Will changes in sorghum processing improve broiler chick performance

by

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Abstract

Grain sorghum is an ingredient that may be included in broiler chicken diets. However, when compared to corn, the utilization of energy in sorghum is inadequate. Sorghum contains kafirin, phenolic compounds, and phytate. These factors are considered part of the reason why sorghum has decreased energy utilization. Another factor effecting sorghum energy utilization is its vulnerability to "moist heat." Two experiments were conducted to test the effects of particle size, conditioning temperature, and the inclusion on sodium metabisulfite in sorghum-based diets for broiler chickens. In the first experiment it was found that a finely ground sorghum had increased gain:feed ratio (G:F) and body weight gain compared to other particle sizes independent of conditioning temperature. Gain:feed ratio was significantly improved when conditioning temperature was 65.5°C compared to 93°C. In the second experiment sodium metabisulfite was added to diets pelleted at 2 conditioning temperatures. The inclusion of sodium metabisulfite at 1.75 g/kg of the finished diet lead to a significantly lower feed efficiency. Sodium metabisulfite may be beneficial but it may also require a higher inclusion level. The results of these studies indicate that sorghum may be added to broiler rations but processing at higher temperatures can negatively impact nutrient utilization.

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Chapter 1 - Literature Review

Introduction

Grain sorghum is the 3rd most produced cereal grain in the United States after corn and wheat, which makes it an ideal energy source for pigs, poultry, and beef cattle. Corn has always been considered the standard energy source for broilers from a producer's perspective. Corn is plentiful, accessible, and the yellow pigment provides color to egg yolks and chicken skin. In comparison, sorghum is not a widely accessible crop in the broiler belt in the United States, and nutritionists have long valued sorghum as less nutritious than corn for poultry. Potentially negative compounds in sorghum such as kafirin, phenolic compounds, and phytate may cause the utilization of starch and energy to be subpar compared with corn. Kafirin is the dominant protein fraction in sorghum. Studies have indicated that high kafirin levels lead to decreased nutrient utilization. For this reason, the slight advantage of greater protein content for sorghum over corn is partly negated. Previously, it was thought that only condensed tannins were responsible for the anti-nutritive properties of sorghum thus there is extensive literature devoted to research (Liu et al. 2015). It appears polyphenolic compounds and phenolic acids, as well as non-tannin phenols have a negative impact on nutrient availability. Polyphenolic pigments are responsible for the red color in sorghum which leads to the assumption that white sorghum is superior (Liu et al. 2015).

The processing method of sorghum may also impact performance. Sorghum is susceptible to moist heat processing such as pelleting. When sorghum is pelleted, disulphide cross-linkages are formed binding the starch granules and reducing the energy available to poultry.

Conflicting research suggests that sorghum particle size plays a role in performance. In trials broilers fed coarse ground sorghum has outperformed those fed finer ground sorghum (Selle et al., 2016). However, in some studies broilers fed diets with fine ground sorghum have outperformed those fed coarse ground sorghum (Mikkelsen et al., 2008).

Research has shown that including reducing agents in sorghum-based diets has improved performance, but this seems to be dependent on sorghum properties (Truong et al., 2015). Additional research has shown, that by using a rapid visco-analyser (RVA) the starch pasting profiles, promatest solubilities, and grain textures may be determined and used to indicate sorghum quality (Selle et al., 2012). Using these methods, it may be possible to determine which sorghum types will benefit from the addition of reducing agents. It may be possible that with an RVA analysis of sorghum and the addition of a feed additive sorghum may yield similar performance results as a traditional corn-based ration.

What is sorghum?

Grain sorghum has many varieties and cultivars. It can be grown as grain, forage or as a sweet crop. Sorghum is considered one of the most efficient crops in conversion of solar energy and use of water. It is known as a drought tolerant crop that is environmentally friendly. The United States is the world's leading producer of grain sorghum, having produced 363 million bushels in 2017 (nass.usda.gov). The sorghum belt runs from South Dakota to Southern Texas on dryland acreage. The highest producing state is Kansas which produced over 200 million bushels of grain sorghum compared to the second highest producing state which is Texas at 94.5 million bushels (nass.usda.gov).

History of sorghum

It is thought that sorghum originated in Northeastern Africa. The spread of 5 different varieties of sorghum can be attributed to the movement of various tribal groups in Africa. From there, sorghum spread to India, China, and eventually Australia. Ben Franklin wrote the first known record of sorghum in the U.S. in 1757 when he wrote about its application in broom making. From 1853 to 1910, 31 forage and grain sorghums were introduced into the U.S. from India, China, and Africa.

Grain Sorghum

Grain sorghum can range from tight headed and round panicle, to an open, droopy panicle that may be short or tall. Different varieties include red, orange, bronze, tan, white, and black colored sorghum. Red, orange, and bronze are the most widely grown varieties and are typically used in all segments of the sorghum industry. Tan, cream, and white are traditionally made into flour for the food industry.

Forage and Biomass Sorghum

Forage sorghum can grow between 8 and 15 feet and its main use is silage for livestock feed. Depending on the species and variety it can be used for grazing pasture, hay production, and green-chop. This type of sorghum does not usually produce a seed head. The tallest of the sorghums, standing nearly 20 feet tall, is biomass sorghum. It has been bred to produce a large amount of non-grain biomass. These hybrids are used for the production of ethanol.

Sweet sorghum is grown for sorghum syrup. Unlike grain sorghum, sweet sorghum is harvested for the stalks rather than the grain and is crushed similar to sugarcane or beets to produce syrup. At one time sweet sorghum was the predominate table sweetener in the U.S.

Today, typically sweet sorghum is used to produce whiskey, rum, and is also used for biofuel and chemical production.

Sorghum in Poultry Rations

Sorghum is included in diets for pigs, poultry, and feed-lot cattle as a source of energy. The energy provided by sorghum is mostly derived from starch, as shown by Black, et al., (2005). The concept of the "Bermuda Triangle" was developed by Liu et al., (2015). The triangle is made of three factors inherent in sorghum that are responsible for poor energy utilization. The factors are: kafirin, the dominant protein fraction in sorghum; phenolic compounds, including condensed tannin; and phytate or *myo*-inositol hexaphosphate (IP_6). Kafirin concentrations may be increasing in sorghum due to various breeding programs, which would decrease nutrient quality and availability in sorghum. Most sorghum crops no longer contain high-levels of condensed tannin; however, the non-tannin phenolic compounds may negatively impact energy utilization (Selle et al., 2010a).

Sorghum suffers from the stigma of condensed tannin (CT), an antinutritive polyphenolic compound associated with "bird-proof" sorghums. Many nutritionists believe sorghum still contains some level of CT, but the Poultry Research Foundation subjected more than 60 sorghum samples to the quantal Clorox bleach test (Waniska et al. 1992). When grain sorghum is submerged in bleach the outer pericarp is dissolved revealing a black pigmented testa indicating the presence of CT, or the absence of a pigmented testa indicates no CT content. None of the 60 samples tested possessed a pigmented testa.

