

Quality in the Feed Grain Market

M.R. Taverner

*Taverner Minds, 38 Froggatt St. Turner ACT 2612 tav-mind@netspeed.com.au
Consultant to GRDC*

FEED GRAINS ARE A GROWING AND SIGNIFICANT MARKET

Livestock industries are a major market for grains on Australia's east coast and a significant market for grain exports from WA and SA. Hafi and Connell (2003) have estimated that 80% of the annual demand for nearly 9 mmt of feed grains (cereals, oilseeds and pulses) is from livestock industries in the eastern states. An analysis of this demand is shown in Figure 1 and suggests that the current usage is shared almost equally between ruminant animals (feedlot cattle and dairy cows) and non-ruminant animals (pigs and poultry). The demand for feed grains is increasing and within 5 years is expected to exceed 10.5 mmt (8.4 mmt cereal grain). During this time it is expected the increase in demand will be greater for ruminants than for non-ruminants and in 2007 there will be more than 5 mmt feed grain used by the feedlot cattle and dairy industries alone. In their ABARE report, Hafi and Connell (2003) estimated that in 2003 our national production of cereal grains that appeared to be for feed markets was 18 mmt (of which nearly 60% was wheat). More than half of this was subsequently exported from WA and SA.

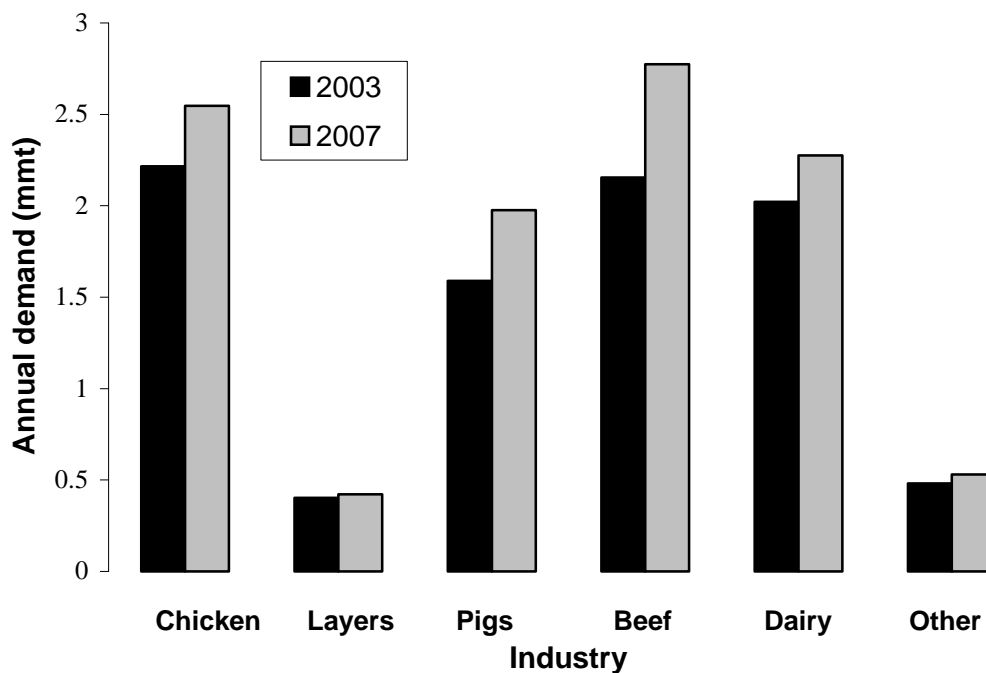


Figure 1. Annual demand in 2003 and 2007 for feed grains (cereals, pulses and oilseeds) by each Australian livestock industry (Hafi and Connell 2003).

