NUTRITIONAL VALUE OF SORGHUM FOR POULTRY FEED IN WEST AFRICA

by

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B.S., Agronomic and Veterinary Institute Hassan II, Rabat, Morocco, 1990
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AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2009

ABSTRACT

A total of 2,840 1-d-old broiler chicks and 450 1-d-old layer chicks were used in three experiments to determine the nutritional value of corn- and sorghum-based diets in poultry reared in West Africa. In the broiler experiments, birds fed corn had greater average daily gain ($P < 0.001$) with similar carcass weight and yield for birds fed corn- vs sorghum-based diets ($P > 0.18$). Particle size treatments did not affect growth performance or carcass characteristics ($P > 0.20$). In the layer experiment, birds fed sorghum had greater body weight at d 126 ($P < 0.001$), started laying earlier ($P < 0.01$), ate more feed ($P < 0.01$), and produced more eggs ($P < 0.01$) than birds fed the corn-based diet. However, there was no difference in average egg weight among birds fed corn vs sorghum ($P > 0.85$). In conclusion, sorghums produced in West Africa are a good alternative to corn when fed to broiler chicks and laying hens.

Key Words: Corn, Sorghum, Particle-size, Broilers, Layers

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Dedication

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CHAPTER 1 -

Sorghum in Poultry Diets: A Review of the Literature

INTRODUCTION

Grain sorghum (*Sorghum bicolor* (L.) Monch) is a drought resistant cereal that is produced worldwide. Sorghum is the fifth most important crop after wheat, rice, corn, and barley (Bryden et al., 2009). However, in West Africa sorghum is the 2^{nd} most important cereal grain after millet and just before corn (Table 1.1). Also, sorghum is the primary alternative feedstuff for corn in the U.S., Central America, South America, and Asia and for wheat in Australia. In contrast to corn use in the Americas, in Africa and India sorghum is a staple food used secondarily as feed (Maunder, 2002; Abdoulaye et al., 2006).

Major sorghum producing countries are the U.S., India, Nigeria, Mexico, China, Sudan, Argentina, and Australia. Worldwide the area planted to sorghum steadily increased from 24 to 46 million ha between 1950 and 1980, but has decreased and stagnated at 41 million ha for the past 20 years. Globally average yield increased from 0.57 to 1.48 metric tons/ha (260%) from 1950 to 2000 whereas the sorghum yield in the U.S. averaged 4.4 metric tons/ha during that same time period. According to Maunder (2002), from 1992 to 1994 Africa was producing 17.1 million metric tons (27% of the world's production) on 21.8 million ha (48% of the world's planted area).

The major constraints for sorghum production in West Africa are water stress, availability of seeds of improved varieties and hybrids, fertilizers, and pest and disease control. To cope with abiotic stress, drought-tolerant varieties and hybrids were released in North Africa (Sudan) in 1983 and Niger in 1992 (INTSORMIL, 2007). However, the acceptance and widespread adoption of these improved genotypes of sorghum will take many years. Because of the high cost of production inputs and low income of producers, Africa with 12% of the world's population uses only 2% of the world's fertilizer. Fertilizer and pesticide accessibility to producers are key factors in boosting sorghum production in West Africa just as in any other location around the globe.

Finally, sorghum is subject to parasite threats such as *Striga*, ergot, and *Fusarium* in Africa. *Striga* is a plant parasite that attaches to sorghum roots from where it takes nutrients and inhibits plant and seed yield. *Striga* affects almost 40% of the sorghum grown in Africa causing over $90 million United States Dollar (USD) in crop damage. *Striga* resistant varieties for sorghum in East and West Africa have been developed but their acceptance and widespread use will take decades to accomplish (INTSORMIL, 2007). Ergot (*Claviceps africana*) is a constraint in Africa, Australia, and India mainly when planting is delayed (Bandyopadhyay et al., 2002). Ergot can cause crop loss, and ergot alkaloids are toxic to cattle, poultry, and swine (INTSORMIL, 2007). In addition to ergot, *Fusarium verticillioides* can infect sorghum and millet and produce mycotoxins.

Among insects, midge (*Contarinia sorghicola*) is a major sorghum pest in Africa and Australia. Midge resistant varieties tested in Niger in 2006 performed well (INTSORMIL, 2007) and the widespread use of these varieties will contribute in more grain of good quality.

The next issue worth noting is one of marketing and utilization. In Africa, Australia, and the U.S. sorghum generally is less expensive than corn or wheat (Abdoulaye et al., 2006; Blein et al., 2009). However, there remains a perception of suboptimal performance in birds fed sorghum-based diets compared to those fed corn- or wheat-based diets (Table 1.2). Thus, the objectives of this review are:

1. To understand the reasons for the perception (true or false) of lower performance in birds fed sorghum-based diets
2. To identify the main anti-nutritional factors in sorghum grain, their actual effects on poultry performance and how to prevent/alleviate their negative effects
3. To make some recommendations regarding improvement in utilization of sorghum in poultry diets especially as related to West Africa.

SORGHUM GRAIN PHYSIOCHEMICAL CHARACTERISTICS

Production environment, processing, and physiochemical characteristics are major factors affecting the nutritional value of sorghum grain. Albin (1975) studied the effect bushel weight (435, 601, 639, 665, 691, and 742 kg/m^3) and seed size (< 2.8 or > 2.8 mm) on the nutritional value of sorghum. Dry matter, crude protein, ether extract, gross energy, and ash were similar among samples of sorghum with different bushel weights, but there was a linear increase in crude fiber as bushel weight decreased. Lower values for starch availability and gelatinization with steam flaking were reported for sorghum with test weights < 511 kg/m^3. Similarly, ADG and G:F for pigs fed diets with 408 kg/m^3 sorghum (0.67 kg and 263 g/kg) were lower than for pigs fed diets with 611 kg/m^3 sorghum (0.71 kg and 284 g/kg) and 691 kg/m^3 sorghum (0.70 kg and 270 g/kg) (Tribble et al., 1987). In broilers, there was a linear decrease in ADG, G:F, and metabolizable energy (ME_n of 3,535 to 3,268 kcal/kg) when birds were fed sorghum with 701 to 446 kg/m^3 (Hancock et al., 1990). Irrigation and nitrogen fertilization increased the yield of utilizable nutrients in both corn and sorghum grain (Hancock et al., 1990) moreover, it seems likely that these two management tools could be effective at preventing the negative effect of environmental stress as seen with test weight.

