3	Quantitative	7.46
	AME combined Canadian/PGLP results	290	280	13.9	1.24			0.87	0.45	2.8	Good	0.90
Layers												
	AME of grain (MJ/kg)	92	87	12.7	0.84	0.69	0.46	0.62	0.62	1.4	Unsatisfactory	1.24
	Diet intake (g/bird/day)	92	89	130.2	14.29	0.64	8.55	0.46	10.48	1.4	Unsatisfactory	21.0
	Grain intake (g/bird/day)	92	89	100.3	11.01	0.64	6.58	0.46	8.07	1.4	Unsatisfactory	16.1
	Diet AME intake (MJ/bird/day)	92	89	1.46	0.17	0.51	0.12	0.30	0.14	1.2	Unsatisfactory	0.28
	Grain AME intake (MJ/day)	92	89	1.28	0.15	0.42	0.11	0.27	0.13	1.2	Unsatisfactory	0.26

AME intake index (0-100+)	92	89	76.0	8.84	0.42	6.76	0.27	7.59	1.2	Unsatisfactory	15.2
Chemical/physical properties amino acids											
Alanine (% as received)	141	134	0.579	0.21	0.95	0.05	0.90	0.07	3.2	Excellent	0.13
Arginine (% as received)	141	135	0.627	0.17	0.88	0.06	0.85	0.07	2.6	Good	0.13
Aspartic Acid (% as received)	141	133	0.715	0.13	0.91	0.04	0.84	0.05	2.5	Good	0.11
Cystine (% as received)	141	133	0.258	0.07	0.93	0.02	0.92	0.02	3.5	Excellent	0.04
Glutamic Acid (% as received)	141	131	3.379	1.21	0.97	0.22	0.94	0.30	4.0	Excellent	0.60
Glycine (% as received)	141	135	0.482	0.12	0.96	0.02	0.94	0.03	4.2	Excellent	0.06
Histidine (% as received)	141	133	0.332	0.09	0.93	0.02	0.90	0.03	3.2	Excellent	0.05
Isoleucine (% as received)	141	132	0.456	0.12	0.96	0.02	0.94	0.03	4.0	Excellent	0.06
Leucine (% as received)	141	129	0.958	0.28	0.96	0.05	0.93	0.07	3.9	Excellent	0.14
Lysine (% as received)	141	135	0.367	0.10	0.95	0.02	0.93	0.03	3.8	Excellent	0.05
Methionine (% as received)	141	134	0.213	0.05	0.90	0.02	0.86	0.02	2.7	Good	0.04
Phenylalanine (% as received)	141	132	0.621	0.17	0.96	0.03	0.94	0.04	4.1	Excellent	0.08
Proline (% as received)	141	133	1.280	0.44	0.96	0.09	0.93	0.11	3.8	Excellent	0.23
Serine (% as received)	141	134	0.608	0.15	0.96	0.03	0.95	0.03	4.6	Excellent	0.07
Threonine (% as received)	141	135	0.408	0.08	0.95	0.02	0.91	0.02	3.4	Excellent	0.05
Tryptophan (% as received)	141	132	0.130	0.03	0.61	0.02	0.55	0.02	1.5	H-L	0.04
Tyrosine (% as received)	141	134	0.407	0.09	0.95	0.02	0.95	0.02	4.3	Excellent	0.04
Valine (% as received)	141	132	0.615	0.14	0.96	0.03	0.93	0.04	3.7	Excellent	0.08
Fatty acids											
Linoleic Acid (% total fat)	187	174	51.439	8.40	0.97	1.47	0.94	2.09	4.0	Excellent	4.18
Oleic Acid (% total fat)	187	178	22.354	10.41	0.97	1.71	0.96	2.17	4.8	Excellent	4.34
Palmitic Acid (% total fat)	187	183	17.405	3.09	0.88	1.05	0.85	1.18	2.6	Good	2.36
Stearic Acid (% total fat)	186	177	1.525	0.46	0.58	0.30	0.54	0.31	1.5	H-L	0.62
Non-starch polysaccharidss											
Arabinoxylan - insol. (% as received)	141	133	4.70	1.77	0.94	0.45	0.82	0.74	2.4	Quantitative	1.49
Arabinose - insol. (% as received)	141	137	2.20	0.60	0.89	0.20	0.72	0.32	1.9	H-L	0.64
Galactose - insol. (% as received)	141	135	0.21	0.06	0.43	0.04	0.35	0.04	1.2	Unsatisfactory	0.09

		Xylose - insol. (% as received)	141	136	3.39	1.50	0.92	0.43	0.84	0.60	2.5	Good	1.19
		Total Insoluble NSP (% as received)	141	133	8.08	2.52	0.85	0.97	0.80	1.13	2.2	Quantitative	2.27
		Beta Glucan (% as received)	140	135	1.53	1.58	0.97	0.27	0.92	0.45	3.6	Excellent	0.89
		Total Soluble NSP (% as received)	141	132	1.65	1.32	0.95	0.29	0.89	0.43	3.1	Excellent	0.86
*		Total_free_sugar (% as received)	141	135	1.77	0.66	0.85	0.25	0.74	0.34	2.0	Good	0.67
*		Cellulose (% as received)	141	136	3.29	1.67	0.89	0.56	0.83	0.68	2.4	Good	1.37
	Proximates												
		Moisture (%)	187	184	10.38	1.05	0.63	0.64	0.56	0.69	1.5	H-L	1.38
		Moisture (%)	138	134	10.40	1.08	0.82	0.45	0.65	0.64	1.7	H-L	1.27
		Crude Fat (% as received)	138	130	2.11	0.59	0.94	0.14	0.92	0.17	3.6	Excellent	0.33
		Crude Protein (% as received)	138	132	12.61	3.05	0.96	0.58	0.96	0.63	4.9	Excellent	1.26
*		Acid Detergent Fibre (% as received)	188										
*		Englyst Neutral Detergent Fibre (% as received)	187										
*		Crude_fibre	138	134	3.29	1.22	0.92	0.35	0.87	0.44	2.8	Good	0.88
	Starch												
		Enzyme-digestible Starch (% as received)	187	180	51.79	11.98	0.97	2.11	0.95	2.69	4.5	Excellent	5.38
		Resistant Starch (% as received)	187	168	1.82	1.27	0.23	1.12	0.20	1.15	1.1	Unsatisfactory	2.29
		Enzyme-digestible Starch (% as received)	140	132	55.30	6.46	0.91	1.89	0.87	2.32	2.8	Good	4.65
		Resistant Starch (% as received)	140	125	2.07	1.20	0.33	0.98	0.24	1.05	1.1	Unsatisfactory	2.09
		Total Starch (% as received)	140	133	57.26	6.46	0.93	1.69	0.87	2.33	2.8	Good	4.66
	Other												
		Amylose (% as received)	141	132	28.62	2.38	0.36	1.90	0.16	2.18	1.1	Unsatisfactory	4.36
		Oligosaccharides (% as received)	141	136	0.38	0.20	0.86	0.07	0.65	0.12	1.7	H-L	0.23
*		Tannin_total	141	131	0.19	0.09	0.90	0.03	0.79	0.04	2.2	Good	0.09
		Gross Energy (MJ/kg)	187	183	16.88	0.53	0.94	0.13	0.93	0.14	3.8	Excellent	0.28
		Gross Energy (MJ/kg)	141	135	16.72	0.24	0.60	0.15	0.52	0.17	1.4	Unsatisfactory	0.33

Hydration Capacity	187	182	48.20	19.51	0.93	5.30	0.89	6.44	3.0	Excellent	12.9

* This measurement was only used in the monogastric (as fed) calibrations and has no equivalent ruminant (dry matter) calibration

* This measurement was only used in the ruminant (dm) calibrations and has no equivalent monogastric (as fed) calibration

Table 45. Summary of NIR calibrations considered to be of greatest value of the grains and livestock industries.

Animal type	Measurement (units)	NIR Calibrations						
		Whole grain scan			Milled grain scan			Comments
		RPD	Accuracy	95% limits	RPD	Accuracy	95% limits	
Ruminants								
Sheep	DMD of cereal grains fed at maintenance (%)	3.0	Excellent	4.3	3.4	Excellent	3.8	Milled samples slightly better: whole grain valuable
	Cereal grain ME maintenance (MJ/kg DM)	2.9	Good	0.56	3.0	Excellent	0.54	Little advantage from milled
Cattle	Cereal grain ME (MJ/kg DM) ex-sorghum	2.9	Good	0.52	3.0	Excellent	0.50	Little advantage from milled
	Starch in dried ground faeces (%)	10.4	Excellent	1.8				Excellent – assessing processing efficiency
	Acidosis index (0-100+)				2.2	Quantitative	20	Useful for ruminants & horses: needs validation in case study
	Total acid production 5h *in vitro* (mM)				3.6	Excellent	1.78	Input for AusBeef model
Herbivores								
Whole oats	48 hr *in sacco* DMD (%)	2.8	Good	9.8				Useful for oat breeding
	Hull ADL (lignin) (%)	2.4	Quantitative	2.8				
	Test weight (kg/hl)	2.8	Good	4.0				Useful for oat breeding
	Hull percent of whole grain (%)	2.6	Good	5.4				Useful for oat breeding

Pigs	Grain faecal DE (MJ/kg)	2.3	Quantitative	0.75	2.2	Quantitative	0.76	DM basis slightly more accurate than as fed; whole better than milled
	Ratio ileal:faecal DE	1.6	H-L	0.07	1.5	High-Low	0.07	Whole grain slightly better; same result for DM or as fed
	Faecal DE intake index (0-100+)	1.5	H-L	21.8	1.5	High-Low	20.6	Whole grain & milled similar; same result for DM or as fed
Broilers	Grain AME (MJ/kg)	2.2	Quantitative	1.12	2.6	Good	1.0	Milled better than whole; DM slightly better than as fed
	Grain AME (Canadian+PGLP)				2.8	Good	0.9	Small improvement
	Grain AME intake index (0-100+)	2.1	Quantitative	8.6	2.3	Quantitative	7.5	Little advantage milled; same result for DM or as fed
	Ileal DE (MJ/kg)	2.1	Quantitative	1.36	1.8	High-Low	1.6	Whole better than milled; DM and as fed similar
Layers	Grain AME (MJ/kg DM)	1.5	High-low	1.11	1.6	High-Low	1.05	Milled and whole grain similar; DM slightly better than as fed
	Grain intake (g DM/bird/day)	1.5	High-low	14.2	1.4	Poor	14.6	Insufficient accuracy to be useful
	Grain AME intake index (0-100+)	1.3	Poor	13.2	1.2	Poor	15.2	Insufficient accuracy to be useful
Grain Characteristics								

	Crude protein (% DM)	4.2	Excellent	2.0	8.3	Excellent	1.1	Milled more accurate
	Crude fat (% DM)	3.8	Excellent	0.74	7.1	Excellent	0.46	Milled more accurate
	ADF (% DM)	4.8	Excellent	1.6	4.3	Excellent	1.7	Whole more accurate
	NDF (% DM)	2.2	Quantitati ve	6.3	2.6	Good	5.5	Milled more accurate
	Starch (% DM)	4.2	Excellent	6.9	5.0	Excellent	5.8	Milled more accurate
	Enzyme digestible starch (%DM)	4.2	Excellent	6.0	4.5	Excellent	5.4	
	Total insoluble NSP (% DM)	3.3	Excellent	3.6	3.2	Excellent	3.6	
	Total soluble NSP (%DM)	2.7	Good	1.1	2.6	Good	1.1	
	ß-glucans (% DM)	3.2	Excellent	1.1	3.7	Excellent	0.94	
	Arabinoxylan (% DM)	2.8	Good	2.5	2.8	Good	2.5	
	Arabinose (% DM)	2.1	Quantitati ve	0.7	2.0	Quantitati ve	0.7	
	Xylose (% DM)	3.6	Excellent	1.9	3.2	Excellent	2.1	Whole more accurate
	Oligosaccharides	3.7	Excellent	0.42	4.5	Excellent	0.36	
	Alanine (g/100g protein)	4.3	Excellent	0.92	4.8	Excellent	0.88	
	Arginine (g/100g protein)	3.6	Excellent	0.76	3.7	Excellent	0.72	
	Aspartic acid (g/100g protein)	2.5	Good	1.1	3.7	Excellent	0.86	
	Proline (g/100g protein)	2.4	Quantitati ve	2.0	3.3	Excellent	1.42	
	Serine (g/100g protein)	1.7	High-Low	0.42	1.8	High-Low	0.44	
	Lysine (g/100g protein)	3.0	Excellent	0.5	3.4	Excellent	0.48	
	Leucine (g/100g protein)	4.8	Excellent	1.0	4.2	Excellent	1.2	
	Cystine (g/100g protein)	2.0	Quantitati ve	0.42	2.0	Quantitati ve	0.40	
	Methionine (g/100g protein)	1.5	High-Low	0.34	1.5	High-Low	0.34	
	Phenylalanine (g/100g protein)	1.7	High-Low	0.54	1.9	High-Low	0.48	
	Tyrosine (g/100g protein)	2.4	Quantitati ve	0.36	2.2	Quantitati ve	0.38	
	Threonine (g/100g protein)	1.8	High-Low	0.34	1.8	High-Low	0.36	
	Valine (g/100g protein)	1.6	High-Low	0.56	1.7	High-Low	0.50	

	Linoleic acid (% DM)	3.4	Excellent	4.5	4.0	Excellent	4.18	
	Oleic acid (% DM)	3.7	Excellent	5.6	4.8	Excellent	4.34	
	Palmitic (% DM)	2.2	Quantitative	2.6	2.6	Good	2.36	
	Hydration capacity (% increase)	3.0	Excellent	13.4	3.0	Excellent	12.9	
	Gross energy (MJ/kg DM)	2.9	Good	0.34	3.8	Excellent	0.28	Milled more accurate

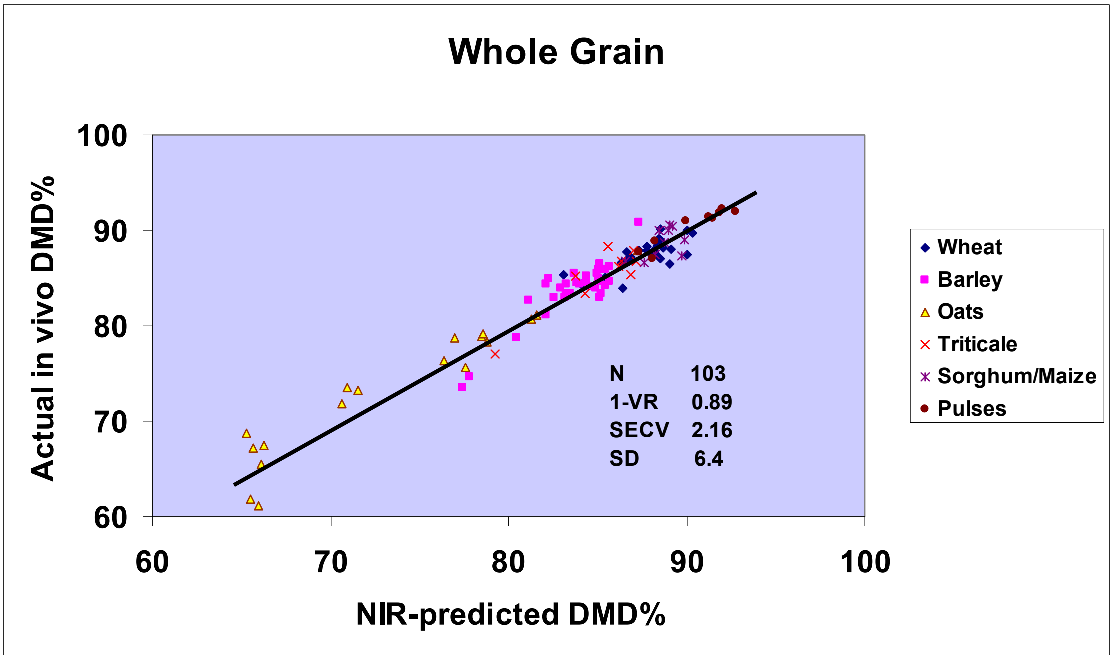
Energy value of cereal grains fed to sheep at maintenance

Dry matter digestibility (% dry matter)

Dry matter digestibility across the whole digestive tract of 103 grains was measured in sheep fed rations containing 70% grain and 30% lucerne hay at maintenance. The grains examined included wheat, barley, sorghum, triticale, oats, one maize sample and several pulses.

The NIR calibration established for dry matter digestibility of the grain alone can be used to assess relative digestibility, which should reflect the energy availability expected from cereal grains or pulses fed to sheep at maintenance.

A calibration, which is based on scans of whole grains, is of most use to the grains and livestock industries. The relationship between NIR predicted values and observed DMD (%) follows.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 3.0. The calibration is rated as 'excellent' with predictions being within 4.3% digestibility units in 95% of samples measured.

The calibration based on a scan of milled grain was slightly stronger with a 1-VR value of 0.91, a RPD of 3.4 and with predictions being within 3.8% digestibility units in 95% of samples measured.

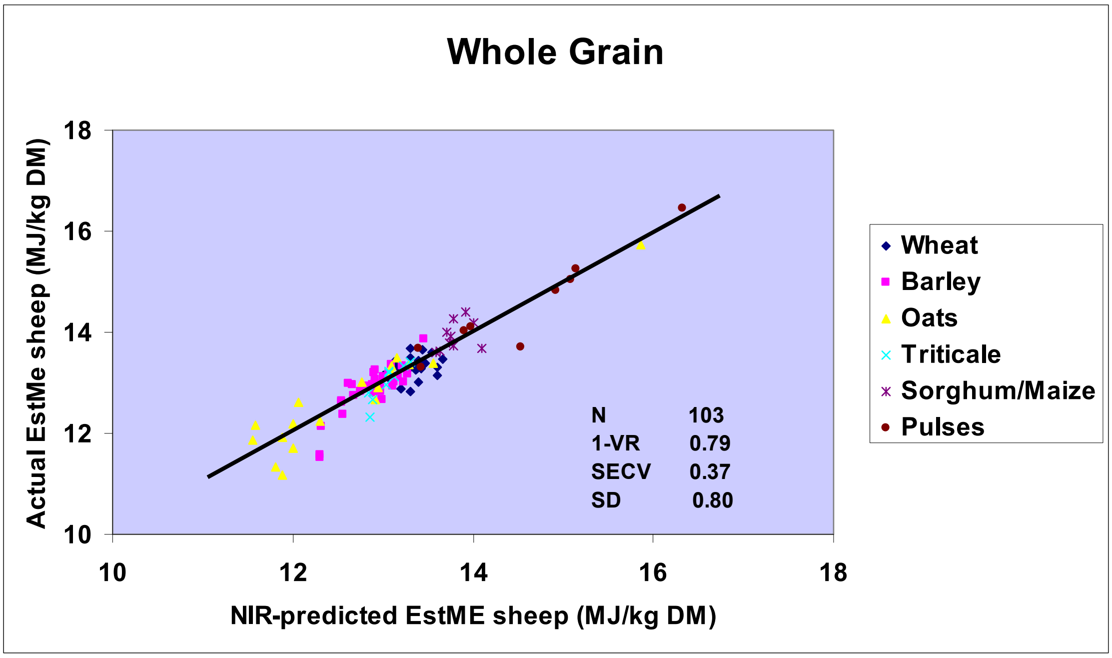
Metabolisable energy (ME) content of cereal grain (MJ/kg DM)

The ME content of 103 grains including wheat, barley, sorghum, triticale, oats, one maize sample and several pulses was calculated from observations on the whole tract digestibility of organic matter using the following equation:

$$ME\ (MJ/kg\ DM) = 0.858 + 0.138\ DOMD\ (\%) + 0.272\ EE\ (\%)$$

Where, DOMD is the digestible organic matter in the DM (%)
= 100 × ((feed DM – feed ash) – (faecal DM – faecal ash)) /feed DM,
and EE is the ether extract content of the grain. The equation was established from the analysis of a large number of experimental observations with sheep and cattle from around the world and has been adopted by the Australian Fodder Industry Association.

The NIR calibration established for the ME content of grains reflects the energy availability expected from cereal grains or pulses fed to sheep at maintenance. The relationship between NIR predicted values and calculated ME values (MJ/kg DM) follows.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.9. The calibration is rated as 'good' with predictions being within 0.56 MJ/kg in 95% of samples measured.

The calibration based on a scan of milled grain was slightly stronger with a 1-VR of 0.89, a RPD of 3.0 and with predictions being within 0.54 MJ/kg in 95% of samples measured.

Energy value of cereal grains fed to cattle ad libitum

Metabolisable energy (ME) content of cereal grain (MJ/kg DM)

The Metabolisable energy (ME) content of cereal grains for cattle fed *ad libitum* was established from a comparison of whole tract dry matter digestibility (DMD) for 24 grains fed to cattle *ad libitum* and sheep at maintenance (Figure 86). This relationship, excluding sorghum, was used to predict the DMD and hence ME of cereal grains for cattle (Figure 87).

Figure 86

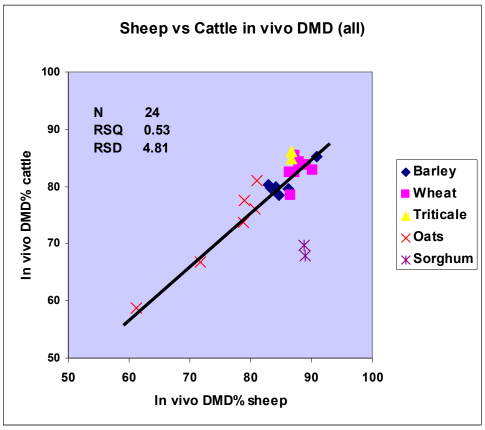
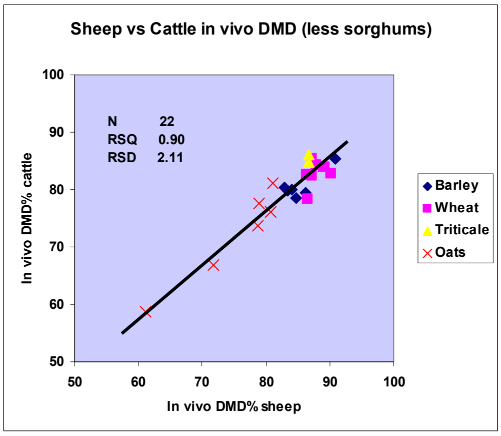
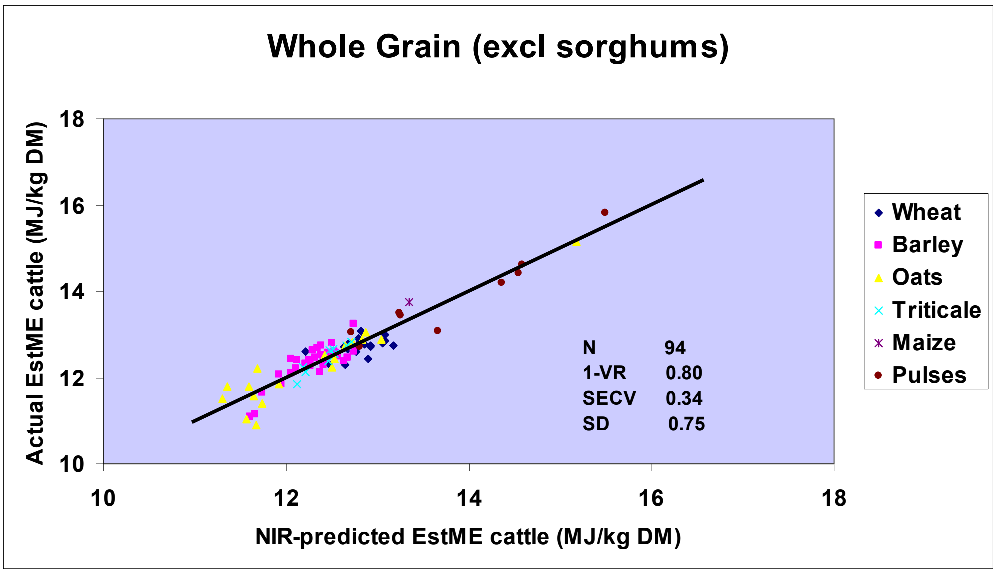


Figure 87



The relationship between NIR predicted values and calculated ME values for grains fed to cattle *ad libitum* follows.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for ‘cross validation’ as determined by the calibration software.

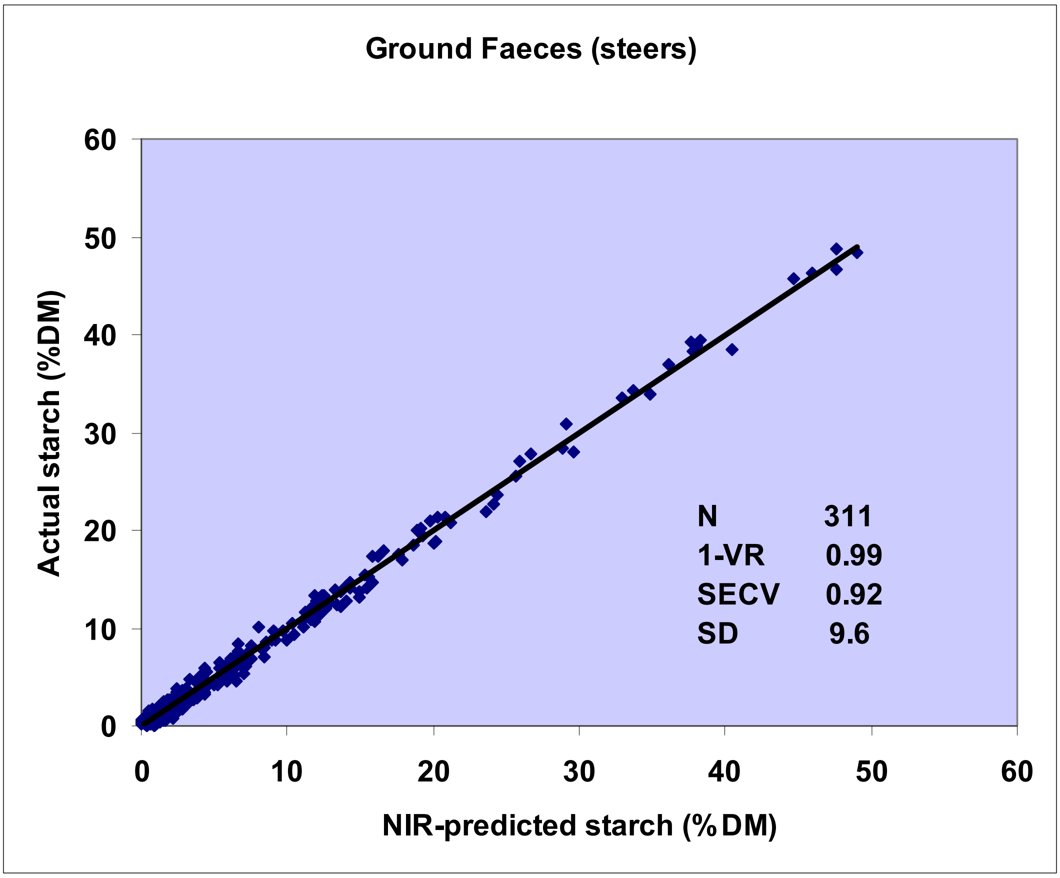
The value of the calibration based on whole grain scan is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.9. The calibration is rated as ‘good’ with predictions being within 0.52 MJ/kg in 95% of samples measured. For the calibration based on milled grain, RPD was 3.0 and predictions within 0.50 MJ/kg in 95% of samples measured.

Starch in cattle faeces

The proportion of starch in cattle faeces can be used to indicate the digestibility of grain and the amount of energy from the grain likely to be wasted. A measure of starch in faeces is an excellent method for assessing the efficiency of grain processing, particularly for sorghum.

Faeces collected from all individual cattle treatments during PGLP were dried and ground through a 1 mm screen and then scanned. The scanned samples were ball-milled to ensure that all starch within grain particles was released and then analysed for starch. The NIR calibration was established using scans and starch analyses from 311 faecal samples in which the starch content ranged from 0.01 to 48.7% of dried faeces.

The relationship between NIR predicted values and measured values for starch (% DM) in cattle faeces follows.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for ‘cross validation’ as determined by the calibration software. The value of 0.99 indicates an extremely robust calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 10.4. The calibration is rated as 'excellent' with predictions being within 1.8% starch in dried faeces in 95% of samples measured. This calibration is particularly valuable for assessing the effectiveness of grain processing in feedlot or dairy cattle.

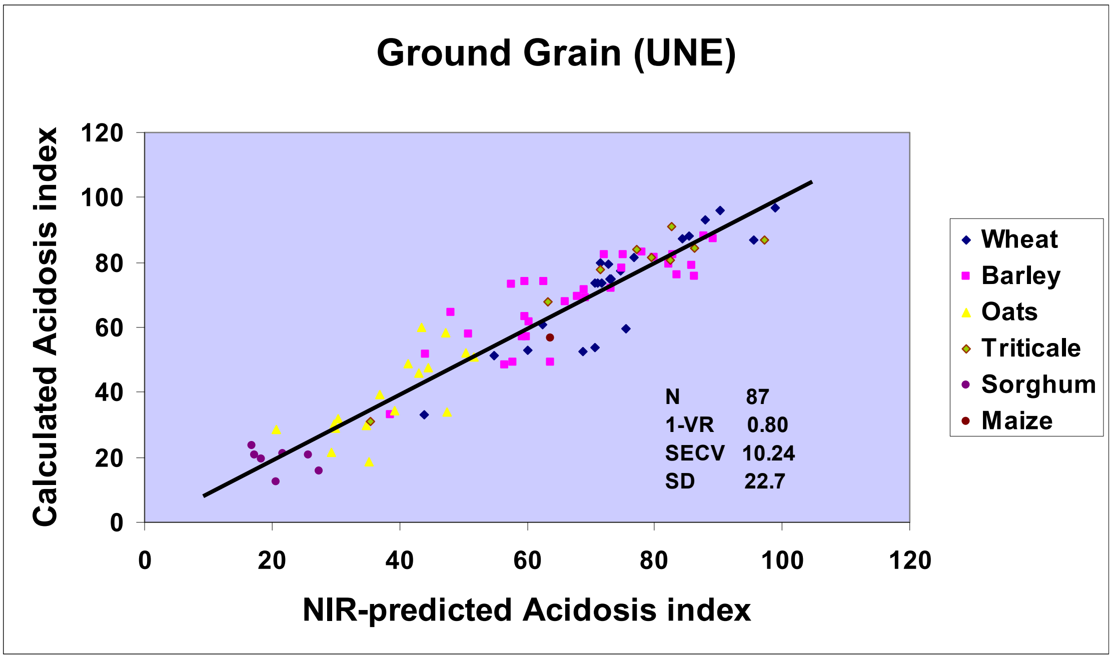
Acidosis – 'hotness of grain' index

An index predicting the relative potential for a grain to cause acidosis in ruminants was calculated from the rate of starch disappearance from rolled grains held in a bag within the rumen of cattle for 6 hrs, the starch content of the grain, total acid production during a 5 hr *in vitro* fermentation assay, the lactic acid production during the 5 hr fermentation assay and the buffering effect of the NDF content of the grain through saliva release during mastication. The values obtained for each grain were divided by the highest value to provide an index with potential values from 0 to 100+

The 'hotness' index as calculated from the grains fed to sheep and cattle has a value ranging from 12 for a sample of sorghum to 100 for a naked oat grain sample.

The index requires further experimental validation as well as confirmation using the AusBeef simulation model. However, it is has been judged as being a useful interim method for assessing relative chances of a grain for causing acidosis.

The relationship between NIR predicted values and calculated values for 'hotness' index follows.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.8 indicates moderate robustness of the calibration.

