[Sorghum TechNote PRF 1-14]

Sorghum: An enigmatic grain

Ha Truong
Poultry Research Foundation, The University of Sydney
425 Werombi Road Camden NSW 2570

1 Introduction

This, the first sorghum TechNote, is derived from an invited text-book chapter: 'Sorghum: an enigmatic grain for chicken-meat production' by my colleagues Peter Selle, Sonia Liu and Aaron Cowieson. All references mentioned below are listed in this publication (Selle *et al.*, 2013). A number of the issues raised in this introductory sorghum TechNote will be considered in more detail in subsequent editions.

While wheat is the dominant grain, sorghum makes up approximately one-third of the cereal base of Australian broiler diets as either sorghum *per se* or as wheat-sorghum blends. The Australian annual sorghum harvest averaged 2.236 million tonnes from 2008 to 2012, inclusive, and the entire crop could be utilised as an animal feedstuff, primarily for pigs, poultry and feedlot cattle. However, up to 500,000 tonnes of sorghum may be exported annually, which indicates that these livestock industries are somewhat reluctant to incorporate sorghum into their diets despite the fact that sorghum is usually available at a discounted price relative to wheat.

In Australia, if not other countries, sorghum is an enigmatic grain for chicken-meat production because the performance of broiler chickens on sorghum-based diets is considered to be either occasionally or routinely inferior to those offered wheat-based diets. Broiler performance on sorghum-based diets has been described as "sub-optimal". However, our view is that "inconsistent" is probably a better description. For example, in a recently completed Poultry Research Foundation feeding study, sorghum-based diets supported significantly better performance than wheat and numerically outperformed maize-based diets.

2 Factors influencing the performance of broiler chickens offered sorghum-based diets

2.1 Pellet Quality

There are concerns about the pellet quality of sorghum-based broiler diets, which is not surprising given the 61°C starch gelatinisation temperature of wheat is considerably lower than 73°C of sorghum. Consequently, in order to achieve adequate starch gelatinisation and acceptable pellet quality sorghum-based diets are usually steam-pelleted at high conditioning temperatures, often in excess of 90°C. Nevertheless, concerns about pellet quality remain and poor pellet quality and the presence of fines reduce feed intakes and weight gains. Recently, we evaluated sodium metabisulphite inclusions in sorghum-based broiler diets. Sodium metabisulphite quadratically improved pellet durability indices as shown in Figure 1. Therefore there are ways and means of improving the pellet quality of sorghum-based diets and apart from the use of additives such as sodium metabusulphite, the inclusion of some wheat in the formulation is an example.

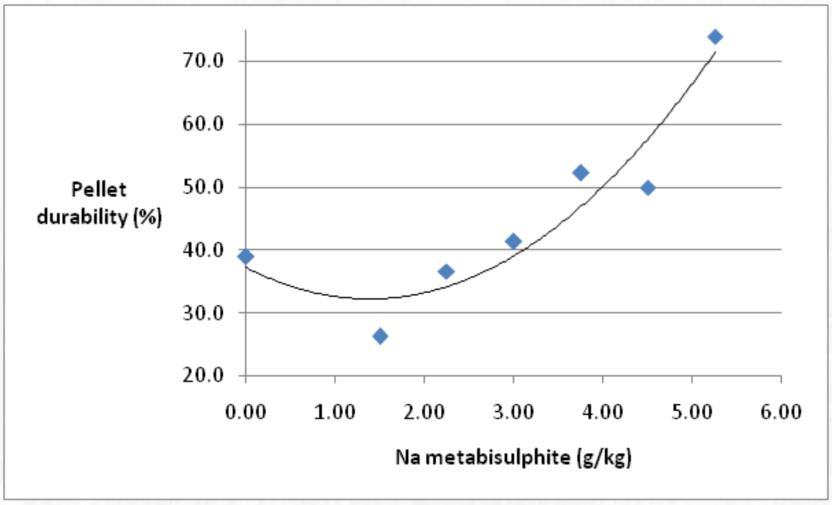

Figure 1 The effect of sodium metabisulphite dietary inclusion rates in sorghum-based diets on pellet durability

2.2 Protein quality of sorghum

Considerable emphasis has been placed on the relatively poor protein quality of sorghum as a causal factor for its real or perceived shortcomings as a feedstuff for broilers with a particular focus on the kafirin component of sorghum protein. However, in a typical sorghum-based broiler diet, the amount of total protein derived from sorghum is in the order of 30% and the dietary inclusion of sorghum is primarily as a source of energy, the majority of which is derived from starch, and not protein.