Techniques such as the single kernel characterization system (SKCS) have been adapted for sorghum (Bean et al., 2006) and are practical and useful to assess the physiochemical characteristics of sorghum, thus helping to predict the nutritional value of sorghum grain. Lee et al. (2002) studied the relationship of sorghum kernel diameter 2.36 mm (small), 2.80 mm (medium), and 3.35 mm (large) to physiochemical and processing properties. The authors reported that for large, medium, and small grain, loss after 1 min decortications was 5.5, 6.5, and 18.5%, crude protein was 12.7, 12.2, and 12.4%, starch was 75.7, 74.7, and 74.5%, and ash was 1.56, 1.60 and 1.78%. In addition, Travis et al. (2006) reported ME values of 3.51 Mcal/kg for corn, 3.48 Mcal/kg for sorghum offspring of a large-seeded male parent (KS115), and 3.36 Mcal/kg for normal-seeded hybrids (Table 1.3). Thus, the authors concluded that use of KS115 as a mean of increasing seed weight and fat content would improve the nutritional value of sorghum grain.

PROTEINS IN SORGHUM GRAIN

Corn typically has 1% more crude fat than sorghum, but typically sorghum has 1% more crude protein than corn. Otherwise, the gross physiochemical characteristics of corn and sorghum are similar and these cereals have similar amino acid profiles (Table 1-4). These facts lead Rooney and Serna-Saldivar (2000) to suggest that reports of low performance in poultry and swine fed sorghum-based diets resulted from protein and starch characteristics and possibly use of sorghum with high tannin and phytate content.

Protein content in sorghum is variable and ranges from 10 to 6% with approximately 80, 16, and 3% of the protein in the endosperm, germ, and pericarp respectively (Gualtieri and Rapaccini, 1990; Rooney and Serna-Saldivar, 2000). The major protein fraction in sorghum is the kafirins (alcohol soluble) followed by alkali soluble or acid extractable (Bryden et al. 2009). Kafirins are storage proteins found in protein bodies, while glutelins are localized in the protein matrix. Kafirins are characterized as α-, β-, and λ- and they comprise 70 to 80% of total protein in sorghum (Hamaker et al., 1995; Salinas et al., 2006). Within the kafirins, α-, β-, and λ-kafirins represent 75, 15, and 10%, of the total protein (Oria et al., 1995). The amino acid composition of β-and λ-kafirins are unique because of their high content of cysteine and histidine that increase disulfide linkage formation among the different protein fractions. Kafirins also have high content in proline, glycine, glutamine, and asparagine (Table 1-5) which place them among the list of proline-rich-proteins (PRP). The PRP have 1,000 times the affinity for tannins compared to the other proteins and are thought to be the first defense in humans and other mammals adapted to high tannin food (Butler et al., 1992).

Researchers at Purdue University developed sorghum mutants with high digestibilities of protein and starch. Oria et al. (2000) demonstrated that the shape of protein bodies is a key factor in sorghum protein digestibility. In highly digestible sorghum proteins, transmission-electronic-microscopy revealed that α-, β-, and λ-kafirins are localized within protein bodies. The protein bodies were irregular in shape, folded, and had numerous deep invaginations. Protein bodies of normal sorghum were spherical and contained no invagination and the λ-kafirins were concentrated at the base of the folds instead of at the protein body periphery. Furthermore, Benmoussa et al. (2006) demonstrated that the mutant line (111) has spherical starch with dense channels (i.e., many pores).

STARCH AND ENERGY IN SORGHUM GRAIN

Starch is the major proximate component (63 to 74%) and the major energy supplier in sorghum grain (Perez-Maldonado and Rodriguez, 2007). Starch granules consist of a linear polysaccharide called amylose (20-30% of starch) and a highly branched polysaccharide called amylopectin (70-80% of starch). Sorghum starch granules are surrounded by a protein matrix that can limit access of enzymes (Oria et al., 2000; Benmoussa et al., 2006).

Other factors important to the energy value of sorghum include channels or pores on starch granules that are sites for enzyme entry (Benmoussa et al., 2006), granule size, starch-lipid complexes, kafirin content (Watterson et al., 1993; Cao et al., 1998), and kernel size (Ioerger et al., 2007). Additional factors affecting sorghum starch digestibility are waxiness and hardness. Waxy starch is more digestible than starch of non-waxy (conventional) sorghum (Table 6). Unfortunately, waxy sorghums have lower yields compared to non-waxy lines (Rooney and Serna-Saldivar, 2000) and seed companies have placed no emphasis on developing high-yielding waxy germplasm. Data from 280 sorghum samples in Australia revealed a range in kernel diameter from 2.4 to 4.8 mm and diameter was negatively correlated to percentage vitreousity. Vitreous endosperm contains more protein, kafirins and disulfide bonds than floury endosperm which has more soluble protein (Bryden et al., 2009). Cao, et al. (1998) reported feed:gain of 1.49 in broilers fed soft sorghum-based diets vs 1.68 for birds fed medium and hard sorghum-based diets. The differences in kafirin structure likely contribute to the differences in bird performance reported by Cao et al. (1998). Abdelrahaman and Hoseney (1984) reported that sorghum's cross-linked kafirins cause hardness.

PHENOLIC COMPOUNDS IN SORGHUM GRAIN

Cheeke (1998) classified phenolic compounds as simple phenol, phenolic acids, hydrolysable tannins, condensed tannins, lignin, and lignans. All of them consist of one or more aromatic (benzene) and one hydroxyl group which enable formation of cross linkages with proteins such as kafirins, cellulose, and phytate. Among cereals, a unique characteristic of sorghum is having some cultivars that produce large amounts of condensed tannins. Total phenols in sorghums range from 2 to 103 g/kg, while they are negligible in corn and wheat and 14 g/kg in barley (Bravo, 1998).

Using the vanillin-HCl method for condensed tannin determination, the presence of a testa, and the testa color allowed Price et al. (1978) and Cheng et al. (2009) to provide sorghum breeders and users a practical and useful approach to determination of tannin content . The authors stated that white sorghum without testa or with purple testa and yellow or red sorghum without testa have very low percentage of tannins (0.0 to 0.2% tannin); whereas white, yellow or red sorghums with brown testa have medium to high tannin content (1.2 to 12.8%).