In a 'normal' year ABARE suggest that feed grain supply in the eastern states will meet domestic demand but with growing regional deficits in areas such as SE Queensland. Hammer et al. (2003) used climate and crop yield records to forecast that in 85% of years (and in all El Nino years) future regional feed grain demand will outstrip supply in Queensland and northern NSW. This suggests a fundamental weakness in the geographic location of Australian intensive livestock industries relative to grain supply. The 2002/03 drought demonstrated the fine balance of feed grain supply and demand and suggested a growing dependence for grain importation to maintain the viability of livestock industries on the east coast.

The demand for feed grains is growing both domestically and globally. Zhou (2003) has suggested that global feed use of cereals will more than double in the next 25 years while food use will increase 50%. The increased demand for feed grain is fuelled by rapid increases in demand for livestock products, especially in developing countries. Taking China as an example, Zhou (2003) projected that by 2010, China's demand for feed grain is expected to exceed that of food grain.

Despite the growth in this market and given that particularly in Australia, grains fed to livestock are likely to vary widely in feeding quality, it is perhaps surprising that these grains are not selected for purchase or use based on characteristics that are closely related to their feed or nutritional value for animals. Prices paid are often determined by the protein content of the grain, which has little relevance for intensive livestock production, or negotiated with little information about the likely efficiency of use and effect on animal performance.

DRIVERS OF END-USE VALUE FOR FEED GRAINS

There are various characteristics of a grain that affect its value to different sectors of the feed industry. Currently these features are generally not used as a basis for rational trading largely because the market signals are not sufficiently strong and also because there has been no convenient and accurate way to monitor these end-use values of feed grains.

(a) Food safety: The safety of feed grains is of over-riding concern and influence on value. Greatest focus for feed grain safety is on grain contaminants that can lead to animal product contamination and food safety risk. Hazards include chemical residues from pesticides, herbicides, grain protectants, crop fertilizers and other environmental exposure as well as residues from certain mycotoxins such as aflatoxins that can accumulate in milk.

Market requirements are clear but trading and payment based on direct measures of these features remains problematical:

- there is first a problem of accuracy with measurement, which is affected largely by sampling issues;
- then there is a problem with convenience where current assays for most food safety concerns cannot be delivered quickly; and finally
- there is often a problem with interpretation of measured values, which is particularly an issue with mycotoxins where these often act in concert and measures for individual toxins can be of limited value.

There is another list of hazards to animal health and performance from a larger range of fungal toxins (including aflatoxins, fumonisins, ergots and others) and natural plant toxins that usually occur in grains contaminated with weed seeds (such as pyrrolizidine alkaloids from the seeds of heliotrope or crotalaria plants). Of general concern also is ingredient contamination by pathogenic spoilage organisms and increasingly of the GM status of the grain.

In a study for the stock feed industry, Murray (2001) found that the major perceived concerns of the dairy, pork, and beef cattle industries related to chemical residues. An analysis of survey data however, showed that the level of pesticide residues on ingredients is extremely low and would not present a food safety risk in respect of finished feed products. Murray (2001) also reported that chemical residues from ingredients are further reduced in finished products by manufacturing processes and high temperatures, chemical reaction and dilution. Monitoring evidence from the National Residue Survey (NRS) indicates that cereal grains do not contain excessive levels of chemical residues from treatments used in the production and storage phase. These national survey data show the low-risk status of cereal grains for chemical residues and further show that pesticide residues are rarely found in meat above the defined Maximum Residue Limit (MRL).

Similarly with mycotoxins, hazard exposure in Australian grains is extremely low. Unlike the situation in North America, Asia or Europe, Australian wheat has been found to be much less likely to be contaminated with significant levels of mycotoxin (Pitt 1999). It has been estimated that the total annual costs of mycotoxins to US economy are in the order of \$US1.5bn (CAST 2003). Although there are exceptions, most livestock producers in Australia will have little experience or awareness of mycotoxins affecting the performance of their herds or flocks. While every grain producer will have an experience of a wet harvest and some occasional mouldy grain, Australia has an enviable position of relatively low risk associated with mouldy and mycotoxin-affected grains.