Kafirin, at around 54%, is the dominant protein fraction in sorghum and the second fraction is glutelin at around 33%. However, these percentages vary and as the total protein content of sorghum increases the proportion of kafirin rises at the expense of glutelin, as shown in Figure 2, which is based on data generated by Taylor *et al.* (1984).

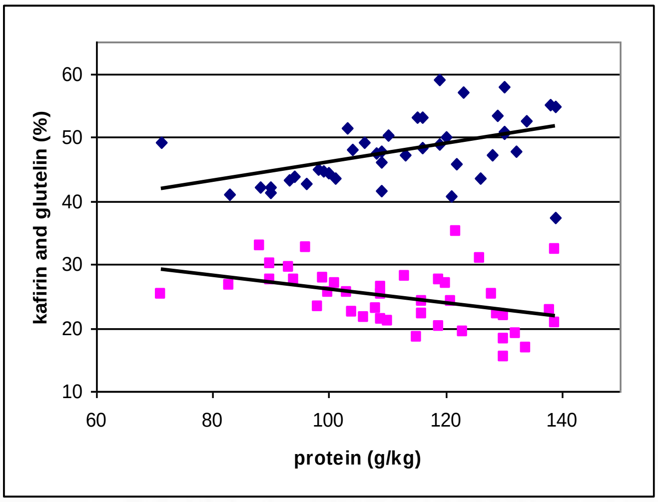

Figure 2 Relationships between sorghum protein concentrations and kafirin and glutelin as proportions (%) of protein (adapted from Taylor et al. 1984).

Kafirin is a poor source of digestible amino acids due to its inherent hydrophobicity, the structure of protein bodies and its amino acid profile. With the exception of leucine, kafirin contains low levels of essential amino acids, especially lysine. However, it should be possible to accommodate for the poor protein quality of sorghum by judiciously formulating diets using determined amino acid levels and applying conservative digestibility values to them. Almost certainly, the more important issue is whether or not kafirin has a negative effect on starch utilisation and the consensus seems to be that it does, although dissenting opinions have been expressed (Gidley *et al.*, 2011)

Kafirin protein bodies and starch granules are located in close proximity to each other in sorghum endosperm where they are both embedded in a glutelin protein matrix (Figure 3). This close proximity potentially facilitates both physical and chemical interactions by which kafirin could compromise starch/energy utilisation. It is our intention to investigate this issue more closely in a current sorghum starch project.

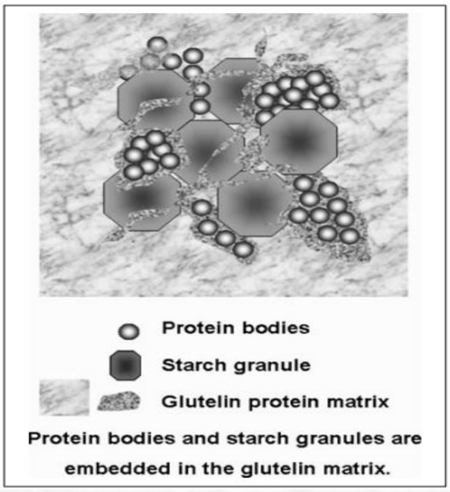

Figure 3 Sorghum protein bodies in relation to starch and the glutelin matrix (De Mesa-Stonestreet *et al.*, 2010)

2.3 Energy derived from sorghum starch

While sorghum may provide 30% of protein in a sorghum-based broiler diet about 60% of its energy density is derived from the starch component of sorghum. Concerns have been expressed about the adequacy with which the starch/energy component of sorghum is utilised by broiler chickens (Black *et al.,* 2005). On the basis of *in vitro* data generated by Guiberti *et al*. (2012) based on 51 grain samples, the digestibility of sorghum starch is clearly inferior to that of maize, wheat and barley. The potential digestibility of sorghum starch (70.4%) was remarkably less than that of maize (95.0%), wheat (92.8%) and barley (88.6%).

In a recent Poultry Research Foundation study, conventional diets based on a red sorghum (Buster) were steam-pelleted at conditioning temperatures of 65, 80 and 95°C and starch digestibility coefficients in the distal ileum ranged from 0.841 to 0.860. Obviously, at less than 0.900, this is indicative of poor sorghum starch digestibility which is emphasised by the comparison of this red sorghum with a white sorghum (Liberty) in diets steam-pelleted at 95°C. Here the ileal starch digestibility of Liberty (0.910) was 5.8% higher than Buster (0.860).

