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The energy value of cereal grains, particularly wheat and sorghum, for poultry

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Summary

Results from the Premium Grains for Livestock Program were analysed to identify variation in the energy value for laying hens and broiler chickens of cereal grains including wheat, barley, oats, triticale, sorghum and rice. There was wide variation in apparent metabolisable energy (AME) within and between grain species for both layers and broilers. While the range in AME values was similar for most grains in layers and broilers, there were varying responses to specific samples. AME values tended to be higher in layers than broilers for barley, frosted triticale and naked oat samples. More AME was obtained from rice by broilers. There was little relationship between AME content of grains and the amount eaten by layers or broilers. When wheat and sorghum, the most common grains used by the Australian poultry industry, were compared, AME was considerably higher for sorghum in both layers and broilers. The intake of sorghum based diets was also higher for layers, but not for broilers. Layers offered sorghum based diets consumed 13% more AME daily than those offered wheat based diets. However, for broilers, daily intake of AME was similar for sorghum and wheat based diets. Despite a similar daily intake of AME, broilers offered wheat based diets grew 20% faster and used 13% less feed than those offered sorghum based diets. The poor utilisation of energy from sorghum based diets was attributed to a low availability of amino acids, with arginine as possible first limiting amino acid, due to the low content and digestibility of sorghum proteins. In addition, asynchrony in the timing of absorption of amino acids from casein, the main protein source in the experimental diets, and glucose from the delayed digestion of starch granules surrounded by a relatively indigestible protein matrix is thought to have contributed to the lower utilisation of energy from sorghum than from wheat based diets.

I. INTRODUCTION

Cereal grains are the major source of energy for commercial poultry and represent from 60-70% of the diet. However, the capacity of cereal grains to provide energy to birds varies widely between and within grain species (Hughes and Choct, 1999). The amount of energy supplied by a grain depends on both the extent of digestion and the amount eaten. The extent of digestion depends on the adequacy of enzymes within the digestive tract capable of breaking specific chemical bonds in each grain component, accessibility of the enzymes to the chemical components and the time the enzymes and component are associated. Much of the variation between grains in energy digestibility is explained by differences in gross chemical composition (Black, 2000). However, other factors, particularly those that affect the accessibility of enzymes to specific grain components, can affect markedly the digestibility of grain components and availability of energy. The amount of a diet consumed by animals depends primarily on the requirements for nutrients to meet metabolic demands, the volume of the digestive tract and the rate of passage of digesta through the tract (Forbes, 2005). The efficiency with which available

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energy is utilised for chicken growth or egg production depends on its synchronous availability for metabolism in body tissues with amino acids and other essential compounds.

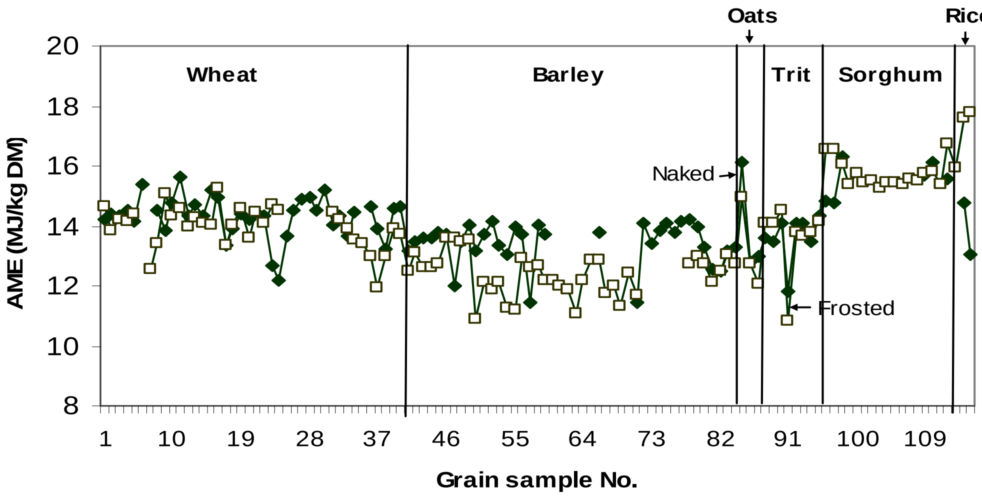
The "Premium Grains for Livestock Program" was established in 1996 by the Grains Research and Development Corporation and other industry funding bodies to examine the capacity of cereal grains to provide energy for different animals including cattle, sheep, pigs, laying hens and broiler chickens. Major aims of the Program were to identify reasons for differences between cereal grains, to develop methods for improving their quality and to enhance marketing opportunities for grains in the Australian livestock industries. Results from the Program are presented to illustrate the variation between grain samples in their capacity to provide energy for both laying hens and broiler chickens. Particular emphasis is placed on the comparison between wheat and sorghum, which are the grains most commonly used within the Australian poultry industry.