The amount of CT in sorghum varies but the addition of a feed enzyme may be beneficial. Liu et al. (2013) observed similar weight gain and feed efficiency in sorghum-based diets, compared to corn-based diets; however, both outperformed birds fed wheat-based diets.

Ao and Choc (2004), reported that broilers reached heavier body weights when fed a sorghum-based diet compared to those fed wheat and barley to 21 days post-hatch. Selle et al., (2010b) observed that broilers offered a non-supplemented, sorghum-based diet outperformed those fed wheat-based diets in growth performance. Moreover, when an exogenous xylanase was added to both diets, the wheat-based diet was superior. Because sorghum is non-viscous and contains low levels of non-starch polysaccharides (NSP), the lack of response from a xylanase feed enzyme is not surprising. Unlike sorghum, wheat is viscous and contains a higher level of NSP. This leads to a more pronounced effect from an NSP enzyme.

The causes of poor growth performance of broilers offered sorghum-based diets have been extensively reviewed (Bryden et al., 2009a, Bryden et al., 2009b, Selle et al., 2010a, Selle et al., 2011, Liu et al., 2013). Research demonstrated that kafirin is poorly digestible due to its hydrophobicity (Duodu et al., 2003, Belton et al., 2006). The amino acid profile of kafirin has an excess of amino acids, especially lysine (Mosse et al., 1988). Cosgrove (1966) believes that at pH level less than the isoelectric point of protein, electrostatic attractions between positively charged lysine, arginine, and histidine are crucial to the protein-phytate complex formation. Therefore, it is unlikely to form protein-phytate complexes. Selle et al., (2012) observed that the potential phytate-protein interaction may reduce the solubility of protein and therefore decreases its digestibility. Liu et al., (2015) believes this could lead to the lack of "extra-phosphoric" effects following the addition of phytase in sorghum-based broiler diets.

When condensed tannin is present in sorghum it can decrease broiler performance (Duodu et al., 2003). Worldwide, the amount of grain sorghum still containing CT is decreasing every year though higher CT varieties are still planted in areas where there is intense bird damage. However, non-tannin phenolic compounds may also be the cause of poor broiler performance (Beta and Corke 2004). White sorghum is considered CT free and has lower non-tannin phenolic compounds. Liu et al., (2013) observed that diets containing white sorghum had an increase in amino acid digestion when compared to red sorghum-based diets. Soluble conjugated and insoluble bound phenolic acids could be the reason broilers perform better when offered white sorghum-based diets compared to other varieties.

The primary purpose for including phytase in a broiler diet is to liberate phytate-bound phosphorus (P); (Selle et al., 2007) Sorghum contained an average of 2.41 g/kg P and the proportion of phytate-bound P was greater in sorghum (82.7%) than barley (67.3%) and wheat (74.9%). Truong et al., (2014) observed the effects of phytase in sorghum-based diets. Phytase significantly improved apparent disappearances rates of phytate in the proximal jejunum, distal jejunum, proximal ileum and distal ileum in broilers. Toe ash was also significantly increased from 11.68% to 12.29% in sorghum-based broiler diets supplemented with phytase (Liu et al., 2014). However, responses to phytase in sorghum-based broiler diets still seem to be less robust due to its amino acid profile compromised of an abundance of arginine, histidine, and lysine. The high levels of arginine, histidine, and lysine don't allow phytate to readily bind to kafirin, therefore limiting the effect that phytase may have in a sorghum-based diet. At a low pH, the formation of protein-phytase complexes in the gut may be key to the anti-nutritive properties of phytate and their attenuation generates the "extra-phosphoric" protein and energy responses to phytase (Selle et al., 2012).

Processing Sorghum

As early as 1962, Jensen et al., (1962) observed that in comparison to mash diets, pelleting may reduce the time and energy it takes to eat because prehension is facilitated which voluntarily increases feed intakes. Poultry diets can be steam pelleted to offer various benefits to increase broiler performance. Some of these benefits include decreased feed waste, less selective feeding, reduced ingredient segregation, destruction of pathogenic organisms, thermal modification of starch and protein, and increased palatability (Behnke et al., 1996).

The process of preparing feed to be pelleted includes grinding, mixing, conditioning, pelleting and cooling. After the diet is mixed, it is put into a conditioner where steam is added. The hot steam causes the starch to gelatinize and creates a soft sticky pliable mixture. From the conditioner the feed is forced through a pellet die and is cut to length by a knife. After the pellet is formed it is cooled by forced air to help the pellet retain its shape. The quality of the pellet is sometimes measured by the pellet durability index or PDI. The PDI is measured by spinning pellets in a box, sifting the fines and broken pellets, then weighing the number of fines and the number of remaining intact pellets. The percentage of remaining pellets is the PDI. Pellet durability is very important because decreased pellet durability leads to a reduction in the benefits of a pelleted ration (Truong et al., 2015). Grain sorghum can be difficult to pellet due to its vulnerability to "moist heat" (Selle et al., 2010a). When a sorghum-based diet is being conditioned, it typically requires a higher temperature (68-78 °C), to achieve a more complete starch gelatinization compared to corn (62-72 °C). The higher pelleting temperature required for sorghum can be beneficial as it would produce a better-quality pellet and reduce fines in the feeder. This means less sorting and high feed intake. The downside to the high pelleting temperature is an increased manufacturing cost and a risk of nutrient damage caused by high temperatures.

Elkin et al., (1991) compared a sorghum-based mash diet to a sorghum-based pelleted diet. They observed that a substantial increase in weight gain as well as an improvement in feed efficiency in the broilers fed the pelleted diets. These diets were pelleted at 82 °C. Studies performed by Nir et al., (1995) and Cramer et al., (2003) again compared broilers fed mash versus pellet sorghum-based diets and observed that pelleting did not lead to any significant increases in growth performance. These results may be due to sorghum exposed to moist heat-like the pelleting process has been shown to reduce the amino acid digestibility to a substantial extent (Mitaru et al., 1985). Douglas et al., (1990) observed that pelleting low-tannin, sorghum-based broiler diets improved weight gain by 13.4% and feed efficiency by 7.1% to 21 days of age compared to mash diets.

Given the conflicting research presented by Douglas et al., 1990, Nir et al., 1995 and Cramer et al., 2003, it is still unclear if pelleting a sorghum-based diet has a significant impact on broiler performance. Because sorghum may be susceptible to moist heat, it is possible that the steam pelleting process introduces enough moisture to cause deleterious effects on broiler performance.

Particle size can play an important role in performance of broilers fed sorghum-based diets. Nir et al., (1987) studied the impact of pelleting, particle size, and grinding method of sorghum-based diets on broiler performance. The grinding methods were a coarse grind by a roller mill and a fine grind by a hammer mill. Nir et al., (1987) reported no significant effects due to particle size or grinding method. In another study, Nir et al., (1990) reported a significant weight gain in broilers from 7 to 21 days of age on body weights of broilers that were fed coarsely ground sorghum (888 µm) compared to finer grinds (555 or 702 µm). Another study performed by Mikkelsen et al., (2008) observed that finely ground sorghum significantly improved broiler growth performance than those fed coarsely ground sorghum.