Presently, Australian sorghums almost certainly do not contain condensed tannin, a potent polyphenolic anti-nutritive factor (as will be discussed in a later TechNote). Nevertheless, sorghum contains considerably more phenolic compounds than barley, maize or wheat and red sorghums contain more phenolic compounds than white sorghum. This is because the red hue of sorghum grain is actually generated by certain polyphenolic compounds. Now we have recent evidence that appears to suggest that phenolic compounds (including 'non-tannin' polyphenolics and phenolic acids such as ferulic acid) are interacting with and compromising sorghum starch utilisation. Other factors that may be impeding starch digestion include kafirin, glutelin and phytate. The identification of the important causal factors would facilitate appropriate breeding programs to select sorghum varieties with higher starch digestibility that would be more suitable feedstuffs for chicken-meat production.

2.4 Sorghum grain texture and particle size

The texture of grain sorghum is governed by the ratio of 'hard' (corneous/vitreous) to 'soft' (floury/opaque) fractions of the endosperm. Recently, we completed a survey of 32 local sorghums; using the Symes particle size index (PSI) to determine hardness, the average PSI for the 32 sorghums was 10.0 with a range of 8 to 14. A PSI of 8-12 is classified as "very hard" and a PSI of < 8 is "extra very hard". Australian sorghums probably possess harder grain textures than sorghums grown elsewhere in the world.

As demonstrated by Cabrera (1994), the optimum particle size for grain sorghum is strongly influenced by its texture or 'hardness'. The size of the screen in the hammer-mill largely dictates sorghum particle size in the final steam-pelleted diet. Even in steam-pelleted diets, sorghum particle size has a considerable bearing on both starch digestibility and efficiency of feed conversion. This is illustrated in Figures 4 and 5 where the optimal hammer-mill screen size for a white sorghum in steam-pelleted diets for both FCR and starch digestibility in the proximal ileum was in the order of 3.75 mm. Furthermore, grain particle size has significant influence on gizzard weights, where larger particles stimulate gizzard development resulting in heavier gizzards (Figure 6).

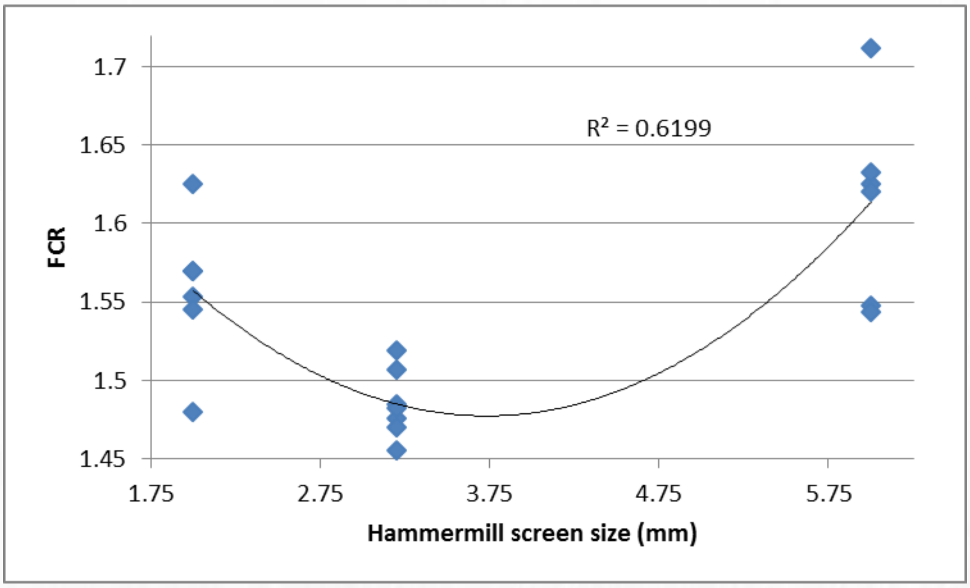

Figure 4 The quadratic relationship (r = 0.787; P > 0.001) between hammer-mill screen size for grinding white sorghum (Liberty) prior to incorporation into diets steam-pelleted at 90-95°C and feed conversion ratios of broiler chickens.