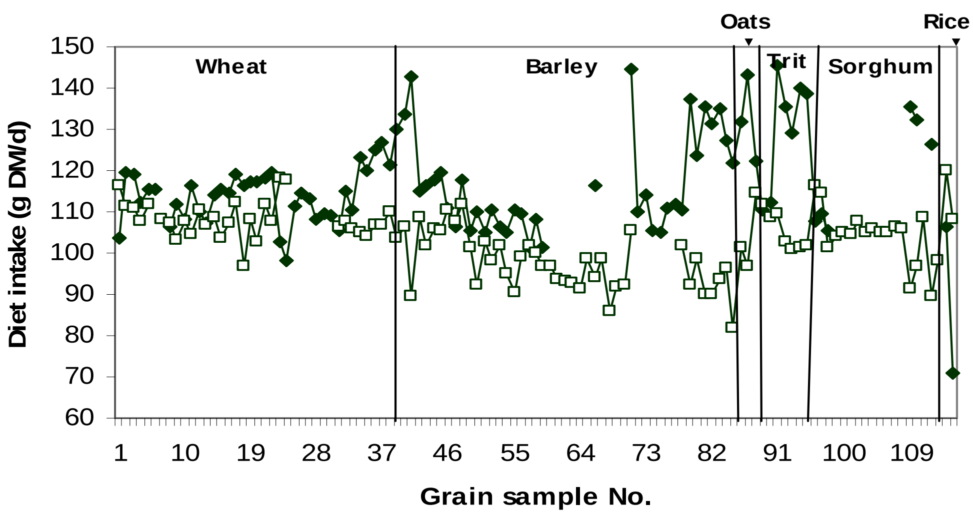
II. VARIATION IN THE ENERGY VALUE OF CEREAL GRAINS FOR POULTRY

The cereal grains investigated included wheat, barley, oats, triticale, sorghum and rice and individual samples were collected from a variety of sources with the aim of obtaining the largest possible variation in grain quality. The grains were coarsely milled and comprised 77% of the diets for layers and 80% for broilers. The diets contained 8.5% casein for layers and 15.5% for broilers with added calcium, phosphorus, vitamins and DL-methionine. All diets were cold pelleted. Experiments were conducted with broiler chickens from 22 days of age and with laying pullets. Common grains were included across experiments and statistical procedures used to produce values that were adjusted for differences between experimental periods, cages, birds and experiments. Apparent metabolisable energy (AME, MJ/kg dry matter (DM)) of the diet and of the grain was calculated and total feed intake determined. Growth rate and feed conversion ratio (FCR, g feed/g gain) were determined for broilers.

As illustrated in Figure 1, AME in layers ranged from 12.2-15.6 for wheat, 11.4-14.2 for barley, 12.8-16.1 for oats, 11.8-14.3 for triticale, 14.8-16.3 for sorghum and 13.0-14.8 for rice. Corresponding range in AME values for broilers was 11.9-15.3 for wheat, 10.9-13.6 for barley, 12.1-14.9 for oats, 12.1-14.5 for triticale, 15.3-16.7 for sorghum and 17.6-17.8 for rice. There was little difference in the AME value of the same grains between layers and broilers except layers generally obtained more energy from barley, frosted triticale and the naked oat sample than broilers, suggesting a greater capacity to deal with fibre and with fat than broilers. However, layers obtained less AME than broilers from rice. This difference is difficult to explain because rice is normally highly digestible for most animal species. The results presented in Figure 1 show also that sorghum AME values for both layers and broilers are consistently higher than the AME values for wheat.

