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Review

Strategies to enhance the performance of pigs and poultry on sorghum-based diets

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A B S T R A C T

Grain sorghum is grown for consumption by both human and animals; sorghum-based diets are offered to ruminants, pigs and poultry. Sorghum is included in animal diets primarily as an energy source, being largely derived from starch. However, the efficiency of utilisation of energy from sorghum is variable and this may be problematic for animal production. Starch granules are surrounded by kafirin protein bodies and both are embedded in the glutelin protein matrix in the sorghum endosperm. Protein–starch interactions in the sorghum endosperm may limit starch hydrolysis and its availability. The digestibility of protein/amino acids in sorghum is usually inferior to the other cereal grains. Kafirin, which is the dominant protein fraction in sorghum, is poorly digested and deficient in basic amino acids, especially lysine. Sorghum contains more phenolic compounds and phytate than the other cereal grains and both phenolics and phytate may impede digestion by directly or indirectly binding with protein and starch. As considered in this review, various feed processing technologies have been evaluated to improve sorghum utilisation in pigs and poultry. Sorghum varieties with a hard endosperm tend to be more popular in breeding programmes due to their insect resistance and high yield. The texture of sorghum grains varies with the proportions of corneous and floury endosperm. The extent of particle size reduction and its uniformity following grinding is critical to growth performance in pigs and poultry. Sorghum is especially vulnerable to hydrothermal processes which markedly reduce the *in vitro* pepsin digestibility of sorghum proteins. Thus steam-pelleting, steam-flaking and wet-extrusion, which involve heat and moisture, may lead to undesirable physico-chemical changes in sorghum including disulphide linkage formation in kafirin protein bodies. Dry-extrusion where heat is generated by friction may enhance starch digestibility by gelatinising starch and disrupting sorghum structures without the addition of moisture. Combining reducing agents with hydrothermal processes may enhance the solubility and digestibility of sorghum protein by either cleaving disulphide linkages or preventing their formation. The inclusion of exogenous enzymes in pig and poultry diets is an established practice to improve performance of monogastric species and phytate-degrading enzymes are of particular relevance due to the relatively high phytate contents in sorghum. Additional strategies including irradiation may also have potential to enhance nutrient utilisation in sorghum. Pigs and poultry may respond differently to any strategy due to fundamental differences in gastrointestinal structure and physiology, which is particularly true of grain particle size.

Abbreviations: AME, apparent metabolisable energy; AMEn, nitrogen corrected AME; DM, dry matter; FCR, feed conversion ratio; GE, gross energy; N, nitrogen; NSP, non-starch polysaccharide; PDI, pellet durability index.

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1. Introduction

The performance of pigs and poultry on sorghum-based diets may not always be comparable to diets based on maize and other cereals. This may be due to, in part, the possibility that sorghum contains condensed tannin although tannin-free crops are becoming increasingly available on a global basis. Nevertheless, any strategies that can be developed to enhance the performance of pigs and poultry on sorghum-based diets would be beneficial.

Sorghum (*Sorghum bicolor* (L.)) is an important cereal that can be grown under drier conditions than those suitable for maize, and its annual global production in 2011 was 63 million tonnes (Swick, 2011). Sorghum is used as part, or sometimes as the entire, cereal grain base in diets for pigs and poultry (Kopinski and Willis, 1996; Selle et al., 2010a). Sorghum, like other cereals, is rich in starch (~700 g/kg) and has a protein concentration from 115 to 137 g/kg; sorghum has a nitrogen corrected apparent metabolisable energy (AMEn) ranging from 13.5 to 17.7 MJ/kg (Hughes and Choct, 1999). In 17 sorghum samples, Bryden et al. (2009a) reported a range of 71–118 g/kg crude protein with a digestibility coefficient range of 0.69–0.84. Nevertheless, sorghum is potentially an attractive energy source for the livestock and poultry industry.

Although the chemical composition of sorghum is similar to maize, sorghum has been associated with sub-optimal, or inconsistent poultry performance (Black et al., 2005; Bryden et al., 2009b). One limitation to the nutritional value of sorghum in non-ruminant species may be kafirin, which is the dominant protein in sorghum with an approximate concentration of 544 g/kg grain protein (Paulis and Wall, 1979). The poor digestibility of kafirin is due to its low solubility and structure of protein bodies and it has an unfavourable amino acid profile as it contains a paucity of basic amino acids, especially lysine (1.5 g/kg protein) (Mosse et al., 1988). As reviewed by Duodu et al. (2003), the poor protein digestibility in sorghum is due to an array of exogenous (grain structure, polyphenols, phytate and cell wall components) and endogenous (disulphide crosslinking, kafirin hydrophobicity and protein secondary structure) factors.

Grain sorghum contains relatively high concentrations of phytate or phytic acid (Doherty et al., 1982). In addition to chelating minerals, phytate binds protein through binary or ternary complexes; moreover, it may bind starch directly or indirectly through starch-granule associated protein (Baldwin, 2001; Oatway et al., 2001). In sorghum endosperm, starch granules are surrounded by numerous kafirin protein bodies and both are embedded in the glutelin protein matrix. Starch and protein interactions may affect starch gelatinisation and enzyme hydrolysis (Rooney and Pflugfelder, 1986). Due to relationships between phytate, starch and protein in sorghum, it is likely that the enzymatic degradation of phytate would contribute to enhanced starch and protein utilisation. Some sorghum varieties may contain condensed tannin which has pronounced anti-nutritive properties. However, a number of countries, including USA and Australia, are now producing 'tannin-free' sorghums.

Vitreousness of sorghum endosperms vary from 100 to 880 g/kg (Cagampang and Kirleis, 1984), but sorghum with a hard texture, and a higher proportion of vitreous endosperm, are widely planted because they are more resistant to fungal infection and insect attack during development than soft grains (Chandrashekar and Mazhar, 1999). However, sorghum with harder endosperms is associated with higher kafirin concentrations (Chandrashekar and Kirleis, 1988; Selle, 2011). Moreover, starch granules in vitreous endosperm are embedded in a firm protein matrix, while starch granules are loosely associated with papery sheets of protein in floury endosperm (Palmer, 1972; Hoseney et al., 1974). Beta et al. (2001) reported a significant correlation between sorghum endosperm textures and pasting temperatures; pasting temperatures increased with the hardness of sorghum grains. Cagampang and Kirleis (1984) showed that amylose concentrations increased from 249 to 290 g/kg starch when grain hardness (vitreousness) increased from 100 to 880 g/kg. Grinding processes such as hammer-milling physically reduce grain particle size and may disrupt endosperm structures.

Feed processing technologies used for sorghum could play a major role in improving its value as an animal feedstuff. One challenge in sorghum processing is the vulnerability of sorghum to 'moist-heat' (Selle et al., 2010b). Hamaker et al. (1986) showed an average 20.2% reduction in protein digestibility (0.803 *versus* 0.641) in sorghum following wet-cooking