Animal nutritionists are interested in tannins because they bind protein, cellulose, hemicelluloses, pectin, phytate, and minerals to form, indigestible complexes (Van Soest, 1994). Many studies have reported that diets with tannin-sorghum affect feed intake and feed efficiency in broilers (Amstrong et al., 1974; Sell et al., 1985; Douglas et al., 1990; Gualtieri and Rapaccini, 1990; Nyachoti et al., 1997; Hancock, 2000). Butler et al. (1992) suggested that tannins coagulate and precipitate proteins (including digestive enzymes) while Sell et al. (1984) and Nyanmambi et al. (2007) argued that tannins reduced crypt depth, intestinal wall thickness, and sucrase activity with increased mucus production. Donald et al. (2008) reported similar intestinal morphology for broilers chicks fed corn-, sorghum-, and wheat-based diets although birds fed corn- and wheat-based diets had better growth performance compared to those fed the sorghum-based diet. Lucbert and Castaing (1986) reported ME of 3,306, 3,028, and 2,888 kcal/kg for sorghum with 0.23, 1.0, and 1.4 % tannins and concluded ME decreased by 40 kcal for each 0.1% tannin above 0.23%. Douglas et al. (1990) reported ME of 3,838 and 3,200 kcal/kg for low- and high-tannin sorghum, respectively. The authors reported that adding animal fat can improve nutritive value of tannin-sorghums. As for protein utilization, when compared with corn, apparent amino acid digestibility for low-, medium, and high-tannin sorghum was 73, 41, and 22%, respectively, in growing chicks (Rostagno et al., 1974). However, Donkoh et al. (2009) reported ileal amino acid digestibilities of 86.2% for corn, 85.5% for low-tannin (0.38% CE) sorghum, and 80.6% for high-tannin (1.87% CE) sorghum.

Egg production, egg weight, and yolk coloration were decreased when tannic acid was 2% of layers diets (Gualtieri and Rapaccini, 1990). Armanious et al. (1973) reported sorghum with 0.6% or less tannin content could be used in layer diets with adequate methyl donors (e.g., methionine) and xanthophylls. In addition, Sell et al. (1984) reported no negative effect of tannins and a positive effect of methionine addition in layers fed sorghum-based diets. In a 24-wk trial in Kenya, Jacob et al. (1996) reported egg production of 71% for layers fed corn-based diets vs 65% for those fed sorghum-based diets with 3.7% tannins. However, Ambula et al. (2003) reported that varying tannin level from 0 to 3.1% of the diet by graded inclusion of high-tannin sorghum did not affect egg production (69 to 71%), egg weight (57 to 61 g), and egg specific gravity (1.083 vs 1.090 mg/mL). In a 42-d experiment, corn, low-tannin sorghum (0.6%), high tannin sorghum (3.7%), and bentonite (2.5 or 5%) were tested in layers. Birds fed low- tannin sorghum performed better than birds fed corn or high- tannin sorghum. Bentonite treatment did not improve the nutritive value of the high-tannin sorghum (Ambula et al., 2003). Similarly in an 18-month experiment, Issa et al. (2007) reported 57% egg production for layers fed low-tannin (0.3%) sorghum vs 47% for birds fed a corn-based diet. However egg weight (48 g) was similar for all birds.

It is thought that tannins provide protection for plants against fungi, bacteria, birds, and herbivores (Nyachoti et al., 1997; Perez-Maldonado, 2008). Monge et al. (2007) reported that broiler chicks can tolerate dietary tannin concentrations of 1.35% before their growth performance is compromised. Fortunately, most cultivated sorghums do not contain condensed tannins (Hagerman and Butler, 1998; Abdoulaye et al., 2006) and it is well established that sorghum can be used as the sole grain source in either broiler or layer diets without compromising performance (Parthasarathy et al. 2005; Travis et al., 2006; Issa et al., 2007; Nyannor et al., 2007).

PHYTATE IN SORGHUM GRAIN

Phytate is a mixed salt of phytic acid (myo-inositol hexaphosphate) that occurs in plant feedstuffs. Digestibility of plant phosphorus in monogastrics ranges from 23 to 69% with a value of 42% for sorghum (Wu et al., 2004). In addition to its ability to bind with P, phytate's anti-nutritional properties include its ability to complex with protein and minerals (Bryden et al., 2007). In contrast to tannins, sorghum phytate content has not been reduced through breeding research. Results of six surveys conducted between 1968 and 2003 showed that total P content in sorghum ranged from 3 to 4 g/kg and phytate-P content ranged from 2.1 to 2.4 g/kg (Nelson et al., 1968; Selle et al., 2003).

To improve the digestibility and utilization of P from phytate, poultry producers can use phytases. Use of bacterial phytase (*E.coli*) or fungal phytase (*A. niger*) has been shown by several authors to enhance P utilization in livestock and poultry (Michel and Edwards, 1996; Denbow et al., 1998; Dilger et al., 2004). Jondreville et al. (2009) stated that the two enzyme types have similar efficiency in broilers. However, Cowieson et al. (2004) reported reduced endogenous amino acid flow with phytase supplementation. But, the reduction was greater with bacterial phytase compared to fungal phytase.

TREATMENT AND PROCESSING OF SORGHUM TO ENHANCE ITS NUTRITIONAL VALUE

Early sorghum processing methods consisted essentially of chemical and mechanical detoxification as well as amino acid and mineral supplementation. However, during the last two decades processing sorghum grain by grinding, crumbling, pelleting, expanding, extruding, and steam flaking has become popular.

Processing to enhance its nutritional value

Alkali treatments to improve nutritional value of tannin sorghum include use of sodium or potassium hydroxide, sodium bicarbonate, and wood ash (Amstrong et al., 1974; Chavan et al., 1979). Price and Butler (1978) used ammonia concentrate (350g NH_3/kg) at room temperature for 7 days to reduce tannin concentration in high-tannin sorghum, while Mitaru et al. (1984) suggested ensiling high-tannin sorghum at 70% dry matter and at 25 ºC for 2 days. Kyarissima et al. (2004) reported a 62% tannin reduction with the wood ash method, however sprouting after wood ash treatment improved tannin reduction to 85%.

Supplementing the diet with 0.15 to 0.30% methionine or choline prevented the deleterious tannin effects (Sell et al., 1984). Douglas et al. (1990) reported that adding 1 to 2.5% fat was needed in sorghum-based diets with variable tannin content to achieve ME content similar to that of corn-based diets fed to broilers.

Grinding and hydro-thermal processing

Grinding grains before mixing into diets is thought to improve feed homogeneity, increase surface area for enzymatic degradation, and reduces selective feeding/sorting. However, results of particle size studies in broilers have shown conflicting results. In the U.S. broiler industry, cereal grains are usually ground through a hammermill equipped with screens having openings of 4 to 5 mm (Behnke, 2009). However, Reece et al. (1986) reported a 35% reduction in energy input and a 27% increase in hammermill throughput by increasing screen openings from 4 to 6 mm. In addition, Deaton et al. (1995) stated that increasing particle size from 679 to 1,289 μm saved 50% of energy cost without compromising body weight and feed efficiency in broilers at 49 d of age housed in either moderate (21ºC) or high (31ºC) temperature.