This does not mean there are no risks of mycotoxins in Australian grain. About half of the grain used for livestock in Australia does not pass through the bulk handling system and misses the great diluting effects of this process. For grains that are direct-traded, there is often less ability and opportunity to monitor quality that might screen higher risk loads. Individual 'hot' loads of grain can be presented to livestock and cause direct and severe problems as well as more indirect and longer-term problems to animal performance. We do therefore need to manage the risks of livestock receiving mycotoxin-contaminated grain. Indeed Taverner (2003) suggested that changing practices in crop choice and agronomy and also possible changes in climate are increasing the risk of mycotoxin contamination.

(b) Drivers of value for processors: The primary aim of grain processing for all animals is to increase digestion of starch in the small intestine; for cattle there is the extra concern to slow the rate of starch fermentation in the rumen. In achieving this, the miller is looking for grain quality and functional characteristics that include

- the ease / power input / cost required to break a grain;
- the degree to which milling produces an even distribution of particles; and
- the ease / power input required to sufficiently gelatinize the starch to enable pellet binding without increasing the proportion of 'resistant starch' and reducing the subsequent digestibility of the starch.

Another increasingly important functional characteristic in grain processing for feed use is the potential response of the grain to dietary enzyme supplementation. Diets for most broilers and some pigs are supplemented with dietary enzymes that are mostly targeted at carbohydrates in wheat and barley. It is clear in both species that not all wheats respond to enzyme supplementation to the same extent and that there is an interaction between enzyme type and wheat quality (Choct et al 1999).

Management of grain quality in this situation is the skill of the miller to optimize the milling process to accommodate variation in grain quality. He does this with few tools or direct measures of grain quality. He will know from experience that some grains such as sorghum, are harder to pellet than others, but there are few clear measures by which grain can be valued for these functional characteristics. Data are accumulating however, both on the extent and on the possible cause of variation between grains in their response to processing (Premium Grains for Livestock Program, PGLP 2004).

Based on their observation that soft sorghum required less energy to process (especially fine grind) than the medium and hard sorghums and that waxy sorghum required less energy to steam-flake than all other genotypes, Cao et al (1999a) suggested there is a strong genotype x processing procedure interaction. This has been confirmed by Australian research (PGLP 2004) that is working to quantify the ability of sorghum to steam-flake or to steam pellet. From this work there is the prospect of NIR measures to predict the most suitable processing technique for each grain. Such a measure could be used to choose and value grain on a direct NIR measure of its specific processing characteristics.

What is more challenging in this regard however is to consider using a greater understanding of the grain quality to optimize or customize grain processing to its end-use. For example, in their work in Kansas with baby pigs, Cao et al (1999b) reported differences in digestibility that suggested fine grinding seemed to have the greatest promise in soft sorghum while steam flaking was most useful for the medium and hard endosperm genotypes.

Australian research is working with industry to understand the opportunities that different processes offer to improve the nutritional value of grains for each livestock industry (PGLP 2004). At an extreme is the obvious need to process sorghum differently for cattle than for poultry – with dry milling, the digestibility of sorghum starch across the whole digestive tract of poultry is 99% compared with 87% for cattle (Rowe *et al.* 1999). This marked difference in digestion of sorghum starch between cattle and poultry is thought to be due to differences in the capacity of cattle digestive enzymes to degrade the protein matrix that surrounds each starch granule. Unlike poultry, the digestive processes in cattle are unable to break this protein layer and for cattle, sorghum requires the more rigorous disruption of the starchy endosperm by steam-flaking so as to gain access by digestive enzymes to sorghum starch (Black et al. 2001).

More subtly however, research suggests that even within a grain such as barley, there is significant variation both in structural and starch characteristics that the miller may need to take into account. Differences in cell wall thickness for example, may enable those samples with thinner or more brittle cell walls to undergo less costly processing such as rolling instead of hammer-milling in order to improve nutrient digestibility. Similarly, variation in starch characteristics may render some barley samples more susceptible to damaging starch retrogradation and reduced digestibility in traditional processing involving heat and pressure (PGLP 2004).