There was little relationship between the AME content of cereal grains and the amount of the diet eaten for either layers or broilers (Figures 1 and 2). The range in intake was similar for wheat and sorghum in broilers, but the mean value of 108 g/d was higher for wheat than the mean of 104 g/d for sorghum. With layers there tended to be a higher intake for sorghum than for wheat (120 vs 115 g/d), but the range was larger between sorghum samples. The total intake of AME or energy available to the birds for metabolism was similar between wheat and sorghum for broilers with values of 1.52 and 1.54 MJ/d, respectively. Thus, although sorghum has a consistently higher AME content than wheat, the lower intake of sorghum means that there is little difference in total energy availability between the two grain species for broilers. However, for layers, the mean AME intake was considerably higher for sorghum based diets than for wheat based diets (1.64 vs 1.45 MJ/d), suggesting that layers obtain more energy from sorghum than from wheat based diets.





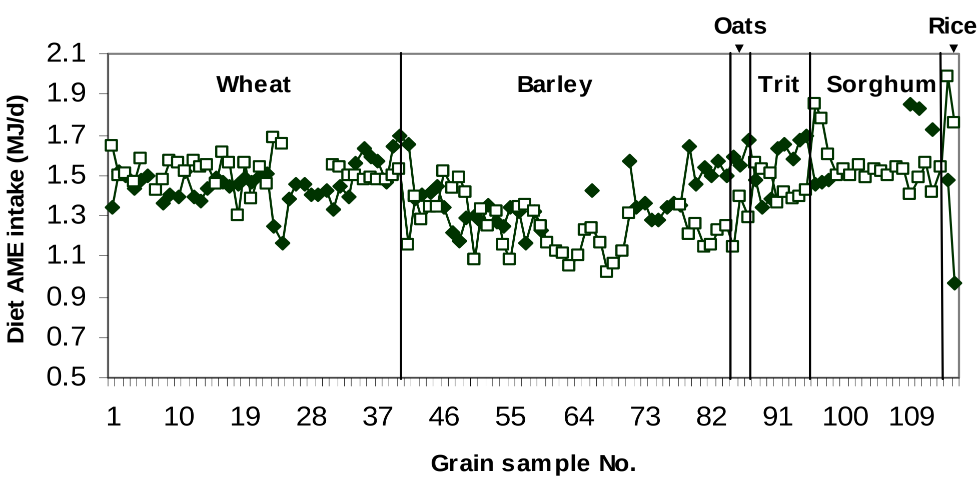


Figure 1. AME, diet intake and AME intake for laying hens (♦) and broiler chickens (□) fed different cereal grains. "Trit" means Triticale.

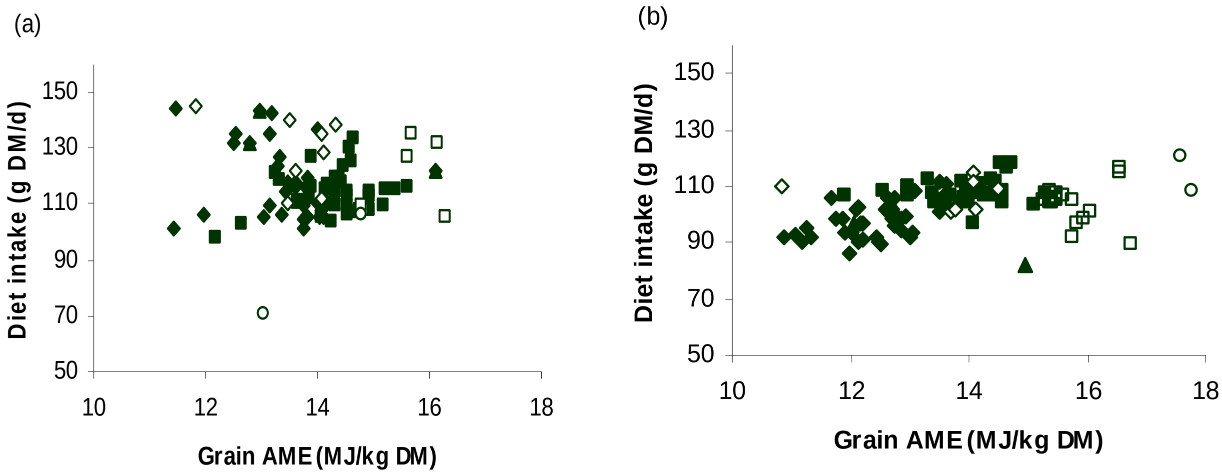


Figure 2. Relationship between diet intake and AME content of the grain for laying hens (a) and broiler chickens (b) given different cereal grains: wheat (■), barley (♦), oats (▲), triticale (◊), sorghum (□) and rice (○).