Healy et al. (1994) reported data from an experiment where corn and sorghums were ground to 900, 700, 500, and 300 μm. From day 0 to 7 d, maximum feed efficiency was achieved with particle sizes of 500, 500 and 300 μm for corn, hard endosperm sorghum, and soft endosperm sorghum, respectively. For d 0 to 21, maximum gains in body weight were achieved with particle sizes of 700 μm for corn, 500μm for hard endosperm sorghum, and 300 μm for soft endosperm sorghum. Gizzard weights were less for birds fed ground cereals with particle sizes of 300 μm. Similarly, Mikkelson et al. (2008) reported that broiler chicks fed a coarse, wheat-based diet outperformed those fed a coarse, sorghum-based diet. However, broiler chicks fed fine sorghum-based diets had numerically better growth performance than birds fed a finely ground wheat-based diet. Douglas et al. (1990) reported improvements of 8% in ADG and 3% in feed efficiency for broilers fed sorghum ground to 837 μm compared to birds fed sorghum ground to 1,786 μm. In contrast, Parsons et al. (2006) reported improved nutrient retention in broilers fed corn-based diets when corn particle size was increased from 781 to 1,042 μm. However, growth performance and energy metabolism decreased when corn particle size exceeded 1,042 μm because of an increase in size and maintenance requirement for the gastro-intestinal tract. Biggs and Parson (2009) reported that feeding broilers 10 to 20% whole grain of barley, sorghum, and wheat from d 0 to 21increased gizzard weights, ME, and amino acid digestibility.

In addition to the effects of grinding, Douglas et al. (1990) reported that pelleted diets improved weight gain and feed efficiency in broilers by 13 and 7%, respectively, compared to a mash diet. Similarly, Elkin et al. (1991) reported large improvements in weight gain (42%) and feed efficiency (15%) with a diet pelleted at 55 to 66ºC vs mash sorghum-based diets. In contrast, Nir et al. (1995) obtained only modest improvements in weight gain and feed efficiency for broilers fed sorghum based diets pelleted at 85 ºC. Cramer et al. (2003) fed broilers mash and crumbled sorghum-based diets pelleted or expanded at 85 ºC. Growth performance was similar for birds fed mash or crumbles. Finally, Cao et al. (1998) reported that broiler chicks fed extruded diets had lower performance to d 21 compared to those fed steam-flaked sorghum.

Bryden et al. (2009) reported that starch gelatinization usually does not exceed 200 g/kg following steam conditioning and pelleting. The temperature at which sorghum starch gelatinizes (68 to 78ºC) exceeds that of corn (62 to 72ºC) and wheat (58 to 64ºC), implying that sorghum-based diets require a greater temperature during pelleting. However, pelleting sorghum-based diets at higher temperatures (82 to 90ºC) may induce the honey comb protein matrix to collapse, especially in vitreous sorghum. This collapse inhibits starch expansion, denies amylases access to their substrates, and reduces starch digestibility in cooked sorghum meal (Ezeogou et al., 2008). Thus, there is little consensus about the need to pellet sorghum-based diets to maximize nutrient utilization and growth performance in poultry.

EFFECTS OF KAFIRINS, TANNINS, AND PHYTATE IN SORGHUM-BASED DIETS

As previously stated, condensed tannins are only partially responsible for variation in nutrient digestibility in sorghum grain cultivars. Perez-Maldonado and Rodriguez (2007) reported that amino acid ileal digestibly for non-tannin sorghum in poultry varied from 73 to 82% with poor digestibility of cysteine (53%), histidine (69%), threonine (63%), and tryptophan (71%). Likewise, Vasan et al. (2008) reported amino acid digestibilities of 85% in corn and 73% in sorghum with lower values observed for cysteine, histidine, threonine, and arginine in sorghum. Oria et al. (2000) demonstrated that protein body shape and exposure and β- and λ-kafirin location are key factors in sorghum protein digestibility. β-and λ-kafirins bind to each other as well as to α-kafirins, tannins, and phytate to form stable complexes (Taylor et al., 2007).

Elkin et al. (1996) evaluated amino acid digestibility and TME of 20 sorghum cultivar with an average protein content of 10.7%. The sorghums had a range in tannins from 2 to 38 g/kg. The α-kafirins were assayed using a SDS-PAGE procedure. As shown in Table 1.8, α-kafirin (r = - 0.79) was negatively correlated with the mean essential amino acids digestibility, even more closely than tannin content (r = -0.60). In addition, there was a strong negative correlation between α-kafirins and TME_n (-0.81) whereas the negative correlation between tannin and TME_n was not significant. The correlation between kafirins and total protein also was not significant. Finally, correlations between "combined tannin and kafirin" and digestibility of individual amino acid and TME_n were consistently negative and significant (Table 1-8).

As presented in Table 1.9, Ravindran et al. (2006) suggested that amino acid digestibility is high in tannin-free or very low-tannin sorghums compared to tannin sorghums. The authors went on to suggest that an increase of 0.1% in tannin can induce a decrease of 10% in digestibility of most amino acids with twice that much reduction for sulfur amino acids and lysine. Additionally, an increase of 0.35% dietary phytate reduced amino acid digestibility by 3.6% (Ravindran et al., 2006). In a 42-d growth assay, Hassan et al. (2003) evaluated the effect of tannins (2.8 vs 13.8 g/kg) on growth performance and mineral absorption in broiler chicks. Response criteria were weight gain, feed intake, gain:feed, and total tract absorption of eight minerals. Depression in weight gain, feed intake, and gain:feed were 4, 1, and 2% respectively. For mineral absorption, Na, Mg, and Zn were the most affected with 10, 5, and 5%

reductions, respectively. Those results are in agreement with Monge et al. (2007) who reported that up to 14 g/kg tannins had no significant negative effect on broiler growth. Tannins and phytate have the capacity to alter Na metabolism which may impair intestinal nutrient absorption. Ravidran et al. (2006) reported more Na excretion by broilers fed high phytate diets. Inclusion of phytase helped to alleviate the loss of sodium. Supplementation with sodium bicarbonate improved dietary electrolyte balance and prevented the adverse effects of tannins. However, addition of sodium bicarbonate at levels higher than 2.5 g/kg (Table 1.10) reduced growth performance (Banda Nyirenda and Vohra, 1990).