(c) Drivers of Nutritional value: Grains are most generally valued by livestock industries for their capacity to provide dietary energy. Whilst features of grain quality that the livestock industries must account for include the contents of proteins, amino acids, fats and trace nutrients such as mineral and vitamin content, the most valued feature of grain quality is content of available energy coupled with characteristics that encourage intake. Black (2001) has reported how variation in energy available to animals from cereal grains can have a substantial impact on the profitability of intensive animal enterprises. He cites work of Kopinski (1997) who predicted that a change of approximately 5 % in the DE content of wheat grain (0.70 MJ/kg) could alter the annual profitability of a 200 sow piggery from \$7,500 to \$15,000 depending on grain price.

More recently Black et al (2003) reported work in which a standard least-cost feed formulation approach was been used to estimate the economic cost of varying the available energy content of cereal grains by 1 MJ/kg for the major classes of livestock. 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 1.

Table 1. Economic implications for livestock industries of increasing the available energy content of cereal grains by 1 MJ/kg.

Industry sector	Unit value \$/t
Pig	14.30
Broiler	26.90
Layer	24.07
Dairy	7.48
Feedlot	14.20
Average	17.39

This analysis suggested that Livestock enterprises can capture an average of \$17.40/t of grain for *each* extra MJ of available energy in a grain that can be recognized and incorporated into the diet.

New tools are emerging to enable those in the feed industry to achieve this recognition. Van Barneveld (2001) reported on the development of accurate NIR calibrations for pig digestible energy (DE) in cereal grains and these are now offered to industry as a commercial service. Reported variation in available energy content within grain types of more than 20% supports the potential benefits from this NIR tool. For example, Kruk et al (2001) analysed grains over a four-year period to 2001 and reported a range of about 2.5 MJ/kg in DE content for wheat (from 12.3 to 14.8 MJ/kg) and barley (from 11.9 to 14.3 MJ/kg). There are however, costs and practical considerations such as equipment, sampling, measurement accuracy and cost of grain segregations that will need to be considered in implementing new tools to measure feed quality. It is likely that the commercial incentive to monitor, value and possibly trade grain on its nutritional content will start with the larger and often most price sensitive operators in the pork and poultry industries. There will be various incentives to share this value in the supply chain and important in this process will be a shared knowledge of the energy content of the grain and signals for grain growers to increase the production of high energy grains.

Nutritional drivers of feed grain quality extend beyond a measure of DE. For cattle and for pigs, the availability of energy is influenced by the site of digestion of the cereal starch. For both species, the objective is to digest the grain's starch in the small intestine. Fermentation of starch in either the cow's rumen or the pig's hindgut reduces the efficiency of energy utilization in the animal. Furthermore, a high rate of starch fermentation in the rumen can lead to serious animal health problems with acidosis. So the objective in selecting grains for cattle is to choose for characteristics that reduce the rate and extent of starch fermentation in the rumen while achieving complete digestion of starch by the end of the small intestine.

While the site of grain digestion is not a factor influencing value for poultry, there is evidence of other grain quality factors that influence feed intake in broilers. Scott (2004) has reported 'serious concern' of factors in wheat that are as yet unidentified, that limit the voluntary feed intake by broilers. He reported that the variability in feed intake between wheat samples exceeded 20% and that this was not correlated to measures of AME. Scott's hypothesis is that these effects are related to differences between wheats in the rate of digesta passage. This concept of a separate range of grain quality factors that affect feed intake compared to energy availability was also reported by Cadogan (1999). He demonstrated that when different wheats were used in diets for young pigs, feed intake varied by nearly 50%. In 2003, Cadogan and Choct (2003) like Scott (2004), suggested that these effects are mediated partly through the digesta rate of flow and are related to the characteristics of the non-starch polysaccharide.

It is suggested therefore, that the drivers of feed grain quality might differ for ruminants and non-ruminants. It has recently been suggested in the PGLP (2004) that 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.