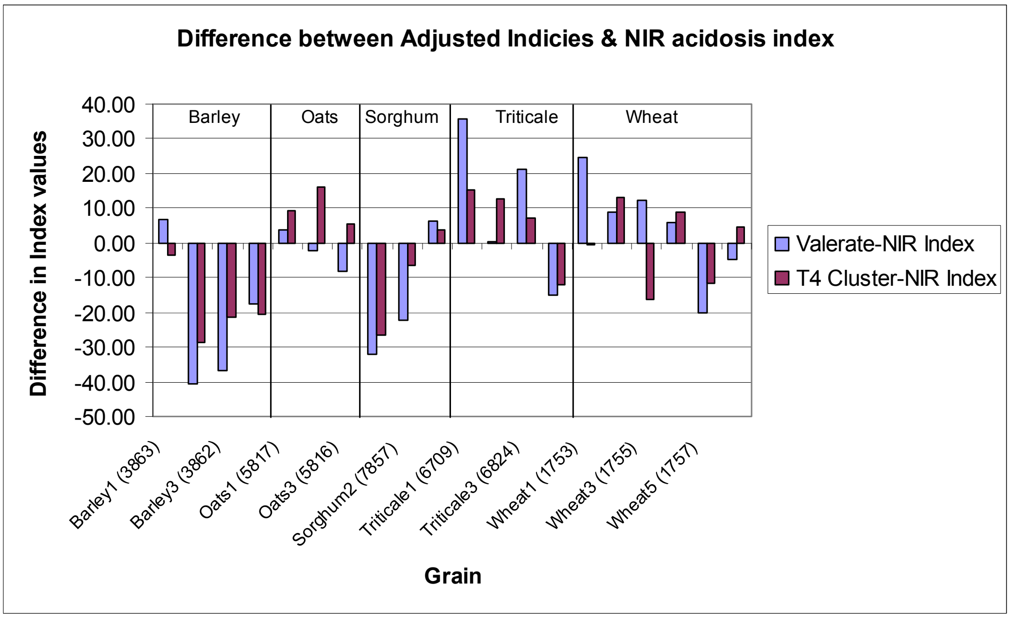
The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.2. The calibration is rated as ‘quantitative’ with predictions being within an index value of 20 in 95% of samples measured. The calibration is considered useful for distinguishing between grains that have reasonably wide differences in potential ‘hotness’. Grains with ‘hotness index’ values greater than 75-80 could potentially cause acidosis and a reduction in feed intake when fed *ad libitum* to ruminants.

Case study evaluation of Acidosis index calibration

The case study conducted by Bovine Research Australia measured acidosis by the cluster T4 discriminant analysis (calculated from concentrations of valerate, butyrate and ammonia at 4 hours after feeding) and valerate concentration analyses for 21 grains selected using the above NIR calibration to have wide differences in the PGLP *in vitro* acidosis index. The measured cluster T4 and valerate concentrations were converted to the acidosis T4 cluster index and valerate index to have values within a similar range to the PGLP acidosis index.

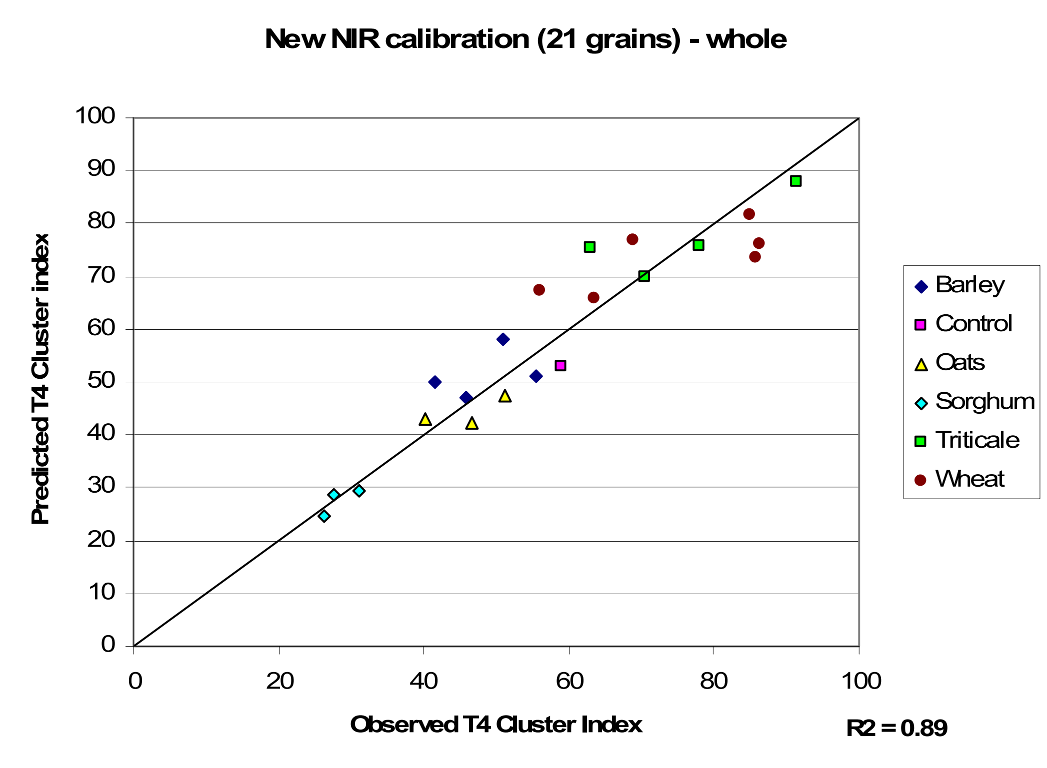
There were strong correlations (Spearman rank) between NIR predicted acidosis index and the cluster T4 (correlation coefficient = 0.732, P=0.0003) and valerate concentrations (correlation coefficient = 0.528, P=0.017). These results provide validation for the NIR model as it is significantly correlated with the valerate concentrations and discriminant cluster analysis. The valerate means and discriminant cluster analysis results were strongly correlated. The cluster analysis has previously been shown to be the measure that was most closely related to biological outcomes of acidosis, milk production, milk fat content and lameness. Thus, the cluster T4 index is considered to be the more accurate *in vivo* measure of acidosis.

Despite the strong correlation between the NIR predicted acidosis index values and the cluster T4 index and valerate index values, the Figure below shows that the accuracy of the NIR predicted values for some grains was not high. Although the PGLP NIR predicted values were closer to the observed cluster T4 index values than the valerate index values, there was clear evidence that the NIR acidosis index values were too high for barley and sorghum and too low for oats and triticale.



Difference between PGLP Acidosis Index and *in vivo* acidosis indices.

A new NIR calibration was fitted to the 21 Acidosis cluster T4 index established from the case study results. The predicted results using the new NIR calibration are compared with the observed results in the Figure below. The new NIR equation predicted 89% of the variance observed (R^2=0.89). However, the predicted discrimination in the acidosis T4 cluster index was less than observed in the experiment for the 6 wheat samples, with the observed lower values being predicted to be high and the higher values predicted to be low. Discrimination for the other grain types was showed reasonable accuracy. However the observed range for these grains was smaller than for wheat.



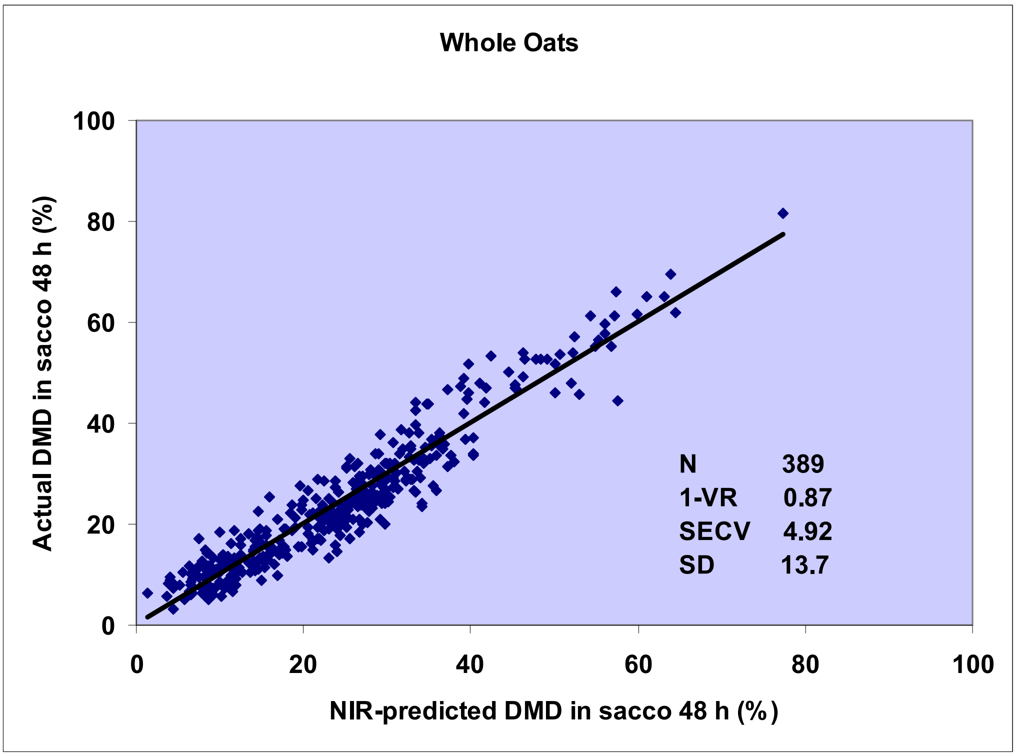
Predicted compared with observed acidosis T4 cluster index using new NIR calibraion

Value of oat grains for herbivores

Dry matter digestibility – 48 hr in sacco (%)

The disappearance of dry matter during a 48 hr suspension of whole oats in nylon bags in the rumen of cattle ranged from 3.1 to 85.9% when over 400 oat grain samples were examined. The *in sacco* DMD was shown to be negatively related to the lignin content of the hull, with all grains having more than around 6% hull lignin being poorly digested. However, even with grains that contained less than 6% hull lignin, *in sacco* DMD ranged from 10 to 85%. In one experiment with cattle, there was a strong relationship between *in sacco* DMD, *in vivo* DMD and animal performance.

An NIR calibration for 48 hr *in sacco* DMD (%) was established to identify oat samples that are likely to vary widely in animal performance. The calibration has the potential to identify differences between oat samples in animal productivity even when the lignin content of the hull is less than 6%. The relationship between NIR predicted values and measured 48 hr *in sacco* DMD (%) follows.



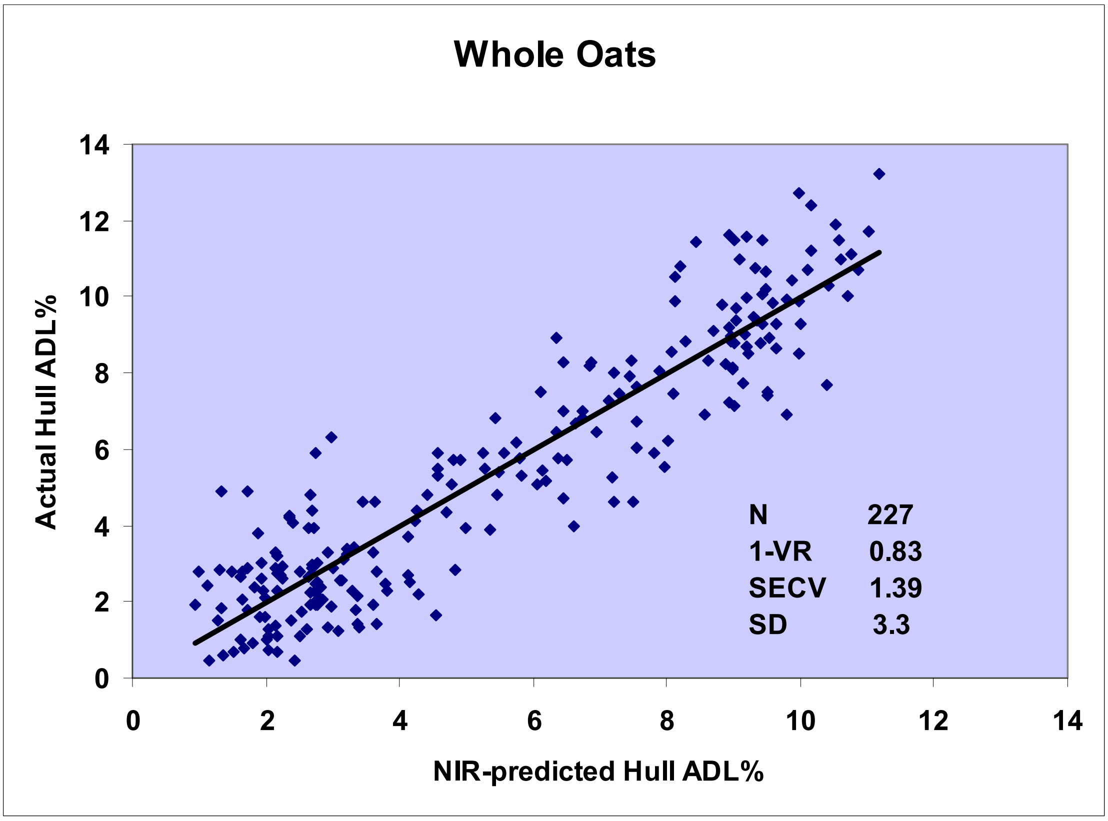
1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.87 indicates moderate robustness of the calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.8. The calibration is rated as 'good' with predictions being within 9.8 *in sacco* DMD (%) in 95% of samples measured, which would translate to around 3 DMD % in cattle.

Hull ADL (lignin) content (%)

Oat grains with hull lignin contents above around 6% DM have low digestibility (48 hr *in sacco* <50% DMD) in animals. A rapid method for screening samples with high lignin content could be of value to oat breeders for screening out low productivity lines.

The lignin content of hulls from 227 oat grain samples were analysed for lignin. The whole grains were scanned before dehulling and a calibration for hull lignin content derived. The relationship between predicted values and measured hull lignin content (acid detergent lignin, ADL, % DM) follows.

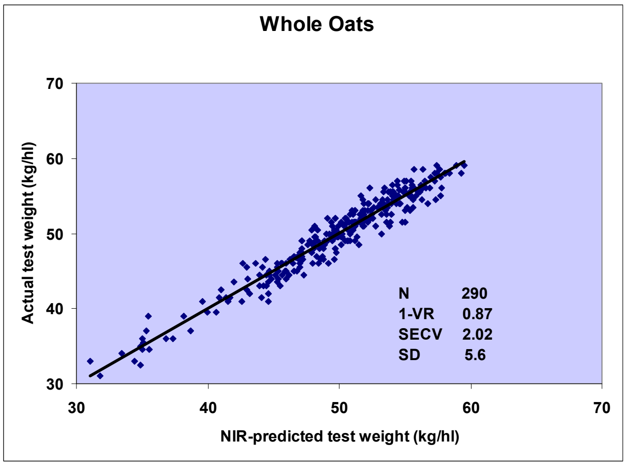


1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.83 indicates acceptable robustness of the calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.4. The calibration is rated as 'quantitative' with predictions being within 2.8 % in 95% of samples measured. The calibration is useful for general screening of samples that are likely to differ substantially and could be a valuable screening test for oat breeders.

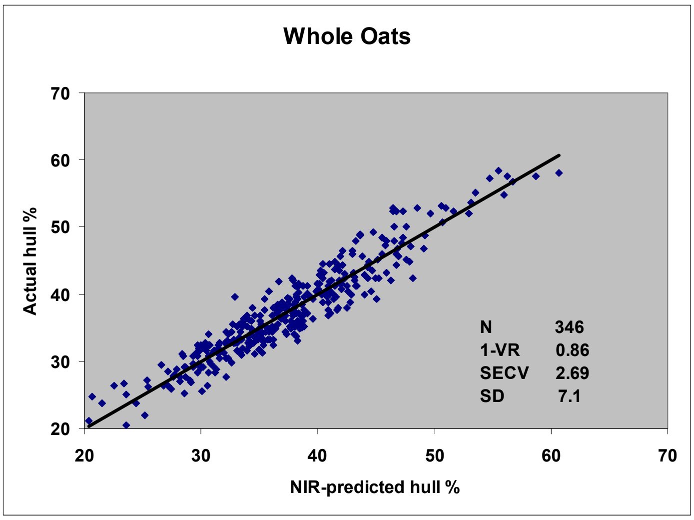
Test weight (kg/hl) and hull (%)

Test weight is used commonly in trading oat grains as an indicator of available energy. Results from PGLP show a poor relationship between test weight and 48 hr *in sacco* DMD. However, NIR can be used to provide an estimate of test weight. The relationship between predicted values and measured test weight (kg/hl) follows.



The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.8. The calibration is rated as 'good' with predictions being within 4.0 kg/hl in 95% of samples measured.

The percent hull in oat grains is inversely related to starch content and energy availability. Although 48 hr *in sacco* DMD is a more reliable measure of energy availability, the percentage of hull in oat grains can be estimated with reasonable accuracy using NIR. The relationship between predicted values and measured hull (%) follows.



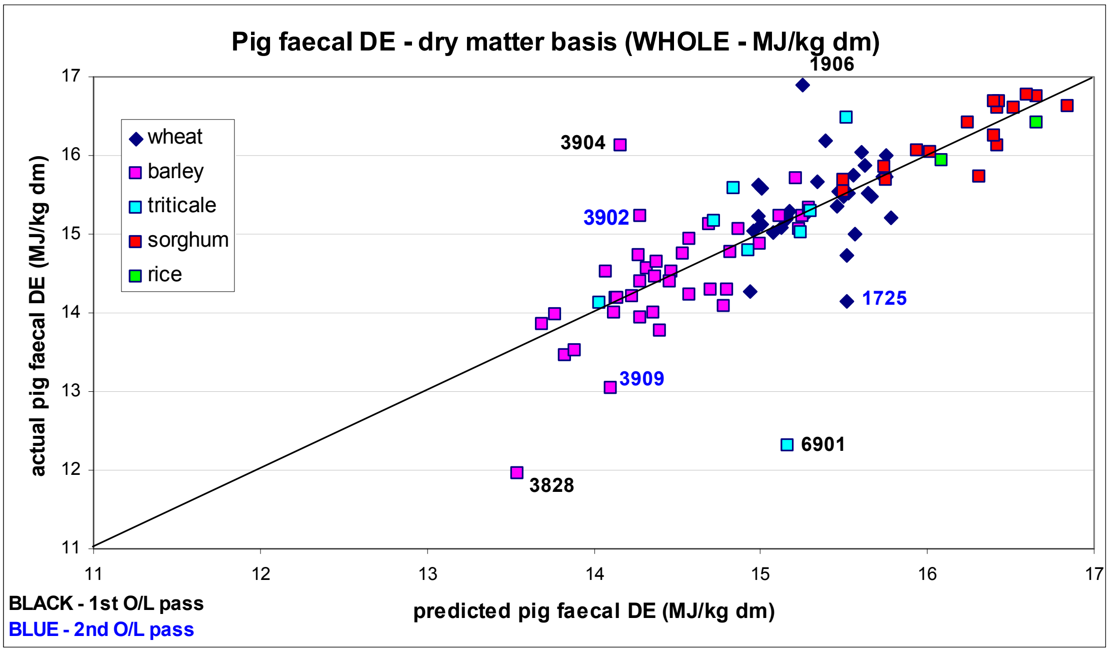
The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.6. The calibration is rated as 'good' with predictions being within 5.4 kg/hl in 95% of samples measured.

Faecal DE for pigs

The faecal DE content of 98 grains including wheat, barley, sorghum, triticale and rice was measured in pigs weighing 35-40 kg fed diets containing 94% grain and added dicalcium, phosphate, salt, minerals and vitamins with a celite marker.

The NIR calibrations for grain faecal DE can be used to predict the available energy content of grains for pigs, which is particularly useful for least-cost feed formulation. The calibrations were established from both whole and milled grain scans, when faecal DE was calculated on a dry matter and as-fed basis.

The relationship between NIR predicted values and observed faecal DE (MJ/kg DM) in pigs is presented below for whole grain scans.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.79 indicates acceptable robustness of the calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.2. The calibration is rated as 'quantitative' with predictions being within 0.76 MJ/kg DM in 95% of samples measured. The grain samples predicted as outliers were rain damaged (1725) and normal Currawong (1906) wheat, frosted Arapiles barley (3828), a sample of Schooner (3904) and Tantangara (3909) barley, and a sample of Tahara (6901) triticale

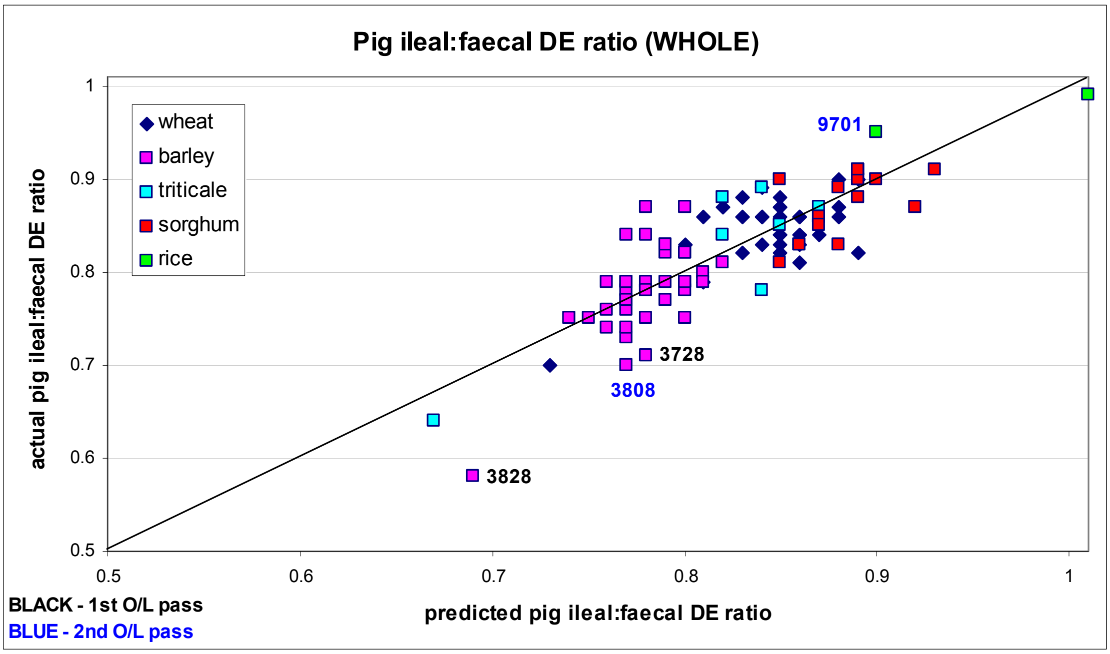
The relationship between NIR predicted values and observed faecal DE in pigs was developed for milled grain scans and on an as-fed basis. The other calibrations were slightly less robust with a RPD value of 2.1 and predictions being within 0.75 MJ/kg as-fed for 95% of samples measured.

Ratio of ileal:faecal DE for pigs

The ileal and faecal DE content of 98 grains including wheat, barley, sorghum, triticale and rice was measured in pigs weighing 35-40 kg fitted with T cannulae and fed diets containing 94% grain and added dicalcium, phosphate, salt, minerals and vitamins with a celite marker.

The NIR calibrations for ileal:faecal DE ratio can be used to predict the proportion of available from grains that is digested in the small intestines of pigs. The calibrations were established from both whole and milled grain scans, with the results being the same whether expressed a dry matter or as-fed basis.

The relationship between NIR predicted values and observed ileal:faecal DE ratio in pigs is presented below for whole grain scans.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.59 indicates a relatively low robustness of the calibration.

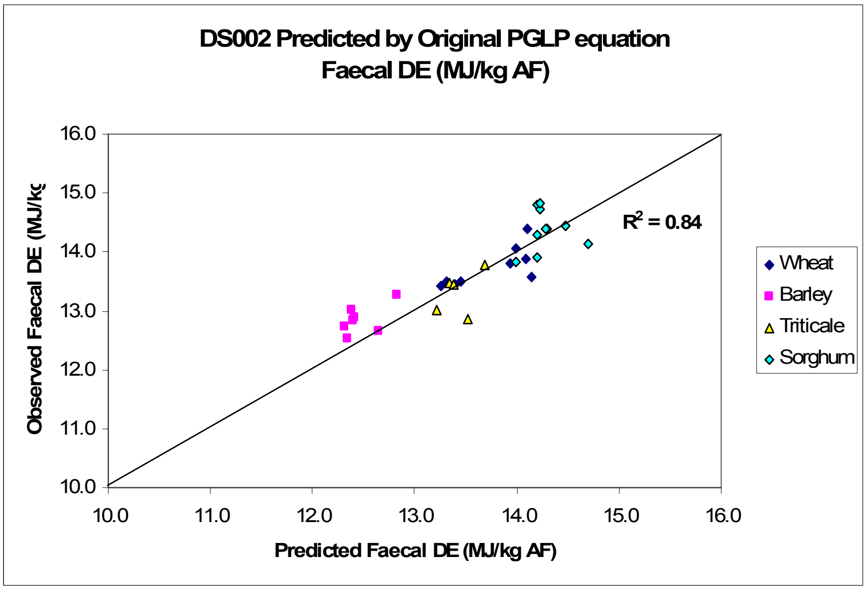
The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 1.5. The calibration is rated as only being able to distinguish between high and low values with predictions being within 7% digestion in the small intestines in 95% of samples measured. The grain samples predicted as outliers were rain damaged black naked barley Nigundidum (3728), Grimmett barley (3808), frosted Arapiles (3828) and rice (9702).

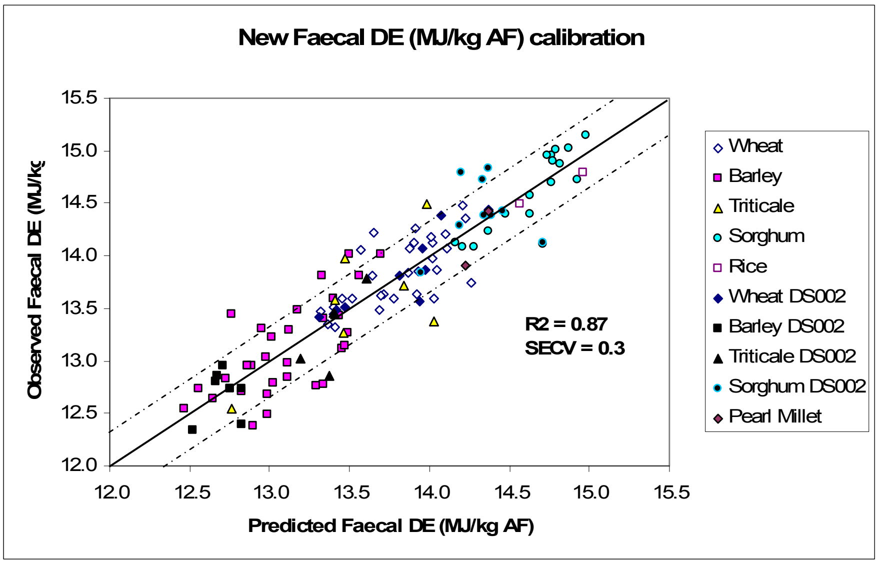
The relatively poor NIR calibration for ileal:faecal DE ratio resulted from a low accuracy of the ileal DE NIR which had a RPD of 1.9. The accuracy of the calibration for ileal:faecal DE ratio was slightly better for whole grain than milled grain scans.

Updated Pig DE calibrations with results from Pork CRC

The Pork CRC with GRDC has invested in additional research to evaluate and enhance the NIR calibrations for pigs. The first experiment investigating the faecal and ileal DE content of an additional 32 grains (wheat 9, barley 7, triticale 5, sorghum 9, pearl millet 2) has been completed. The methods used on the Pork CRC experiments were identical to those used during PGLP experiments. The full analysis of the experiment is covered in the statistical report for experiment DS002.

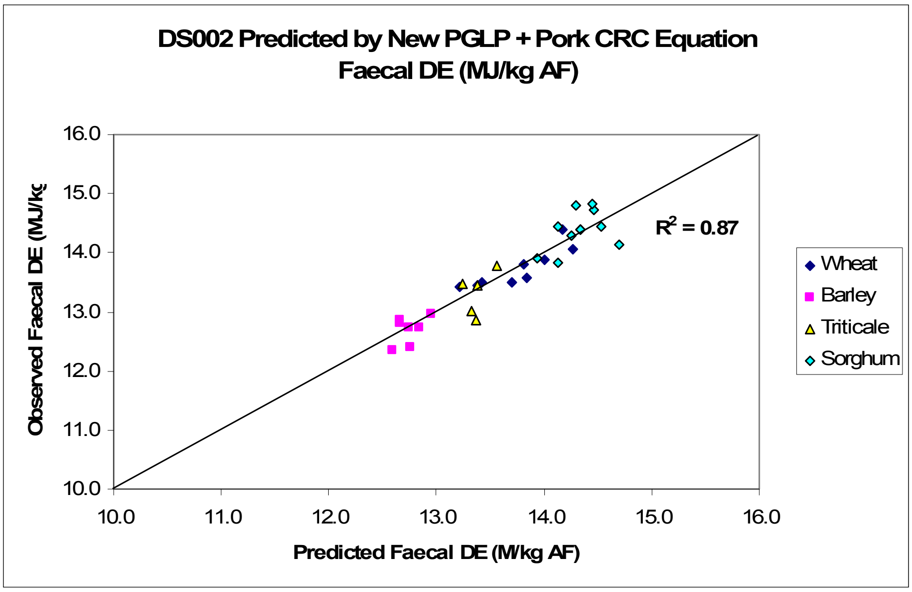
The results shown in the figure below were used first to assess the accuracy of the original PGLP NIR calibration for predicting faecal DE (MJ/kg AF) for a new set of grains. The original NIR calibration accounted for 84% of the variation observed in the experimental results for the new grains. The largest difference between predicted and observed results was for one triticale sample at 0.66 MJ/kg.



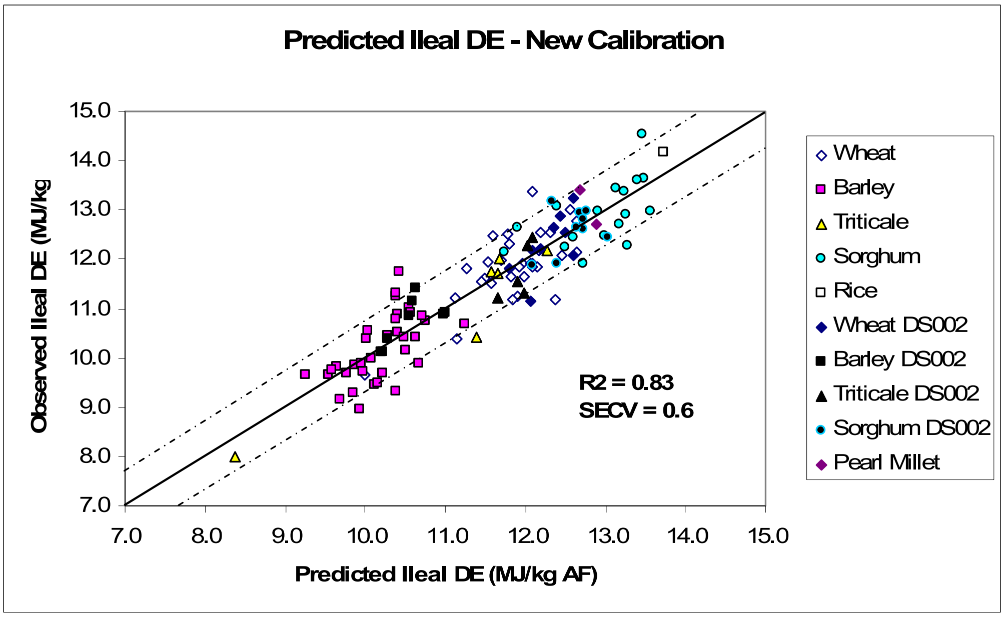


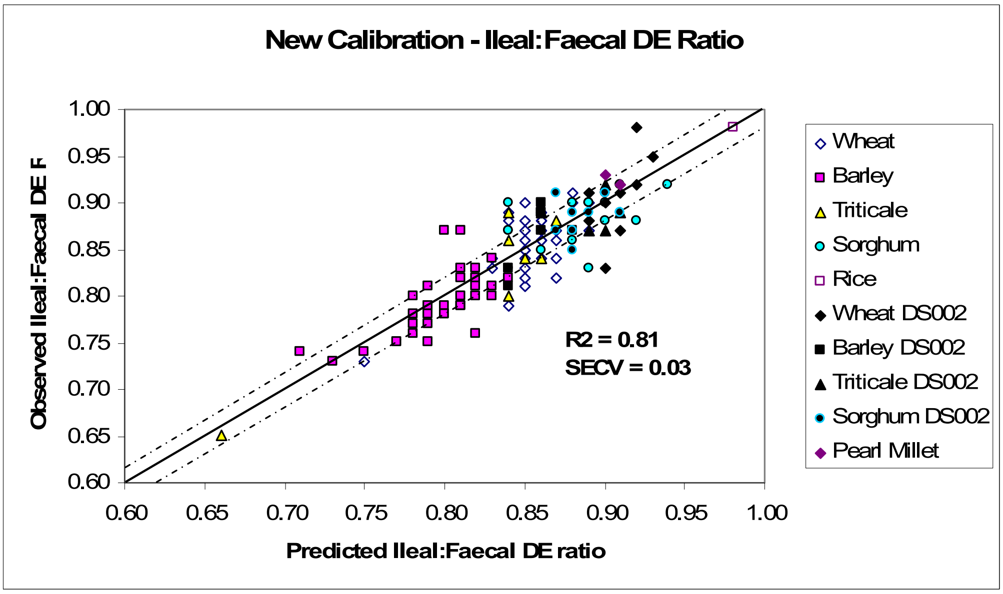
Results from the Pork CRC experiment were added to the PGLP dataset and a new NIR calibration using 129 cereal grain samples was developed. The predicted values using the new calibration are compared with the observed values for faecal DE (MJ/kg AF) in the figure above. The new NIR calibration accounted for 87% of the observed variation in faecal DE across all observations including those from PGLP plus those from the recent Pork CRC experiment. The calibration represents a small improvement on the original PGLP calibration, which accounted for 84% of the variation. The original calibration predicted with an accuracy of ± 0.38 MJ/kg, whereas the accuracy of the new calibration is substantially improved to predict within ± 0.30 MJ/kg.