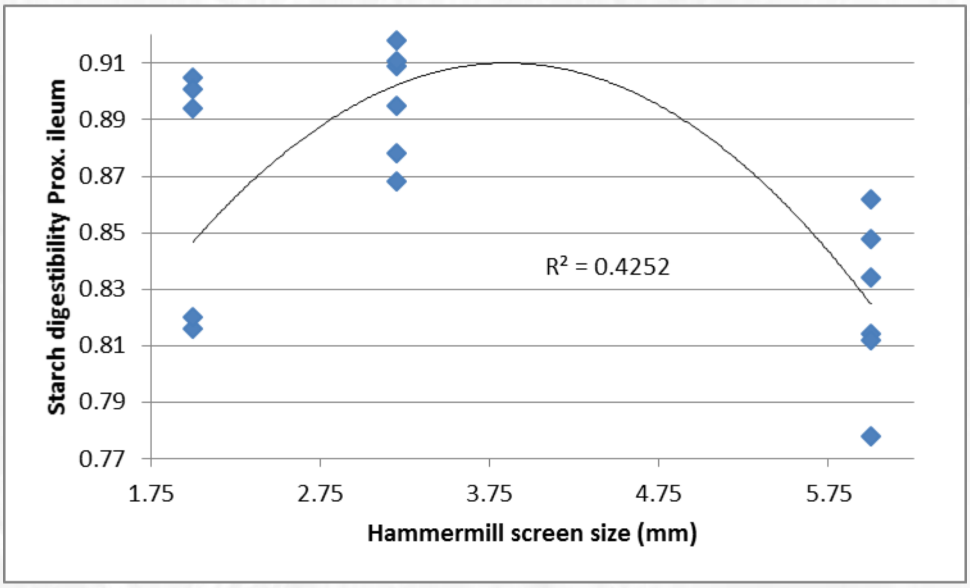

Figure 5 The quadratic relationship (r = 0.652; P > 0.05) between hammer-mill screen size for grinding white sorghum (Liberty) prior to incorporation into diets steam-pelleted at 90-95°C and starch digestibilities in the proximal ileum of broiler chickens.

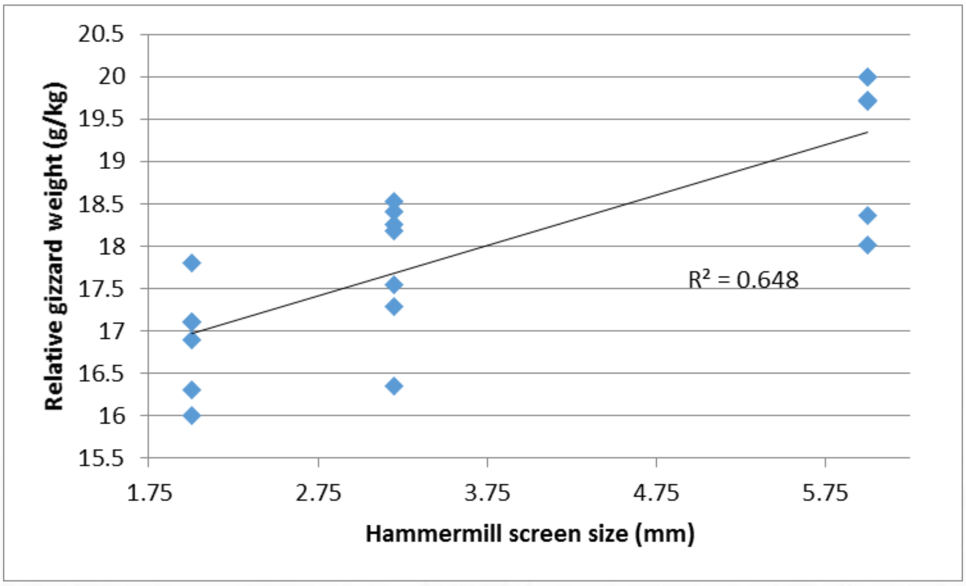

Figure 6 The linear relationship (r = 0.805; P > 0.0001) between hammer-mill screen size for grinding white sorghum (Liberty) prior to incorporation into diets steam-pelleted at 90-95°C and relative gizzard weights of broiler chickens.

As mentioned, the optimum particle size of a given sorghum will be governed by its grain texture. This particular sorghum had a Symes PSI texture of 12. The likelihood is that sorghums with different textures would also have different optimal particle sizes/hammer-mill screen sizes to maximise feed conversion and starch digestibility. The importance of sorghum particle size in this respect may be more important than in wheat, for example. These findings suggest that more attention should be paid to the texture of sorghums and hammer-milling sorghum through the most favourable screen size in order to improve broiler performance.