The Tannin Issue

Tannin is a polyphenolic compound found in sorghum in upwards of 100 g kg^{-1} whereas the concentrations in barley, maize, and wheat are negligible (Bravo 1998). Condensed tannins are distinguished from other polyphenolic compounds by their capacity to bind protein (Spencer et al. 1988). Evidence from Jansman (1993) suggests that tannin has the ability to precipitate 12 times its weight of protein. Makkar (1989) observed similar results whereby tannins are quantified on the basis of protein precipitation. Rodrigues et al., (2007) observed that high tannin concentrations were significantly correlated with decreased live weight gain ($r = -0.723$; $P < 0.005$) and feed efficiency ($r = 0.733$; $P < 0.005$) in broiler chickens to 21 days of age. These results were not significant at 42 days of age but the increased tannin levels in the diet tended to yield lower breast meat weights ($r = -0.513$; $P < 0.07$).

Grain sorghum can be divided into 3 categories: Type I, Type II, and Type III. Type I sorghums do not have a pigmented testa and are tannin-free. Type II sorghums have a pigmented testa layer and contain condensed tannins. Type III sorghums are labeled “bird-proof” and have tannin in the testa and pericarp. Type III sorghums are considered “bird-proof due to the high levels of CT. The pericarp is the outside layer of grain sorghum and beneath that is the testa. Performing a simple Clorox Bleach Test (Waniska et al., 1992) removes the pericarp revealing the testa indicating the presence or absence of CT. Average tannin concentrations were found to be 0.28, 4.48, and 11.95 g kg^{-1} in type I, II, and II respectively (Dykes and Rooney 2006). Clearly, the amounts of tannin in sorghum may vary considerably. The tannin, or proanthocyanidin, in sorghum grain is representative of the simplest condensed tannins, compromising a linear polymer of epicatechin terminal units (Hagerman et al., 1997). Tannin concentrations in sorghum are determined by the acidified vanillin method (Burns 1971).

Catechin equivalents are expressed as tannin concentrations using a conversion factor of 0.42 (Price et al., 1978).

Rooney (2005) stated that 99% of contemporary sorghums in the US do not contain tannin. Walker (1999) similarly stated that sorghum produced in Australia is also tannin free. Walker (1999), concluded that Type I sorghums are often erroneously referred to as "low-tannin" sorghum, whereas in fact they do not contain tannin. The low tannin values reported in the study are obtained when non-tannin phenols, present in all grain sorghum, react with the vanillin and contribute to the measured value of catechin equivalents. Walker (1999), cited Boren and Waniska (1992) concluding that when suitable blanks are used, Type I sorghums are found to be tannin free. Hagerman et al., (1978) also reported that non-tannin, phenolic compounds may be erroneously reported as tannin.

Kafirin

Sorghum protein is comprised of kafirin, glutelin, globulin, and albumin. Virupaksha and Sastry (1968) observed that kafirin was the dominant protein fraction representing 54.1% of sorghum protein followed by glutelin (33.4%), globulin (7.0%), and albumin (5.6%). Kafirin and glutelin are in close physical proximity to the starch granules located in the sorghum endosperm. This could cause a negative influence on the nutrient utilization of sorghum protein. Taylor (1984), analyzed 41 sorghum samples and found average concentrations of 54.0 g/kg of kafirin and 27.1 g/kg of glutelin and a crude protein content of 111 g/kg. Kafirin was positively correlated ($r = 0.469$; $P < 0.005$); with sorghum protein content, whereas glutelin was negatively correlated ($r = -0.401$; $P < 0.01$). This evidence suggests that quantifying sorghum quality by protein content may lead to increased kafirin concentrations in grain sorghum crops. Kafirin content is usually determined by the Landry and Moureaux method (1970).

Kafirin is divided into 3 major components: α-kafirin, β-kafirin, and γ-kafirin, on the basis of solubility, structure and molecular weight. In protein bodies, the central core of α-kafirin is enveloped by the peripherally located β-kafirin, and γ-kafirin components. As a total proportion of kafirin, Oria (1995b) reported α-kafirin (0.673), β-kafirin (0.227), and γ-kafirin (0.100). Similarly, Chamba et al. (2005) reported α-kafirin (0.820), β-kafirin (0.075), and γ-kafirin (0.105). Hicks et al., (2001) observed different results where β-kafirin accounted for 0.687 of total kafirin in comparison to 0.231 and 0.082 for α-kafirin and γ-kafirin respectively. The conflicting results from the studies show that the make-up of kafirin can vary, which leads to a different amino acid profile of grain sorghum.

It is generally accepted that kafirin is a poor source of digestible amino acids. Duodu et al., (2003) emphasized the negative impact of 'moist-heat' on sorghum protein digestibility. The poor digestibility was attributed to several factors including the hydrophobicity of kafirin, disulphide cross-linkages involving cys, secondary protein structural changes and the phytate content of sorghum. The authors determined that the cross-linkages in β-kafirin, and γ-kafirin was crucial to the poor digestibility. Gao et al., (2005) observed that disulphide cross-linkages promote kafirin aggregation and secondary structural changes with an increase with β-sheets.

Exposing sorghum to 'moist-heat' such as steam pelleting reduces the digestibility of protein in grain sorghum. Eggum et al., (1983) observed the adverse effects of cooking sorghum on its protein digestibility, which was exacerbated in sorghums with high polyphenol contents. Mertz et al., (1984) found that the *in vitro* pepsin digestibility of cooked sorghum (0.69 %) was inferior to cooked wheat (0.86 %) and corn (0.85 %). Hamaker et al., (1987) also observed that wet cooking reduced pepsin digestibility of sorghum by 24.5% in comparison to corn (4.1%), wheat (5.4%), rice (9.1%), and barley (13.0%).

A study by Duodu et al., (2002), found that *in vitro* protein digestibility of sorghum was reduced by 41.6% compared to 6.9% in corn, when cooked in 95 °C water for 10 minutes. Oria et al., (1995a) observed cooking sorghum reduced *in vitro* protein digestibility by 24.6% compared to uncooked sorghum and that disulphide cross-linking was more prevalent in γ-kafirin. In another study by Oria et al., (1995b), cooking sorghum decreased *in vitro* protein digestibility by 37.0% compared to uncooked sorghum and increased amounts of β-kafirin and γ-kafirin in pepsin digestion residues compared to α-kafirin. The hydrothermally induced disulphide cross-linkages impede the digestion of the central α-kafirin core is surrounded by a layer of highly insoluble protein. Kafirin is more resistant than corn to pepsin digestion when sorghum is exposed to moist- heat as Oria et al., (1995a) reported that cooking sorghum flour increased undigested residues of α-kafirin (0.31 to 0.48), β-kafirin (0.15 to 0.41) and γ-kafirin (0.14 to 0.28). Oria et al., (2000) also observed that lysine-rich sorghum has protein bodies with invaginated structures in which α-kafirin is exposed but protein digestibility wasn't affected to the same level as a standard grain sorghum.