When the new calibration was used to predict the values for the 32 grains used in the Pork CRC experiment, it accounted for 87% of the variation compared with 84% of the variation accounted for by the original PGLP calibration. The observed faecal DE values are compared with those predicted from the new calibration in the figure below. The accuracy of prediction of the observed values for the grains from the Pork CRC experiment was improved with the greatest discrepancy being 0.56 MJ/kg AF for one sorghum sample. Apart from the same triticale sample as identified above where the predicted value was 0.5 MJ/kg AF different from the observed value, other predictions were within 0.3 MJ/kg AF.



New calibrations were also developed for ileal DE (MJ/kg AF) and ileal:farcal DE ratio using both the original PGLP and the Pork CRC results. Figures showing the predicted and observed results for ileal DE and ileal:faecal DE are shown below.





A comparison of the statistics for the new and old NIR calibrations for predicting pig DE are given in the Table below and show that the addition of the Pork CRC results has substantially improved the accuracy of the NIR predictions for faecal and ileal DE and the ileal:faecal DE ratio. The greatest improvement was for the ileal:faecal ratio. However, the improvement in all variables indicates that continued research within the Pork CRC to strengthen and enhance the calibrations is a worthwhile investment. A subsequent experiment is in progress and includes 50 grain samples, many of which have been weather damaged through severe water stress, germination or a combination of both water stress followed by germination. A further experiment is planned to include a range of new barley, triticale and sorghum cultivars.

Table. Comparison of statistics for the original PGLP NIR calibration and a new calibration combining results from PGLP and the Pork CRC for pig DE.

Variable	**NIR calibration**	**R^2**	**SECV***	**RPD#**
Faecal DE (MJ/kg AF)	New	0.87	0.30	2.22
	PGLP	0.84	0.38	2.21
Ileal DE (MJ/kg AF)	New	0.83	0.58	2.18
	PGLP	0.85	0.68	1.96
Ileal:Faecal DE	New	0.81	0.03	1.85
	PGLP	0.69	0.05	1.56

* SE of calibration: accuracy of prediction at P=0.95
# Ratio of prediction to deviation: > 2 predictive > 3 excellent

Predicting pig DE values from grain characteristics compared with NIR calibrations

The PGLP data has been further analysed to develop the most statistically significant regression equation for predicting pig faecal DE (MJ/kg DM). The statistical report describing the analyses and results (44 sn004) is attached to this report. The variables that were shown to contribute significantly to predicting pig faecal DE (MJ/kg DM) were insoluble xylose ($P<0.0001$), specific weight ($P=0.045$) and lignin ($P=0.022$), with grain species also being significant ($P<0.0001$). The equations were as follows:

Barley = 14.934 + -0.212 × insol xylose + 0.021 × specific wt + -0.339 × lignin

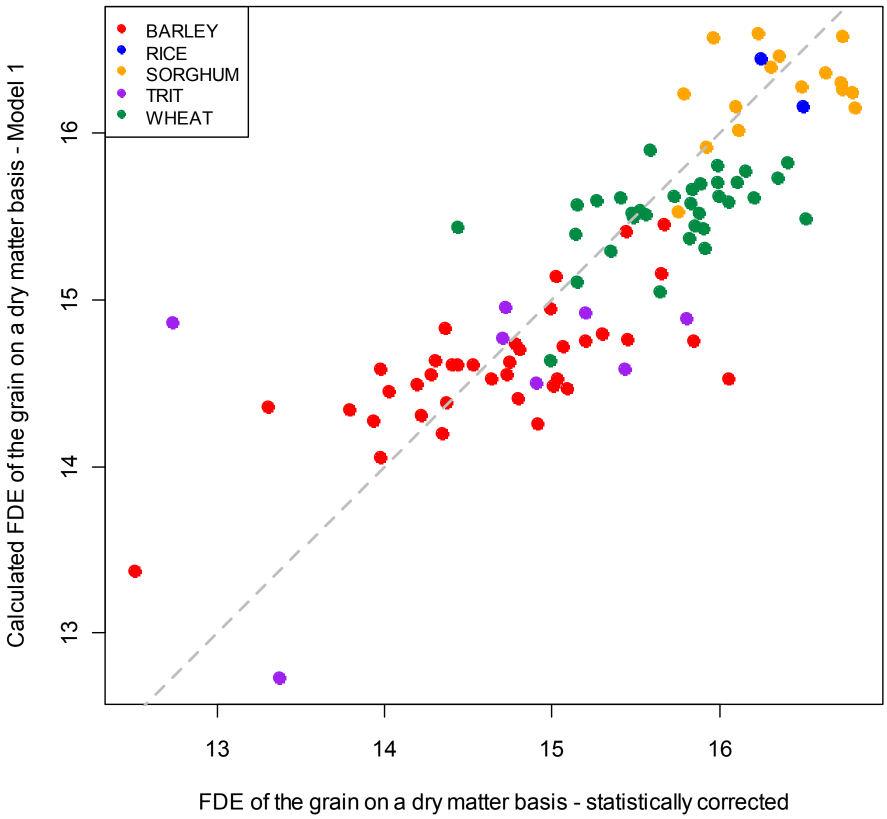
Rice = 15.173 + -0.212 × insol xylose + 0.021 × specific wt + -0.339 × lignin

Sorghum = 15.65 + -0.212 × insol xylose + 0.021 × specific wt + -0.339 × lignin

Triticale = 14.852 + -0.212 × insol xylose + 0.021 × specific wt + -0.339 × lignin

Wheat = 15.442 + -0.212 × insol xylose + 0.021 × specific wt + -0.339 × lignin

The observed faecal DE (FDE) values are compared with the predicted values in the Figure below. The equation accounted for 0.70% of the observed variation ($R^2 = 0.70$), which is considerably less than the accuracy of the original PGLP NIR equation ($R^2 = 0.84$). The regression equations compared with the new NIR calibration do not predict as accurately and particularly the values for individual grain samples within a grain species.



\The best equations for predicting ileal DE (MJ/kg DM) included insoluble arabinoxylan (P<0.0001), hydration capacity (P<0.0001) and lignin (P=0.002). The effect of grain species was also significant (P<0.0001). The equations were:

Barley = 11.722 + -0.173 × insol arabinoxylan + -0.031 × Hyd capacity + -0.617 × lignin

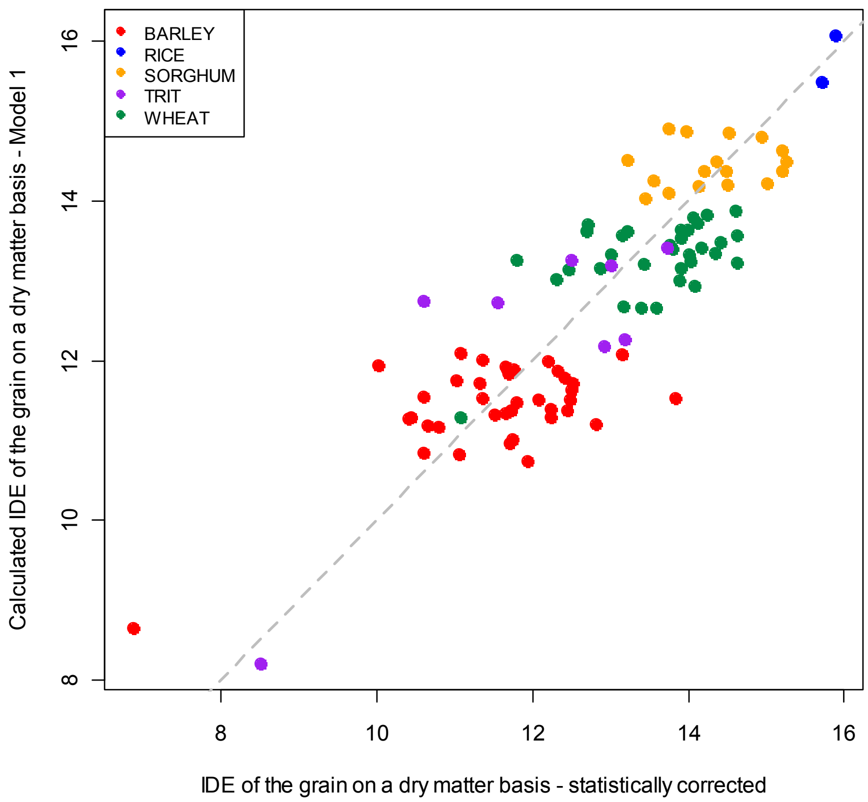
Rice = 14.076 + -0.173 × insol arabinoxylan + -0.031 × Hyd capacity + -0.617 × lignin

Sorghum = 13.404 + -0.173 × insol arabinoxylan + -0.031 × Hyd capacity + -0.617 × lignin

Triticale = 13.408 + -0.173 × insol arabinoxylan + -0.031 × Hyd capacity + -0.617 × lignin

Wheat = 13.514 + -0.173 insol arabinoxylan + -0.031 × Hyd capacity + -0.617 × lignin

The observed ileal DE (IDE) values are compared with the predicted values in the Figure below. The equation accounted for 0.74% of the observed variation (R^2 = 0.74), which is considerably less than the accuracy of the original PGLP NIR equation (R^2 = 0.85). The regression equations compared with the new NIR calibration do not predict accurately the value for individual grain samples within a grain species.



Conclusions

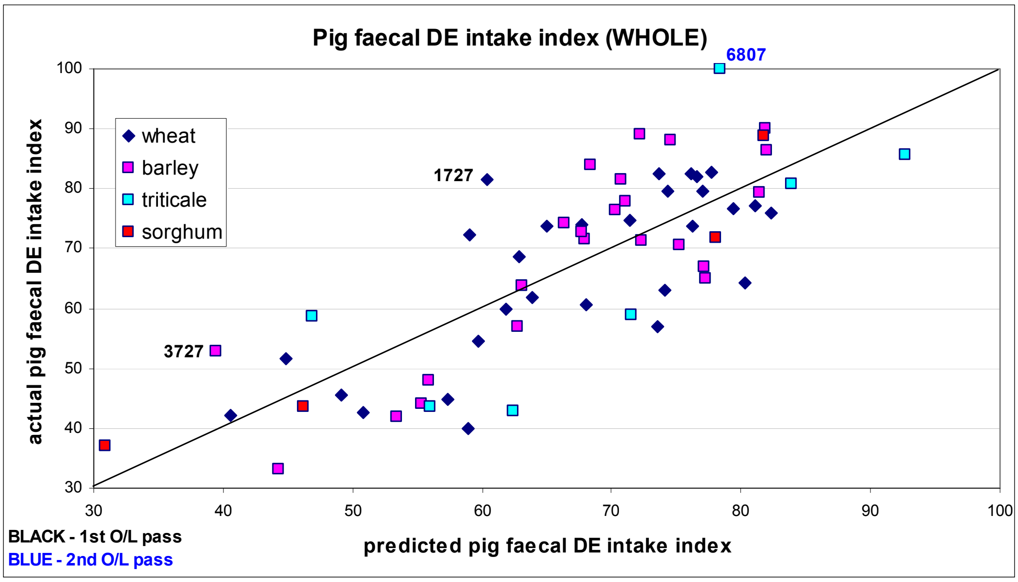
The NIR calibrations, particularly those that have incorporated 32 new samples from the Pork CRC experiments have been shown to predict the faecal and ileal DE values with greater accuracy than statistically significant regression equations using grain characteristics. This result suggests that NIR technology covers more of the characteristics within a grain that determine its digestibility in pigs than can be identified from the measurement of individual grain characteristics.

Faecal DE intake index for pigs

Feed intake was determined for 63 grains including wheat, barley, sorghum and triticale in weaner pigs approximately 7 kg for 21 days. The pigs were fed the same diets used for determining the DE content of the grains which contained 94% grain and added dicalcium, phosphate, salt, minerals and vitamins with a celite marker. Corrected daily feed intake values were multiplied by the faecal DE content of the diet to calculate faecal DE intake. The values obtained for all grains were then divided by the highest value to calculate the faecal DE intake index.

The NIR calibrations for faecal DE intake can be used to predict the relative energy intake from the grain and be used as a guide for ranking grains according to their capacity to stimulate growth rate in pigs. The calibrations were established from both whole and milled grain scans, with the results being the same whether expressed a dry matter or as-fed basis.

The relationship between NIR predicted values and observed faecal DE intake index in pigs is presented below for whole grain scans.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.58 indicates a relatively low robustness of the calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 1.5. The calibration is rated as only being able to distinguish between high and low values with predictions being within 20.6 intake index units in 95% of samples measured. The grain samples predicted as outliers were a sample of Oxley wheat (1727), rain damaged Gilbert barley (3727) and a sample of Credit triticale (6807).

The relatively poor NIR calibration for faecal DE intake index reflects the wide variation in the intake measurements obtained with the weaner pigs and the calibration needs further development to be of great assistance to pig and grains industries. The accuracy of the calibration was similar for whole grain and milled grain scans.

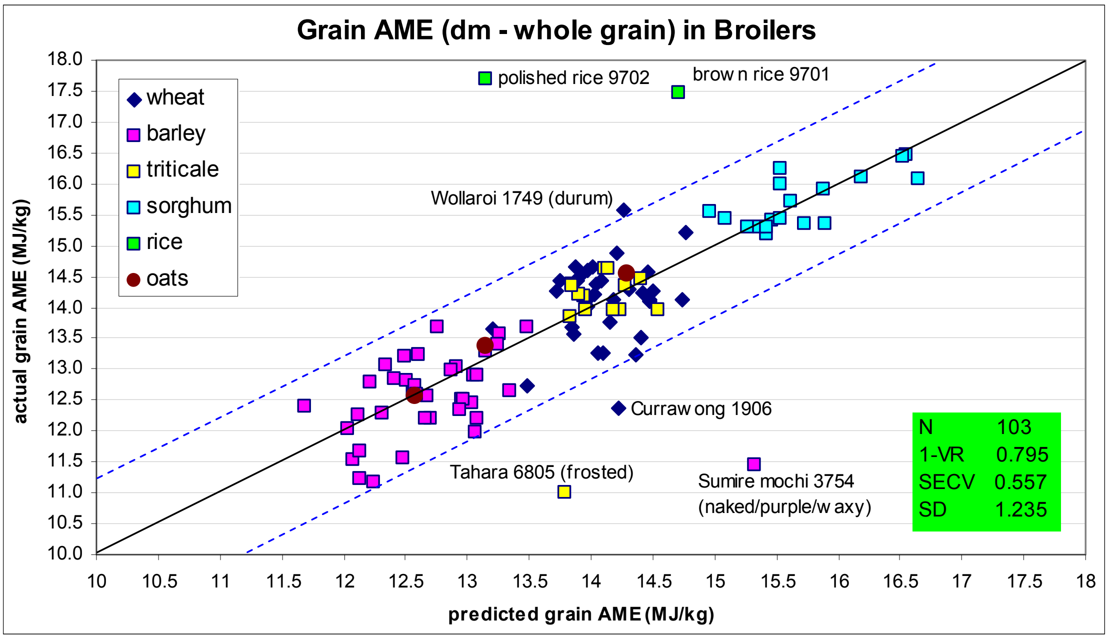
Apparent Metabolisable Energy of cereal grains for broilers

PGLP calibration

The AME content of 109 grains including wheat, barley, sorghum, triticale, oats and rice was measured in male and female chickens from 22 days of age when fed diets containing 80% grain, 15.5% casein and added calcium, phosphorus, vitamins and DL-methionine.

The NIR calibrations for grain AME can be used to predict the available energy content of grains for broilers, which is particularly useful for least-cost feed formulation. The calibrations were established from both whole and milled grain scans when AME was calculated on a dry matter and as-fed basis.

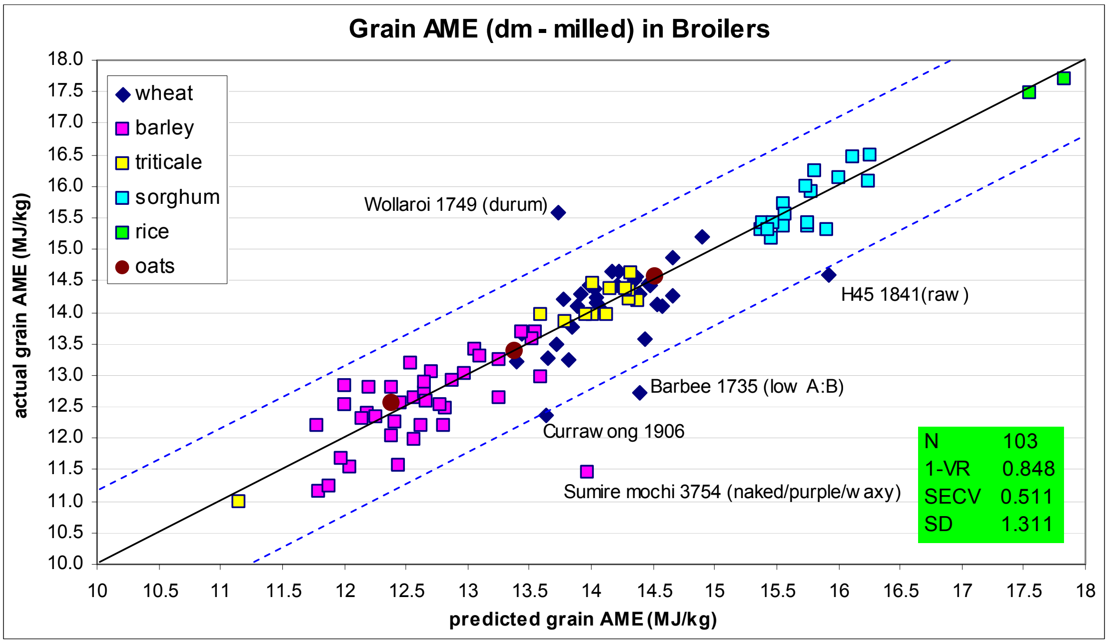
The relationship between NIR predicted values and observed AME (MJ/kg DM) in broilers is presented below for whole grain scans. The dashed lines represent ± 1 standard deviation from the observed mean values with individual grains predicted to be outside this range identified.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.80 indicates acceptable robustness of the calibration.

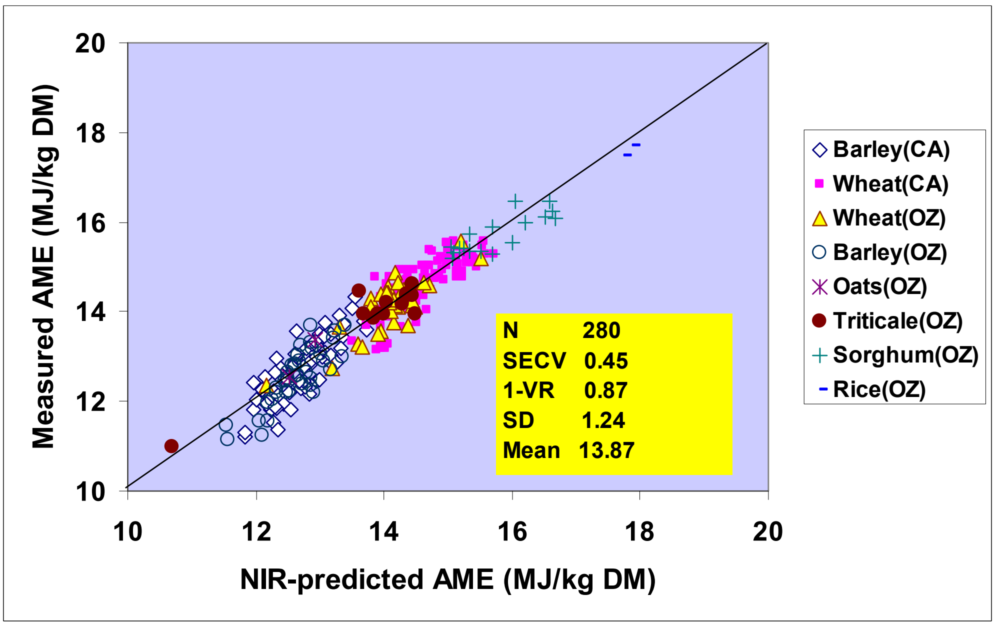
The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.2. The calibration is rated as 'quantitative' with predictions being within 1.12 MJ/kg DM in 95% of samples measured. The grain samples predicted to be outside 1 SD of the experimental mean included rice and a sample of naked, purple, waxy barley.

The relationship between NIR predicted values and observed AME (MJ/kg DM) in broilers is presented also for milled grain scans. The calibration is slightly more robust with a RPD value of 2.6, which is rated as 'good', and predictions being within 1.02 MJ/kg DM for 95% of samples measured. Predictions on an as-fed basis were a little less accurate than those on a dry matter basis with RPD being only 2.0 when the calibrations were developed using whole grain scans.



Canadian and PGLP samples

Broiler AME measurements have been made also by Tom Scott on 181 wheat and barley samples from Canada. These grains have been scanned when milled and the Australian and Canadian instruments standardised to allow incorporation into a single calibration. The NIR predicted values using the combined calibration are compared with observed AME values for broilers follows.



Compared with PGLP results alone, 1-VR improved from 0.85 to 0.87, RDP from 2.6 to 2.8 and the 95% of samples limit from 1.02 to 0.90 MJ/kg DM.

The predicted values for all grains fed to broilers within PGLP using the combined Canadian-PGLP calibration are compared below with the predictions from the PGLP calibration. The comparison shows marked differences between the two predictions for 5 grain samples. These samples are also those that were ‘outliers’ when the PGLP NIR calibration predictions were compared with observations. The PGLP calibration values, Canadian-PGLP calibration values and observed values shown for these 5 grains in Table 46 indicate that the combined calibration has superior accuracy for these grains.

Table 46. Prediction of broiler AME for selected grains using the NIR calibration developed from PGLP results alone or in combination with Canadian results from Tom Scott.

Grain ID	Grain	Grain AME (MJ/kg DM)		
		Observed	PGLP pred	Can-PGLP pred
1735	Wheat; Barbee	12.73	14.39	13.19
1749	Wheat; Wollaroi	15.57	13.73	15.20
1841	Wheat; H45 non screen	14.60	15.92	14.70
1906	Wheat; Currawong	12.37	13.64	12.17
3754	Barley; Somire mochi	11.55	13.98	11.54

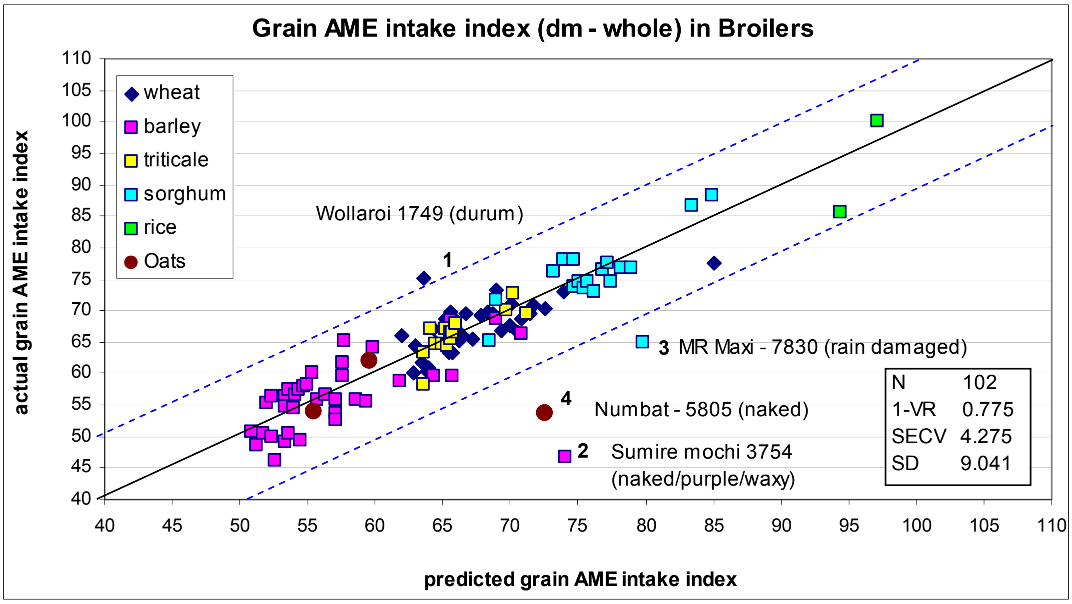
These comparisons suggest that the combined Canadian-PGLP NIR calibration is the most suitable for assessing the AME value of grains for broiler chickens. This calibration has only been established for milled samples. The Canadian and Australian instruments need to be standardised for whole grain scans, before the calibration can be established for whole grains.

AME intake index for cereal gains for broilers

The energy value of a grain to broilers depends both on the available energy content of the grain expressed as AME (MJ/kg) and on the amount of the grain eaten. In general, the daily intake of AME will be positively related to the growth rate and performance of birds.

The intake of grain by broilers was also recorded during experiments determining the AME content of grains within PGLP experiments. Thus, the intake of AME (AME intake/bird, MJ/bird/d) could be calculated for the different grains fed to broilers. Because AME intake is not commonly used to rank the energy value of grains, the values were converted to an index by dividing the AME intake value for each grain by the highest value. The values derived were multiplied by 100, such that grains could be ranked with values potentially from 0 to 100+.

The AME intake index values were then used to develop an NIR calibration AME intake index using scans from whole grain. The relationship between predicted values and calculated AME intake index values (0-100+) follows. The dashed lines represent ± 1 standard deviation from the observed mean values with individual grains predicted to be outside this range identified.



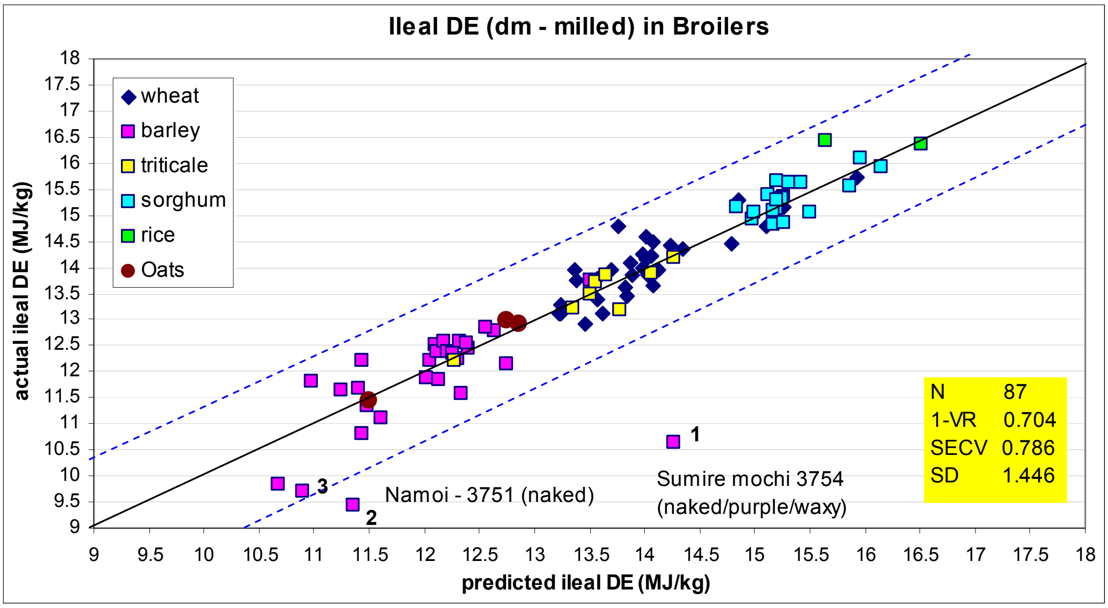
1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 2.1. The calibration is rated as 'quantitative' with predictions being within 8.6 index units in 95% of samples measured. The grain samples predicted to outside 1 SD of the experimental mean included a naked, purple, waxy barley, a naked oat grain, rain damaged sorghum and a durum wheat. Equivalent calibration statistics for milled grain show a RPD value of 2.3 and 95% of sample predictions being within 7.5 index units. The results suggest that the calibration should be useful for selecting grains that should produce higher rates of broiler performance.

Ileal DE of grains for broilers

Ileal digestible energy (DE) was estimated for the grains used to measure AME by using a marker to estimate digestion of energy to the end of the ileum. Because the digestion that takes place in the digestive tract of chickens is almost complete when digesta passes the ileum, the prediction of ileal DE will add little in terms of poultry nutrition to the AME values.

The relationship between the NIR predicted values and measured values for ileal DE (MJ/kg DM) are shown for milled grain scans below.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for ‘cross validation’ as determined by the calibration software. A value of 0.70 indicates relatively low level robustness of the calibration.

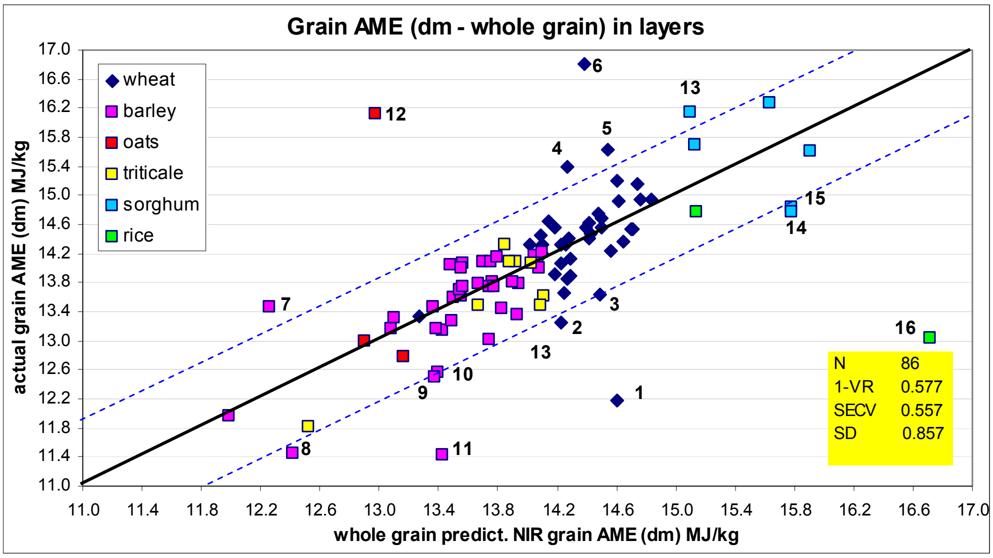
The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 1.8. The calibration is rated as ‘High-Low’ (i.e. distinguishes only between high and low values) with predictions being within 1.6 MJ/kg DM in 95% of samples measured. The robustness of the calibration was slightly better with the whole grain scans; RPD = 2.1 rated as ‘quantitative’ with predictions being within 1.36 MJ/kg DM in 95% of samples measured. When expressed on an as-fed basis, RPD for the whole grain scan was intermediate at 2.0.