III. ASSOCIATION BETWEEN AME AND BROILER PERFORMANCE

There is a poor relationship between the AME content of grain and either growth rate of broiler chickens or the efficiency with which feed is converted to body weight gain (FCR) both within and between cereal grain species (Figure 3). However, there are stronger relationships between total daily AME intake and either growth rate or FCR, particularly within grain species (Figure 4). 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 rather than sorghum based diets (FCR 1.55 vs 1.85).

These 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 1). Despite diets having similar AME content, replacing sorghum for wheat in diets significantly reduced the efficiency of feed energy use.

Table 1. 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 ($P<0.05$)

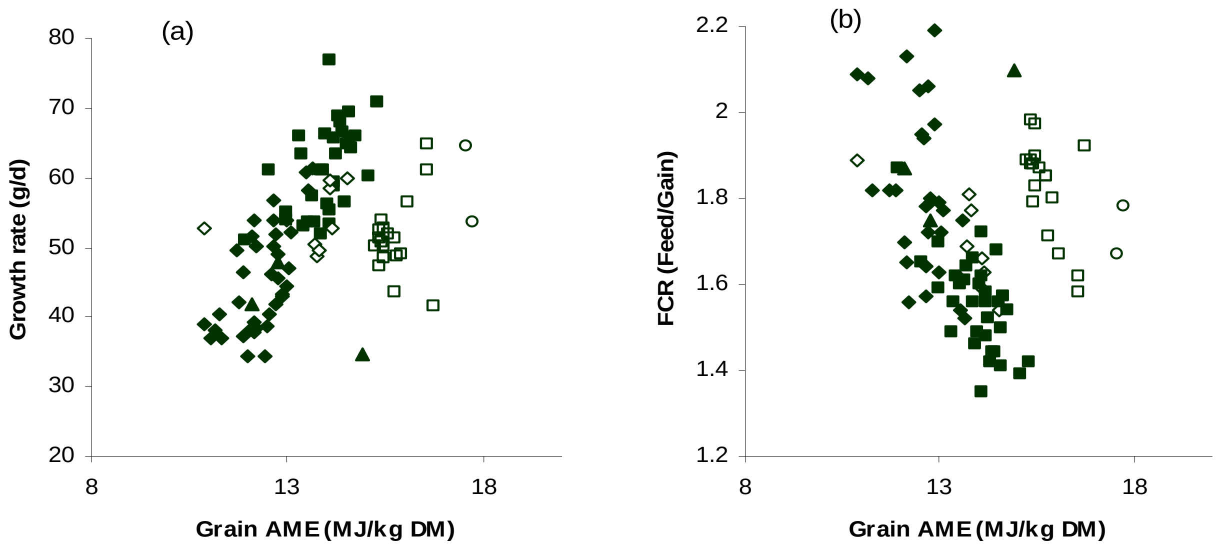


Figure 3. Relationship between grain AME content and growth rate (a) and feed conversion ratio (FCR) of broiler chickens given different cereal grains: wheat (■), barley (♦), oats (▲), triticale (◊), sorghum (□) and rice (○).