Cooking sorghum results in decreased protein digestibility (Oria et al., 1995a). This may be due to the increase in disulphide cross-linkages in β-kafirin and γ-kafirin caused by exposure to moist-heat. Sorghum varieties with high polyphenol contents may be more at risk to moist heat.

Kafirin content negatively influences sorghum protein quality (Selle 2011) but the impact may not be significant because kafirin constitutes roughly 15% of total protein in a sorghum-based broiler diet. The reactions between kafirin and the starch granules that negatively impact starch utilization have not been identified. However, the physical proximity of kafirin protein bodies, starch granules, and glutelin protein matrices in sorghum endosperm may be significant.

Starch in sorghum endosperm is greater than kafirin protein, which suggests that the magnitude of biophysical starch-protein interactions is limited by the amount of kafirin (Gidley et al., 2011).

Taylor et al., (2005), demonstrated how kafirin can compromise starch/energy utilization. Starch granules are larger and more plentiful than kafirin protein bodies, 15 μm and 1 to 3 μm, respectively, in the sorghum endosperm. Another possible barrier to starch digestion is the endosperm cell walls. Taylor et al., (2005) thought it was possible that the endosperm cell walls formed a barrier to digestion. Cell walls are rich in insoluble glucuronosrsbinoxylan-type pentosans and are intimately bound to the glutelin protein matrix, quite possibly via ferulic acid, a phenolic compound that is abundant in grain sorghum.

Interactions involving disulphide linkages between β- and γ-kafirin on the periphery of protein bodies and proteins on the surface of starch granules may have the ability to slow starch digestion (Truong et al., 2015). Poor starch utilization in sorghum-based broiler diets can be contributed to a combination of 3 factors: disulphide cross-linkages, glutelin protein matrices, and proteins in sorghum endosperm forming a web-like protein network. However, kafirin content is most likely the main driver of the poor nutrient utilization and with kafirin content increasing in sorghum due to selective breeding for high protein concentration, is a challenge to the poultry industry. Having a low protein sorghum may provide increased digestibility in broilers.

Reducing Agents

Including a reducing agent during the processing of a sorghum-based broiler diet has been shown to improve protein digestion in broiler chickens (Choi et al., 2008). Sulphite reducing agents such as sodium sulphite (Na2SO3) and sodium metabisulfite (Na2S2O5), have the capacity to cleave disulphide cross-linkages and have been shown to improve *in vitro* starch and protein digestibility (Hamaker et al., 1987, Rom et al., 1992, Choi et al., 2008). Sodium metabisulfite (SMBS) has been reported to significantly decrease disulphide cross linkage formation and also increase free sulphydryl groups *in vitro* (Selle et al., 2013). Sodium metabisulfite significantly improved energy utilization in broilers offered sorghum-based diets by 0.56 MJ compared with those fed sorghum-based diets with added SMBS.

In another study performed by Selle et al., (2014), graded amounts of SMBS linearly decreased the concentration of disulphide bonds, linearly increased free sulphydryl groups, and protein solubility of the diets. From the same study, adding SMBS at 1.50 g/kg in sorghum-based broiler diets significantly improved apparent metabolizable energy (AME) by 0.36 MJ and feed conversion ratio by 2.47% compared to diets without SMBS. A follow up study performed by Liu et al., (2014) observed that the addition of SMBS produced more slowly digestible starch which was associated with improved energy utilization and feed efficiency. This may be due to a product of the slowly digestible starch conserving energy at the enteral and parentral levels.

In a preliminary study by Selle et al., (2013), broilers were fed sorghum-based diets with increasing amounts of SMBS. The broilers were able to tolerate SMBS at 5 g/kg before a negative impact on feed intake occurred. Inclusion levels under 5 g/kg appeared to have the ability to enhance nutrient utilization of broilers fed sorghum-based diets. Of the 5 studies performed during this experiment, 4 of the studies used a diet completely comprised of sorghum while 1 diet used a sorghum-based diet. A total of 8 different sorghum varieties were used over the course of the experiment. Out of the 8 used, 7 of the grain sorghum varieties produced a positive response in energy utilization (AME, ME:GE ratio, and AMEn) with up to 5.25 g/kg SMBS added. The average SMBS inclusion of 2.84 g/kg increased AME by 0.27 MJ, AME by 0.32 MJ, and ME:GE ratio by 1.90%. In the 4 studies using a diet completely comprised of sorghum, feed conversion was increased by added SMBS on average by 1.37%. Paterson et al., (1996, 1997) believed it would be advantageous if these improvements stem mainly from reductions of disulphide cross linkages and increased solubility of proteins, perhaps especially kafirin, or from starch depolymerization. Most likely SMBS affects both starch and protein digestive dynamics to some capacity and improves energy utilization in broiler chickens (Liu et al., 2015). Based on reports by Selle et al., (2013, 2014), it seems that the addition of SMBS and strain of grain sorghum used will contribute to the magnitude of response on growth performance. Sodium metabisulfite has shown the ability to positively enhance broiler performance when broilers are offered a grain sorghum-based diet that has been exposed to a "wet cooking" process such as steam pelleting.

Truong et al., (2015) believed that the positive effects of SMBS on energy utilization and feed conversion stem from either the oxidative-reductive depolymerization of starch polysaccharides or the reduction of disulfide cross-linkages in proteins. It was suggested that the oxidative-reductive depolymerization reactions generated slowly digestible starch and this was responsible for the observed improvements in broiler performance.

Truong et al., (2015) studied the effects of combining SMBS with phytase in sorghum-based diets for broilers. The combination of phytase and SMBS had no significant interaction on growth performance of broilers. However, SMBS alone improved weight gain by 3.27%. The combination of phytase and SMBS numerically increased starch digestibility ($P > 0.05$). The lack of significant response to the combination of the 2 feed additives is not a surprise. Selle et al., (1999) observed the addition of a fungal phytase to a phosphorus adequate sorghum-based diet did not improve growth performance compared with non-phytase containing diets. The absence of a response to phytase could be due to the 'extra-phosphoric' effects of phytase. These stem in part from the prevention of *de novo* binary protein-phytate complex formation in the proventriculous and gizzard by the exogenous enzyme hydrolyzing phytate before complex formation (Selle et al., 2000).

Individually, SMBS and phytase supported higher N digestibility than the combination. The lack of positive responses from the combination of the feed additives could be due to the reduction of disulphide cross-linkages from feeding SMBS. The reduction of cross-linkages alters the structure of proteins and diminish their propensity to be complexed by phytate, which would attenuate phytase responses (Truong et al., 2015). Another possible cause for the lower phytase reaction could be to SMBS reducing disulphide cross-linkages in the enzyme itself therefore reducing its bio-efficacy.