Apparent Metabolisable Energy of cereal grains for layers

The AME content of 92 grains including wheat, barley, sorghum, triticale, oats and rice was measured in laying hens fed diets containing 77% grain, 8.5% casein and added calcium, phosphorus, vitamins and DL-methionine.

The NIR calibrations for grain AME can be used to predict the available energy content of grains which is particularly useful for least-cost feed formulation. The calibrations were established from both whole and milled grain scans.

The relationship between NIR predicted values and observed AME (MJ/kg DM) in laying hens is presented below for whole grain scans. The dashed lines represent ± 1 standard deviation from the observed mean values with individual grains predicted to be outside this range identified.



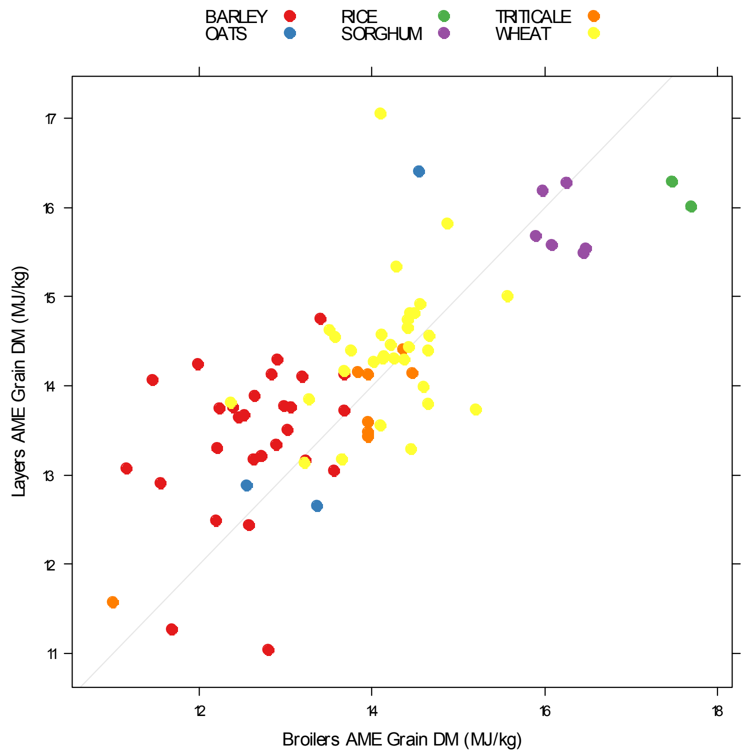
1	H45 - 1826>2.2mm
2	Currawong - 1909
3	Chara - 1828<2.2mm
4	Qal 2000 - 1728 (soft)
5	Marshall - 1739 (red)
6	Janz - 1902
7	Nigrinudum - 3734 (naked/black)
8	Arapiles - 3828 (frosted)
9	Tantangara - 3909
10	Tantangara - 3906
11	Tallon - 3756<2.2mm
12	Numbat 5805 (naked)
13	Waxy isoline - 7828
14	Normal isoline - 7711
15	Waxy isoline - 7710
16	Polished rice - 9702

1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.58 indicates a low robustness of the calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 1.5. The calibration is rated as 'High-Low' (i.e. distinguishes only between high and low values) with predictions being within 1.1 MJ/kg DM in 95% of samples measured. Grains that were major outliers include polished rice, naked-high fat oats, plump H45 wheat and Tallon barley screenings. The calibration based on milled grain was improved only slightly with RPD = 1.6 and 95% of measured samples being within 1.05 MJ/kg DM.

Predicting layer values from broiler values

A comparison between AME (MJ/kg DM) values measured for broilers and layers when fed the same grains is shown below. The relationship between broiler and layer AME values produced an R^2 = 0.54. The relationship is slightly different from that presented in Table 6 because the latter was established only for the 39 grains fed in common to ruminants, pigs, broilers and layers. The comparison below suggests that layers obtain more energy from poorer quality barley and wheat than broilers, but broilers tended to extract mor energy per kg from rice and sorghum. The layers also obtained more AME from one wheat sample and a naked oat sample than broilers.



A thorough statistical analysis of the characteristics of cereal grains that may be associated with the differences in AME between broilers and layers has been undertaken. The purpose of this analysis was to determine whether it is possible to improve the prediction of layer AME values by using NIR predicted broiler values and adjusting these using specific characteristics of the grains that are related to the differences observed in AME between layers and broilers. A full report of the statistical analysis is provided in the file attached to this report (42 layers and broilers November 2007). In these analyses, the layer response is calculated as the layer AME value minus the broiler AME value. The following Table shows those characteristics of grains that have a high probability (P<0.05) of being associated with the difference in AME for layers compared with broilers.

Grain variables with a high probability (P<0.05) of being associated with the difference in AME values between layers and broilers (AME layer-AME broiler).

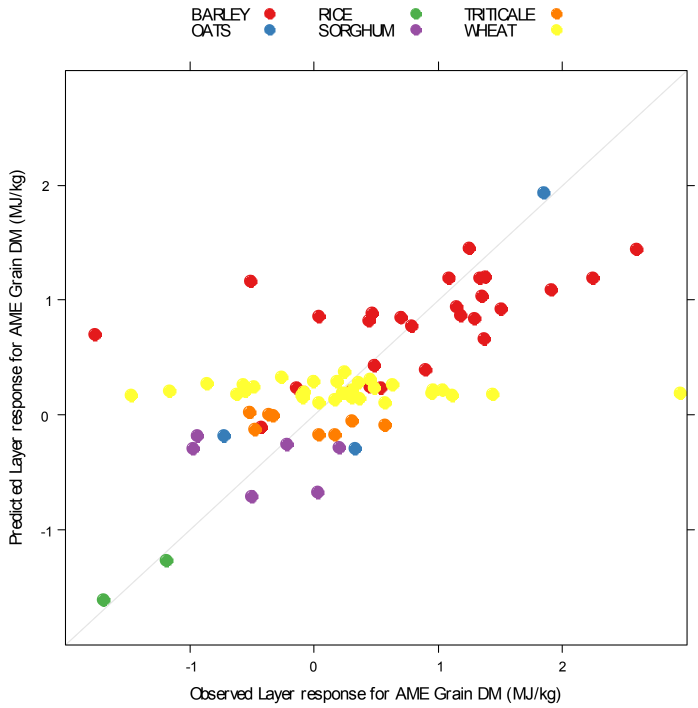
Grain variable	P value	Slope
Crude fibre	0.002	-0.220
ADF	0.006	-0.176
Whole grain peak viscosity	0.008	0.006
Cell walls (β-glucan + soluble arabinoxylan)	0.013	0.139
β-glucan	0.014	0.143
Whole grain holding viscosity	0.017	0.008
Total soluble NSP	0.022	0.228
Soluble glucose	0.023	0.297
Whole grain final viscosity	0.035	0.004
Oleic acid	0.044	0.068
Specific weight	0.045	0.027

Information in the Table suggests that layers digest better and have a higher AME content than broilers for those diets with grains that contain more cell wall material, have a higher whole grain viscosity, contain more lipid and have a higher specific weight. Alternatively, broilers obtain more AME than layers from diets high in fibre content. The longer and more mature digestive tract in layers is probably responsible for the higher energy yield form viscous diets with more cell wall, higher viscosity and higher lipid contents. However, dietary fibre is known to partially overcome the negative effects of viscous digesta in broilers, which suggests that diets high in fibre could have a greater positive impact on AME in broilers than in layers. Specific weight is negatively related to fibre content.

When the variables in the Table above are rationalised to remove those that are highly correlated with each other, statistical analysis showed cell walls, oleic acid and ADF, as well as grain type (P<0.001), were significant in a multiple regression equation predicting the difference in AME between layers and broilers. The equation for each grain species was as follows:

Barley difference = 0.618 + 0.458 × Oleic (P=0.034) + 0.113 × Cell Wall (P=0.042) - 0.087 × ADF (P=0.024)
Oat difference = -0.156 + 0.458 × Oleic (P=0.042) + 0.113 × Cell Wall (P=0.042) - 0.087 × ADF (P=0.024)
Rice difference = -1.631 + 0.458 × Oleic (P=0.042) + 0.113 × Cell Wall (P=0.042) - 0.087 × ADF (P=0.024)
Sorghum difference = -0.616 + 0.458 × Oleic (P=0.042) + 0.113 × Cell Wall (P=0.042) - 0.087 × ADF (P=0.024)
Triticale difference = -0.036 + 0.458 × Oleic (P=0.042) + 0.113 × Cell Wall (P=0.042) - 0.087 × ADF (P=0.024)
Wheat difference = 0.242 + 0.458 × Oleic (P=0.042) + 0.113 × Cell Wall (P=0.042) - 0.087 × ADF (P=0.024)

Although these equations predict the observed response (difference between layer AME and broiler AME) with reasonable accuracy, R^2=0.73, the Figure below shows that they discriminate poorly within a grain species.

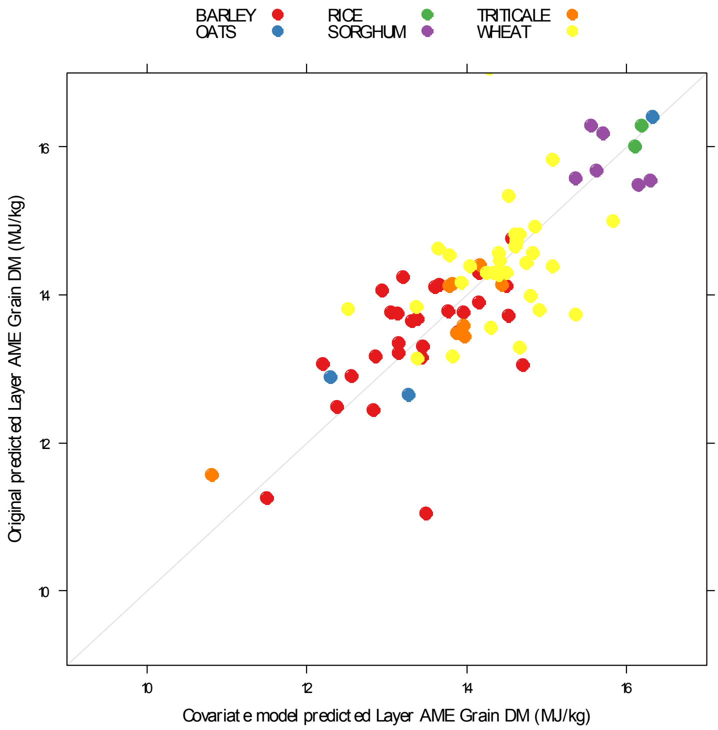


Relationship between observed response (layer AME – broiler AME) and the response predicted using the above equations based on oleic acid, cell walls (β-glucan + soluble arabinoxylan) and ADF content (% DM) of the grains. R^2=0.73.

Further analyses showed that crude fat (P=0.054) could replace oleic acid in equations with almost no apparent loss in accuracy of prediction (R^2=0.73). The resulting equations were:

Barley difference = 0.462 + 0.168 × Crude fat + 0.109 × Cell Wall - 0.094 × ADF
Oat difference = 0.178 + 0.168 × Crude fat + 0.109 × Cell Wall - 0.094 × ADF
Rice difference = -1.608 + 0.168 × Crude fat + 0.109 × Cell Wall - 0.094 × ADF
Sorghum difference = -0.604 + 0.168 × Crude fat + 0.109 × Cell Wall - 0.094 × ADF
Triticale difference = -0.154 + 0.168 × Crude fat + 0.109 × Cell Wall - 0.094 × ADF
Wheat difference = 0.102 + 0.168 × Crude fat + 0.109 × Cell Wall - 0.094 × ADF

The broiler AME values plus the values predicted from these difference equations were used to predict layer AME values for all diets fed to layers and are compared with the original observations in the Figure below. Approximately 64% of the variation in observed layer AME values was accounted for by the prediction equations (R^2=0.64). This value is a little higher than the R^2=0.56 obtained when layer AME was predicted using the NIR calibrations. The results suggest that when those grain variables significantly contributing to the differences in AME between layers and broilers are taken into account, layer AME can be predicted with slightly more precision than by using the NIR calibrations established. However, because the equations did not discriminate well between grains within a grain species, the equations are considered to be of limited value for predicting within grain species layer AME.



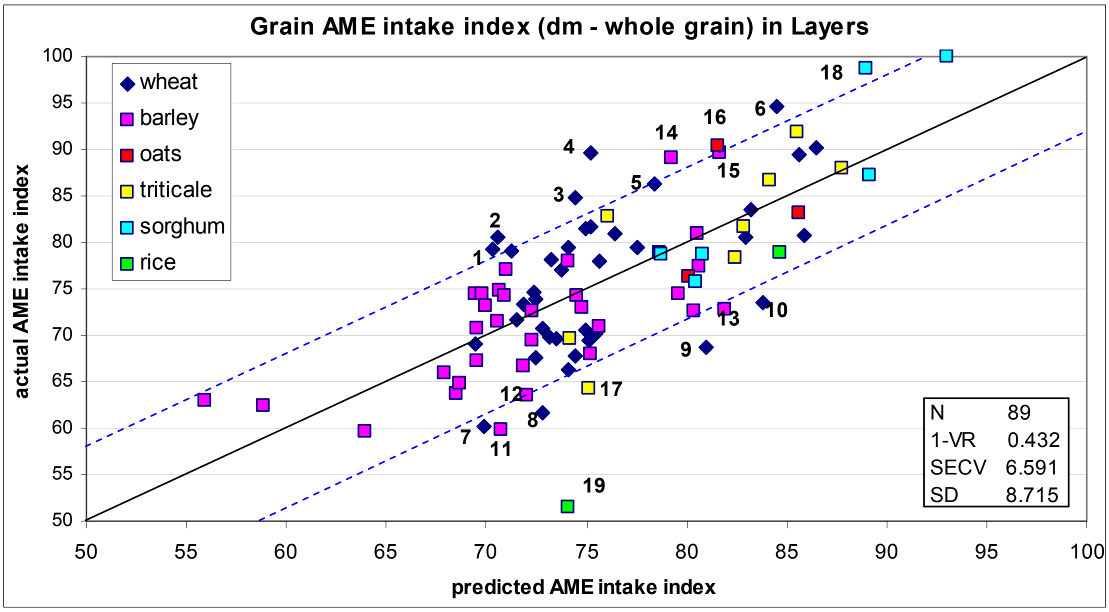
Relationship between predicted AME of grain for layers using the equations above that include crude fat and the observed AME values (R^2=0.64).

AME intake index for cereal gains for layers

The energy value of a grain to layers depends both on the available energy content of the grain expressed as AME (MJ/kg) and on the amount of the grain eaten. In general, the daily intake of AME will be positively related to performance of birds.

The intake of grain by layers was also recorded during experiments determining the AME content of grains within PGLP experiments. Thus, the intake of AME (AME intake/bird, MJ/d) could be calculated for the different grains fed to layers. Because AME intake is not commonly used to rank the energy value of grains, the values were converted to an index by dividing the AME intake value for each grain by the highest value. The values derived were multiplied by 100, such that grains could be ranked with values potentially from 0 to 100+.

The AME intake index values were then used to develop an NIR calibration using scans from whole grain. The relationship between predicted values and calculated AME intake index values (0-100+) follows. The dashed lines represent ± 1 standard deviation from the observed mean values with individual grains predicted to be outside this range identified.



1-VR (1-Variance Ratio) is the fraction of the variance in observations accounted for when some of the observations are used for 'cross validation' as determined by the calibration software. A value of 0.43 indicates low level robustness of the calibration.

The value of the calibration is assessed by (RPD) the Ratio of Prediction to experimental Deviation (SD/SECV) = 1.2. The calibration is rated as 'poor' with predictions being within 13 index units in 95% of samples measured. Development of the NIR calibration from scans of milled grain samples did not improve the accuracy of the prediction.

Predicting layer values from broiler values

Similar statistical analyses to those conducted for AME were undertaken comparing AME intake (MJ/day) between layers and broilers. The following Table shows those characteristics of grains that have a high probability (P<0.05) of being associated with the difference in AME intake for layers compared with broilers. The information in the Table suggests that layers eat less feed that contains high protein or cell walls, but more that contains tannins than broilers.

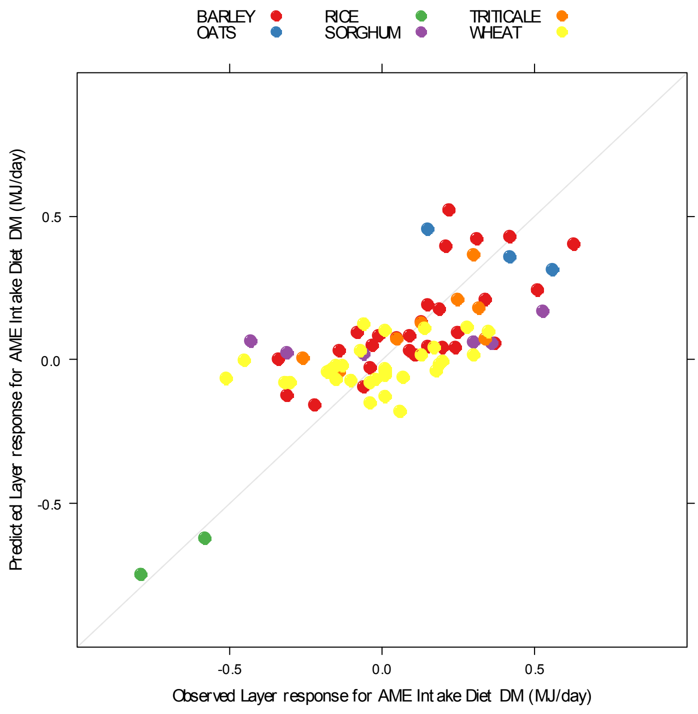
Grain variables with a high probability (P<0.05) of being associated with the difference in AME intake values between layers and broilers (AME intake layer-AME intake broiler).

Grain variable	P value	Slope
Crude protein	<0.001	-0.037
β-glucan	0.001	-0.054
Cell walls (β-glucan + soluble arabinoxylan)	0.001	-0.050
Total tannins	0.002	0.650

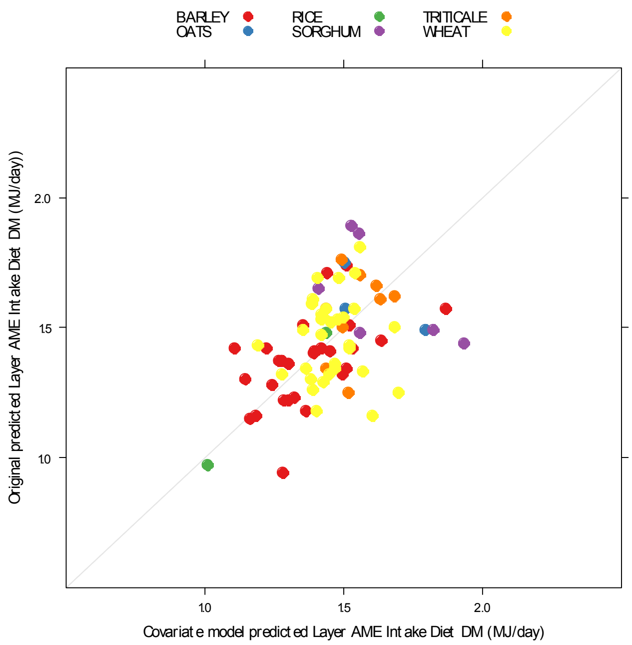
When cell walls replaced β-glucan, each of the three variables along with grain species (P<0.001) were significant in a multiple regression equation predicting the difference between AME intake of layers and broilers. The equations are given below:

Barley difference = 0.300 + 1.390 × Total Tannin (P=0.006) - 0.018 × Cell Wall (P=0.001)
- 0.031 × Crude Protein (P=0.009)
Oat difference = 0.345 + 1.390 × Total Tannin (P=0.006) - 0.018 × Cell Wall (P=0.001)
- 0.031 × Crude Protein (P=0.009)
Rice difference = -0.600 + 1.390 × Total Tannin (P=0.006) - 0.018 × Cell Wall (P=0.001)
- 0.031 × Crude Protein (P=0.009)
Sorghum difference = -0.011 + 1.390 × Total Tannin (P=0.006) - 0.018 × Cell Wall (P=0.001)
- 0.031 × Crude Protein (P=0.009)
Triticale difference = 0.221 + 1.390 × Total Tannin (P=0.006) - 0.018 × Cell Wall (P=0.001)
- 0.031 × Crude Protein (P=0.009)
Wheat difference = 0.219 + 1.390 × Total Tannin (P=0.006) - 0.018 × Cell Wall (P=0.001)
- 0.031 × Crude Protein (P=0.009)

Although these equations predict the observed response (difference between layer AME intake and broiler AME intake) with reasonable accuracy, R^2=0.72, the Figure below shows that they discriminate poorly within a grain species.



Relationship between observed response (layer AME intake – broiler AME intake) and the response predicted using the above equations based on total tannin, cell walls (β-glucan + soluble arabinoxylan) and crude protein content (% DM) of the grains. R^2=0.72.



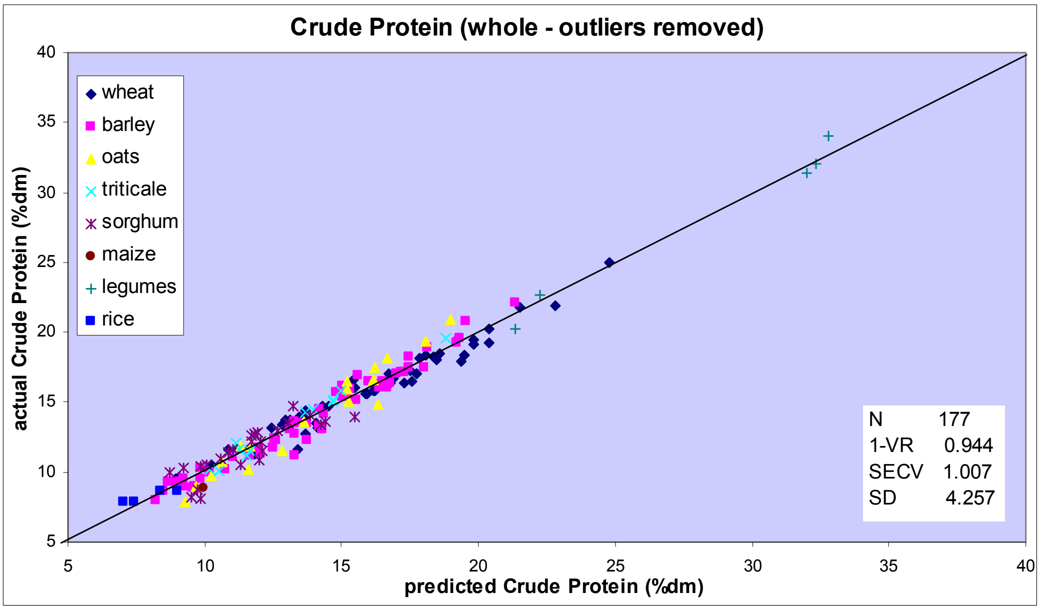
Relationship between predicted AME intake of the diet for layers using the equations above including total tannin, cell walls and crude protein (R^2=0.27).

The broiler AME values plus the values predicted from these difference equations were used to predict layer AME values for all diets fed to layers and are compared with the original observations in the Figure above. Only 27% of the variation in observed layer AME intake values was accounted for by the prediction equations (R^2=0.27). This value is substantially lower than the R^2=0.55 obtained when layer AME intake for the diet was predicted using the NIR calibrations. The results suggest that when those grain variables significantly contributing to the differences in AME intake between layers and broilers are taken into account, layer AME intake is not predicted with more precision than by using the NIR calibrations established.

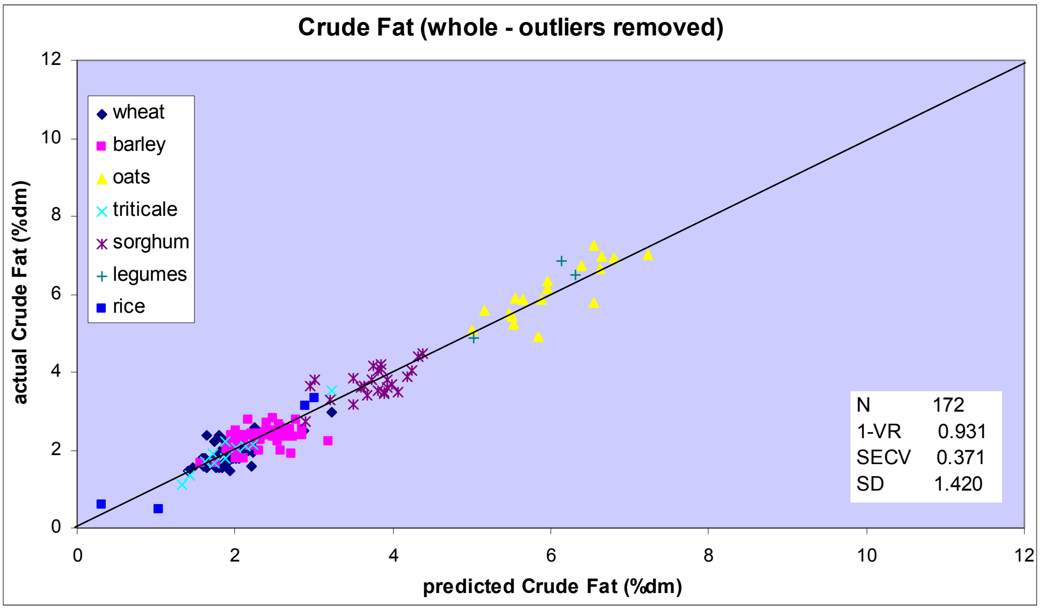
Grain chemical & physical characteristics

The accuracy of the calibrations is given in the master Table in this report. Chemical and physical analyses were conducted on 187 grains fed to animals. Graphs for NIR predicted values using whole grain scans compared with measured values are given for those grain characteristics listed in the Table.

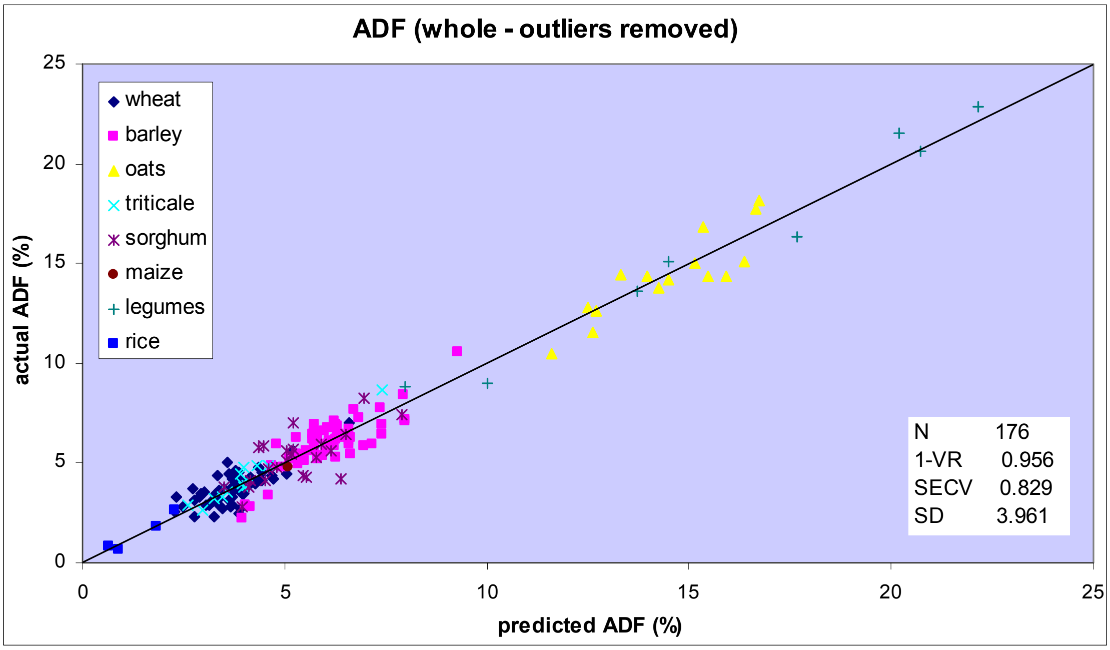
Crude Protein (% DM)



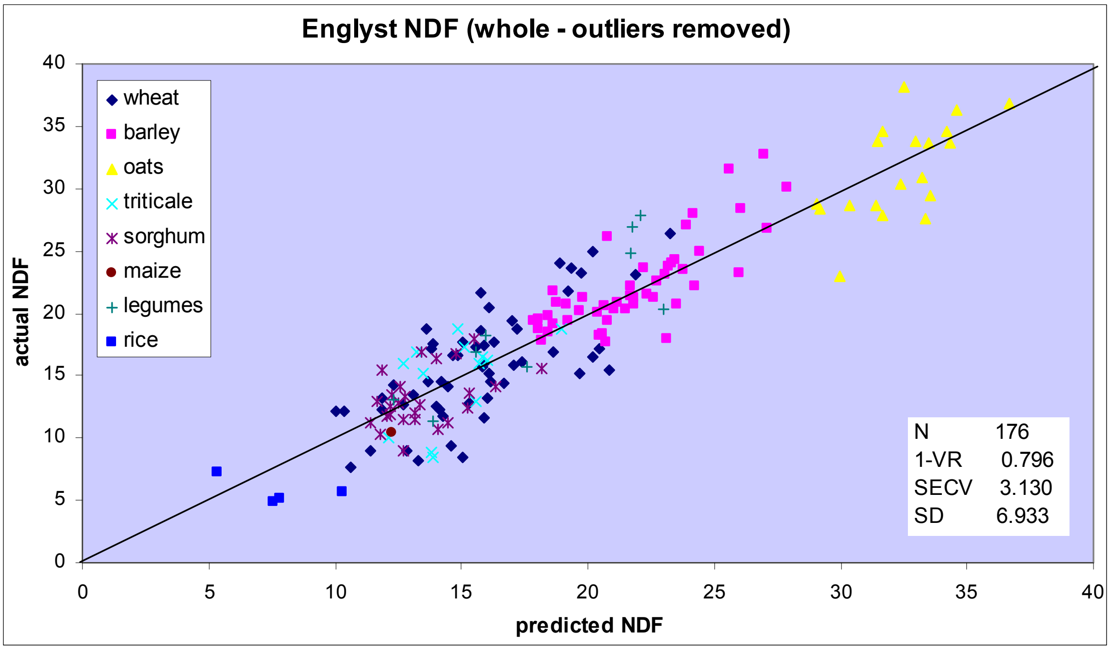
Crude fat (ether extract) (% DM)