It is encouraging that research is identifying grain characteristics that can move us towards selecting for more ideal grains for cattle. Introducing the waxy gene for example, can increase the enzyme digestibility of starch more than the increase in rumen fermentation. Research is continuing to explore other characteristics that might lead to further reduction in the rate of fermentation that involves more resistant endosperm cell walls, harder grains with slower rates of hydration.

Quite different grain characteristics seem to be required to achieve the ideal cereal grain for monogastric animals (PGLP 2004). The following characteristics have been suggested by PGLP research:

- 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 having a short chain-length

In particular the endosperm cell wall attributes differ markedly from that required in superior grains for cattle. Furthermore, superior grains for pigs and poultry are likely to be softer, have faster rates of hydration, have quite different starch structure and non-starch polysaccharide profile. Other than to focus on yield and other agronomic qualities, there seem to be few generic feed grain quality traits used in cereal breeding programs. It is likely that for each grain type, separate plant breeding programs and selection criteria are required for different animal industries.

DEVELOPMENTS THAT WILL IMPROVE THE QUALITY OF FEED GRAINS

In most cases, there appears to have been a gulf in understanding between the grain industry and its livestock industry customers. Despite the significant domestic and export market for Australian grain as livestock feed, it has seemed that grain trading has had little acknowledgement for the quality requirements of the livestock industries. Common trading standards of protein content, bulk density and perhaps even screenings and falling number, that are important for food industry uses, are not particularly relevant for the feed industry (or their significance is very different).

The development that will most change the trading of feed grains, is an increased understanding by both the grain and livestock industries of what are the drivers of grain quality for each livestock industry. Associated with this new understanding, is a capacity to measure and to manage these quality attributes.

Food safety: To ensure stockfeed is presented as fit for purpose, millers are increasingly seeking formal assurances that their feed grains comply with regulatory requirements and meet certain standards. This can include Quality Assurance programs and certification that relates to all chemical treatments and applications including seed treatments, pre-emergence herbicide treatments, and various other applications to the growing crop.

The technology of grain protection is changing to reduce chemical insect control. Murray (2001) estimated that the amount of grain protectants used in Australia has declined in recent years from a high level of about 85-90% of all grain treated in the 1970s to about 20-30% currently.

New tools are emerging that will provide rapid test methods such as ELISA to enable specific quality assurance along with evidence of compliance with recommendations by individual producers and market guarantees for specific lots of produce. The new technology applied to this testing may enable a single ELISA-based kit for testing for a range of residues in grains for use on-farm, at receipt or in the mill.

Risk analyses are driving research to minimize mycotoxins in feed grains. For example in a recent sorghum ergot program with Queensland DPI, grains, pork, layer and cattle feedlot industries, collaboration resulted in new information on the tolerance of most of the animals to the ergot toxin, a new ELISA assay and new information on the many agronomic and genetic aspects of the infection. This led to integrated management programs and standard operating procedures that have been incorporated into quality assurance schemes for the ergot mycotoxins in sorghum (Blaney et al. 2001). This program has appeared to reduce the impact and lessen the threat of this mycotoxin to the Australian economy. There are active research programs to develop similar local knowledge and management plans for other mycotoxins including DON in wheat and Fusarium toxins in maize.

For the Fusarium fungi, plant genetic resistance is potentially the most powerful management tool. There are reports of moderate success in reducing aflatoxin and fumonisins in field tests with aflatoxin-resistant corn germ plasm, and active breeding programs are underway for all major crops affected by aflatoxin contamination. As yet however, there appear to be no commercially available genotypes with adequate resistance. In Canada, where there is a major plant breeding effort for fusarium head blight (FHB), lines with resistance are expected in the next few years with

wheat and within the next decade for barley – the challenge varies between crops and is particularly tough for barley where FHB has been described as the most complex of barley diseases in memory.