2.5 Steam-pelleting temperatures

The PRF has investigated conditioning temperatures at which the diets are steam-pelleted in relation to broiler performance. The effects of steam-pelleting diets based on two red sorghums at conditioning temperatures of 65 and 97ºC when offered only as intact pellets are instructive. The higher conditioning temperature increased feed intake by 3.31% but weight gain by only 0.68% as feed conversion ratios were compromised by 2.46% (1.549 versus 1.588).

In essence, higher conditioning temperatures for steam-pelleting sorghum-based broiler diets have a negative impact on efficiency of feed conversion, protein solubility and N digestibility coefficients. However the negative impact is moderate and this is probably due to two compensatory factors. High steam-pelleting temperatures are associated with better quality and harder textured pellets, where importantly the merits of pellets with higher breaking forces on broiler performance have been demonstrated (Parsons *et al.,* 2006). In addition, increasing conditioning temperatures ranging from 65 to 97ºC at which mediumly-ground sorghum-based diets were steam-pelleted significantly increased relative gizzard weights by more than 8%. Thus the negative impacts of high conditioning temperatures may be attenuated partially by increases in gizzard weight, and presumably function.

2.6 Feed additives in sorghum-based diets

A range of feed additives may be included in sorghum-based diets including several exogenous feed enzymes and reducing agents. However, there is the impression that performance responses in broilers offered sorghum-based diets to exogenous enzymes in general are somewhat muted and this caveat includes phytase. As advanced by Cosgrove (1966), at pH levels less than the isoelectric point of proteins, electrostatic attractions between positively-charged arginine, histidine, and lysine residues with polyanionic phytate molecules are crucial to binary protein-phytate complex formation. If so, it follows that phytate would not readily bind kafirin due to its paucity of basic amino acids. This may in turn limit ‘extra-phosphoric’ responses to exogenous phytases in sorghum-based diets.

Most proteases do not appear to have the capacity to reduce disulphide bonds and those located in the β- and γ-kafirin fractions in the periphery of kafirin bodies are believed to be important as they impede the digestion of the central α-kafirin core. Nevertheless, Sultan *et al.* (2010, 2011a,b,c) reported a series of promising results in N digestibility following the inclusion of a protease in ‘all-sorghum’ diets. Also, the PRF has found that a *Bacillus lichenformis*-derived protease improved protein (N) digestibility in one sorghum study and the digestibility of amino acids in a subsequent study.

Reducing agents have the capacity to cleave disulphide bonds including those located in the periphery of kafirin protein bodies and, therefore, reducing agents such as sodium metabisulphite may have the potential to enhance protein digestibility of sorghum-based diets. However, in a preliminary assessment, 5.0 g/kg sodium metabisulphite significantly increased starch digestibility by 3.8% (0.966 versus 0.931) in the proximal ileum and by 3.3% (0.980 versus 0.949) in the distal ileum; in contrast, sodium metabisulphite did not significantly influence protein digestibility. There outcomes were not anticipated and it is probable that sodium metabisulphite depolymerised starch polysaccharides by oxidative-reductive reactions. Predictably our investigations into sodium metabisulphite have continued and will be considered in future Technotes.

3. Conclusion

The performance of broiler chickens offered sorghum-based diets is not necessarily inferior to wheat and in fact may be comparable or even better. However, it is conceded that inconsistency is an issue where wheat-based diets are advantaged by NSP-degrading feed enzymes with predominantly xylanase activity and better pellet quality. Nevertheless, strategies can be adopted to enhance the performance of broiler chickens offered sorghum-based diets.

It is our contention that the major reason that sorghum is an enigmatic grain for chicken-meat production is poor utilisation of energy derived from starch coupled with the fact that the underlying causal factors have not been identified. Kafirin is frequently implicated as perhaps the single most important negative factor. However, it is our suggestion that both phenolic compounds and phytate, perhaps in tandem, are negatively influencing sorghum starch digestibility. Finally, it is our belief that sorghum would cease being an enigmatic grain for chicken-meat production if the reasons for the poor utilisation of energy derived from starch are elucidated and addressed.

Acknowledgement

The Poultry Research Foundation gratefully acknowledges the encouragement and ongoing financial support of RIRDC Chicken-meat for a series of sorghum orientated projects.

Reference

Selle PH, Liu SY, Cowieson AJ (2013) Sorghum: An enigmatic grain for chicken-meat production. In: ‘Sorghum: Production, growth habits and health benefits’. (Patricia C. Parra, editor) pp. 1-43. Nova Science Publishers: Hauppauge, NY.