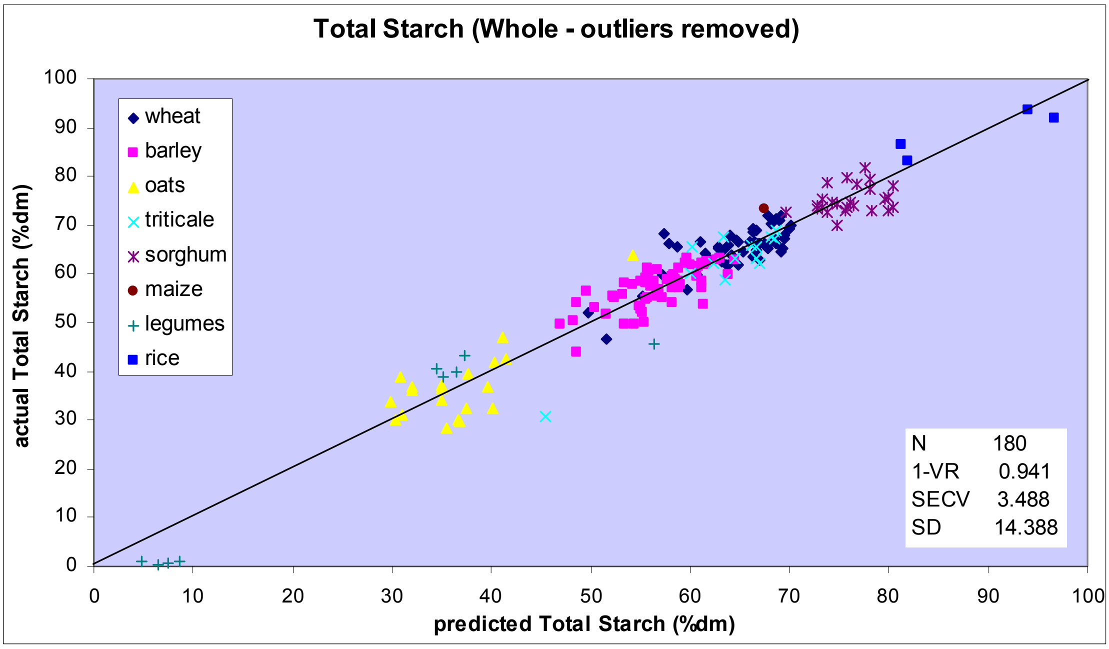
Acid detergent fibre (ADF, % DM)



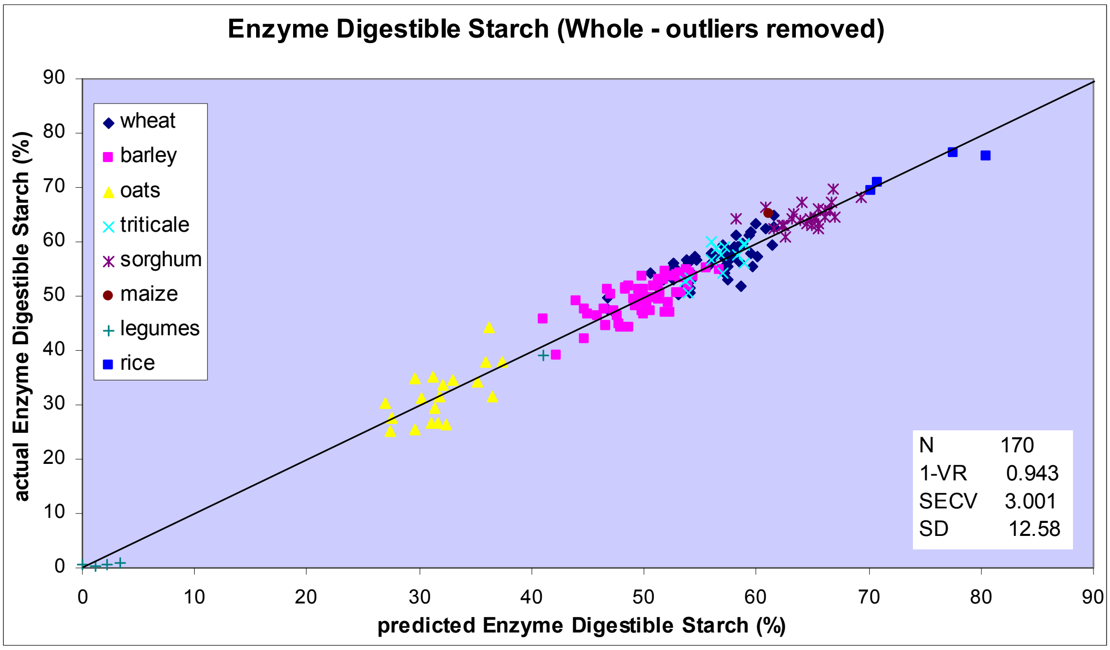
Neutral detergent fibre (NDF, % DM)



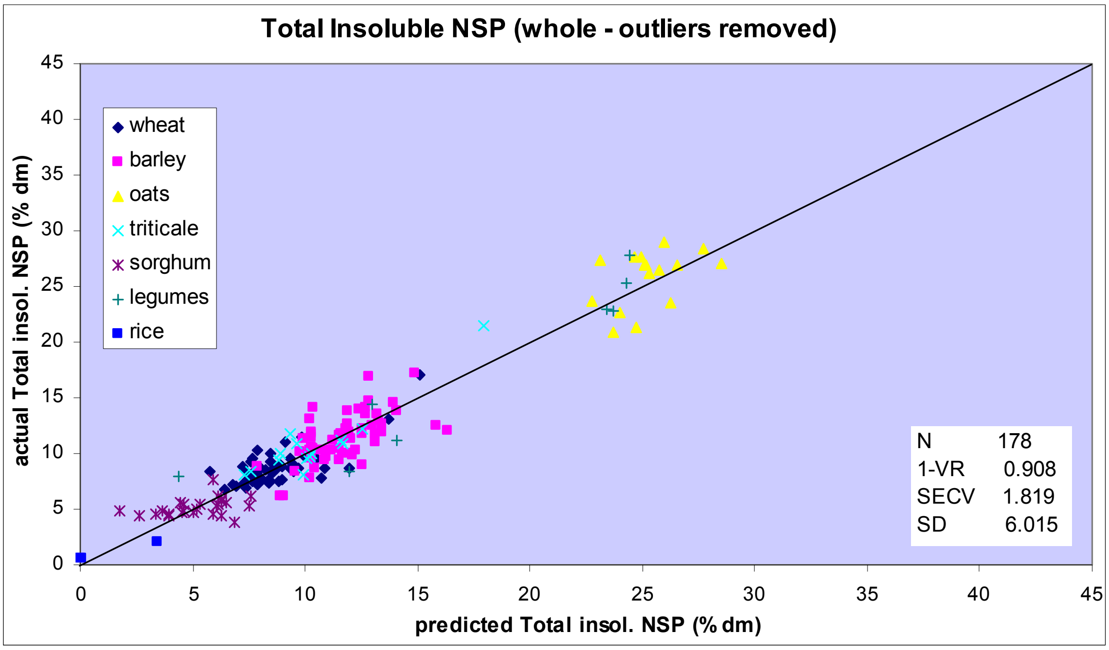
Starch (% DM)



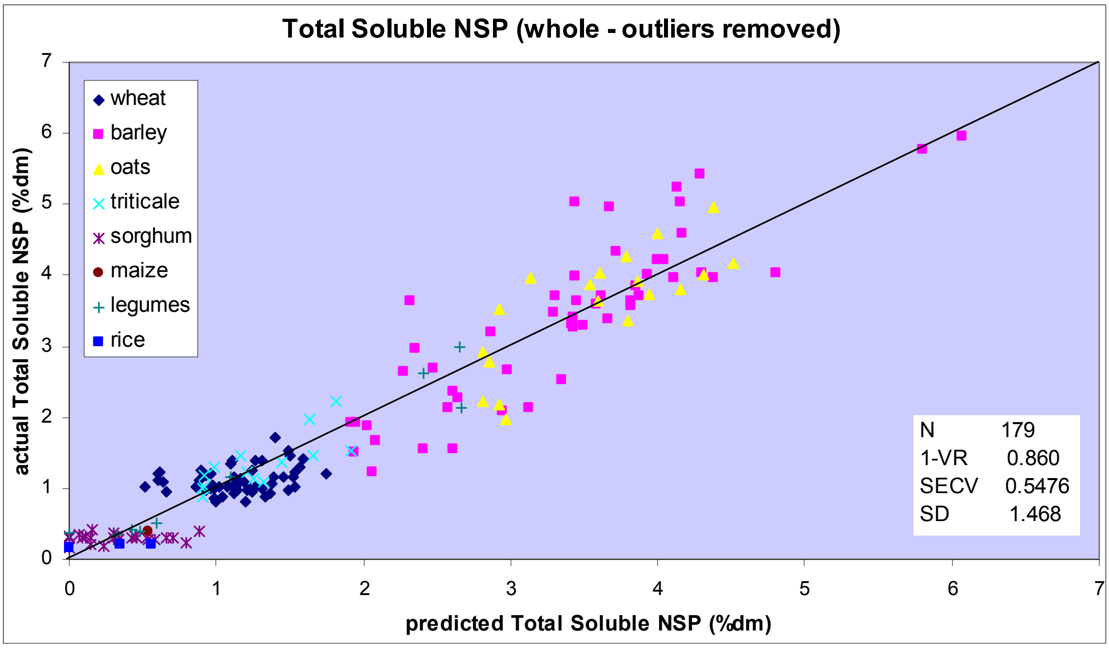
Enzyme digestible starch (% DM)



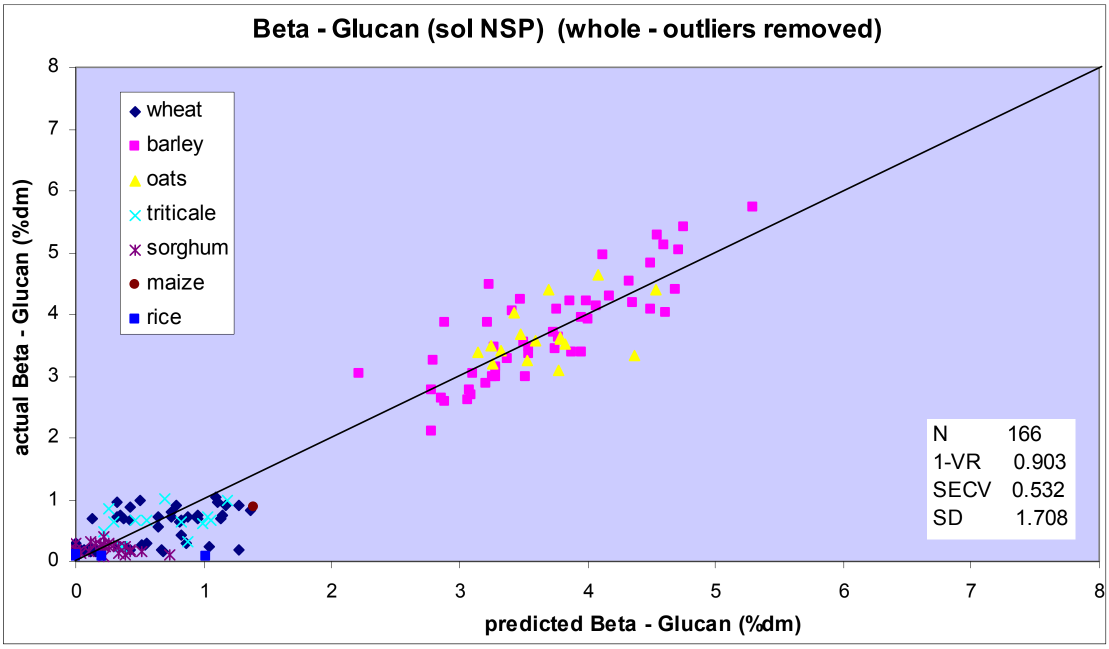
Total insoluble NSP (% DM)



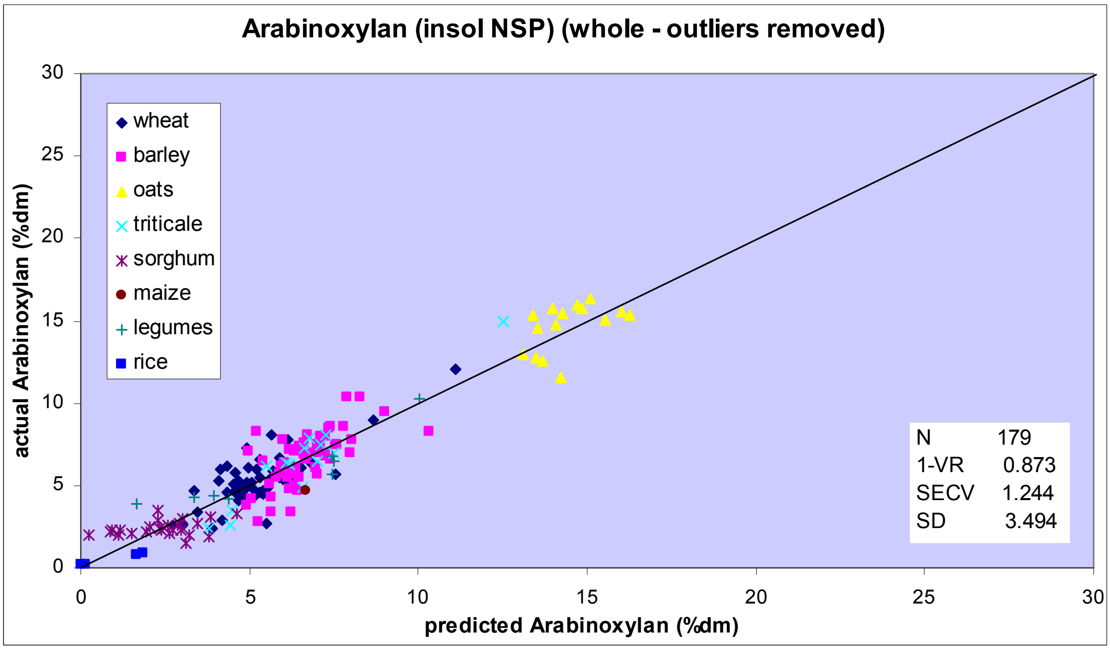
Total soluble NSP (% DM)



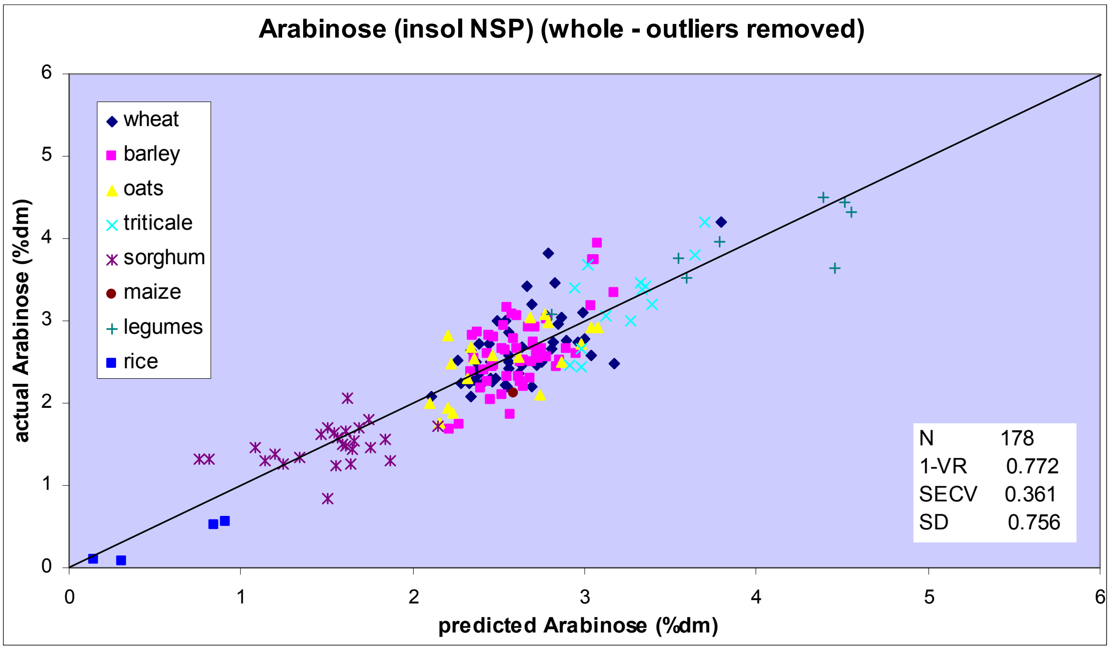
ß-glucan (% DM)



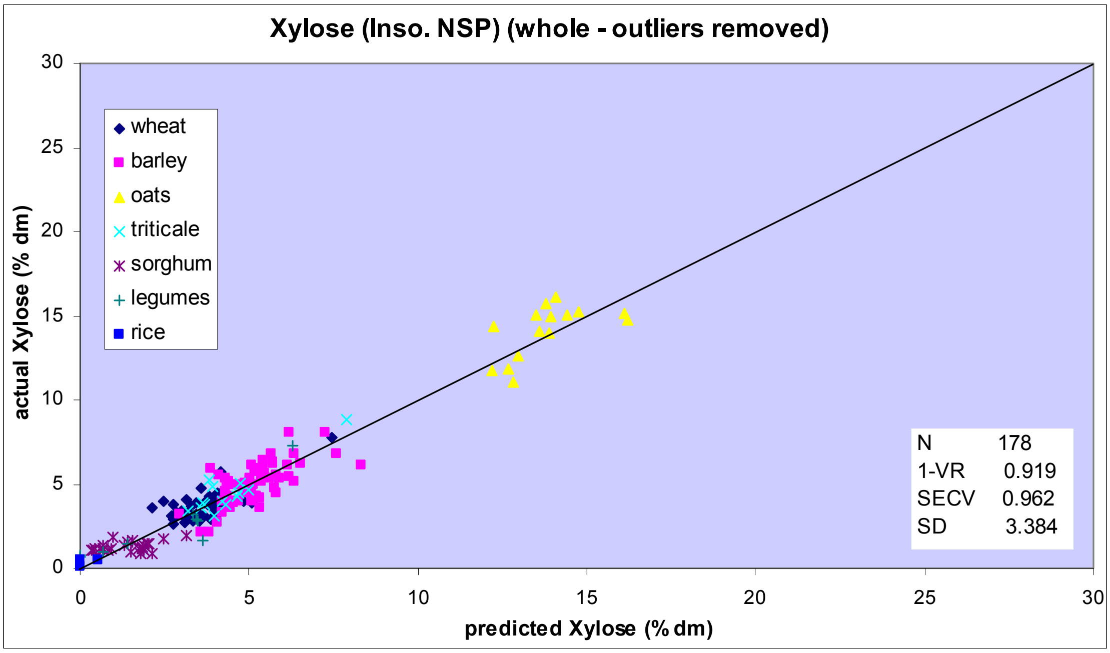
Arabinoxylan (% DM)



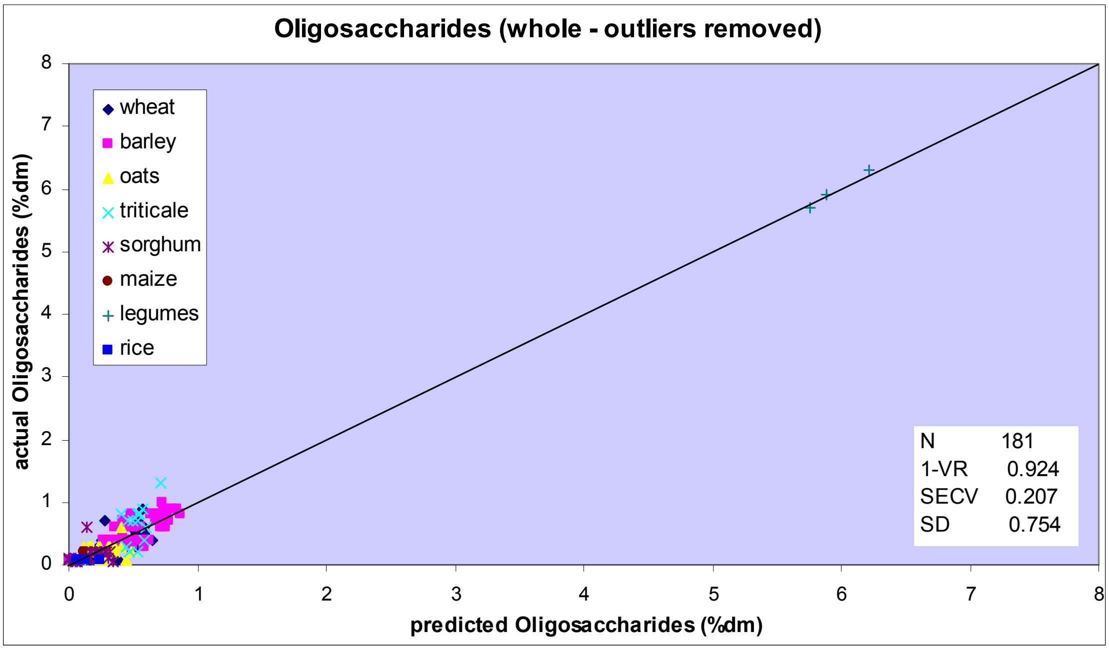
Arabinose (% DM)



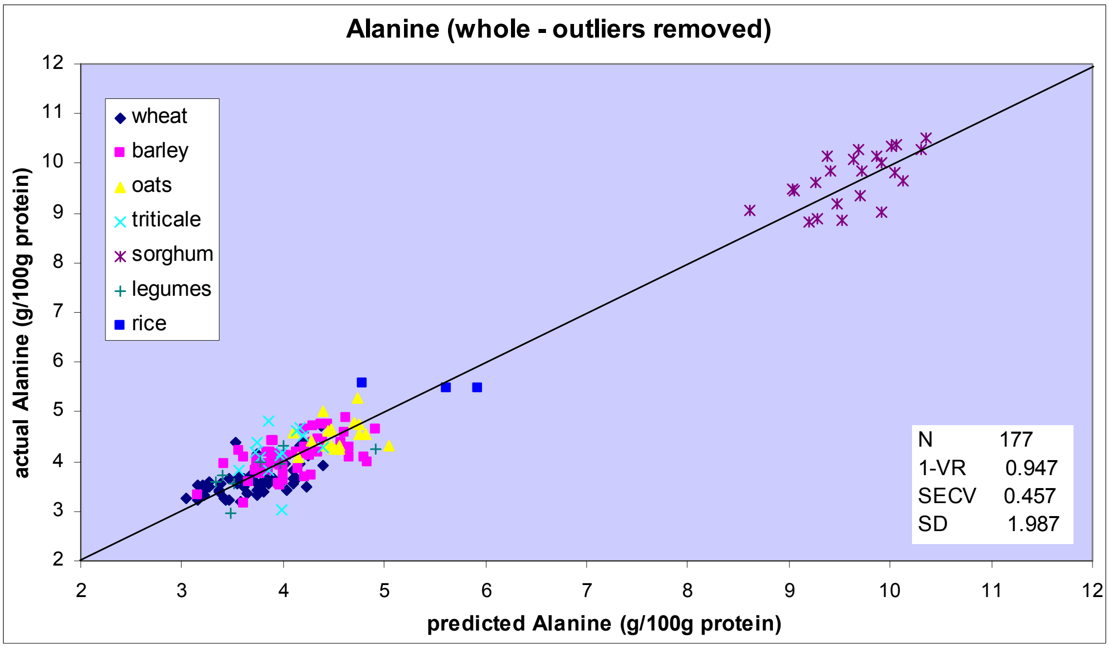
Xylose (% DM)



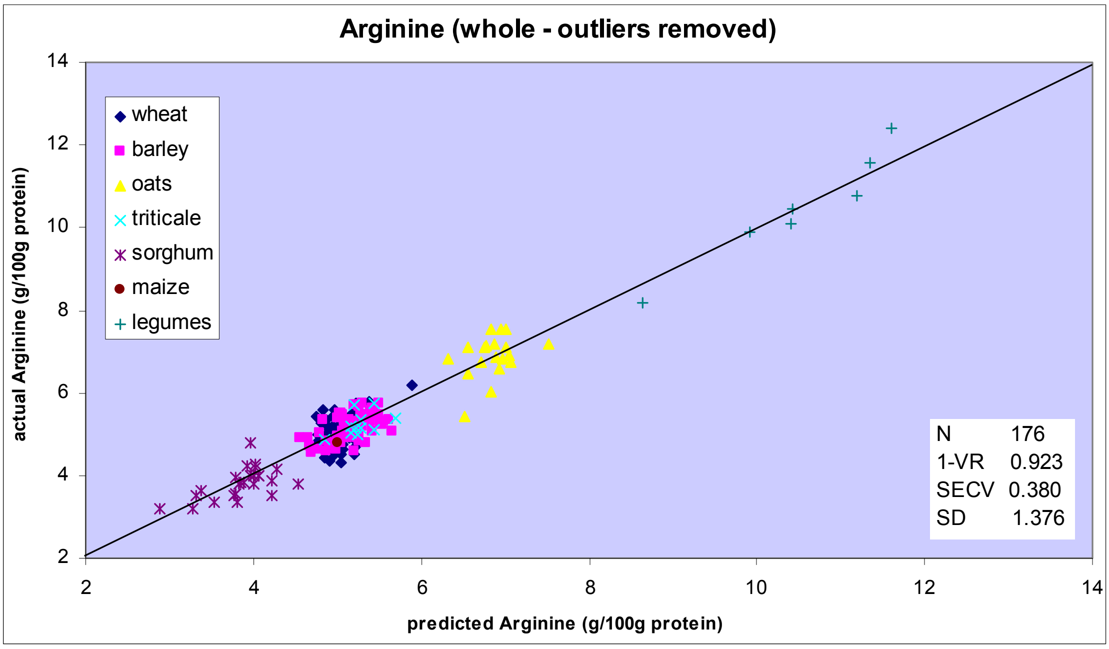
Oligocassharides (% DM)



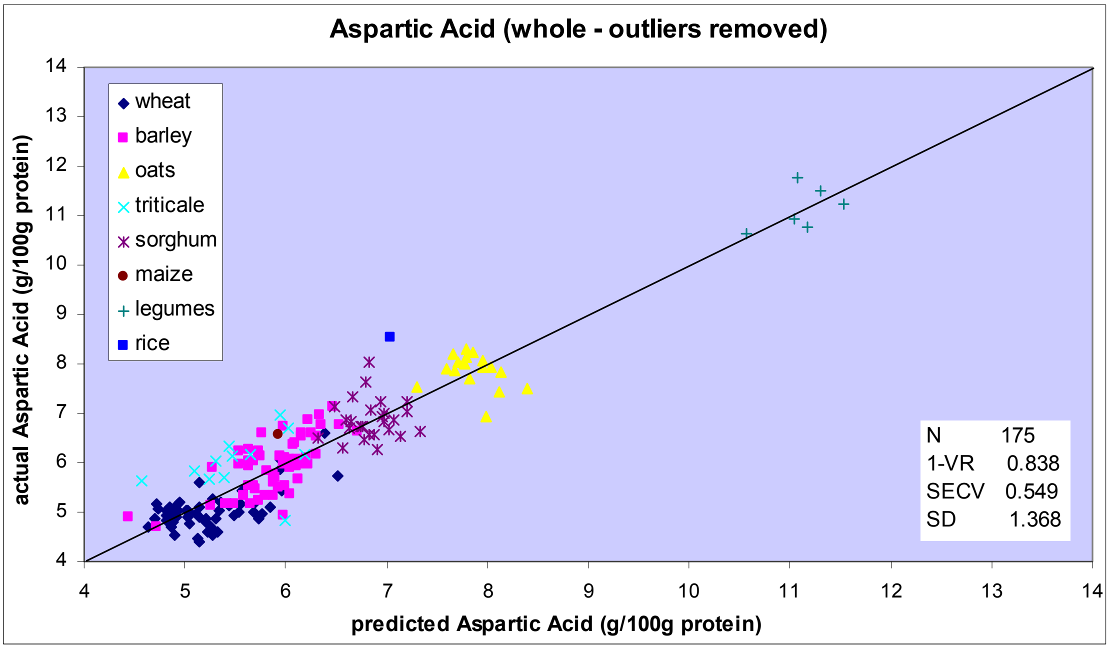
Alanine (g/100 g protein)



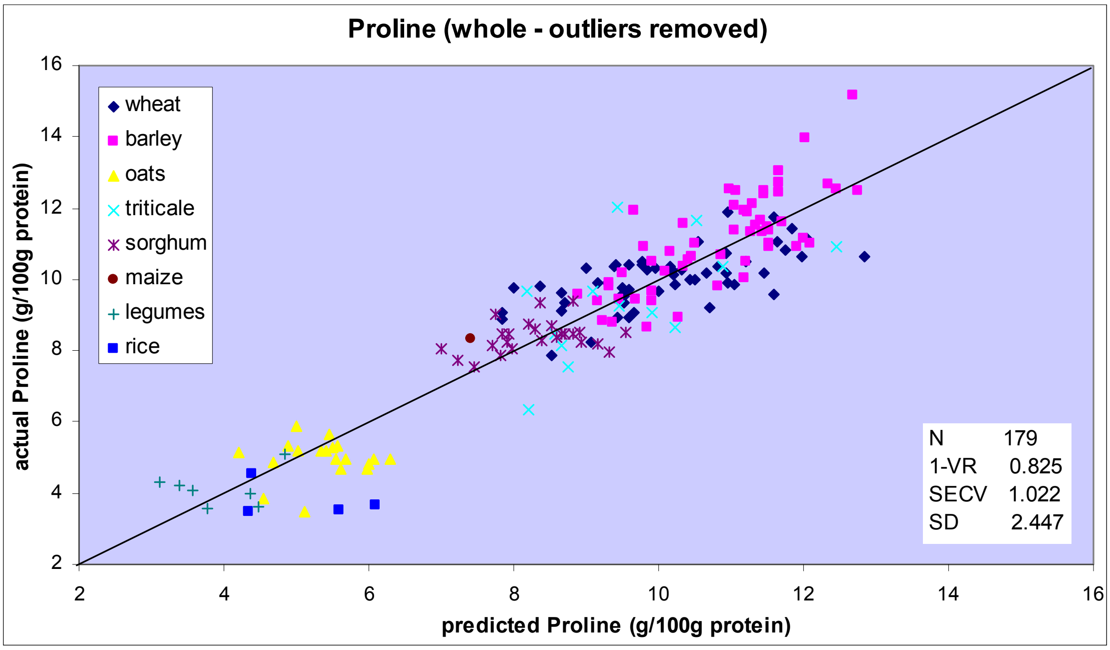
Arginine (g/100g Protein)



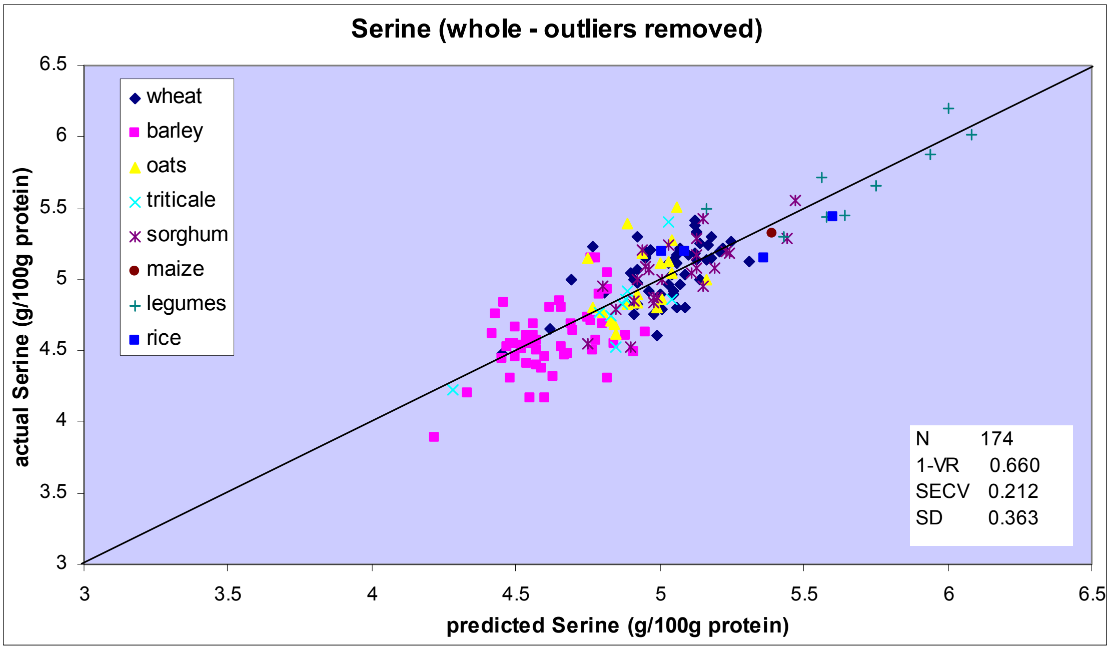
Aspartic acid (g/100g protein)