In conclusion, based on the research discussed in this review it is possible to include sorghum into a broiler diet. The amount of sorghum in the diet may be determined by several factors including cost, addition of enzymes, or the addition of a reducing agent. When formulating broiler feeds with grain sorghum, producers should consider variety, particle size, processing conditions, and additives that all may influence sorghum feeding value for broilers.

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Chapter 2 - The effects of conditioning temperature and particle size of grain sorghum on the performance of male broiler chicks during the starter phase

Abstract

Grain sorghum may be grown in areas that receive less rainfall compared to corn. Although selection of sorghum varieties with limited tannins has increased nutrient digestibility when fed to poultry, sorghum-based diets offer a unique challenge due in part to the presence of kafirin, phenolic compounds, and phytate. Selection for increased protein yield in sorghum has led to increases in kafirin which is a major protein component of grain sorghum. When sorghum is steam conditioned and pelleted, evidence suggests that kafirin proteins may be damaged resulting in decreased nutrient utilization. A study was designed to determine feed manufacturing effects on sorghum-based broiler diets. A sorghum-soybean meal-based starter diet was formulated to meet breed specifications for broiler chicks. A roller mill was used to grind sorghum to 2 geometric mean particle sizes (PS): fine (398 μm) and coarse (766 μm) compared with unground sorghum (1760 μm). A CL-5 type CPM laboratory scale pellet mill was fitted with a 4 mm die and a 12.7 mm thickness. Each of the treatments were then conditioned to low (65.5 °C) or high (93 °C) temperatures for 26s, pelleted, then cooled and crumbled using a 2.5 mm roller gap on a lab scale crumble roll. Diets were provided to Cobb 500 male broiler chicks with 6 replications per diet and 6 chicks per cage for 18d in a Petersime battery unit. Performance data was analyzed by PROC Mixed of SAS and means were analyzed using the LSMEANS procedure of SAS. The results indicate that high (93°C) conditioning temperature (CT) improved pellet quality as determined by pellet durability testing. Diets with

higher durability resulted in larger crumbles. The chicks fed diets with whole sorghum had reduced growth performance compared to those fed ground diets. Conditioning temperature significantly improved gain:feed ratio (G:F) with a *P*-value of 0.023. Whereas particle size significantly improved feed intake (FI), bodyweight gain (BWG) and G:F with *P*-values of 0.029, 0.008, and <0.0001 respectively. The interaction of CT and PS was only significant in G:F, *P*-value = 0.013. The results indicate that sorghum PS was more important than CT when measuring growth and feed conversion of broiler chicks.

Introduction

Sorghum is an economically advantageous, energy dense grain grown in some areas that has slightly less energy than corn (Douglas et al., 1990). The energy in sorghum is derived from starch which presents a challenge for digestion in poultry. Liu et al., (2015) identified 3 factors that could be responsible for the poor starch and energy utilization: kafirin, phenolic compounds, and phytate. The starch in sorghum per se isn't poorly digestible, but it is these factors that contribute to the sub-standard starch and energy utilization.

Kafirin is the dominant protein fraction in sorghum. Virupaksha and Sastry (1968) reported that kafirin accounts for 54.1% of endosperm protein in sorghum. It is in protein bodies that are intertwined with the glutelin protein matrix inside the sorghum endosperm. Gidley et al., (2011) demonstrated the close physical proximity of these elements could be hindering starch utilization. The endosperm cell wall could also be inhibiting utilization. Taylor et al., (1984) reported that kafirin levels were positively correlated (r = 0.469; $P < 0.005$) with sorghum protein concentrations. Thus, selecting sorghum quality based on protein concentrations may result in increased kafirin levels.

Condensed tannin is a polyphenolic compound found in sorghum that negatively impacts broiler performance (Nyachoti et al., 1997; Duodu et al., 2003). In “non-tannin” sorghum, phenolic compounds still decrease starch and protein utilization (Beta and Corke 2004). Red (non-tannin) sorghums are pigmented with polyphenols, anthocyanins, and anthocyanidins and these phenols all bind to starch (Taylor 2005). The phenolic compounds are in the pericarp and aleurone layer of sorghum whereas the starch granules reside in the endosperm. Without further processing it is unlikely any interaction between the starch and phenolic compounds would occur. Interactions may be initiated by grinding or steam-pelleting and take place during digestion (Liu et al., 2015). Based on Liu’s research it is likely that condensed tannin is not solely responsible for the anti-nutritive factors in sorghum but that the phenolic compounds found in sorghum play a vital role as well.

Phytase is an enzyme commonly added to broiler diets that helps break the bond of phosphate from the inositol ring of phytate. Phytate has been shown to negatively affect energy and protein utilization in broiler chickens (Selle and Ravindran, 2007; Selle et al., 2000; 2010). Phytase releases phytate bound phosphorous which increases phosphorous utilization. However, Ravindran et al., (2005) and Wu et al., (2004) reported that phytase has a reduced impact on starch and protein digestion in sorghum-based diets compared to a corn or wheat-based diets. Wu et al., (2004) suggested that the “extra-phosphoric” responses to phytase in sorghum are less pronounced than in other grains. The “extra-phosphoric” effects of phytase were largely due to phytase attenuating protein-phytate complex formation (Liu et al., 2015).

When grain sorghum is fed to broilers it is processed. It can be ground and used in a mash or pelleted diet. Pelleting poultry diets can lead to an increased rate of gain and improved feed efficiency. During the pelleting process steam is added to the feed in the conditioner to add moisture and heat to the diet. This gelatinizes starch granules and increases starch digestibility. Grinding feed decreases particle size and increases overall surface area. The larger surface area leads to increased feed utilization and nutrient digestion. Studies by (Gabriel et al., 2006; Amerah et al., 2007,2008) show that feeding larger particle sizes compared to small particle sizes can lead to improved bird health due to increased gizzard function and by altering microbial populations within the bird's gastrointestinal tract.

Therefore, the objective of this study was to test different particle sizes, conditioner temperatures, and their combinations in order to best utilize grain sorghum in broiler diets

Materials & Methods

The 6 sorghum-based broiler diets were manufactured at the Kansas State University O.H. Kruse Feed Mill. The 6 diets were all nutritionally identical, the only difference was the sorghum PS (see table 1). Sorghum was ground with a roller mill (RMS Roller Grinder, Model 924, Harrisburg, SD). There were 2 mean particle sizes produced; fine (398 µm) and coarse (766 µm) grind. Whole sorghum (1,760 µm) was also included as a 3rd treatment. Particle size was measured by Ro-Tap analysis and Pellet Durability Index was found using a tumble box (see table 2). The diets were mixed for 180 s with a mixer (Sudenga, Model No. M750) and pelleted on a pellet mill (CPM pilot scale single pass conditioner & pellet mill, CL5) with a 4 mm die and 12.7 mm thickness. The 3 diets were pelleted at 65.5 °C with a 26s conditioner retention time. The conditioning temperature was adjusted to 93 °C and the same die was used to produce 3 diets. The temperature of the conditioner was measured by placing a digital thermometer at the end of the conditioner before the pellet die. After pelleting, all 6 diets were crumbled on a lab scale crumble roll (CME Ecoroll7) that used a 2.5 mm gap.