IMPLICATIONS

Among the five major cereals produced worldwide, sorghum is unique for its physical characteristics, kafirin proteins, high proportion of phytate, and ability to produce tannins. During the last five decades, the effects of tannins, phytate, kafirins, and starch characteristics have been evaluated in sorghum-based feeds and foods. Most of the presently cultivated sorghums are tannin free. However, less progress towards phytate-free sorghums has been made, and tannins sometimes still are found in sorghum.

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Table 1.1. Cereal and legume production in West Africa[a]

Cereal	Production, tons		Increase, %
	1990	2006	
Millet	5,183,641	14,477,496	279
Sorghum	5,445,024	13,899,135	255
Corn	2,129,165	11,778,729	553
Rice	3,199,964	9,091,018	284
Legumes[b]	1,191,194	4,787,657	402

[a]Adapted from Blein et al.(2008)
[b]Cowpea, beans, and peas

Table 1.2. Effects of sorghum-based diets on poultry performance

Reference	Weight gain, g			G:F, g/kg			Egg production, %			ME, kcal/kg			Amino acid digestibility,%		
	C[a]	FLTS[b]	MHTS[c]	C[a]	FLTS[b]	MHTS[c]	C[a]	FLTS[b]	MHTS[c]	C[a]	FLTS[b]	MHTS[c]	C[a]	FLTS[b]	MHTS
1	-	-	-	-	-	-	-	-	-	-	-	-	-	73.0	31.5
2	667	636	583	565	556	508	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	3,306	3,044	-	-	-
4	575	556	571	617	553	578	-	-	-	-	-	-	-	-	-
5	-	703		670	649		-	-	-	-	-				
6	-	-	-	-	-	-	-	-	-	-	-	-	-	81.4	60.9
7	580	-	644	-	-	719	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-	82.0	79.0	
9	796	807	-	714	730	-	-	-	-	4,023	4,054	-	77.8	86.7	-
10	528	-	230	610	-	439	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	3,672	3,476	-	-	-	-
12	370	-	358	403	-	408	-	-	-	-	-	-	-	-	-
13	949	951	-	768	745	-	-	-	-	3,510	3,440	-	-	-	-
14	321	326	269	393	402	247	-	-	-	-	-	-	-	-	-
15	273	252	-	621	-	-	-	-	-	-	-	-	-	-	-
16	711	733	966	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-	3,105	3,173	-			
18	-	-	-	-	-	-	-	-	-	3,134	2895	2,608	86.2	85.5	80.6
19	-	-	-	-	-	-	-	69.2	46.6	-	-	-	-	-	-
20	-	-	-	-	-	-	70.9	-	64.7	-	-	-	-	-	-
21	-	-	-	-	-	-	68.5	69.0	69.2	-	-	-	-	-	-
22	-	-	-	-	-	-	89.0	88.0	-	-	-	-	-	-	-
23	-	-	-	-	-	-	47.0	56.0	-	-	-	-	-	-	-

[a]C=corn; [b]FLTS= free/low-tannin sorghum; [c]MHTS = medium/high-tannin sorghum. [1]Rostagno et al., 1974; [2]Luis and Sulivan,1980;[3]Lucbert and Castaing, 1988; [4]Banda-Nyirenda et al.,1990; [5]Healy et al., 1994; [6]Elkin et al., 1996; [7]Nyachoti et al., 1996; [8]Ravindran et al.,1999; [9]Elkin et al., 2002; [10]Kyarisiima et al., 2004; [11]Nadeem et al., 2005; [12]Oduho and Baker, 2005;[13]Travis, et al; 2006; [14]Nyamambi et al., 2007; [15]Issa et al., 2007; [16]Nyannor et al., 2007; [17]Ravindran et al., 2008; [18]Donkoh et al., 2009[18]Donkoh et al., 2009; [19]Sell et al.,1984; [20]Jacob et al., 1996; [21]Ambula et al., 2003; [22]S Parthasarathy et al., 2005; [23]Issa et al., 2007.

Table 1.3. Physical and chemical characteristics of maize and sorghum hybrid grain samples[a]

Hybrid	Physical characteristics		Chemical composition, %					ME, Mcal/kg[d]
	Seed wt., g/ 100 seed	AHI, s[b]	Protein	Fat	Fiber	Ash	NFE[c]	
ASA3042xKS115	3.76	15.2	13.5	3.6	2.7	1.6	70.8	3.59
AWheatlandxKS115	4.14	15.1	12.9	3.8	2.3	1.5	71.5	3.37
ASA3042xEastin-1	2.69	14.9	14.1	3.4	2.1	1.5	70.9	3.29
AWheatlandxEastin-1	2.93	16.0	13.3	3.5	2.1	1.6	71.4	3.34
ASA3042x RTx435	2.39	16.0	13.2	3.4	2.1	1.6	71.9	3.36
AWheatlandxRTx435	2.53	16.7	12.1	3.1	2.0	1.6	73.3	3.32
ASA3042xRT2737	2.25	15.6	12.7	3.4	2.3	1.6	72.1	3.46
AWheatlandxRT2737	2.36	14.7	12.3	3.4	2.3	1.6	72.6	3.32
Maize	-	15.0	10.2	3.8	2.2	1.4	73.8	3.51
Mean	2.88	15.5	12.7	3.5	2.2	1.5	72.0	3.39
LSD (0.05)	0.26	1.73	1.1	0.3	0.6	0.2	1.3	0.20

[a]Adapted from Travis et al. (2006)
[b]AHI = Average hardness index
[c] NFE = Nitrogen free extract
[d]ME = Metabolizable energy

Table 1.4. Nutrient content of corn and sorghum as a percentage of NRC requirement, in 0- to 3-wk old broiler chicks[a]

Nutrient	Requirement, %	Nutrient content, % of requirement[b]	
		Corn	Sorghum
Protein[c]	23.0	38	41
Arginine	1.25	31	29
Gly + Ser	1.25	57	58
Histidine	0.35	67	65
Isoleucine	0.80	37	45
Leucine	1.20	85	98
Lysine	1.10	24	20
Met + Cys	0.90	41	38
Phe + Tyr	1.34	52	62
Threeonine	0.80	37	37
Tryptophan	0.20	31	41
Valine	0.90	46	50

[a]Adapted from the Poultry NRC (1994)
[b]Values are nutrient concentration in corn or sorghum as a percentage of the requirement.
[c]There is no protein requirement in broilers chicks. The value of 23% simply is that expected in a corn-soybean meal-based diet

Table 1.5. Approximate amino acid profile of α-, β-, and λ-kafirins (mole, %) in sorghum[a]