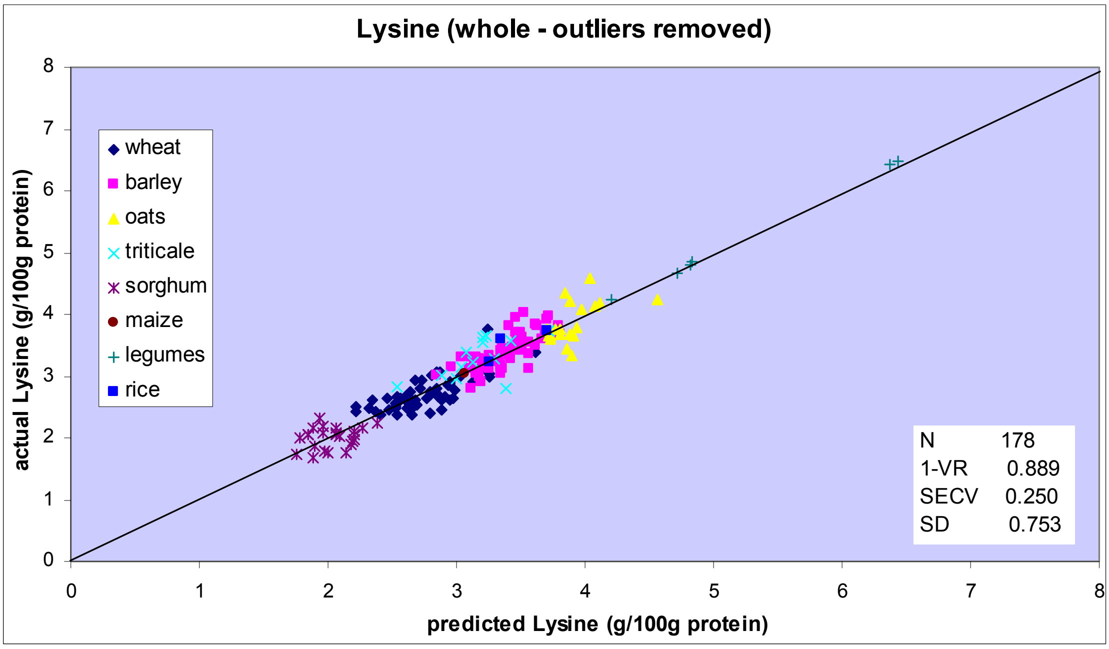
Proline (g/100g protein)



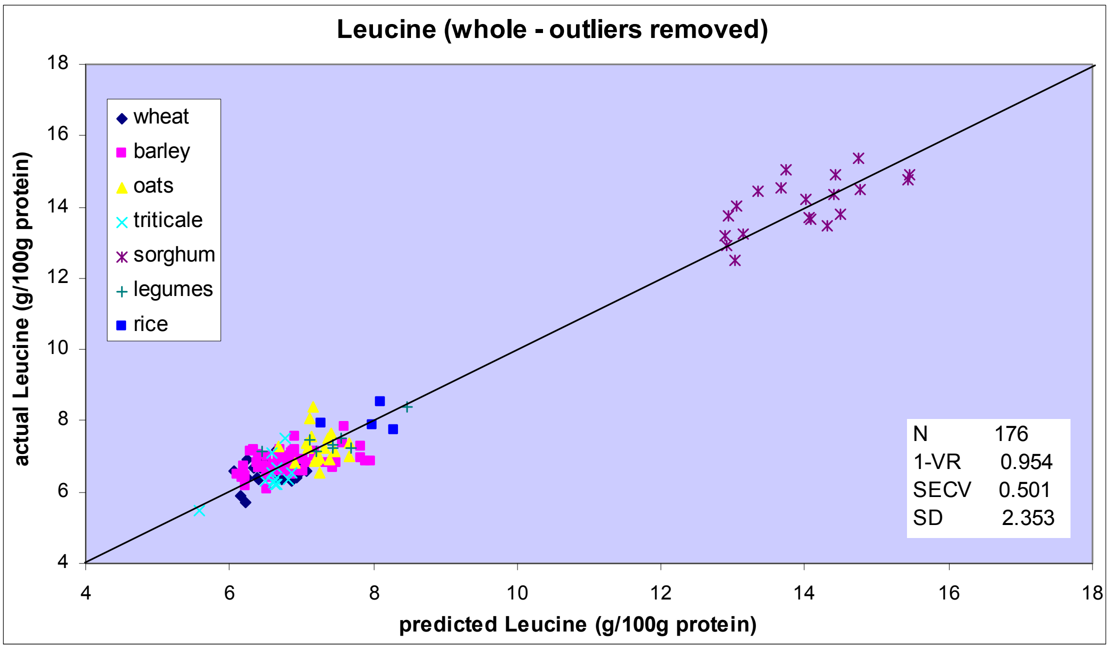
Serine (g/100g protein)



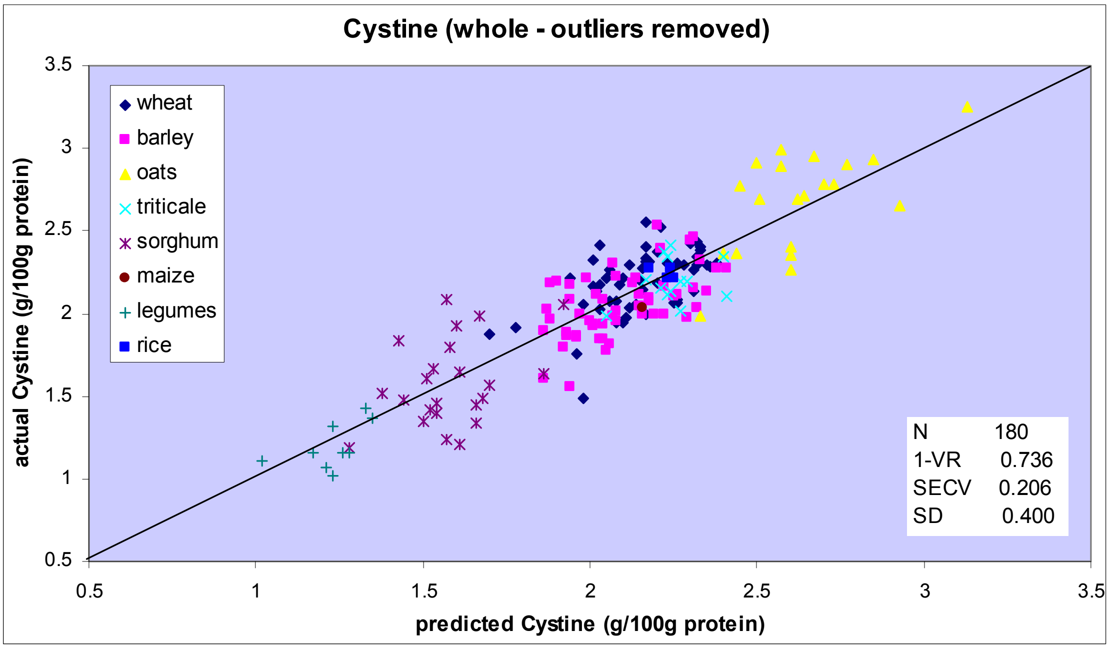
Lysine (g/100g protein)



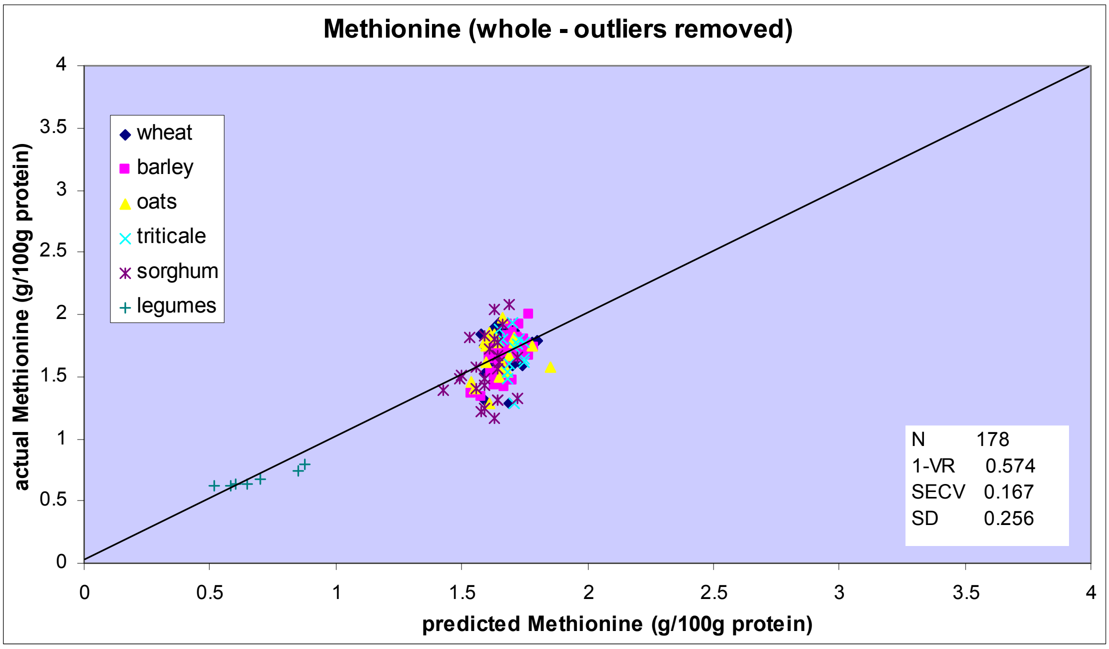
Leucine (g/100g protein)



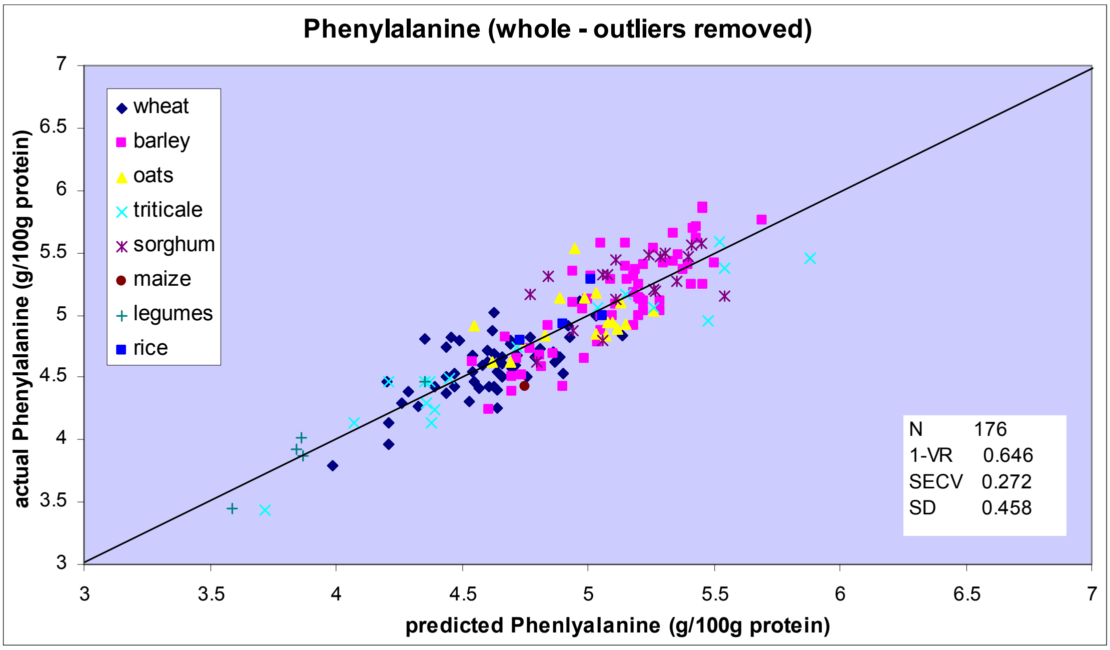
Cystine (g/100g protein)



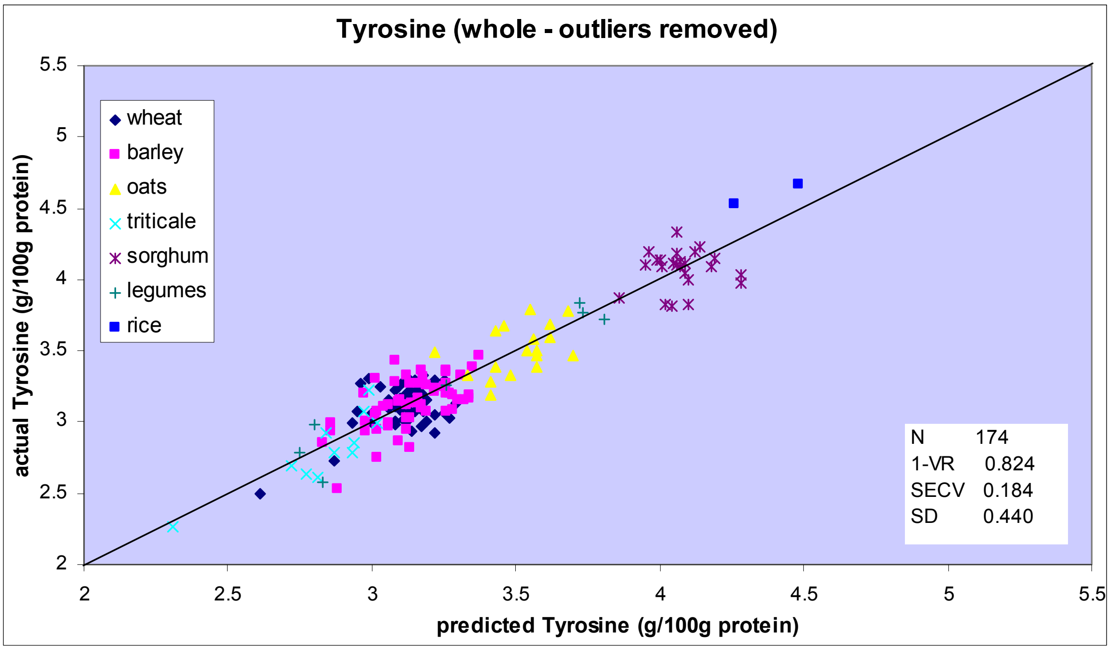
Methionine (g/100g protein)



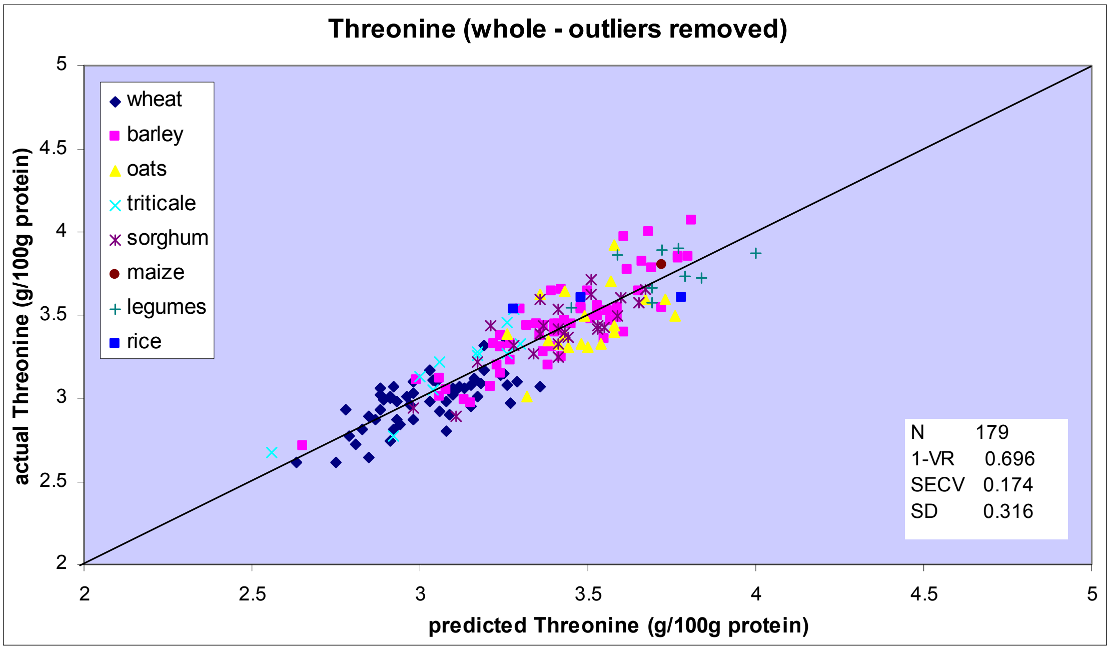
Phenylalanine (g/100g protein)



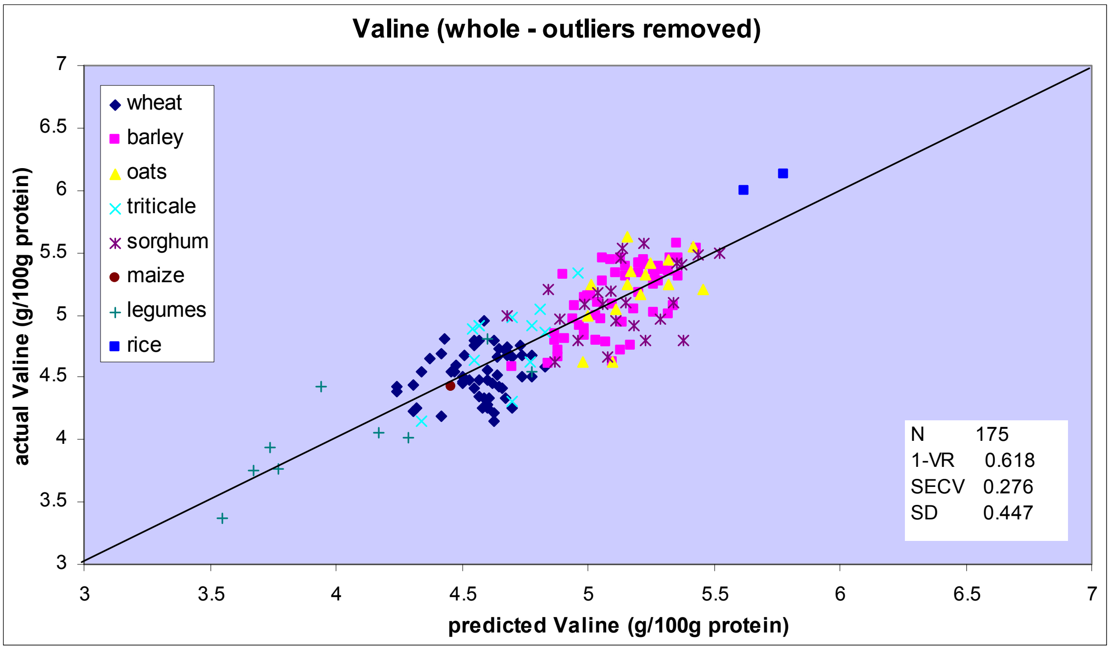
Tyrosine (g/100g protein)



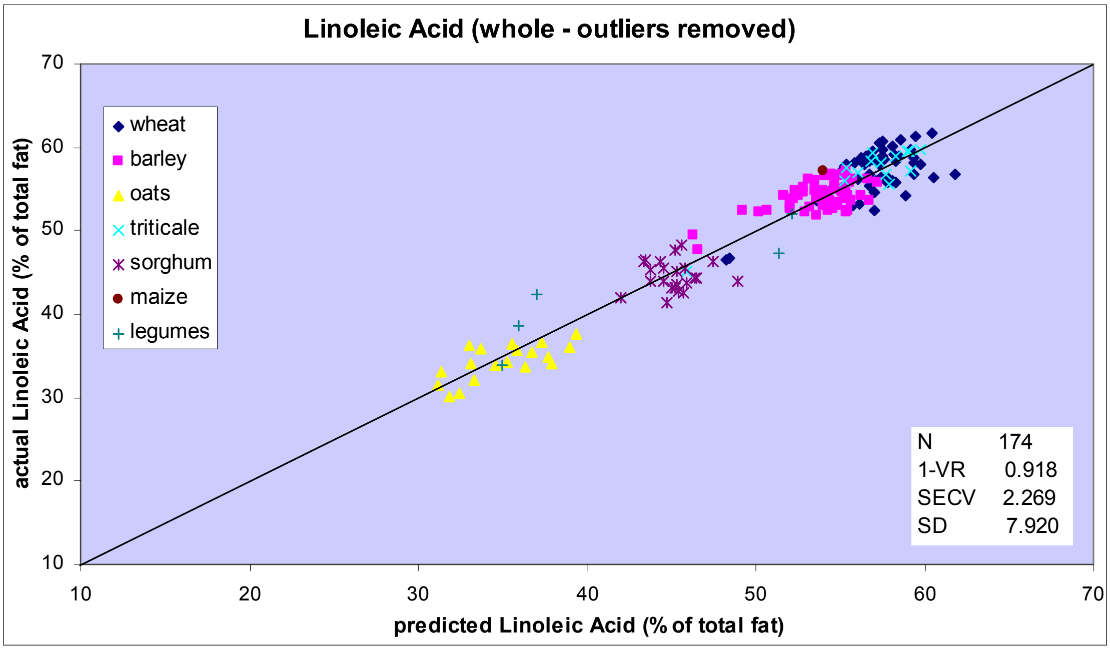
Threonine (g/100g protein)



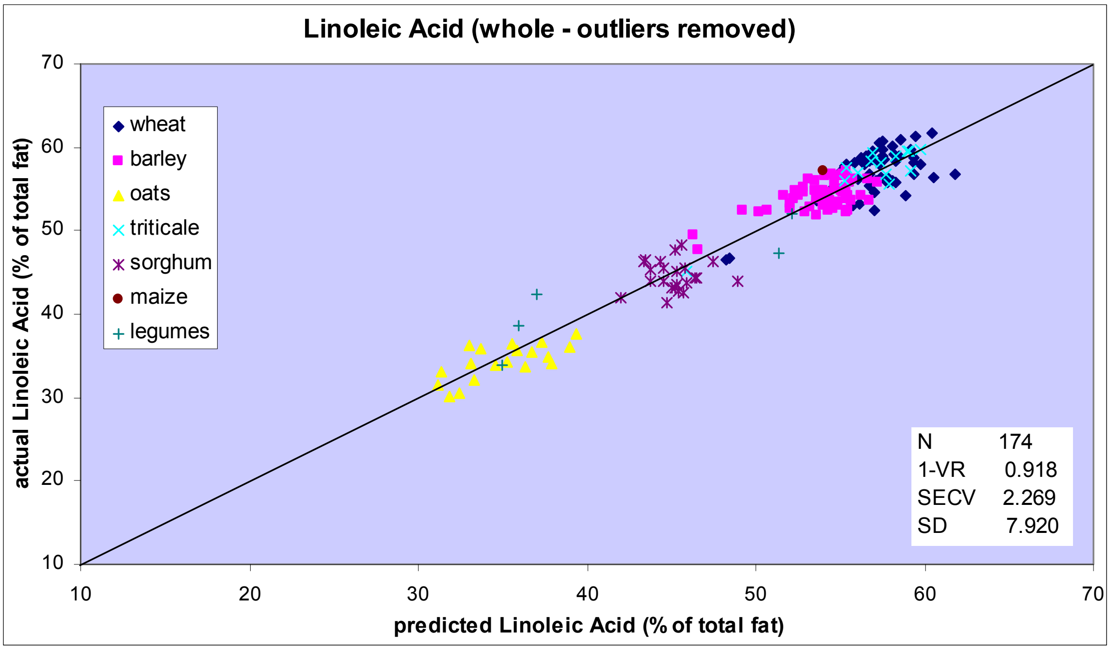
Valine (g/100g protein)



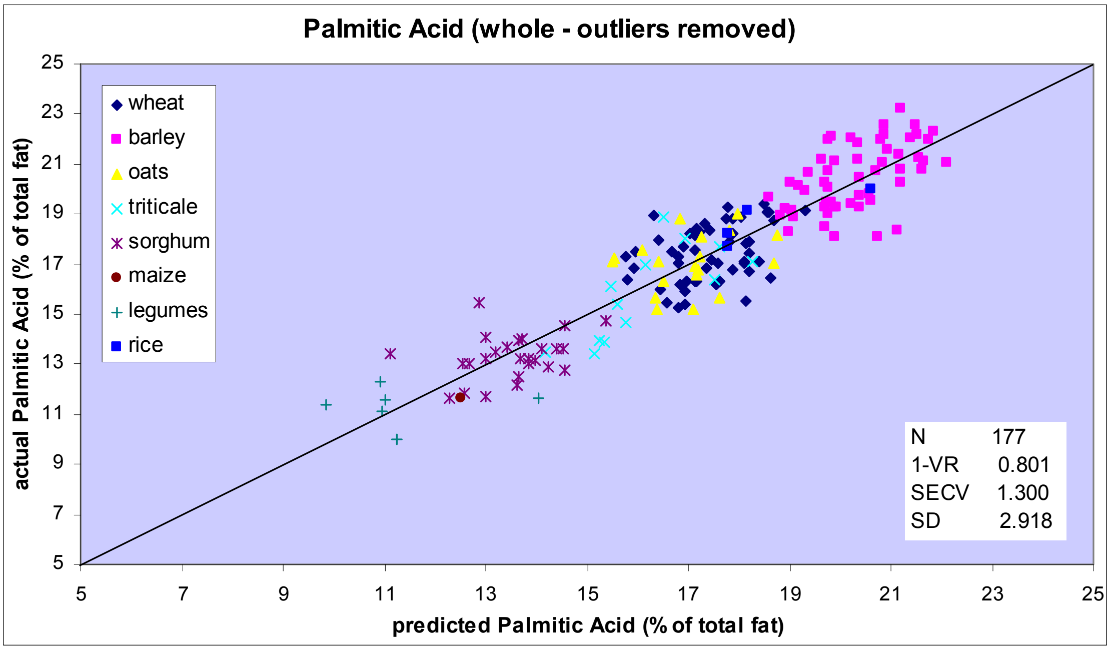
Linoleic acid (% total lipid)



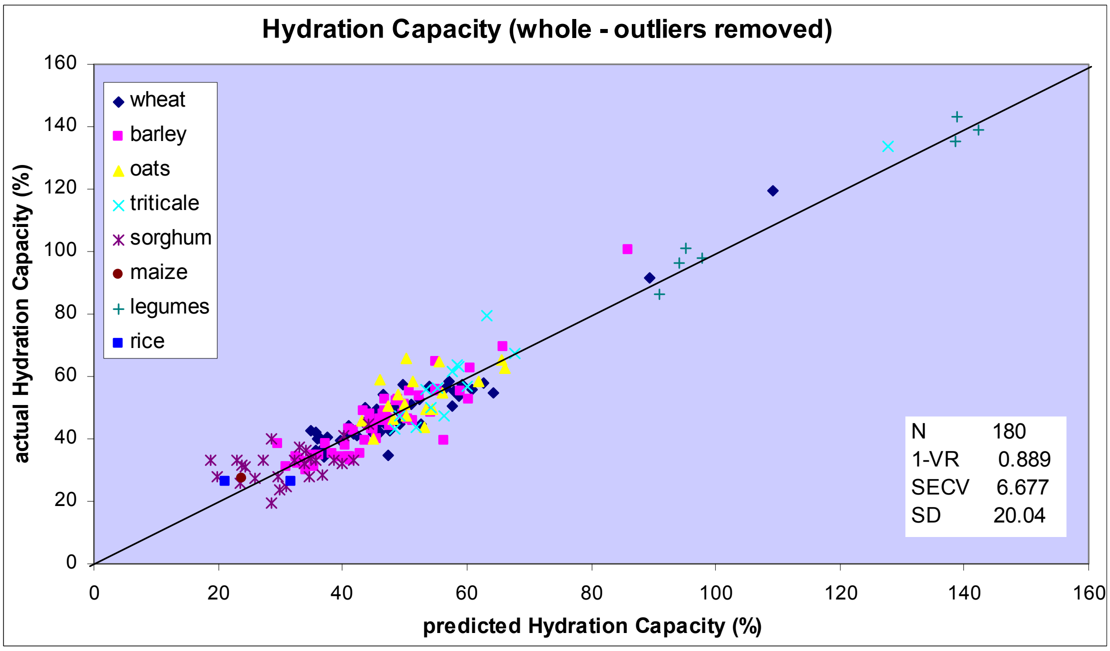
Oleic acid (% total lipid)



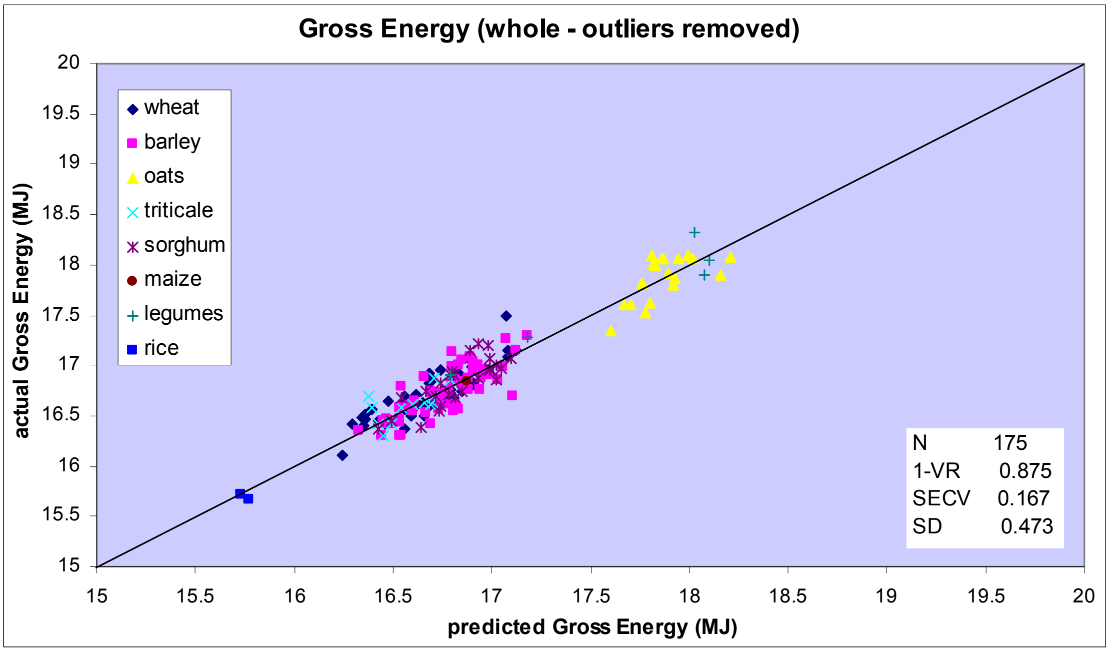
Palmitic (% total lipid)



Hydration capacity (% increase in weight)



Gross energy (MJ/kg DM)



Value of NIR calibrations for the grains and livestock industries

The PGLP has developed the most extensive and robust set of NIR calibrations ever produced for determining the available energy content and available energy intake for cereal grains offered to ruminants, pigs and poultry and for predicting chemical composition of the grains. Research within the Program has demonstrated for the first time that individual cereal grain samples can be of greater nutritional value for one animal type than another. In addition, the research showed that digestibility of cereal grains was poorly related feed intake for all animal types. Productivity and profitability of an intensive animal enterprise depends on total available energy intake, whereas the efficiency of feed use depends both on the digestibility and intake of a grain based diet. Consequently, the NIR calibrations developed within PGLP are extremely valuable for and the only realistic method for determining the relative productivity of any grain sample for each animal industry.

The development of these NIR calibrations and their application within the grains and livestock industries goes along way towards meeting the overall objectives of PGLP and is the basis for a rational system of trading grains for livestock. In addition, the calibrations are of great value to cereal grain breeders because of their ability to screen individual plants or lines for their nutritional value for each livestock type.