This study was conducted using Petersime battery brooders located in an environmentally controlled room at the Kansas State University Poultry Farm. The care of the birds used in the trial conformed to the Guide for Care and Use of Agricultural Animals in Agriculture Research and Teaching (FASS). Each pen held 6 Cobb 500 male broiler chicks. There 6 replications per treatment. The duration of the study was 18 d. Feed and water were offered *ad libitum* with a 24 h light schedule. On day 18, body weights and feed intake were measured and used to calculate G:F. Performance data was analyzed by PROC Mixed of SAS and means were separated using the LSMEANS procedure of SAS.

Results

The pellet durability index (PDI) of the 6 diets range from 66% to 93%. The diet with the highest PDI was conditioned at 93 °C and included unground sorghum. The diet with the worst PDI was the coarse ground sorghum conditioned at 93 °C. Crumble particle size was also measured. The diet with the largest crumble particle size (2445 μm) was the unground sorghum conditioned at 93 °C, while the smallest (1211 μm) with the fine ground sorghum conditioned at 65.5 °C.

The only main effect interaction observed was in G:F (*P*-value = 0.013). This interaction was caused by the numerical increase of FI by CT and the significantly increased FI and BWG by PS.

There were no CT by PS interactions ($P > 0.10$) observed for any response criteria except for G:F. In birds fed 65.5 °C conditioned diets, increasing particle size worsened FE. However, in 95 °C conditioned diets, G:F was poorest for broilers fed the coarse ground sorghum, compared with fine ground sorghum, with those fed the whole sorghum intermediate.

Broiler chicks fed diets containing the fine sorghum had significantly ($P < 0.05$) greater BWG (0.70 kg) compared to the diets containing coarse and whole sorghum, 0.65 kg and 0.66 kg respectively.

The diets conditioned at 65.5 °C had a significantly increased G:F (0.756) than compared to the diets conditioned at 93 °C (0.736). Conditioning temperature did not impact any other performance trait.

Feed Intake was significantly increased ($P < 0.05$) in the diets with fine and coarse ground sorghum and 93 °C CT when compared to diets with whole sorghum at 65.5 °C and 93 °C CT. Chicks fed finely ground diets had a significantly greater ($P < 0.05$) BWG, compared to chicks fed all other diets except the whole grain sorghum conditioned at 65.5 °C. Gain:feed ratio was also significantly improved ($P < 0.05$) in diets with fine grinding, when compared to all other treatments. The results from the study indicate that the particle size may have more of an impact on performance of birds being fed a sorghum-based diet than CT.

Discussion

Steam pelleting is used in the production of broiler feed to improve performance through increased nutrient utilization. Cereal grains are ground to increase surface area while also increases nutrient utilization. After mixing, broiler feeds are subjected to heat and moisture during the pelleting process. In the present study, the effects of PS and CT on sorghum-based broiler diets were investigated. In agreement with Truong et al., (2015), the results showed that increasing CT leads to a significant decrease in FE. Sorghum is vulnerable to “moist heat” which can lead to decreased protein solubility due to the increase in disulphide cross-linkages formed during the steam pelleting process. In a review, Duodu et al., (2003) discussed the negative impact “moist heat” can have on sorghum protein digestibility by cooking sorghum in boiling water. This is attributed to the relative hydrophobicity of kafirin, disulphide cross-linkages involving the glutelin protein matrix, and the phytate content of sorghum. This could be a likely cause for the poorer G:F observed in the present study.

In a study involving both hard and soft sorghums, Healy et al., (1991) observed that diets with a geometric mean PS of 900 µm were associated with the poorest FE and BWG, whereas diets with a geometric mean PS of 500 µm were associated with the greatest BWG and FE, similarly to the results reported in the present study. Using hard sorghum, Cabrera et al., (1994) reported that decreasing PS from 1000 to 400 µm improved BWG (5.5%), FI (7.5%), and FE (5.1%) of broilers from 7 to 28 days of age. Using soft sorghum increasing PS from 400 to 1000 µm improved BWG (10.7%), FI (2.0%), and FE (5.5%). Given these results it appears sorghum grain texture may be an influential factor in digestibility, but further investigation is required. In the present study PS did significantly improve BWG and FE with p-values of 1.08% and 1.06% respectively. The diets with the finely ground sorghum numerically outperformed all the other diets based on FI, BWG, and FE.

In contrast to results from the present study, an experiment was conducted by Selle et al., (2016) that compared sorghum-based diets with different geometric mean PS. The results showed that BWG and FE were optimized by diets containing larger PS (approximately 1,400 µm), regardless of type of sorghum. Similarly, Nir et al., (1990) reported comparing broilers fed a “fine” and a “coarse” (unspecified PS) diets resulted in birds fed the “coarse” diet having an increased BWG by almost 5%. Supporting earlier results, Nir et al., (1995) observed an increase in overall performance in broilers 7 to 21 d offered corn-, sorghum-, and wheat-based diets with a geometric mean PS of 1,130-1,230 µm compared to diets with a mean PS of 570-670 µm. The treatments with the greatest BWG and FE from the present study were observed in diets containing finely ground sorghum. Increased PDI may lead to less sorting at the feeder. Smaller PS also increases surface area inside the bird's gastrointestinal tract which leads to an increase in nutrient digestion. Generally, the cost of grinding a grain to a smaller PS can be made up by an increase in performance traits similar to what was seen in the present study.

Based on the present research, sorghum can be a beneficial ingredient in broiler diets when ground to a fine geometric mean PS and steam pelleted at a 65.5 °C CT. Various conflicting research for and against including grain sorghum in broiler diets shows that further research into processing sorghum is needed.

Table 2.1 Starter Diet Formulation and Nutrient Composition (%, as-fed basis)

Ingredient	**Diet**
Sorghum 11%	63
Soybean meal 46.75% CP	30
Soybean oil	2
Limestone	1.6
Monocalcium phosphate 21%	1.7
Salt	0.5
Sodium bicarbonate	0.2
L-Lysine HCL	0.2
DL-Methionine	0.3
L-Threonine	0.1
Poultry vitamin premix[1]	0.3
Choline chloride 60%	0.1
Calculated composition	
Crude protein, %	20.2
Lysine, %	1.22
Methionine, %	0.62
Total sulfur amino acids, %	0.96
Threonine, %	0.85
Calcium, %	1.0
Phosphorous, %	0.71
Sodium, %	0.28

[1] Provided by Nutrablend, Neosho, MO NB 3000 Supplied at per kg of diet .02% manganese, .02% zinc, .01% iron, .0025% copper, .0003% iodine, .00003% selenium, .69 mg folic acid, 386 mg choline, 6.61 mg riboflavin, .03mg biotin, 1.38 mg vitamin B_6, 27.56mg niacin, 6.61 mg pantothenic acid, 2.20 mg thiamine, .83 mg menadione, .01 mg vitamin B_{12}, 16.53 IU vitamin E, 2133 IU vitamin D_3, 7716 IU vitamin A.