Amino acid	α-kafirins	β-kafirins	λ-kafirins	Weighted mean[b]
Arginine	0.8	2.7	2.0	1.1
Histidine	1.2	0.9	6.9	1.8
Isoleucine	4.4	2.3	2.6	4.1
Leucine	15.1	12.0	9.0	14.2
Lysine	0.4	0.5	0.4	0.4
Methionine	0.6	5.7	1.0	1.0
Phenylalanine +tyrosine	6.3	4.9	3.9	5.9
Threonine	3.2	4.6	4.2	3.4
Valine	4.8	5.2	5.8	4.9
Alanine	15.2	13.4	6.3	14.1
Aspartic acid	5.6	3.3	0.6	4.9
Cysteine	1.1	4.9	6.9	2.0
Glutamitic acid	21.8	17.7	13.8	20.7
Glycine	4.1	6.8	8.6	4.8
Proline	8.9	9.7	22.6	10.0
Serine	5.8	4.6	5.0	5.6

[a]Adapted from Shull et al. (1992)
[b]Based on proportions of 0.820 α-kafirins, 0.075 β-kafirins, and 0.105 λ-kafirins

Table 1.6. In vitro digestion of starch from sorghum and corn genotypes varying in ratio of amylose:amylopectin[a]

Grain	Starch content, g/kg	Amylose in starch, g/kg	Starch enzyme digestion, g/kg
Sorghum			
Conventional	660	460	300
Non-waxy isoline	640	350	330
Waxy isoline	630	240	560
Corn			
Cultivar 1	638	0	550
Cultivar 2	663	300	350
Cultivar 3	586	570	210

[a]Adapted from Black et al. (2005)

Table 1.7. Correlation among tannin content, TAAD of essential amino acid, and TMEn for 12 sorghum samples[a]

	Tannins, g/kg catechin equivalent	
Item	r[b]	P=[d]
Arginine	0.52	***
Histidine	0.52	***
Isoleucine	0.51	***
Leucine	0.60	***
Lysine	0.46	***
Methionine	0.46	***
Phenylalanine	0.30	**
Threonine	0.54	***
Valine	0.61	***
TME_n[c]	-0.44	***

[a]Adapted from Elkin et al. (1996)
[b]Relationship between tannins and TAAD for essential amino acids was Y = 75.44-10.6X (R = 0.58 ***)
[b]Relationship between tannins and TAAD for essential amino acids was Y = 3,653-88X (R = 0.44 ***)
[c]TAAD = true amino acid digestibility, mean of nine essential amino acids determined cecectomized cockerels.
[c]TME_n = Nitrogen-corrected metabolizable energy
[d]** P ≤ 0.01; **** P ≤ 0.001

Table 1.8. Correlation among protein content, tannin content, kafirins, TAAD, and TMEn for 12 sorghum samples[a]

	Protein	Tannin[b]	α-kafirins[c]	TAAD[d]	TME_n[e]
Protein	1.00				
Tannin	0.18 (0.51)	1.00			
Kafirin	0.22 (0.49)	0.44 (0.57)	1.00		
TAAD	-0.20 (0.54)	-0.60 (0.04)	-0.79 (0.02)	1.00	
TME_n	-0.152 (0.636)	-0.44 (0.128)	-0.81 (0.002)	0.79 (0.002)	1.00

[a]Adapted from Elkin et al. (1996)
[b]Tannin = g/kg catechin equivalent
[c]Kafirin = α-kafirins peak area as determined with SDS-PAGE
[d]TAAD = true amino acid digestibility, mean of nine essential amino acids as determined in cecectomized cockerels
[e]TME_n = Nitrogen-corrected metabolizable energy

Table 1.9. Effects of dietary phytate and tannins on amino acid digestibility in poultry[a]

Amino acid	Phytate (n=18)[b]			Tannin (n=1)[b]		
	10.0g/kg	13.6g/kg	Reduction, %	0.9g/kg	1.9g/kg	Reduction, %
Arginine	0.89	0.87	2.59	0.96	0.80	17.4
Histidine	0.79	0.74	6.08	0.86	0.70	21.9
Isoleucine	0.82	0.79	3.05	0.97	0.87	9.5
Leucine	0.83	0.81	2.64	0.98	0.87	11.1
Lysine	0.87	0.84	3.21	0.96	0.79	18.1
Methionine	0.90	0.89	0.22	0.98	0.93	5.8
Phenylalanine	0.83	0.80	3.37	0.97	0.93	4.2
Threonine	0.77	0.73	5.17	0.96	0.86	10.7
Tryptophan	0.80	0.78	3.00	-[c]	-	-
Valine	0.81	0.77	4.47	0.94	0.86	8.7
Alanine	0.81	0.79	2.95	0.98	0.93	4.8
Aspartic acid	0.80	0.76	4.63	0.98	0.93	4.4
Cysteine	0.66	0.64	3.03	0.96	0.83	14.1
Glutamitic acid	0.87	0.84	2.54	0.98	0.95	2.9
Glycine	0.77	0.73	5.17	-	-	-
Proline	0.81	0.79	2.10	0.92	0.85	7.4
Serine	0.78	0.73	6.26	0.97	0.90	7.2
Tyrosine	0.82	0.79	3.67	0.98	089	8.2
Mean	0.81	0.78	3.56	0.96	0.87	9.8

[a]Adapted from Ravindran et al. (2006)
[b]n= number of sorghum cultivars
[c]Dashes indicate that no data were available

Table 1.10. Effects of sodium bicarbonate on growth performance and nutrients utilization in broilers fed sorghum-based diets[a]

Sodium bicarbonate, g/kg	Weight gain[b] g	Feed:gain	AME, MJ/kg[b]	Nitrogen retention, %[b]
0	583^{y}	2.01	13.88^{x}	63.4^{x}
2.5	616^{z}	1.91	14.41^{y}	72.1^{y}
5.0	582^{y}	2.00	14.07^{x}	71.0^{y}
7.5	555^{x}	2.24	14.46^{y}	70.1^{y}
LSD (P < 0.01)	13	0.33	0.218	3.4

[a]Adapted from Banda Nyirenda and Vohra (1990)
[b]Values in columns with different subscripts differ significantly (P < 0.01).
AME = Apparent metabolizable energy

CHAPTER 2 -

Effects of Sorghum Variety on Growth and Carcass Characteristics in Broiler Chicks Reared in West Africa