Feed processing: The major development in grain processing is our improved understanding

- first, of what needs to be achieved (such as increasing the rate of starch digestion in pigs or reducing the rate of starch fermentation in cattle) and
- secondly, how this might be achieved in each grain (such as fine grinding barley and adding feed enzymes for pigs, or by rolling or coarse grinding barley for cattle)

It is in relation to the second point that there is the potential to use NIR calibrations that might predict a barley's response to enzyme addition (based on its predicted soluble NSP profile), or the accessibility of its starch to microbial fermentation (based on its predicted cell wall content).

There is further potential in these developments to predict the functional characteristics of a grain to assist a feed miller in optimizing his processing. NIR technology offers potential also for in-line application that could lead to automated adjustments and optimisation.

Nutritional quality: A great deal of quantitative information about the composition and nutritional value of a grain for each type of livestock production and the effectiveness of processing will soon be possible from a single NIR scan. This development will likely impact on grain trading and will eventually provide the needed market signals that might drive specific quality improvement in the feed grain industry. As suggested by Brennan and Singh (2000), until there are such signals accompanied by price incentives for quality, there is a poor business case for investment in varietal improvement. They suggested that the aim for feed grain improvement should be yield improvement.

The new NIR tools for nutritional value have only begun to be applied to feed grain breeding programs to understand the genetic possibilities and consequences of selecting for traits specific for nutritional value of different species. It is suggested by O'Brien (2000) for example, that differences in nutritional value between barley cultivars are significant and that specific cultivars with higher value for livestock can be recommended. This approach offers the potential to markedly improve the quality of grain provided to Australian livestock industries overall – once we can rapidly assess grains for their energy value and pellet quality we can for the first time combine information on feeding value, yield and agronomic characteristics and use this to recommend to growers grain cultivars for planting in specific regions of Australia that should give the greatest returns when used as animal feed. Potentially this will also increase both overall quality and certainty of supply.

New trading processes could be adopted readily by grain growers who sell directly to animal enterprises. Whilst there are costs for segregating grains, Australia's grain handling system is changing quickly to accommodate the marketing opportunities in providing grain that more closely meets end-use requirements. There is no need for new systems to enable feed grain segregation – it is more an issue of benefits and costs of allocating existing grain storages. Although substantial potential benefits may arise from using NIR scans to determine the nutritional value of grains, considerable effort is required to develop a marketing system that will capture these benefits and distribute the financial gains across the grain growing, handling and end-user industries. For such a system to be adopted nationally it has been estimated that 80% of grain would need to be traded using predetermined specification and NIR measurement.