[2] Diets were nutritionally identical, the only change was sorghum particle size

Table 2.2 Diet Pellet Durability Index and Particle Size Data

CT[1] × PS[2]	Pellets Remaining (%)	Crumble Particle Size (microns)
65.5 × Fine	0.75	1211
65.5 × Coarse	0.92	1925
65.5 × Whole	0.795	1920
93 × Fine	0.875	2042
93 × Coarse	0.66	1236
93 × Whole	0.93	2445

[1] CT = Conditioning Temperature °C

[2] PS = Particle Size: Fine = 398 µm Coarse = 766 µm Whole = 1760 µm

Table 2.3 The effects of conditioning temperature and particle size of grain sorghum on the performance of male broiler chicks during the starter phase

CT[1]	PS[2]	Feed Intake (kg)	Bodyweight Gain (kg)	Gain:Feed
65.5	Fine	5.31^{ab}	0.70^{b}	0.789^{d}
65.5	Coarse	5.22^{ab}	0.65^{a}	0.747^{bc}
65.5	Whole	4.89^{a}	0.67^{ab}	0.732^{b}
93	Fine	5.47^{b}	0.70^{b}	0.770^{cd}
93	Coarse	5.62^{b}	0.65^{a}	0.694^{a}
93	Whole	5.08^{a}	0.65^{a}	0.744^{bc}
SEM		0.17	0.02	0.01
65.5			0.67^{a}	0.756^{b}
93			0.67^{a}	0.736^{a}
SEM			0.01	0.01
	Fine		0.70^{b}	0.779^{b}
	Coarse		0.65^{a}	0.720^{a}
	Whole		0.66^{a}	0.738^{a}
SEM			0.01	0.01
Treatment Effects			**P-value**	
CT		0.0823	0.6989	0.0232
PS		0.0293	0.0086	<0.0001
CT × PS		0.7435	0.6866	0.0126

[a-b] Numbers without similar superscript are significantly different ($P < 0.05$)

[1] CT = Conditioning Temperature °C

[2] PS = Particle Size: Fine = 398 µm Coarse = 766 µm Whole = 1760 µm

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Chapter 3 - The effects of conditioning temperature and addition of sodium metabisulfite on the performance of male broiler chicks fed sorghum-based rations during the starter phase

Abstract

A reducing agent such as sodium metabisulfite (SMBS) can be added to a sorghum-based broiler chicken ration to help increase energy utilization. This study was conducted to test the effect 1.75 g/kg of SMBS on performance characteristics combined with 2 conditioning temperatures. The present study showed that diets containing SMBS had a significantly lower G:F when compared to other diets. Conditioning temperature had a significant effect on G:F also. The lower CT increased G:F. Bodyweight gain (BWG) was significantly improved in the diet conditioned at 93 °C without the addition of SMBS. Gain:feed ratio was significantly reduced in the diet containing SMBS and conditioned at 93 °C. There were no other significant effects for CT or the addition of SMBS.

Introduction

Because sorghum may be vulnerable to steam pelleting due to the "moist-heat" inducing disulphide cross-linkages (Selle et al., 2010), it may be beneficial to include a reducing agent in hydrothermally processed sorghum-based diets. Sorghum starch has a higher gelatinization temperature (68-78 °C) compared to corn (62-72 °C) (Taylor and Dewar, 2001). Therefore, the steam pelleting process requires higher temperatures to achieve better pellet quality. The protein in sorghum is especially vulnerable to the 'wet heat,' and when processed, disulphide linkages may form in the glutelin protein matrix (Selle et al., 2010). The formation of the disulphide linkages in the β- and γ-kafirin fractions may lead to decreased protein digestion of the α-kafirin core (Selle et al., 2010). For example, Selle et al., (2012) showed that in steam pelleted sorghum-based diets at 90°C the disulphide linkages increased from 33.88 µmol/g protein to 34.95 µmol/g and protein solubility was reduced from 56.3% to 38.3%. Reduced protein solubility has been shown to increase protein denaturation (Choi et al., 2010). Increased protein denaturation may lead to lower quality carcass characteristics.

Several studies have shown that including a reducing agent such as sodium metabisulphite (SMBS) when 'wet cooking' sorghum increases *in vitro* starch and protein digestibility (Hamaker et al., 1987; Rom et al., 1992; Choi et al., 2008). Inclusion of other reducing agents such as dithiothreitol and sodium bisulphite have significantly improved *in vitro* protein digestion in sorghum-based diets during wet-cooking (Choi et al., 2008).

Research has indicated that including the reducing agent SMBS in sorghum-based broiler diets may increase performance of broiler chickens through increased energy utilization (Selle et al., 2013; 2014; Liu et al., 2014; Truong et al., 2016). When SMBS is included at 3.50g/kg of the sorghum-based ration, N-corrected apparent metabolizable energy (AMEn) was increased by 0.42 MJ from 11.43 to 11.85 MJ/kg in broiler diets based on 5 different sorghum varieties (Truong et al., 2016). Sodium metabisulfite included at 1.75 g/kg and steam pelleted at 80 °C was shown to numerically improve weight gain by 3.3 % (Truong et al., 2015). The sulphite reducing agent's, "energy sparing" effect could be attributed to the depolymerisation of starch polysaccharides by oxidative-reductive reactions (Paterson et al., 1996, 1997) and/or the reduction of disulphide cross-linkages in the sorghum protein. Kafirins can form resilient structures between and within protein bodies due to the presence of disulphide cross-linkages which could interfere with digestive enzyme accessibility (De Mesa-Stonestreet et al., 2010). Sorghum requires a higher temperature to gelatinize (68-78°C) when compared to corn (62-

72°C) or wheat (58-64°C), (Taylor and Dewar 2001), thus when steam pelleted, sorghum-based diets need to be pelleted at 90-95°C to achieve the same pellet quality as corn and wheat. In a previous study Seitz et al (2017), found that steam pelleting a sorghum-based diet at 93°C resulted in a worse FE compared to a diet pelleted at 65.5°C. Producers with high pellet durability index requirements could be pelleting between 90-95°C thus reducing nutrient utilization in sorghum-based broiler diets.

Previously, Liu et al., (2014) showed that the inclusion of SMBS significantly improved the rapid visco-analysis (RVA) pasting properties at 7 inclusion levels (0-5.25 g/kg) which linearly decreased final viscosity of starch (r = -0.925) in sorghum-based diets. Presumably the oxidative-reductive depolymerisation reactions generated slowly digestible starch and lead to increased energy utilization and feed efficiency.

A study performed by Abdollahi et al., (2010) observed that increasing conditioning temperatures from 60 to 90 °C significantly decreased ileal starch digestibility. The impact on starch digestibility did not affect broiler performance characteristics such as weight gain and feed efficiency. The lack of correlation between improved digestibility and broiler performance may indicate that broiler growth performance characteristics correlate with starch and protein digestion more so than with digestibility coefficients (Liu et al., 2013).