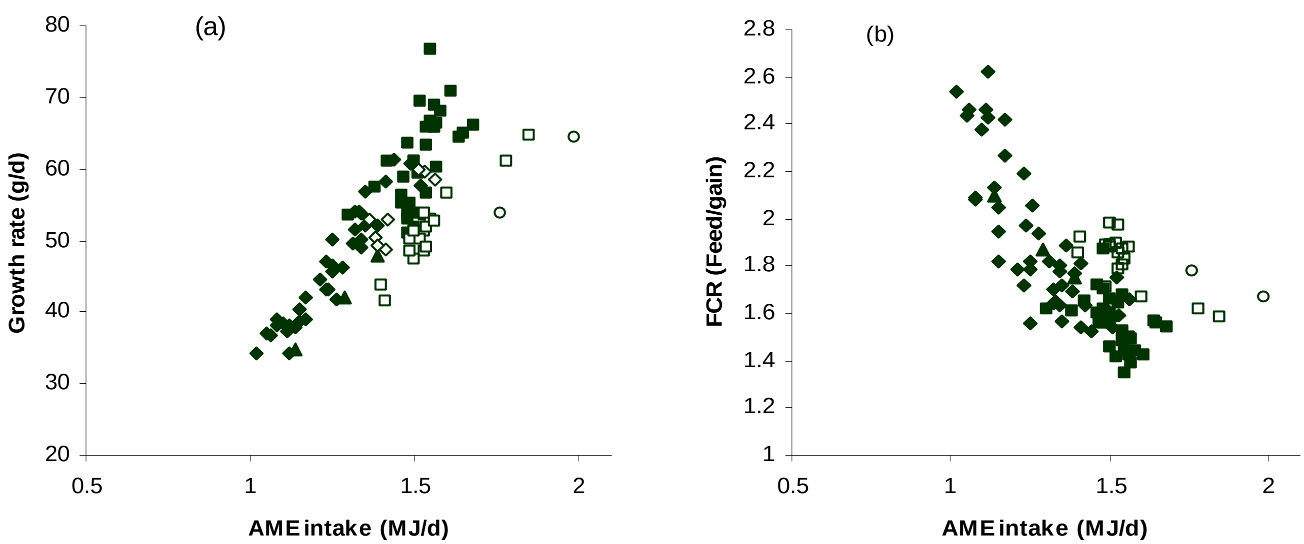


Figure 4. Relationship between total AME intake and growth rate (a) and feed conversion ratio (FCR) of broiler chickens given different cereal grains: wheat (■), barley (♦), oats (▲), triticale (◊), sorghum (□) and rice (○).

IV. POSSIBLE REASONS FOR DIFFERENCES BETWEEN WHEAT AND SORGHUM

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 4b 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 available energy was similar.

There was a strong positive relationship between the efficiency of feed use and the crude protein content of the grain in diets as shown by the decline in FCR (Figure 5a). 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, 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 (Figure 5b).

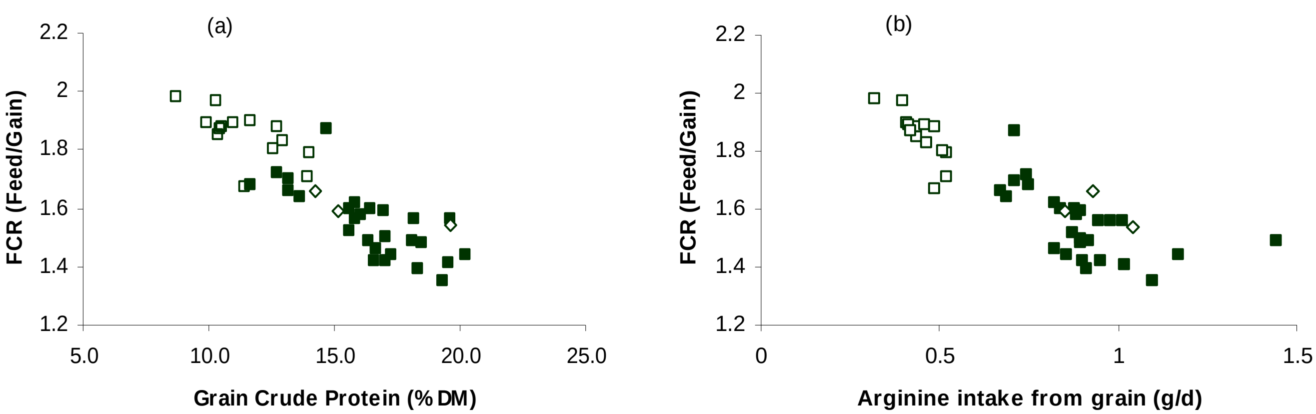


Figure 5. Relationship between feed conversion efficiency (FCR) and grain protein content (a) or arginine intake from grain (b) included in diets for broiler chickens based on wheat (■), triticale (◊) or sorghum (□).

It is known that a small proportion of sorghum proteins, the γ-kafirins, contain high amounts of sulphur rich amino acids that form disulphide bonds and render them relatively resistant to digestion by proteases. The γ-kafirins form on the surface of the protein bodies within the endosperm of sorghum grains and restrict protease enzymes from reaching the more digestible inner proteins of these bodies. Sorghum proteins have been shown to be less digestible than those from other cereal grains because of the presence of these γ-kafirins (Klopfenstein and Hoseney, 1995). However, Silano (1977) reported that the digestibility of protein ranged from 30-70% in different sorghum cultivars and a recent mutant (P21N) has a digestibility of 85% (Oria *et al*., 2000).

The results from 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.