Maintenance and enhancement of calibrations

Although many of the calibrations developed have reasonable accuracy and will be of value for identifying the best likely end-use for any grain sample, the accuracy is generally not sufficient for the legal trading of grain, particularly with the recent new laws relating the use and accuracy for instruments for determining the price of commodities. The calibrations have been used in a series of case studies with the primary aim to demonstrate that individual grain samples selected on the basis of NIR calibrations produce expected different rates of production and feed efficiencies for specific different livestock industries.

A major ongoing activity must be the continued maintenance and enhancement of the calibrations. These calibrations will need to change in response to changes in characteristics of grains as a result of ongoing plant breeding activities. In addition, it is evident from the description of the individual calibrations given above that many do not predict well the energy values of rain damaged or frosted grains. Only few of these grains were examined within PGLP and there were insufficient numbers to be able to develop robust calibrations which predict accurately the energy values for all grains. There is likely also to be a small seasonal variation in the accuracy of the calibrations for specific measures. Furthermore, development of the calibrations will be needed for plant breeders to strengthen the within grain species predictions because the current calibrations are across species. Experience with the development of NIR calibrations for other uses, such as determining the protein content of grains, shows that the accuracy of predictions can be extremely high when there are sufficient grains included to enable the effective use of neural-net methodologies.

Thus, for the grains and livestock industries to obtain the full benefit from PGLP research, further investment in the maintenance and upgrading of the NIR calibrations will be essential.

Comparison of predictions across NIR instruments

The NIR calibrations presented above were developed using the 'top of the range' Foss 6500 instrument, which is excellent for determining the feasibility of calibrations but generally to expensive and of too low throughput to be used widely by grain traders and sectors of the livestock industry. Consequently, a study was undertaken to assess the relative accuracy of NIR calibrations established on several instruments varying widely in price, including those used traditionally by grain traders and livestock feed manufacturers.

A diverse set of 82 grains representing wide range of environments, seasons and weather effects were used for the study: barley (26), wheat (18), triticale (7), oats (12), sorghum (9), maize (1), lupins (4), field peas (2), chickpeas (2), faba beans (1). These 82 grains were used to establish a set of calibrations for each instrument. The comparisons were made across eight instruments with characteristics outlined in Table 47. The accuracy of calibrations for the following grain characteristics was determined for each instrument:

- *In vivo* dry matter digestibility % (sheep)
- Starch (% of DM)
- Crude protein (% of DM)
- Lysine (% of Crude Protein)
- Total insoluble non-starch polysaccharides (% of DM)
- Crude fibre (% of DM)
- Neutral detergent fibre (% of DM)
- Acid detergent fibre (% of DM)

Spectra were collected on whole grains using software specific to each instrument. All spectra were converted to WINISI format (Foss software) and the "optimum" scatter correction and mathematical treatment used for each instrument to provide the combination of settings which gave the lowest possible standard error of cross-validation (SECV) for each instrument and each measurement. A modified partial least squares (MPLS) regression and cross-validation technique was used in each case, with no outlier samples omitted.

Table 47. The NIR instruments used in the cross-instrument comparison and characteristics of each instrument.

Instrument name	Mode	Type	Spectral range (nm)	No. of data points
Foss-NIRSystems 6500	Reflectance	Scanning monochromator	400-2498	1050
Bruker MPA	Reflectance	Scanning FT-NIR	800-2498	1102
Buchi NIRLab N-200	Reflectance	Scanning FT-NIR	1000-2500	1557
Foss Infratec (2)	Transmission	Scanning monochromator	850-1048	100
Perten Inframatic 9200	Reflectance	Fixed filter	1100-1400	12
Zeiss Corona VISNIR	Reflectance	Diode array	380-1700	661
Bran+Luebbe 450	Reflectance	Fixed filter	1445-2345	19
CropScan 2000B	Transmission	Diode array	720-1090	38

The results of the comparison between instruments for each grain characteristic are given in Table 48. The shaded cells in the Table indicate that the error values are the "equivalent lowest" and do not differ significantly. For example, for *in vivo* dry matter digestibility in sheep (%), the lowest SECV value was for the Buchi instrument (1.98). However, statistically, the SECV values obtained with the Foss, Bruker and Perten instruments were not different from that for the Buchi. Strictly, the statistical analysis used should compare biases and standard deviations of the cross-validation predicted errors (ie. SECV corrected for bias). However, biases were all small, with SECV corrected for bias very similar to SECV.

Although there were significant differences in the accuracy of prediction between instruments, these differences were not as great as may have been expected. For example, the instrument with the most accurate calibration for dry matter digestibility in sheep indicated that predictions would be within 4% units for 95% of samples measured compared with 6% for the least accurate instrument.

The high errors for starch were due to huge range in values caused by inclusion of pulses (range 0.5 to 75%, standard deviation 17.5). SECV for Buchi (6.24) and Infratec 2 (6.15) were different from the "equivalent lowest" values, but SECV for Perten (6.29) was not different. This was due to the test taking into account the correlation between 2 sets of prediction errors. When this correlation between 2 instruments is strong, small differences can be significant. The Perten instrument had predictions less well correlated with the others, so it was harder to prove that it was not as good as the “best”.

Table 48. Standard errors of cross-validation (SECV) for various grain quality indicators across different NIR instruments

Instrument	*In vivo* Dry Matter Digestibility (sheep)%	Starch%DM	Crude Protein%DM	Lysine%DM	Total Insoluble NSP%DM	Crude Fibre%DM	Neutral Detergent Fibre%DM	Acid Detergent Fibre%DM
Foss NIRSystems 6500	2.04^{a}	5.17^{ab}	1.33^{a}	0.42^{a}	3.33^{a}	0.77^{a}	3.99^{a}	1.06^{a}
Bruker MPA	2.31^{ab}	5.17^{ab}	1.59^{bc}	0.47^{ab}	3.48^{a}	0.87^{ab}	3.93^{a}	1.05^{a}
Buchi NIRLab N-200	1.98^{a}	6.24^{cd}	2.28^{d}	0.64^{ce}	3.73^{ac}	1.11^{cd}	4.32^{ab}	1.59^{b}
Foss Infratec 1	2.58^{bc}	5.16^{ac}	1.71^{b}	0.51^{ab}	4.17^{bc}	0.91^{ac}	3.77^{a}	1.45^{bc}
Foss Infratec 2	2.50^{b}	6.15^{bd}	1.77^{b}	0.51^{ab}	3.69^{ace}	1.00^{bc}	4.14^{ab}	1.61^{b}
Perten Inframatic 9200	2.36^{ab}	6.29^{abc}	2.24^{d}	0.83^{d}	3.73^{ace}	0.96^{bc}	4.09^{ab}	1.56^{b}
Zeiss Corona VISNIR	2.70^{bc}	5.71^{abc}	2.33^{d}	0.54^{bc}	3.80^{ace}	1.04^{bc}	4.50^{ab}	1.24^{ac}
Bran+Luebbe 450	3.08^{c}	7.91^{e}	3.52^{e}	0.67^{e}	6.04^{d}	1.33^{d}	4.49^{ab}	1.70^{b}
CropScan 2000B	2.54^{b}	8.82^{e}	1.38^{ac}	0.68^{e}	4.36^{be}	1.69^{e}	4.79^{b}	2.10^{d}

Within columns, values with different superscripts differ significantly ($P<0.05$) and the coloured cells are of “equivale

Differences between instruments in the significance of the errors varied with the particular measurement. For example, with measurement of NDF, 8 of the 9 instruments were as good as each other, but for crude protein only 2 instruments were "equal best". Instruments could be "scored" by adding the number of times a given instrument was "the best" or equivalent to "the best" (in respect of SECV) across the 8 grain characteristics, with the maximum possible score being 8. Scores were as follows:

Foss-NIRSystems 6500	8
Bruker MPA	7
Foss Infratec 1	4
Perten Inframatic 9200	4
Zeiss Corona VISNIR	4
Buchi NIRLab N-200	3
Foss Infratec 2	3
Bran+Luebbe 450	1
CropScan 2000B	1

On the basis of the grain characteristics compared and for the particular instruments compared, the Foss and Bruker instruments had the lowest errors and the Bran+Luebbe 450 and CropScan had the highest errors. The instrument comparison was undertaken before results for many of the most important grain characteristics such as AME for broilers and DE for pigs were available for NIR development and the accuracy of individual instruments may differ for these characteristics.

It should also be noted that this trial was conducted under laboratory conditions when the samples were scanned on each instrument in turn side-by-side (in two batches). The same results could not necessarily be expected if the evaluation using the same samples was repeated using different instruments of the same type at different locations, at different times and under different conditions.

The best way to transfer calibrations from one instrument to another is using some form of standardisation, or spectral matching. In this case, exactly the same calibration equation can be used across instruments. However, this is not normally possible when dealing with instruments of different optical configuration from different manufacturers and where different software packages are employed. In many cases, it would be necessary to scan the same set of samples on each instrument, derive separate calibrations, and apply slope and bias corrections where needed using a separate independent sample set. This is far from ideal, but the only option available in some circumstances.

In conclusion, these results suggest that the NIR calibrations can be successfully applied to the instruments more commonly used in the grain trading and livestock manufacturing industries with little meaningful loss in accuracy for most grain characteristics.

Distribution of NIR calibrations across the grains and livestock industries and to plant breeders

Although several licences have been given by GRDC for use of the PGLP developed NIR calibrations for plant breeding purposes, successful use of the calibrations across the feed grain value chain will come only if there is a simple and permanent method for maintaining the calibrations and making them readily available to any enterprise operating within this chain. Approximately three years have been spent undertaking case studies and identifying ways to make the NIR calibrations available across the feed grain value chain. The recommendations are covered in the case study report relating to Component 6: Technology transfer and commercialisation. An agreement has been signed with the Pork CRC to make the calibrations available for commercial use across the whole feed grain value chain and to form the basis for the trading of grains for livestock within Australia. A copy of the business plan is attached to this report.

Industry opportunity: There is an enormous opportunity to improve the basis for trading grains for livestock in Australia based on outcomes from PGLP. These opportunities are outlined in the NIR commercialisation business plan and should be encouraged by all PGLP participants to have them widely adopted.

Rapid methods for predicting the response in nutritional value of individual grains to various mechanical, physical and enzymic processing techniques

Experiments conducted within PGLP examining the responses to processing have been already described in this report. Considerable effort was put into developing methods for improving the effectiveness of processing of sorghum for cattle, but less effort was given to evaluating processing techniques for pigs and poultry. A summary of the status of PGLP activities for determining the effectiveness of processing follows.

Rapid methods for assessing the effectiveness of grain processing for ruminants

Four methods, already described, were developed within PGLP for assessing the effectiveness of processing cereal grains for ruminants.

a) **An *in vitro* assay of rumen fermentation**. This assay was developed at the University of New England for measuring the rate of starch digestion, total acid and lactic acid production from unprocessed or processed grains. The assay was shown to be highly effective for measuring the effectiveness of processing sorghum or other cereal grains for cattle. The assay took approximately 2 days and was used by several feedlot operations to assess the effectiveness of their processing systems. Limitations to the assay were that it was laboratory based, required ongoing funding to maintain the staff and took several days for a result.

   A proposal was made in early 2004 to obtain from commercial feedlots several hundred samples of sorghum, wheat and barley that had been steam-flaked to different degrees of effectiveness, measure starch disappearance and acid production with the *in vitro* assay and develop NIR calibrations for predicting rapidly the effectiveness of processing. Matt George, a nutrition consultant to the feedlot industry, agreed to collect the processed grains for the assay. However, MLA decided not to continue funding PGLP activities and the proposal did not eventuate. The University of New England laboratory ceased to perform the *in vitro* assay and the staff are no longer at the university.

   Industry opportunity: The effectiveness of steam-flaking varies widely in commercial feedlots, with considerable impact on the efficiency of feed use. The opportunity still exists to complete the original proposal and develop NIR calibrations for the rapid, on-site prediction of the effectiveness grain processing, particularly steam-flaking. However, the laboratory assay would need to be reinstated.

b) **The AusBeef model for assessing the effect on cattle performance of grain processing effectiveness.** The AusBeef model which is based on representing the mechanisms determining rumen function and nutrient utilisation by cattle was developed with the capacity to evaluate the effectiveness of grain processing. The model was used to predict the outcomes of the sorghum processing experiment described earlier in the report. The model predicted the results with high accuracy (see Barry Nagorcka's Final Report) showing the growth rates of young cattle was greater when fed dry-rolled sorghum than steam-flaked or extruded grain, but the efficiency of feed use would be lower. The model also predicted that growth rate would be higher for heavier cattle during the fattening phase of growth when fed the heat-processed compared to the dry rolled sorghum.

   Results from Simon Bird's *in vitro* assay for total acid production were an important input for the model and were essential for the accuracy of the predictions. The proposed development of NIR calibrations for predicting the effectiveness of steam-flaking of grains under commercial conditions would greatly enhance the application of the model for determining the consequences on feedlot productivity and profitability.

c) **NIR calibration for predicting faecal starch content.** A highly robust NIR calibration has been developed for predicting the starch content of cattle faeces. This calibration is an excellent and rapid method for assessing the effectiveness of processing of cereal grains fed to feedlot or dairy cattle. The calibration needs to be made available to the feedlot industry and large dairies for rapid assessment of the effectiveness of their grain processing units. A protocol needs to be developed for use and interpretation of the calibration by industry.

d) **NIR calibration for predicting grain Acidosis Index.** A moderately robust NIR calibration has been developed for predicting the relative capacity of a grain to produce lactic acidosis in ruminants. This calibration is highly relevant to grain processing and feeding strategies adopted by managers of intensive ruminant industries. Grains with relatively high capacity to cause acidosis will be processed using methods and feeding strategies that reduce the rate of starch fermentation in the rumen. The accuracy of the calibration for predicting changes in rumen pH is currently being evaluated in a case study conducted by Bovine Research Australia. Results from this work will be used to identify the Acidosis Index value associate with the chances of causing different degrees of lactic acidosis. A protocol can then be developed for use and interpretation of the calibration by the intensive ruminant industries. The calibration is likely also to be of value to the horse industry in the management of laminitis.

Rapid methods for assessing the effectiveness of grain processing for pigs

There were insufficient experiments conducted within PGLP investigating the effects of processing on energy availability for pigs to develop rapid methods for predicting the effectiveness of processing procedures. The highly variable between grain responses in energy digestion observed for rolled grain, ground grain extrusion or whole grain extrusion, indicate that interactions between heat, moisture and pressure with chemical and physical characteristics of the starch, protein matrix and endosperm cell wall constituents in grains need to be understood further before any rapid methods for predicting the effectiveness of grain processing for pigs can be achieved.

The importance of understanding these interactions has been recognised through the results obtained within PGLP which has shown substantial increases in the availability of energy (0.5-1.5 MJ/kg) could be derived for pigs if more energy were digested in the small intestines. The mechanisms causing lower than possible energy digestion in the small intestines of pigs differ for common cereal grains with relatively thick cell walls (wheat, barley and titicale) and for sorghum where the digestion and integrity of the protein matrix surrounding the starch granules appears to be important.

Industry opportunity: The pig industry has recognised the opportunity for using processing methods to improve the digestion of cereal grains in the small intestines and increasing total available energy intake for pigs. A major project in the new Pork CRC will study the interactions between processing techniques and grain characteristics on the digestion of starch and other grain components along the digestive tract of pigs with the aim of modifying existing processing methods or developing new approaches to increase energy availability from cereal grains. Different approaches will be used for grains with thick cell walls and for sorghum. If the project is successful, NIR calibrations will be developed to predict the effectiveness of different commercial grain processing methods for pigs.

Rapid methods for assessing the effectiveness of grain processing for poultry

There were insufficient experiments conducted within PGLP investigating the effects of processing on energy availability and intake for broilers and layers to develop rapid methods for predicting the effectiveness of processing procedures. The highly variable between grain responses in energy availability and bird production observed for rolled grain, ground grain extrusion or whole grain extrusion, indicate similar complex interactions as was found in pigs.

Research within PGLP and other sources indicates that the most important factor limiting energy availability in poultry is the formation of highly viscous digesta through the presence of long-chain cell wall arabinoxylans and glucans which limit the access of digestive enzymes to feed components. The effect of these cell wall substances is greater for broilers than layers because of the less mature digestive system and faster rate of passage of digesta. Addition of xylanase and glucanase enzymes to diets containing grain with significant cell wall structures (wheat, triticale, barley) is now a routine practice within the broiler industry. Although the addition of enzymes reduces the variation in AME content between grains, there is still variation in the response, which may be related to both characteristics of cell wall components and the amount and physical nature of fibre and lipid present in the diet. Furthermore, the addition of enzymes to diets does not reduce greatly the variation in energy intake which largely drives broiler growth rate.

Preliminary regression equations predicting the magnitude of the response in AME and AME intake to the application of enzymes for broilers were developed from chemical characteristics of the grains. These equations demonstrate the possibility of using characteristics such as soluble arabinoxylans, ß-glucans, ADF and lipid content of grains for predicting the response in energy supply to broilers from treating an individual grain. However, there were insufficient grains examined to produce equations with sufficient accuracy to accounted for more than 50% of the observed variation in response.

Industry opportunities: There are opportunities for i) predicting the effectiveness of the enzyme response in AME for individual grains or diets and ii) for determining how to reduce the variation in feed intake following addition of enzymes to broiler diets.

The algorithms developed to predict the likely response in AME and AME intake to the addition of xylanase and glucanase enzymes for any cereal grain sample show promise but are not of sufficient accuracy to promote wide use by the industry. The relatively small number of grains examined both with and without enzymes in PGLP means that additional experiments are required to obtain sufficient information for a robust algorithm to be developed. The research conducted by Bob Hughes at SARDI, Roseworthy, was extensively examined to determine whether results from the large number of experiments involving enzymes could be used in development of algorithms for predicting the likely response of a grain to enzymes. Unfortunately, there were insufficient grains that had been offered with and without enzymes to broilers to be able to develop any sensible relationship. NIR calibrations developed within PGLP could be used determine the chemical characteristics of grains needed as inputs to the algorithm.

A separate research program would be needed to identify the reasons for high variability in feed intake of broilers following addition of enzymes to their diets.

Measurement of the nutritional value of sprouted grains (and other weather damaged grains)

Considerable research was conducted during PGLP investigating the effects of germination, frost damage and high screenings content on the nutritional value of cereal grains for each animal type. Results from these investigations are described in detail in this report. Conclusions about the effects of weather damage on the energy value of grains for animals are summarised below.

Sprouted grain

The energy content of sprouted grains for animals was not decreased and in some circumstances may be increased when compared with non-sprouted grain. The effects of germination were particularly favourable for a barley sample fed to broiler chickens and sorghum fed to cattle. However, the effects of storage on the possible deterioration of sprouted grain or of mycotoxins that may develop needs to be examined. In conclusion, there is no detrimental effect of sprouting *per se* on the energy value of grains for animals. The objectives of PGLP with respect to defining the effects of germination on the energy value of grains for different livestock types were achieved.

Frosted grain

Frost damage reduced the starch content and increased the fibre content of cereal grains. In general, available energy content and available energy intake were reduced in frost affected grains. However, the extent of the depression varied with available energy content and energy intake and also with grain sample and animal type. The observation confirms differential responses to frost in grains across animal types and may indicate that the timing of frost damage is important.

'Pinched' and high screenings grain

Grain samples with a high proportion of screenings result in a small negative effect on the available energy content of cereal grains for ruminants. Similarly, for pigs and poultry, small grain size tends to reduce the available energy content of grains within wheat, barley and triticale, but not within sorghum. However, grain size had no effect on total available energy intake of any animal type and therefore should have no negative effect on animal productivity. The lower available energy content of small grains would mean that efficiency of feed use would be reduced in animals consuming smaller grains despite rates of production not being less than in animals fed larger grains.

Test weight of grain

There was only one significant (positive) relationship between test weight and total available energy intake for the all grain and animal types examined and this relationship was across grain species. The lack of significant within grain relationships suggests that productive energy intake and therefore animal performance is not influenced by the test weight of cereal grains. The information presented in this report suggests that test weight is not a good indicator of the potential energy value of a cereal grain for animals and that accurate NIR calibrations for predicting the available energy content and total available energy intake for each animal type would be of greater benefit for determining the likely productivity obtained from individual batches of grains.

Industry opportunity: There are two opportunities for industry in relation to weather damaged and small grains. First, there is an opportunity for the members of the feed grain value chain to replace its current use of test weight as an indicator of the energy value of cereal grains with NIR calibrations predicting the available energy content and available energy intake index for specific animal types. Second, rain affected and frosted grains were frequently outliers in the NIR calibrations developed because of insufficient numbers being included in the calibration development. There is an opportunity for further investment in animal experiments with weather damaged grains to enhance the predictive accuracy for these grains in updated NIR calibrations.

Selection criteria and breeding objectives for plant breeders aimed at improving the nutritional value of grains for specific forms of livestock production

Development of selection criteria

Several investigations within PGLP showed there were strong genotype (G), environmental (E) and GxE interactions for many of the grain species and grain characteristics studied. For example, the *in sacco* DM digestibility of whole oats, *in vitro* digestibility of oat hulls and lignin content of oat hulls had highly significant G, E and GxE interactions (Final Report by Alan Kaiser). High digestibility oats come primarily from genotypes developed at Wagga Wagga and in Tasmania and not from either South Australia or Western Australia. Similarly, differential G and E effects were observed for NIR predicted sheep dry matter digestibility and pig faecal DE for wheat, barley and triticale cultivars grown at several locations (O'Brien *et al*. 2000). More recently, Glen Fox and his colleagues from the Queensland Department of Primary Industry and Fisheries have recently used the PGLP NIR calibrations to estimate the heritability of several important barley grain characteristics from 2002 experiments across 24 genotypes, six locations with 3 replicates. The heritability values across cattle ME, pig DE, broiler AME and broiler AME index were extremely high ranging from 0.77 to 0.97.

The information presented above suggests that there is a significant opportunity to develop selection criteria for breeding cereal grains that have superior nutritional value for livestock. Results from PGLP show that characteristics determining the energy value of grains and therefore selection criteria for breeding grains most suitable for ruminants differ from those most suitable for pigs and poultry.

The ideal cereal grain for ruminants should allow:

- complete digestion of starch by the end of the small intestines,
- a high proportion of starch digested in the small intestine relative to the rumen,
- a slow rate of starch digestion in the rumen to reduce the risk of acidosis,
- high digestion of non-starch components across the whole digestive tract

The ideal cereal grain for monogastric animals should allow:

- complete digestion of starch by the end of the small intestines,
- a high proportion of starch digestion occurring in the upper section of the small intestines,
- thin and fragile endosperm cell walls with low amounts of non-starch polysaccharides and having a short chain-length

Lipid contents of approximately 5% and rich in unsaturated fatty acids would be beneficial to both ruminants and non-ruminants provided the fatty acids are protected from oxidation.

The above specifications indicate that the endosperm cell wall attributes differ markedly for grains suitable for ruminants compared with non-ruminants and that separate plant breeding programs and selection criteria are required for different grain species and animal types. A summary of specific selection criteria is given below for different gain and animal categories.

Desired grain characteristics for wheat, barley and triticale for ruminants are:

- Thick, intact endosperm cell walls
- High aribinoxylose content
- High whole grain viscosity
- Low acidosis index
- Hard grain to reduce rate of water penetration
- Low fibre and hull content

Desired characteristics for oat grain for ruminants are:

- High *in sacco* digestibility
- Low hull content

Desired characteristics for sorghum for cattle:

- Increased digestibility of kafirin proteins through selection for low S:N ratio
- Protein matrix with non-continuous encapsulation of starch granules
- Waxy endosperm

Desired characteristics for wheat, barley and triticale for pigs and poultry:

- Thin, fragile endosperm cell walls
- Low arabinoxylan and ß-glucan content
- Low whole grain viscosity for poultry
- High starch & low fibre content
- Lipid content of > 5%

Desirable characteristics for sorghum for pigs and poultry:

- Increased digestibility of kafirin proteins through selection for low S:N ratio
- Protein matrix with non-continuous encapsulation of starch granules

Although the selection criteria outlined above were developed for cereal grains, they apply in principle to pulses and there is an opportunity to use the expertise gained within PGLP to develop with pulse breeder, plant selection programs that would make pulse seeds more valuable to livestock.

NIR calibrations have been developed for many of the grain characteristics listed above for use by plant breeders as well as direct predictions of the available energy content and available energy intake indices. An attempt was made through a contract with CSIRO to develop a light microscopy-image analysis system for quantifying endosperm cell wall thickness, cell wall content and cell size. Although the system was shown to be feasible and some quantitative values were obtained, CSIRO showed insufficient interest to complete the project and refine the software to a level where it could be transferred to the Program. Details of this image analysis work are given in the Final Report for project UNE 58.

Collaboration with plant breeders

There was close collaboration between PGLP and several plant breeding groups across Australia including Glenn Roberts from the Temora and Pamela Zwer from the South Australian oat breeding programs, Bob Henzell and David Jordan from the QDPI&F sorghum breeding program, David Poulsen, Andy Inkerman and Glen Fox from the QDPI&F northern barley breeding program, Andy Barr and Amanda Box from the SARDI barley breeding program and Robin Jessop from the University of New England triticale breeding program. A large number of grain samples from these programs were evaluated using *in vitro* assays, chemical analyses, NIR predictions and in a few cases animal feeding trials. Lindsay O'Brien a cereal breeder from University of Sydney Plant Breeding Institute at Narrabri was an important member of the PGLP research team for interacting with cereal breeding groups. Many of the results from these evaluations of plant breeder lines have not been included in any of the specific Final Reports, but are available from the Program Co-ordinator.

Industry opportunities: A major deliverable from PGLP is the list of grain characteristics that could be included as selection criteria for different grain species and types of animal production. Collaboration should continue with plant breeding groups around Australia. There are enormous opportunities to improve the nutritional value of oat grain cultivars by selecting for grains with NIR predicted high *in sacco* digestibility and low hull content. Similarly large improvements in the growth of cattle, pigs and poultry should result from the selection of sorghum grain lines with either more digestible or discontinuous γ-kafirin proteins surrounding the starch granules. In addition, the energy value of wheat, barley and triticale can be improved for pigs and poultry by reducing the negative impact of the endosperm cell walls through applying the selection criteria outlined above. The Pork CRC has a sub-program with barley, triticale and sorghum breeders with objectives to apply outcomes from PGLP and gain the additional 1-2 MJ/kg known to be available for pigs through genetic modification of grain structure.

A ruminant model for predicting the growth and body composition of feedlot cattle offered specific grains with specific processing techniques

A fully mechanistic computer simulation model of rumen function, voluntary feed intake and nutrient digestion and utilisation for growing cattle has been developed by Barry Nagorcka at CSIRO. The animal model was incorporated into a decision support software system called AusBeef for the cattle feedlot industry. A full description of the model and its value to industry are given in the Final Report from Barry Nagorcka. The AusBeef system is the most mechanistic and comprehensive of any such software in the world for the feedlot industry. It has a huge potential to significantly alter and refine management practices and improve industry profitability and competitiveness. A major advantage of the model is its ability to predict the effect of different grain samples and processing systems on animal performance and feedlot profitability.

The model has been used already for developing concepts and research strategies associated with grain use and processing for both the feedlot and dairy industries and helped develop practical and R&D strategies for these industries. For example, the model was used to assess the ability of different feeding strategies to reduce the impact of periods of extremely hot weather on heat production and susceptibility to heat stress for feedlot cattle. It was used also to assess the relative impact on productivity of changes in rumen function and of substitution in dairy cows grazing pasture of different quality when offered varying quantities of grain. Details of these applications are given in reports by Barry Nagorcka to MLA and Dairy Australia.

Although MLA ceased to fund PGLP from July 2004, Barry Nagorcka and his team at CSIRO continued to improve the model and interface for use in feedlots. New features added included prediction of rumen pH from underlying mechanisms. The model was evaluated for feedlot enterprises by Matt George who revealed several important limitations including its inability to deal with situations when mixtures of grains and/or forages were offered to cattle and lack of explicit representation of the effects of climate. Although, introducing the ability for the model to deal with grain or forage mixtures is simple conceptually, a reasonable time would be required to duplicate sections of the code. Barry did not complete this work before his untimely death in December 2005.

Industry opportunities: The AusBeef model has many features that are of great value for developing R&D strategies for the feedlot and dairy industries and for evaluating alternative cattle management strategies. With Barry being no longer present, Dairy Australia are investigating the possibility of employing and international ruminant modelling expert to work with CSIRO to enhance the model and make it suitable for predicting the effects of feeding and climate interactions on milk yield and composition.

A process for improving the pelletability and nutritional value of compound feeds based on cereal grains

Pellet quality is a major issue in the livestock feed manufacturing industry and pellet durability is a key component of pellet quality. Dust caused by the action of pellets rubbing together during transport and handling is the most common complaint for feed manufacturers. Poor quality pellets are most often associated with sorghum but pellet quality is also known to vary with wheat and barley. Identifying grain characteristics that influence pellet quality was an important outcome for PGLP because it may enable the livestock feed manufacturing industry to be more selective in the grains they use or to alter processing conditions to overcome anticipated problems.

Near complete gelatinisation of starch during the pelleting process is thought to be essential in the production of high durability pellets. Starch gelatinisation occurs during the steam conditioning phase of the process and the grain meal needs to be heated to a minimum temperature of 85˚C to achieve satisfactory gelatinisation. Using steam to heat the grain meal to 85˚C results in the addition of approximately 5% water, but if the moisture content of the meal exceeds 18%, the pellet press will choke. Problems with pelleting sorghum arise because the moisture content of the raw grain is high (average 12.5%) and the gelatinization temperature for sorghum starch is the highest of all the cereal grains examined (Table 49). The quality of pellets made from waxy isolines of sorghum was shown to be superior to those made from normal sorghum because of the lower gelatinisation temperature of the starch (Table 41). Pellets made from the waxy isoline were substantially more durable and harder than pellets made from the non-waxy isoline and a sample of the cultivar Buster. However, more amps were needed in the pelleting process and the press had a higher tendency to block.

Table 49. Effect of waxy isoline of sorghum on pellet quality.

Measurement	Sorghum variety Buster (7712)	 Waxy-isoline (7710)	 Non-waxy isoline (7711)
Pellet durability (%)	87	96	76
Particle size (μm)	651	388	454
Pellet hardness (kg)	13	21	15
Comments		Required more Amps a tended to choke pel press	

A large number of wheat, sorghum, barley and triticale grains were collected to determine variability in pellet quality between and within grain type. Grains were selected on the basis of NIR predicted dry matter digestibility in sheep and *in sacco* dry matter disappearance. Grains were pelleted using a small pellet press supplied by Ridley and pellet durability, hardness, production rate and amp requirements measured at the Ridley plant in Pakenham.

Pellet durability was found to be highly variable between and within grain type and varied from 47 to 99% (Figure 88), hardness score from 5 to 23, production rate from 30 to 60 kg/hr and press amps from 10 to 15. The quality of pellets from triticale was consistently high, but it varied widely for the other grains. Surprisingly, wheat, which is often mixed with other grains to improve pellet quality, had the greatest range of pellet durability values and also had the lowest values of any grain. Pelleted grains with a durability value in excess of 90% are regarded as satisfactory by the feed manufacturing industry. There were a significant number of sorghum, barley and wheat samples with pellet durability values below 90%, indicating that each of these grain samples would be associated with quality problems. In contrast, most of the triticale samples tested had very high pellet durability values and may be a better choice than wheat when selecting a grain to mix with other grains to improve pellet quality.