ABSTRACT

A total of 840 1-d-old broiler chicks (Arbor Acres line with an average BW of 31 g) were used in a 60-d experiment to determine the effects of sorghum variety on growth and carcass characteristics. There were 40 chicks/pen and seven pens/treatment with feed and water consumed on an ad-libitum basis. The control diet was corn-based with fishmeal and peanut meal used as the primary protein supplements. The diet was formulated to 1.3, 1.1, and 1.0% Lys for d 0 to 21, 21 to 42, and 42 to 60, respectively. Sorghum was used to replace the corn on a wt/wt basis so that treatments were: 1) corn (imported from Nigeria)-based control; 2) a locally adapted landrace variety of sorghum (Mota Galmi) with red seed, purple plant, and 0.3 mg catechin equivalents/100 mg of grain DM; and 3) an agronomically improved variety of sorghum (IRAT 204) with white seed, tan plant, and no detectable tannins. Average daily gain (ADG) and average daily feed intake (ADFI) were greater ($P < 0.001$) for chicks fed corn vs the sorghums. However, most of this difference was caused by the low ADG and ADFI for chicks fed the agronomically improved sorghum variety vs the locally adapted sorghum variety ($P < 0.001$). Gain to feed ratio was not different ($P > 0.26$) among chicks fed the treatments. Carcass weight, carcass yield, and carcass fat were not different for corn vs the sorghums ($P > 0.35$) but chicks fed the locally adapted sorghum variety had greater carcass weights and yield than those fed the agronomically improved sorghum variety ($P < 0.001$). In conclusion, the locally adapted landrace sorghum was superior in nutritional value to the agronomically improved sorghum and comparable in nutritional value to imported corn.

Key words: Sorghum, Corn, Poultry

INTRODUCTION

In Niger, 80% of the rural population raises animals that include cattle, goats, sheep, and camels. Although, sorghum is the second most produced cereal in Niger (after millet), imported corn remains the main cereal used in poultry feed (Abdoulaye, 2006). With corn importation and an abundant supply of fish meal, backyard poultry and commercial broilers contribute 98 and 2%, respectively of the poultry meat supply while domestic egg production accounts for only 29% of the national egg demand (Maizama et al., 2003). Thus, it is clear that in dry, sahelian countries like Niger, sorghum grain can play an important role in poultry feed (Parthasarathy, 2005; Issa et al., 2007). Comparisons of corn with sorghums produced in West Africa are not available to demonstrate the relative merits of these two cereals. Thus, it is necessary to provide poultry producers and extension personnel with information about sorghum-based diet formulations and feed processing technologies that might allow broiler performance similar to that obtained with corn-based diets. It was the objective of the experiments reported herein to compare corn with sorghum during a 60-day broiler feeding experiment.

MATERIALS AND METHODS

A total of 840 1-d-old broiler chicks (Arbor Acres line with an average Bw of 31 g) were used in a 60-d experiment to determine the effects of sorghum variety on growth and carcass characteristics. There were 40 chicks/pen and seven pens/treatment with feed and water consumed on an ad-libitum basis. Birds were housed on deep litter in an open-sided building with 12-m^2/pen. Vaccinations included Newcastle HB1/Lasota (NVD-I2) and Gumboro (nobilis gumboro 228E). Temperature in the building ranged from 26 to 40°C during the day. The control diet was corn-based with fishmeal and peanut meal used as the primary protein supplements. The diet (Table 1) was formulated to 1.3, 1.1, and 1.0% Lys for d 0 to 21, 21 to 42, and 42 to 60, respectively. Sorghum was used to replace the corn on a wt/wt basis so that treatments were: 1) corn (imported from Nigeria)-based control; 2) a locally adapted landrace variety of sorghum (Mota Galmi) with red seed, purple plant, and 0.3 mg catechin equivalents/100 mg of grain DM; and 3) an agronomically improved variety of sorghum (IRAT 204) with white seed, tan plant, and no detectable tannins. Corn, sorghum, and diet samples were collected and analyzed for proximate components (AOAC, 1990) and particle size. Birds consumed water and food on an ad-libitum basis with body weights recorded on d 0, 21, 42, and 60. At the end of the experiment, 10 birds per pen were randomly chosen and killed for carcass analysis. Response criteria were live weight (at d 0, 42, and 60), average daily gain (ADG), average daily feed intake (ADFI), gain to feed ratio (G:F), and carcass yield, and weights of gizzard, liver, and mesenteric fat.

All growth and carcass data were analyzed as a randomized complete block design using the Proc Mixed procedure of SAS. Live weight was used as a covariate during carcass data analysis and orthogonal contrasts were used to separate treatment means. Comparisons were corn vs the sorghums and locally adated sorghum vs agronomcaly improved sorghum.

RESULTS AND DISCUSSION

Cereal grains and diets (Table 2-2) had similar particle sizes, DM, ash, ether extract, and crude fiber. However, corn had greater nitrogen free extract and sorghums had greater crude protein. As for the growth assay, ADG and ADFI were greater ($P < 0.001$) for chicks fed corn vs sorghum. However, most of this difference was caused by the low ADG and ADFI for chicks fed the improved sorghum variety vs the locally adapted sorghum variety ($P < 0.001$).

Travis et al. (2006) reported 44 to 47g of ADG for d 0 to 21 for Cobb chicks fed nine sorghum-based diets vs 46 g for birds fed corn-based diets. Perez-Maldonado et al. (2008) reported ADG of 39 g for d 0 to 21 and 73 g for d 0 to 42 for Arbor Acres chicks fed 17 Australian sorghum cultivars when the birds were reared in cages in a environmentally-controlled house. In addition, ADG of 32 g was reported for d 0 to 21 when Cobb broiler chicks were fed sorghum-based diets as mash and standard or expanded crumbles (Cramer et al., 2003). For d 0 to 42, the authors reported ADG of 58 and 57g for birds fed standard or expanded sorghum-based diets.

Average daily gain at d 60 (31 to 37g) was lower than the58 and 57g obtained by Cramer et al. (2003) at d 42 with Cobb-500 broiler chicks fed standard or expanded crumbled sorghum-based diets. Finally, Defang et al. (2008) observed 48 g of ADG in Arbor Acres broiler chicks fed a corn-based diet with soybean meal, meat meal, fish meal, cotton seed meal, peanut meal, and wheat middlings as protein supplement in a 49-d experiment. However, when meat meal was replaced with boiled cowpea or black beans, ADG ranged from 38 to 42 g. The low ADG in our experiment likely was caused by extreme heat stress in our naturally ventilated building. Ahmed et al. (2006) reported ADG of 26 to 32 g when broiler chicks reared at a constant 32ºC from d 0 to 42.