Sodium metabisulfite may be advantageous in sorghum-based broiler diets due to its positive effects on energy utilization and feed efficiency as previously mentioned. It may also be advantageous in an economical sense as it can act as a replacement to sodium bicarbonate to maintain dietary levels in a balanced ration.

Materials and Methods

All procedures reported herein were approved by the Kansas State University Institutional Animal Care and Use Committee.

The 4 diets were formulated to meet or exceed recommendations of the National Research Council (NRC, 1994 Table 1). Treatments were arranged as a 2 × 2 factorial arrangement with main effects of conditioning temperature (65.5 °C or 93 °C) or sodium metabisulfite addition (none or 1.75 g/kg) diet. The feed was mixed by a paddle type mixer (Sudenga M750) for 180s prior to pelleting. The pelleting was performed by a lab scale single pass conditioner California Pellet Mill (CL5, CPM, Waterloo, IA) with a 4 × 12mm pellet die. The conditioner retention time was 26 s at 25 psi of steam. After pelleting representative samples were collected and measured for PDI. Pellets were then processed through a lab scale roller mill (Ecoroll7, Colorado Milling Equipment) with a 2.5 mm gap. A representative sample of the crumbles were collected and measured for particle size.

This study was conducted using Petersime battery brooders located in an environmentally controlled room at the Kansas State University Poultry Research Farm. The care of the birds used in the trial conformed to the Guide for Care and Use of Agricultural Animals in Agriculture Research and Teaching (FASS). Each pen held 6 Cobb 500 male broiler chicks with 6 replications per treatment. The study lasted 18 d. Feed and water were offered ad libitum with a 24 h light schedule. On the 18^{th} d body weights and feed intake were measured and used to calculate G:F. Performance data were analyzed by PROC Mixed of SAS and means were separated using the LSMEANS procedure of SAS.

Results and Discussion

The pellet durability index and particle size of the sorghum-based diets are shown in table 3.2. Temperature did have a main effect on FI, as the chicks fed the diets that were pelleted at the higher CT had an increased FI by 5.96%. Temperature also had a main effect on G:F. The diets pelleted at the lower CT had an increased G:F by 5.15%. The inclusion of SMBS also had a main effect on G:F. The diets with SMBS had a significantly lower G:F than the diets without SMBS.

Feed intake per chick was significantly higher in the diet with high CT and SMBS, the diet pelleted at the high CT but without SMBS had the second highest FI per chick. These results could be due to an increased pellet durability leading to a decrease in the number of fines in the feed. Proudfoot and Sefton (1978) found that broiler performance decreased as the proportion of fines increased. Gain:feed ratio for the same diet pelleted at the high CT with SMBS was significantly lower than the other treatments. This could be due to sorghum being vulnerable to "wet-heat" leading to decreased nutrient utilization (Selle et al., 2010). No other broiler performance characteristics were significantly impacted by either the CT or the inclusion of SMBS.

The current study shows that the inclusion of SMBS at 1.75 g/kg might not be beneficial to broilers fed sorghum-based rations. Truong et al., (2015) reported similar results where the inclusion of 1.75g/kg SMBS did not influence growth performance. A 3.27% improvement in weight gain was observed by Truong, but it was not significant. They believed these results could be due to the type of red sorghum added to the diets.

Studies performed by Selle et al., (2014) and Liu et al., (2014) reported positive results when SMBS was included in the sorghum-based diets. It was suggested that the positive effects of SMBS were due to the oxidative-reductive depolymerization of starch polysaccharides which generated slowly digestible starch. The effects are also thought to be contributed to the reduction in disulfide cross-linkages in starch proteins.

Conclusions and Applications

1. SMBS may need to be included at higher amounts to counteract the negative effects of pelleting at higher temperatures.
2. Differences in pellet durability could play a part in the results due to feed form effect.

Table 3.1 Starter Diet Formulation and Nutrient Composition (%, as-fed basis)

Ingredient, %	Diet
Sorghum 11%	63
Soybean meal 46.75% CP	30
Soybean oil	2
Limestone	1.6
Monocalcium phosphate 21%	1.7
Salt	0.5
Sodium bicarbonate	0.2
L-Lysine HCL	0.2
DL-Methionine	0.3
L-Threonine	0.1
Poultry vitamin premix[1]	0.3
Choline chloride 60%	0.1
Calculated composition	
Crude protein, %	20.2
Lysine, %	1.22
Methionine, %	0.62
Total sulfur amino acids, %	0.96
Threonine, %	0.85
Calcium, %	1.0
Phosphorous, %	0.71
Sodium, %	0.28

[1] Provided by Nutrablend, Neosho, MO NB 3000 Supplied at per kg of diet .02% manganese, .02% zinc, .01% iron, .0025% copper, .0003% iodine, .00003% selenium, .69 mg folic acid, 386 mg choline, 6.61 mg riboflavin, .03mg biotin, 1.38 mg vitamin B_6, 27.56mg niacin, 6.61 mg pantothenic acid, 2.20 mg thiamine, .83 mg menadione, .01 mg vitamin B_{12}, 16.53 IU vitamin E, 2133 IU vitamin D_3, 7716 IU vitamin A.

[2] Diets were nutritionally identically except for the addition of sodium metabisulfite.

Table 3.2 Diet Pellet Durability Index and Particle Size Data

CT[1] x SMBS[2]	Pellets Remaining (%)	Crumble Particle Size (microns)
65.6 × 0	75	1198
65.5 × 1.75	92	1236
93 × 0	79	883
93 × 1.75	87	1070

[1] CT = Conditioning Temperature °C

[2] SMBS = Sodium Metabisulfite (g/kg)

Table 3.3 The effects of conditioning temperature and inclusion of sodium metabisulfite on the performance of male broiler chicks fed sorghum-based rations during the starter phase

CT[1]	SMBS[2]	Feed Intake (kg)	Bodyweight Gain (kg)	Gain:Feed
65.5	0	4.11[a]	3.16[a]	0.767[b]
65.5	1.75	4.56[a]	3.39[a]	0.744[b]
93	0	4.66[a]	3.53[b]	0.753[b]
93	1.75	4.18[a]	2.90[a]	0.683[a]
SEM		0.21	0.21	0.02
65.5		4.33[a]	3.27[a]	0.755[b]
93		4.42[a]	3.21[a]	0.718[a]
SEM		0.15	0.15	0.01
	0	4.39[a]	3.34[a]	0.760[b]
	1.75	4.37[a]	3.14[a]	0.714[a]
SEM		0.15	0.15	0.01
Treatment Effects			**P-Value**	
CT		0.6773	0.7647	0.0398
SMBS		0.9346	0.3443	0.0133
CT × SMBS		0.0375	0.0484	0.1845

[a-b] Numbers without similar superscript are significantly different (p<.05)

[1] CT = Conditioning Temperature °C

[2] SMBS = Sodium Metabisulfite (g/kg)

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