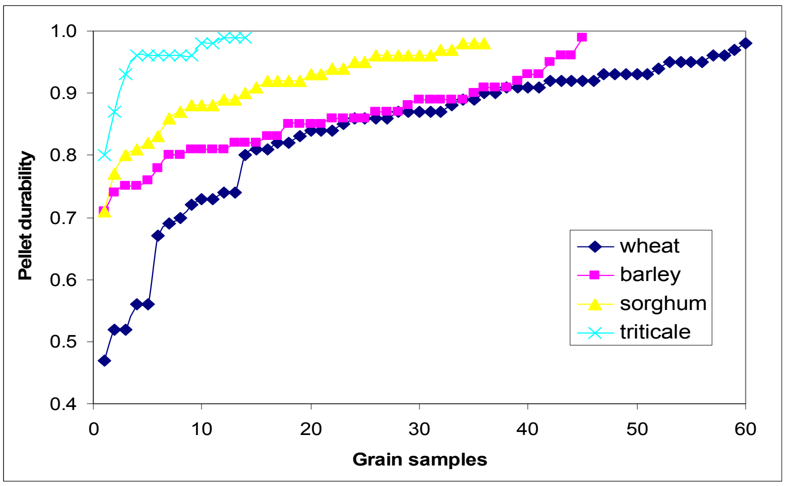


Figure 88. Durability of pellets (expressed as a fraction) for individual grain samples.

Although these results were useful for showing the likely range in pellet quality between grain species and batches within species, there were insufficient replicates in the experiments to confidently remove random experimental effects. Consequently, a precisely designed experiment is in progress at Ridley to obtain statistically corrected pellet quality values. This experiment was planned to be completed in the first quarter of 2006, but the results are not available at 30 June 2006. All grains and pellets are being scanned with NIR. The final aim of the research is to produce a "pelletability" index and NIR calibration where the likely durability, hardness, production rate of pellets and amps needed for the process can be predicted for any sample of grain. Such an index would be invaluable for setting correctly conditions of the pelleting machine and for deciding which grains to blend to improve pellet quality.

Industry opportunities: Intellectual Property relating to the pellet quality index will remain with Ridly Agriproducts for a time specified in the PGLP All Parties Agreement. However, it is probable that the pellet quality index for a grain would be highly correlated with the efficiency of steam-flaking. This index could therefore be extremely useful for the feedlot industry to evaluate the likely effectiveness of steam-flaking for individual batches of sorghum or other grains. The IP agreement with Ridley does not limit use of the index within the Australian feedlot industry.

An extremely comprehensive database on the chemical, physical and morphological characteristics of cereal grains

An analytical data-base has been developed within PGLP that is unique in its size and in the diversity of grains included. It also has the advantage of analytical consistency as most grains were analysed in the same laboratories using the same methods and equipment. As such it is a resource with value to all of grain science and needs to be preserved for the Australian Grains industry and in an appropriate form published in the World Literature so that others will know of its existence and can use it in their work.

Table 50. Chemical and physical measurements made on all grains fed to animals within the Program.

Proximates	**Amino acids**	**Free sugars**
Crude protein[A]	Aspartic acid	Rhamnose
Crude fat[A]	Threonine	Fucose
Crude fibre	Serine	Ribose
ADF[A]	Glutamic acid	Arabinose
N-in-ADF	Proline	Xylose
NDF[A]	Glycine	Mannose
N-in-NDF	Alanine	Galactose
Lignin[A]	Valine	Glucose
Ash[A]	Methionine	Total free sugars
Water[A]	Isoleucine	**Fatty acids**
Anti-nutritional factors	Leucine	Palmitic C16.0
Oligosaccharides	Tyrosine	Palmitoleic C16.1 cis-9

Phytic acid	Phenylalanine	Heptadeconic C17.1 cis-10
Condensed tannins	Lysine	Stearic C18.0
Total tannin	Histidine	Elaidic C18.1 trans-9
Lectins	Arginine	Oleic C18.1 cis-9
Single kernel analysis	Cysteine	Vaccenic C18.1 cis-11
Weight[A]	Tryptophan	Linoleic C18.2 cis-9,12
Diameter[A]	**Insoluble NSP**	Noradeconic C19.0
Hardness[A]	Rhamnose	Linolenic C18.3 cis-9,12,15
Moisture[A]	Fucose	Arachidic C20.0
Physical analyses	Ribose	Eicosenoic C20.1 cis-11
Specific weight (g/Hl) [A]	Arabinose	Eicosadienoic C20.2 cis-11,14
100 g weight[A]	Xylose	Erucic C21.1 cis-13
Hydration capacity[A]	Mannose	Behenic C22.0
Seed colour: L*, a*, b*	Galactose	Tricosanoic C23.0
Acid viscosity [AB]	Glucose	Docostetraenoic C24.4 cis-7,10,13,16
RVA [A]	Total insoluble NSP	Lignoceric C24.0
Enzyme analyses	Arabinoxylans	Pentacosandic C25.0
α-amylase	β-glucans	Sterols
β-amylase	Cellulose	
Starch	**Insoluble NSP**	
Amylose	Rhamnose	
Amylopectin	Fucose	
Total Starch [AB]	Ribose	
Enzyme digestible starch [AB]	Arabinose	
Resistant starch [AB]	Xylose	
Energy	Mannose	
Gross energy	Galactose	
	Glucose	
	Total insoluble NSP	
	Arabinoxylans	
	β-glucans	

[A] Analyses conducted on grains used in pelleting trial. [B] Analyses conducted on pellets

A comprehensive range of chemical and physical characteristics was determined for all grains fed to animals. The grains analysed included 66 wheat, 64 barley, 37 sorghum, 20 oat, 16 triticale, 9 legumes, 6 rice samples and 1 maize sample. The individual analyses were selected on the basis that they may have an influence on nutritional value of cereal grains for any of the forms of livestock production evaluated within PGLP. A full list of the chemical and physical assays undertaken is shown in Table 50. A reduced number of analyses were conducted on at least 80 grains used in the pelleting trial, on the pellets and on all processed material either fed to animals. These analyses for processed material also are identified in Table 50.

In addition, the concentration of a range of phenolic acids, in either ester or ether form, has been determined for oat grain samples varying widely in *in vitro* hull digestibility but having similar lignin content. Starch granule size and surface area were determined on 46 grains (24 wheat, 15 barley, 6 triticale) fed across ruminants, pigs, broilers and layers, The grains were selected, where possible, for a range in A:B granule ratio.

Light and electron microscopy has been used to identify physical characteristics of endosperm cells, cell wall structure, protein-bodies and protein encapsulation of starch granules. NIR spectra have been obtained on whole and ground samples of every grain collected within the Program. The NIR measurements have been used to predict DM digestibility in sheep and DE in pigs for the majority of grains collected. The scans collected could be used to predict any of the grain characteristics for which there are suitable NIR calibrations for all the 3300 grains collected within the Program. All these data are stored in a large database.

Associated with the chemical/physical database are the results from all animal experiments. The combined database provides a unique opportunity for further examine reasons for differences between grains in their capacity for animal production.

The database is stored currently at the University of Sydney, Plant Breeding Institute, Narrabri. Along with the database, 2 kg samples of all grains collected have been stored at -20˚C for future analysis or testing of hypotheses.

Industry opportunities: i) Although a significant effort has gone into exploring associations between grain characteristics and animal digestion, intake and performance variables, a great deal more 'data mining' should be undertaken to explore further these associations and hypotheses developed. ii) The chemical and physical database should be published in detail for use by others within the grains and animal industries.

Recommendations to grain growers on specific cultivars to be grown for each form of animal production

Several experiments have been conducted to determine the relative effect of genotype and environment on nutritional characteristics of different grain species. In one experiment, different cultivars of wheat and barley were sown at three locations over two years and the nutritional value of the grain assessed by NIR prediction of DE for pigs and by *in vitro* enzymic digestion and fermentation of starch (O'Brien *et al.* 2000). The greatest variation in predicted DE for pigs in wheat was due to year, with the effects of both location and genotype not being significant. However, with barley, the greatest variation was due to location, but the effects of genotype and year were highly significant. Similarly, *in vitro* starch digestion was significantly affected by genotype for barley, but not for wheat. These results suggest that differences in nutritional value between barley cultivars are significant and that specific cultivars with higher value for livestock can be recommended for growing.

The NIR scans from all barley cultivar replicated grown by the QDPI&F barley breeding program in 2002 & 2003 have been obtained using a Foss 6500 instrument and the following nutritional characteristics predicted using PGLP calibrations; ME cattle, DE pigs, AME broilers, AME intake index broilers, DE intake index pigs, ADF, NDF, crude fibre, starch, total soluble NSP, insoluble arabinoxylans, soluble arabinoxylans, B-glucans and specific weight. The information is currently being analysed by QDPI&F to determine the range and heritability of the characteristics. Cultivars and lines that are of greater value for one animal type or another will be identified. The resulting animal nutritional value information will be used in the breeding program, but also in combination with agronomic, yield and disease resistance information to identify cultivars that may be most suited to different locations for maximising production of available energy for livestock. An economic analysis should be undertaken to identify the relative impact of yield and available energy contents of the grains to help strengthen these recommendations. These analyses will be undertaken in the next phase of PGLP.

Thorough analyses of the GxE effects on *in sacco* DM digestibility of whole oat grains, *in vitro* digestion and lignin content of oat hulls have been conducted for a wide range of oat grain samples (see Alan Kaiser Final Report). These analyses have been used to make preliminary recommendations about the best oat grains to grow for livestock. For example, cultivars such as Cooba and TO59 had consistently high digestibility, whereas Swan and Yarran had medium digestibility and Echidna and Mortlock low digestibility. However, further analysis of the plant breeder's information using NIR predicted *in sacco* DM digestibility information in conjunction with yield and agronomic information would strengthen these recommendations.

Samples of commercially available and promising new sorghum cultivars from sorghum breeder's collections have been grown at two sites over two years in Queensland by Bob Henzell. In 2002-03, some cultivars were grown with and without irrigation. The quality of pellets produced from these samples is being examined by Ridley Agriproducts. Previously, Simon Bird found that the *in vitro* fermentation of starch from 39 sorghum cultivars and breeders lines ranged from 46-73%, enzyme digestion of starch from 3-37% and digestibility of protein from 22-42%. If these results for the nutritional value of sorghum lines were combined with yield, disease resistance information and heritability information, recommendations for sowing grains with higher value for animals should be possible.

Industry opportunities: The ability to assess rapidly using NIR calibrations the energy value of grains and hopefully soon pellet quality allows for the first time feeding value, yield and agronomic information to be combined to recommend for planting in specific regions of Australia cultivars that should give the greatest returns when used as animal feed. Information is already available on the likely dollar value of increases in the available energy content and available energy intake for each grain and livestock type. By combining this information with yield and underlying grain price, the returns to grain growers from one cultivar over another should be readily calculated. This opportunity will be achieved through continuing collaboration between plant breeders and the PGLP team.

Potential increase in marketing opportunities, including export, for feed gains based on specification and rapid measurement

Numerous presentation and discussions have been made by Program members at National and State meetings for groups associated with the growth, sale and use of cereal grains. A series of specific meetings were held in 2003 with members of organisations along the feed grain value chain including growers, grain handlers, grain traders, plant breeders, livestock feed manufacturers and animal industry end-users. Variation in the nutritional value of cereal grains, the likely cost of this variation and the ability to measure nutritional value of individual grain samples using whole-grain NIR was explained. The potential for using this information to target specific markets was recognised by several of the companies, which are major exporters of feed grains.

The example of a Western Australian hay company was used to illustrate the likely impact of rapid measurement of nutritional value on increasing export demand for Australian feed grains. The WA company pioneered the use of NIR measurement of oaten hay quality to create a new export market in Japan. The specifications and measurement system introduced by the company are now the benchmark for buying hay in Australia and for hay trading in export markets.

Several of the major feed-grain export companies are keen to trial the NIR specification of grain quality in their businesses. The following case studies have been established or are being pursued to determine the likely value of the NIR calibrations and other information derived from PGLP.

- ***ABB Grain*** ABB have tested using the PGLP NIR calibrations 247 individual barley samples from season 04/05, 726 barley samples from season 05/06 and 655 wheat samples from season 05/06 for ruminant ME, acidosis index, broiler AME, broiler AME intake index, pig DE and pig ileal/faecal DE ratio. The study is to determine the range in values from commercial suppliers and the consistency of values between NIR instruments and across time. A summary of the results has been compiled. Statistical analysis is still to be undertaken.

- ***Ridley Agriproducts*** A series of desktop studies is being undertaken using the range in values obtained in PGLP to determine the significance for a large commercial stockfeed manufacturer. Analyses were undertaken for broilers, pigs and ruminants, particularly dairy cows. The main outcomes are covered in the case study report and suggest that the calibrations can be of substantial value to the livestock feed manufacturing industry.

- ***Inghams*** An experiment has been conducted to demonstrate that wheat selected by NIR with low AME and AME intake gives a lower broiler performance and feed efficiency than wheat selected for high AME and AME intake. Two wheat samples have been selected and each will be offered to broilers with and without enzymes. The experiment has demonstrated a significant 6% increase in growth rate and a reduction in 2 days needed to reach market weight for those birds given the high AME-AME intake wheat. These gains translate to an increase in profit of approximately $4m/yr for a 1 m bird/week operation.

- ***QAF*** An experiment is to commence in April 2006 where 8 wheat samples selected by NIR to have a range in DE and DE intake (including low-low, low-high, medium-low, medium-high, high-low and high-high, with standard QAF wheat) to show that the calibrations can be used to select wheat samples that produce different growth rates and feed efficiencies.

- ***Ian Lean acidosis study*** Twenty grains across wheat, barley triticale, oats and sorghum have been selected with a wide range in NIR predicted acidosis index. The study is to evaluate the accuracy of the NIR calibration in acute challenge experiments with cattle where rumen pH, lactic acid concentration and other measures of rumen function will be made. The project is being funded by Dairy Australia.

Industry opportunities: The ability to measure rapidly the quality of individual grain samples for different livestock species provides an opportunity to supply grains of known quality on a consistent basis to specific export markets and therefore provides a competitive advantage over other grain trading countries without this facility. Continuing interaction between the grain trading companies and PGLP over the next few years will ensure that the NIR predictions are used effectively and information on impact of the nutritional value of grains remains relevant to the feed grain value chain.

Information on grain characteristics affecting their nutritional value for humans and rapid methods for measuring these characteristics

The digestive system of humans is very similar to that of the pig. Considerable information has been obtained on the characteristics of grains affecting digestion in the small intestines or hindgut of pigs. This information is relevant to human nutrition with grains having characteristics that increase digestion in the hindgut of pigs being suitable for a similar purpose in humans. Grain species and cultivars with high concentrations on NSP and resistant starch will be of particular interest to dieticians and specialists in human nutrition.

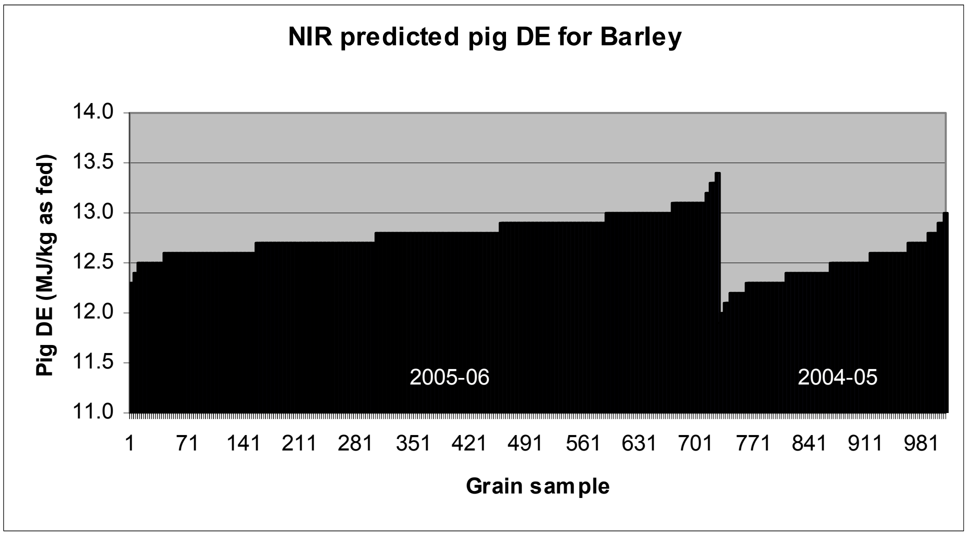
Industry opportunities: Information relevant to human nutrition on all grains analysed within PGLP will be available through the comprehensive, grain composition database. A meeting was held in December 2002 between the GRDC Go Grains group and PGLP members to identify synergies between the projects. The food industry expressed interest in obtaining information on the chemical and physical composition of cereal grains and the factors that influence digestion in the small intestines or large intestines of pigs. The food industry would like additional measurements on grains including vitamins, minerals and antioxidant concentrations. The grains from PGLP stored at -20°C could be used for this purpose. The food industry is also interested in PGLP results on the effect of grain processing on the site of digestion and development of resistant starch. Research following on the PGLP results within the Pork CRC at the University of Queensland will be of particular relevance to the human food and nutrition industries.

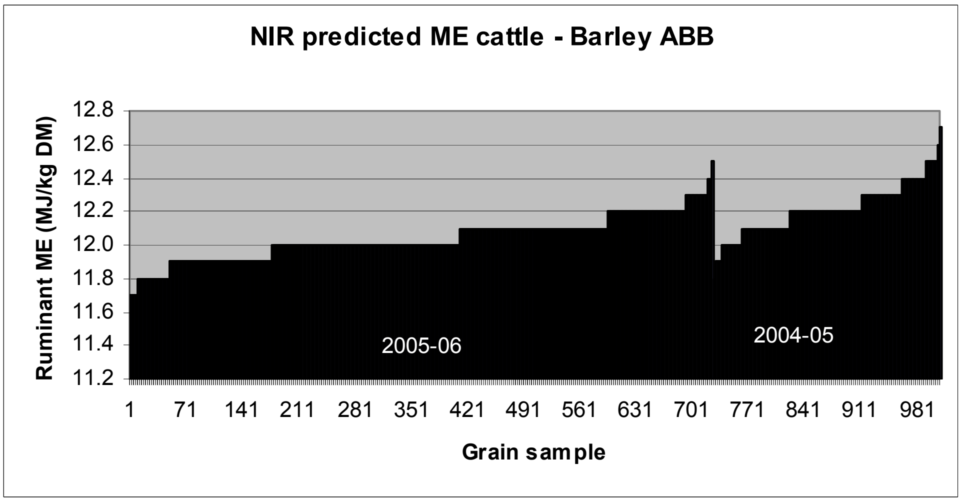
A process for rational basis of trading grains for livestock based on rapid measurement of the factors known to influence nutritional value for each form of animal production

Magnitude of variation between grains in energy supply

Results from PGLP have shown conclusively that 'grains ain't grains'; and it pays to know the difference. There can be a wide variation of up to 3-4 MJ/kg in the available energy content of individual samples from a cereal grain species for all animal types studied, although for other grain species it may be only 1-2 MJ/kg. The total intake of available energy for productive purposes from a grain species varied from 30% to almost 2-fold for different animal types. An additional extremely important finding from the Program was that individual grain samples are best suited for one animal type than another.

The variation observed in NIR predicted pig DE, ruminant ME and acidosis index for over 1000 grains deliveries over two seasons by ABB Grains in South Australia is shown in Figure 89. The graphs confirm that there are some grains that have either high or low energy values with a range of 1.5 MJ/kg for pigs and 1 MJ/kg for ruminants and the acidosis index varying from below 50 to over 90. An important finding was that the 2004-05 year produced grains that had higher energy content and lower acidosis index for ruminants than for 2005-06 grains, whereas the 2004-05 grains were superior on average than the 2005-06 grains for pigs.





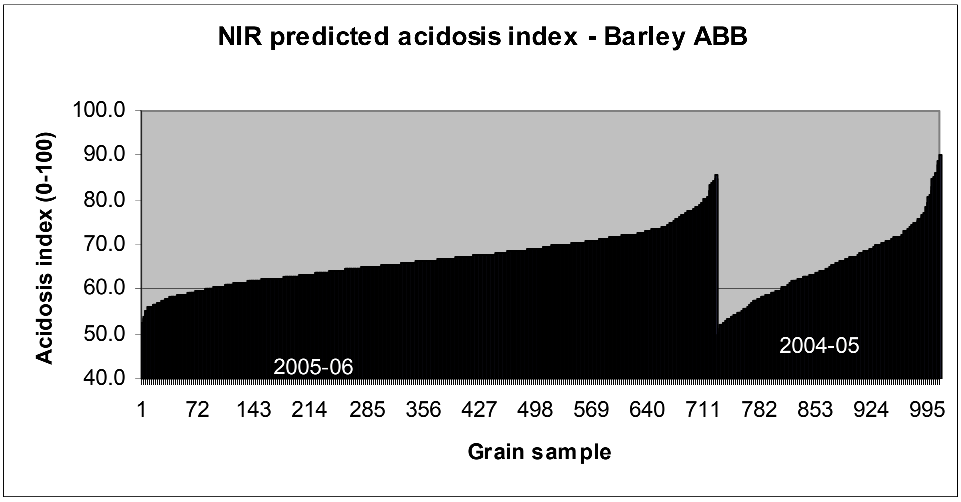


Figure 89. NIR predicted pig DE, ruminant ME and acidosis index for over 1000 samples of barley delivered to ABB Grains in South Australia during 2004-05 and 2005-06.

The case study conducted by Inghams demonstrated also that a wheat sample selected for high AME and AME intake using the NIR calibrations developed in PGLP resulted in broilers reaching market weight 2 days earlier than for a wheat sample selected for low AME and 1.5 days earlier than for the standard wheat sample used by Inghams. These results were for grains to which standard enzymes had been added.

Economic impact of variation between grains

The economic cost of varying the available energy content of a grain by 1 MJ/kg for the major classes of livestock was estimated using a standard least-cost feed formulation approach. Average five-year prices from 1997-2001 were used for ingredients in the analyses with a five-year average price for wheat of $168/t. The predicted impact of a change of 1 MJ/kg on the value of grain and on the total value to the livestock industries are shown in Table 51. The industry consumption figures were taken from ABARE 2002 reports.

Table 51. Economic implications for livestock industries of increasing the available energy content of cereal grains by 1 MJ/kg.

Industry sector	Consumption (mt)	Unit value ($/t)	Industry value ($m)
Pig	1.40	14.30	20.02
Broiler	1.50	26.90	40.35
Layer	0.23	24.07	5.54
Dairy	1.60	7.48	11.97
Feedlot	1.60	14.20	22.66
Total/average	**6.33**	**17.39**	**100.54**

The average value of 1 MJ/kg of energy across the major animal industries using feed grains was estimated to be around $17.50/t. Thus, livestock enterprises can capture $17.50/t of grain for *each* extra MJ of available energy in a grain that can be recognized and incorporated into the diet. If all livestock industries were to identify and use grains with an extra 1 MJ of energy, there would be an annual benefit of $100m to the livestock industries. This indicates the market incentive for grain growers to increase the production of high energy grains.

The case study undertaken by Ridley Agriproducts further investigated the value of changing the available energy content of cereal grains for pigs, broiler, layers and ruminants. The procedure was based on using the *Multimix*® feed formulation software and a wide variety of possible ingredients. The study showed that access to and the relative cost of either high energy raw materials such as tallow and vegetable oils or lower energy raw materials such as millrun, oats hulls, malt combings, pea pollard, rice hulls can greatly change to value of feed grain available energy. There was also a difference in the cost of feed when available energy content was either 1 MJ/kg higher or 1 MJ/kg lower than the control. There tended to be bigger decreases in the price of feed when the energy content of the grain was higher than on the increase in price when energy content of the grain was lower. The larger effect on price that resulted when available energy content of the grain was increased rather than decreased was due to the relative higher price for tallow and vegetable oil that were replaced in the diet than for mill run and other higher fibre components replaced with lower energy grain.

Differences were found for common diets formulated in northern Australia compared with southern Australia, with the effect generally higher in the northern regions where access to ingredients is more limited. The analyses showed that increasing the energy value of cereal grains by 1 MJ/kg resulted in a reduction in the price of the final diet for pigs by approximately $6.50/t in the south and $9.00/t in the north. Similarly an increase in the energy value of 1 MJ/kg was estimated to be worth approximately $9.00/t for layers, $14/t for broilers, $10/t for calves and $3-10/t for lactating dairy cows. These values would all be approximately 30% higher when the effects on the price of grain alone are considered.

Furthermore, when the reduction in costs of feed, labour building use and mortality are considered, Tom Scott estimated that decreasing the time taken for broiler chickens to reach target weight by 1 day would save $0.04/bird. This amount translates into $2m for a 1 million bird/week broiler unit or $40m/year for the Australian broiler industry. The case study at Inghams demonstrated that by using NIR scans of a range of wheat samples and selecting the one with the highest AME and AME intake a saving in 2 days could be achieved. This saving translates into approximately $80m/year for the broiler industry.

There will be various incentives to share this increased return to the livestock industries across the supply chain and important in this process will be a shared knowledge of the energy value of the grain. However, not all the extra value would be captured by the animal and grains industries. Some could be lost through the costs incurred in segregation of grains, the influence of export parity prices, the relative costs of grains used for human consumption and any additional costs in producing the higher energy grain. It was estimated that these additional costs could be around $5/t of grain, reducing the net benefit of an additional 1 MJ/kg of available energy in cereal grain to $12.50/t.

There is also considerable difference between livestock sectors in their potential benefits. The broiler industry is more price sensitive than the dairy industry and an extra 1 MJ/kg in feed grain was worth 3-times more. Similarly, the purchase of grains by the animal industries is more responsive to price than is its production by grain growers. One analysis suggested that the capture of the increase in value/price from increasing the energy value of grain is likely to be around 30% for the grains industry and 70% for the animal industries. This suggests potential net annual gains from increasing available energy by 1 MJ/kg in feed grains of $24m for the grains industry and $56m for livestock industries.

A process for the rational trading of grains for livestock

The following process is suggested for the rational trading of grains for livestock.

- Using a single NIR scan for a sample of cereal grains at the site of collection/delivery predict ruminant ME, acidosis index, pig DE, pig DE intake index, broiler AME, broiler AME intake index, crude protein, NDF, crude fat and starch content.

- Record and make available to grain growers, livestock industries and other relevant people across the value chain the information on the nutritional value of each grain sample.

- Use the scan results to determine the most appropriate use of each individual grain sample. The scan results may be used in combination with other information in spreadsheets or simulation models such as the AUSPIG or AusBeef to assess the impact of feeding the grain on animal performance and enterprise profitability.

- The economic value of each grain parcel can thus be determined for each enterprise and an appropriated price settled between the grower/trader and end user.

The proposed process would mean that grain trading would be based on the value of the grain in terms of animal performance, with grains most suitable for different livestock industries and end uses identified and valued

A series of meetings was held in 2003-04 to discuss the proposal for the rational trading of feed grains with members of organisations along the feed grain value chain including growers, grain handlers, grain traders, livestock feed manufacturers and animal industry end-users. The conclusions from these meetings were in summary:

  - NIR calibrations have potential to significantly improve the description of feed grains for end-users and improve the efficiency of their industries.

  - Some groups are ready to immediately adopt NIR calibrations on a commercial or trial basis to improve management of feed grain quality.

  - In general, the desire by the animal industries for consistent grain of known specification. Many livestock managers believed that it was in their interest to share the added value to their operations with grain growers.

  - More evidence is required on the regional, seasonal and varietal variation in the nutritional value of cereal grains grown in Australia to define the magnitude of differences that exist.

  - Some grain handlers were concerned about the potential costs in segregation of grain types, but would be comfortable to use the NIR predictions to better describe grains for end-users and see this as adding value to their operations.

  - There was concern about using the NIR predictions as a basis for grain pricing at purchase because of the limited number of samples used to derive the calibrations in PGLP. Several traders insisted that the calibrations would need to be continually upgraded to allow for known year to year bias. One trader indicated that 3000 measurements are required before they would be confident to use the NIR predictions for grain payment.

Industry opportunities:

- A significant communication and education program must be initiated to ensure that NIR measurement of grain quality becomes the accepted method of specifying and trading grains for livestock in Australia. One grain trader suggested that the procedure would need to be adopted by 80% of the industry for it to become standard practice.

- PGLP has demonstrated the feasibility of a procedure for using NIR calibrations in the rational trading of grains for livestock that is far superior to the current methods based measurement of test weight and screenings percentage. However, there is a clear need to continually update the NIR calibrations to allow for year to year variation, to clarify predictions for 'outliers' and also to ensure that there are sufficient records for each grain type to ensure accuracy of the within grain predictions. Continuation of animal experiments to determine digestion and intake will be an expensive exercise. Although continuing animal experimentation is optimal, other methods for predicting the feeding value of grain samples should be pursued such as the calculations based on an understanding of the effects of specific grain characteristics. These may be either simple spreadsheet models, as has been developed within PGLP for broiler chickens, or fully mechanistic models such as AusBeef or an ungraded AUSPIG.

Opportunities for further investment

- A major communication and education program must be initiated to ensure that NIR measurement of grain quality becomes the accepted method for specifying and trading grains for livestock in Australia.

- GRDC must establish a viable, long-term strategy to ensure that the NIR calibrations are readily available to all sectors of the feed grain value chain and updated as required.

- Further improvement and validation of NIR calibrations is essential if they are to be used reliably for the trading of grain, formulation of diets in the animal industries and to assist plant breeders. The latter require grain species specific calibrations rather than cereal grain global calibrations as have been established at present. Continual updating of the calibrations will be essential as characteristics of grains change over time as a result of plant breeding programs. The most important calibrations to be improved and updated are:

    - Pig DE, ileal/faecal DE ratio and DE intake index. Current investment by the Pork CRC and assistance from GRDC will allow this to occur over the next 7 years.

    - Broiler AME and AME intake index. Experiments are essential to evaluate the impact of enzymes on the cereal grains (wheat, triticale and sorghum) that have wide differences in NIR predicted values. Co-investment by the broiler industry and GRDC would be needed.

    - Layer AME and AME intake. Current NIR calibrations for layers are poor. It is theoretically possible to calculate values for layers from broiler NIR calibrations. Investment would be required for both development of the theoretical approach and validation through experimentation.

- Work closely with cereal breeders to improve the nutritional value and yields of grains for specific types of livestock. Separate selection criteria need to be established for breeding grains for use by ruminants and pigs or poultry.

    - Strong collaboration is occurring within the Pork CRC and GRDC to develop high yielding barley and triticale cultivars for pigs.

    - Collaboration should continue with the GRDC oat breeding program to select grains that have high digestibility for ruminants (and horses).

    - Collaboration should continue with the sorghum breeding program to evaluate the waxy isolines for cattle, pig and poultry production and to develop lines that have either higher protein digestibility or a protein matrix not fully encapsulating starch granules.

- Understand the reasons for varying effects of different processing methods on the availability of energy in cereal grains for pigs and poultry.

    - A major project within the Pork CRC at the University of Queensland will study the interactions between starch, cell wall and protein matrix chemical and physical characteristics and different processing techniques to identify the reasons for variation in ileal-faecal DE and DE intake observed for individual grains used within PGLP. The research should result in processing techniques that will improve the nutritional value of wheat, barley, triticale and sorghum for pigs. In addition, the research may identify new characteristics to be included in plant breeding programs.

- Refine theoretical models for predicting broiler AME, pig DE and ruminant ME content and intake so they can be used as a means for evaluating outliers obtained when NIR calibrations are used commercially. Some method will be required to determine whether a specific grain sample is true outliers or whether the NIR calibration was inaccurate when the calibrations are to be used for commercial trading of grains for livestock.

- Further analysis of PGLP data and data mining. There are still a large number of analyses that need to be undertaken to gain the most from the current extensive information obtained within PGLP. A meeting was held in December 2005 to identify the outstanding statistical analyses and data exploration still needed. Based on a statistician employed half time on the project the identified work would take a further 3 years.

- Additional chemical analysis on some samples because of presumed inaccuracy in values obtained from laboratories and new analyses required as a result of data mining and Pork CRC projects.

- Ongoing storage of grain samples, collection of grains for Pork CRC for enhancement of NIR calibrations and case studies, analysis of case study results and maintenance of the chemical/physical and animal relational database. Maintenance of the stored grain samples and database is essential for any ongoing research relating to PGLP outcomes.

- Writing of papers and other publications on results from PGLP.

- Modification of the AusBeef model for the dairy industry. Roger Barlow and Dairy Australia are examining ways of progressing the model in the absence of Barry Nagorcka.

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