Tannins are known to bind to digestive enzymes and reduce the digestion and availability of dietary compounds including amino acids in poultry (Nyachoti *et al*., 1997). Although most commercially available sorghum cultivars in Australia have low tannin contents they contain polyphenols which also have some anti-nutritional properties. Similarly, the phytate content of sorghum is higher than other cereal gains and may bind to amino acids reducing their availability (Selle *et al*., 2000). The relationships between FCR and total tannin content and FCR and phytic acid content of grains with daily AME intakes from 1.46-1.61 MJ (Figure 6) indicate that neither tannins nor phytic acid are likely to be the reason for the reduced utilisation by chickens of available energy in sorghum relative to wheat based diets.

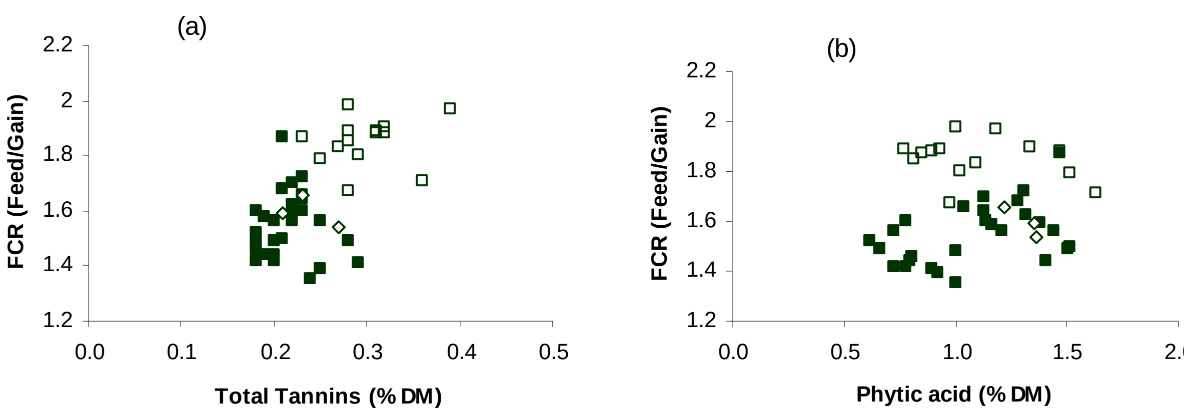


Figure 6. Relationships between feed conversion efficiency (FCR) and the total tannin content (a) or phytic acid content (b) of the grain included in diets for broiler chickens based on wheat (■), triticale (◊) or sorghum (□).

There is evidence that many dietary proteins are not completely hydrolysed to amino acids and are absorbed as small peptides, some of which have an amino acid grouping that cannot be incorporated into body proteins and are excreted from the body. Although such a mechanism occurs, it seems unlikely to be a major reason for the observed differences in the efficiency of use of sorghum and wheat based diets.

Another possible explanation for the poor utilisation of energy available from sorghum is 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.

V. CONCLUSIONS

The analyses presented above suggest that protein availability, with arginine as the possible first limiting amino acid, due to the low content and digestibility of protein restricted the performance of broiler chickens fed sorghum based diets. An asynchrony in the timing of absorption of amino acids relative to glucose from starch digestion also may have contributed to the poor performance of chickens offered sorghum based diets. The asynchrony of amino acid and energy absorption may also have contributed to the observed continuing increase in performance of chickens as the protein content of the wheat grain samples increased to over 30% of the diet. These conclusions need to be supported by experiments in which the and utilisation of amino acids are measured.

The practical implications of these hypotheses for the broiler industry are that the rate of digestion of sorghum proteins needs to be increased and the extent of encapsulation of starch granules with protein matrix reduced either by plant breeding/selection or through processing techniques including the use of effective protease enzymes. In addition, consideration should be given to ensuring that the rate of digestion of dietary protein sources are synchronised with the rate of starch digestion.

The experiments described were conducted with cold pelleted diets and the adverse effects of amino acid deficiency may be exacerbated by the high temperature processing used commonly in industry because of the known reduction in digestibility of sorghum proteins during cooking (Duodu *et al*., 2002). There appears to be considerable opportunity for research and development funding directed towards improving the content and digestibility of proteins in sorghum and to reduce the extent of encapsulation of starch granules by the protein matrix through plant breeding and selection and through improved processing techniques including the identification of highly effective protease enzymes.

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