REFERENCES

- Black, J.L. (2001). Quality feed grains: Research highlights and opportunities. *Proceedings of the Tenth Australian Barley Technical Symposium 2001: A Barley Odyssey*.
- Black, J.L., Blakeney, A.B. and Bird, S.H. (2001). Prospects for improving the feed grain quality of sorghum. In: "*Proceedings of the 4th Australian Sorghum Conference*". CD-rom format: ISBN: 0-7242-2163-8.
- Black, J.L., T. Crimmins and M.R. Taverner (2003). Exploring the case for a rational basis for trading feed grains. Premium Grains for Livestock publication (GRDC)
- Blaney, B., J. Kopinski, S.A. Murray, S. McLennan, R. Moss, J. Downing & J. Dingle (2001). Research on the toxicity of sorghum ergot and its alkaloids. In: "*Proceedings of the 4th Australian Sorghum Conference*". CD-rom format: ISBN: 0-7242-2163-8.
- Brennan, J.P. and R.P. Singh (2000). Economic Assessment of Improving Nutritional Characteristics of Feed Grains. A report prepared for the GRDC. Economic Research Report No. 3. NSW Agriculture.
- Cadogan, D.J. (1999). Agronomic and physico-chemical factors of wheat affecting nutrient availability and performance in pigs. Master's thesis. UNE, Armidale NSW Australia.
- Cadogan, D.J. and M. Choct (2003). Wheat carbohydrate constituents and feed intake in pigs. Ed J.L. Corbett, in *Recent Advances in Animal Nutrition in Australia*. Armidale NSW, UNE.
- Cao, H, J. D. Hancock, B. W. Senne, J. M. Jiang, S. L. Johnston, R. H. Hines, and K. C. Behnke (1999a). Effects Of Sorghum Starch Type, Endosperm Hardness, And Processing Technologies On Growth Performance Of Broiler Chicks And Nutrient Digestibility In Finishing Pigs. US Sorghum Industry Conference www.sorghumgrowers.com
- Cao, H, J. D. Hancock, B. W. Senne, J. M. Jiang, J. R. Froetschner, P. Sorrell, R. H. Hines, and K. C. Behnke (1999b). Effects Of Sorghum Endosperm Hardness And Processing Technologies On Growth Performance Of Broiler Chicks And Nutrient Digestibility In Nursery And Finishing Pigs US Sorghum Industry Conference www.sorghumgrowers.com
- CAST – Council for Agricultural Science and Technology (2003). Mycotoxins: Risks in Plant, Animal and Human Systems. (Task Force Report, ISSN 0194-4088; No.139) Ames, Iowa, USA.
- Choct, M. D.J. Cadogan, R.G. Campbell, and S. Kershaw (1999). Enzymes can eliminate the difference in nutritive value of wheat for pigs. *Manipulating Pig Production VII* (Australasian Pig Science Association).
- Hafi, A. and Connell, P. 2003, *Feed Grains: Future Supply and Demand in Australia*, ABARE eReport 03.21 Prepared for the Grains Research and Development Corporation, Canberra, November 2003.
- Hammer, G.L., Potgieter, a. and Strahan, R. (2003). The reliability of supply of feed grains in the northern region. *Proceedings of the Fifth Australian Maize Conference*, Toowoomba, Feb 2003.
- Kopinski, J. (1997) Characteristics of cereal grains affecting energy value. Final Report, Pig Research and Development Corporation, Canberra.
- Kruk, J.A., Ru, Y.J. and van Barneveld, R.J. (2001). Digestible energy content of wheat, barley and triticale samples measured using near infra-red spectrophotometry between 1997-2001. In "*Manipulating Pig Production VIII*", p. 217, ed P.D.Cranwell. (Australasian Pig Science Association: Werribee).
- Murray, W.J (2001). Assuring the Safety of Stockfeed Products. Report for the Stockfeed Manufacturers Association of Victoria.

- O'Brien, L. (2000) Genotype and environment effects on cereal grains fed to livestock In: Chemical Aspects of Grain in Human and Animal Nutrition, a symposium organised by the Cereal Chemistry Division at the 11th Royal Australian Chemical Institute Convention "Chemistry into the New Millennium" Canberra February 6-11, 2000. P. 13.
- Pitt, J.I. (1999). Clean harvested and stored grain. Report for Grains Research and Development Corporation, Canberra.
- Rowe, J.B., Choct M. and Pethick D.W. (1999). Processing cereal grains for animal feeding. *Australian Journal of Agricultural Research* **50**, 721- 736
- Scott, T.A. (2004). A possible explanation for limited feed intake of wheat-based diets by broilers. Proceedings of Australian Poultry Science Symposium, University of Sydney (in press).
- Taverner, M.R. (2003). The Changing World for Mycotoxin Management. Paper presented to 19th International Feed Industry Symposium. Altech. Lexington, Kentucky, USA (May 2003)
- van Barneveld, R.J. (2001). Managing the nutritional quality of stockfeed ingredients. In "Advances in Nutrition Technology 2001: Proceedings of the 1st World Feed Congress, Utrecht, Netherlands, November 7-9, 2001", pp. 31-45, ed A.F.B. van der Poel, J.L. Vahl and R.P. Kwakkel. (Wageningen Pers).
- Zhou, Zhang-Yue (2003). Feed versus Food: The Future Challenge and Balance for Farming. ATSE Crawford Fund's 2003 Annual Conference on "The Livestock Revolution - A Pathway from Poverty?", Australian Parliament House, Canberra, 13 August 2003