Our feed intake from d 0 to 21 (19 g) was lower than 46 to 61 g/d reported by Cramer et al. (2003), and Travis et al. (2006) for Cobb broiler chicks which would be due to line and rearing conditions. Feed intake can also be explained by the high temperature prevailing in the building (26 to 40°C), and the low 170 mEq/kg DEB. Perez-Maldonado et al. (2008) reported F:G of 57g for d 0 to 21 and 125 g for birds fed sorghum-based diets and reared in environmentally-controlled house.   Ahmed et al. (2006) improved water use by 34%, and feed intake by 16%, when DEB was changed from 174 to 250 mEq/kg with building temperature of 32°C. Henken et al. (1993) reported change in ADFI from 92 to 78 g and in ADG from 35 to 30 g when broiler chicks were reared at 25°C or at temperatures 30 to 40°C.

Lu et al. (2007) reported live weight of 1,876 g when Arbor Acres broilers were raised at 34°C from d 0 to 60 in China, while Sarker et al. (2002) reported 42-d BW of 1,260 to 1,330 g for Arbor Acres chicks reared during winter in Bangladesh. In our study, average live BW at 60 d of age was 2,209 g for birds fed corn-based diets and 2,101 g for birds fed landrace sorghum-based diets. Adeyemo et al. (2007) reported BW of 1,722 to 2,097g at 60 d when Arbor Acre broiler chicks were fed corn fish meal diets supplemented with desert locust meal in the hot weather of Nigeria. During a 56-d growth assay, Jacob et al. (1996) reported BW of 2,028 g for birds fed corn-based diets and 1,899 g for birds fed high-tannin, sorghum-based diets.

As for differences among the treatments in our experiment, growth performance variation from birds fed corn-based diets vs those fed sorghums-based diets, and birds fed the landrace vs the improved sorghum was primarily due to intake. The local sorghum a had low tannin level (0.30 mg CE/100 mg DM) that did not seem to affect its nutritive value. Tannin is harmful to chick performance if it is greater than 1.35 mg CE/100 g DM (Monge, 2007). This substance decreases protein digestibility by complexing with proteins and inhibiting enzyme activity during test tube experiments (Balla, 1999).

Gain:feed ratio from d 0 to 42 was higher ($P < 0.09$) for birds fed corn-based diet compared to birds fed the sorghums, however G:F was similar ($P > 0.11$) for birds fed the landrace vs the improved sorghum (Table 3). Gain:feed from d 0 to 60 was not different ($P > 0.26$) among chicks fed the various treatments. Travis et al. (2006) reported G:F of 723 to 756 g/kg from d 0 to 21 for Cobb broiler chicks fed nine sorghum-based diets vs 767 g /kg for birds fed corn-based diets. In addition, Elkin et al. (2002) observed G:F of 592 g/kg from d 0 to 42 for broiler chicks fed corn-based diets vs 575 to 592 g/kg for birds fed sorghum-based diets.

With BW used as covariate, chicks fed the locally adapted sorghum variety had greater carcass yield ($P < 0.001$) than those fed the improved sorghum variety (Table 2-3). However, carcass yield, carcass fat, gizzard and liver were not different for corn vs the sorghums ($P > 0.16$). Indeed most carcass measurements were similar for all treatments, which favors substitution with sorghum in place of corn if priced more cheaply. Similarly, Perez-Maldonaldo et al. (2008) reported that birds fed sorghum-based diets had similar BW, weight of fat pad, and breast meat yield at d 42 compared to bird fed wheat-based diets. Also, our results agreed with those of Shelton et al. (2004) where pigs fed corn, non-waxy sorghum, and waxy sorghum had similar growth and carcass traits. Finally, Carré (2000) reported that with similar particles size, gizzard weights which were not different in birds fed corn- or sorghum-based diets.

IMPLICATIONS

In summary, the differences observed in performance among birds fed corn-based vs sorghum-based diets primarily were caused by difference in feed intake when the agronomically improved sorghum was the cereal grain. Perhaps most significant to poultry feeding in West Africa, the locally adapted landrace sorghum was superior in nutritional value to the agronomically improved sorghum and comparable in nutritional value of imported corn.

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Table 2.1. Corn- and sorghum-based diets fed to broilers chicks in West Africa (as fed basis)

Ingredient, %		d 0 to 21	d 21 to 42	d 42 to 60
Cereal[a]		58.85	63.00	65.85
Wheat bran		10.00	10.00	7.00
Peanut meal		14.00	11.35	11.00
Fish meal		10.00	8.00	8.00
Blood meal		2.00	2.50	3.00
Bone meal		4.00	4.00	4.00
D,L-methionine		0.20	0.20	0.20
L-lysine HCl		0.20	0.20	0.20
Salt		0.50	0.50	0.50
Premix[b]		0.25	0.25	0.25
Total		100.00	100.00	100.00
Calculated Analysis				
	MEn, kcal/kg	2,805	2,835	2,892
	Total Ca, %	1.22	0.90	0.96
	Available P, %	0.80	0.52	0.52
	CP, %	21.3	20.2	20.1
	Lys, %	1.27	1.14	1.00
	Met, %	0.56	0.57	0.56
	Thr, %	0.88	0.74	0.77
	Trp, %	0.22	0.21	0.21
	DEB, mEq/kg[c]	169	171	170

[a]Sorghum replacd corn on a wt/wt basis

[b]Supplied (per kg of diet): 220 mg of Mg; 220 mg of Zn; 110 mg of Fe; 248 mg of Cu; 33 mg of I; 77,105 IU of Vit A; 27,538 IU of Vit D; 165 IU of Vit E; 0.11 mg of Vit B_{12}; 8 mg of menadione; 66 mg of rivoflavin; 11 mg of thiamin; 66 mg of pantothenic acid; 275 mg of niacin; 14 mg of Vit B_6; 7 mg of folic acid; 3,855 of choline; and 0.33 mg of biotin.

[C]DEB (diet) = sodium + potassium – chloride (mEq/kg as % in diet x valence x 10,000/atomic weight)

Table 2.2. Physical and chemical composition of imported corn and domestically produced sorghums fed to broilers chicks in West Africa (as fed basis)

Item	Corn	Local sorghum	Improved sorghum
Particles size, μm[a]	598	615	611
Moisture, %[b]	9.8	8.0	7.5
Crude protein, %[b]	8.0	10.7	11.7
Ether extract, %[b]	4.8	3.6	3.6
Crude fiber, %[b]	1.9	2.2	1.9
Ash, %[b]	1.2	1.5	2.2
Nitrogen free extract, %[b]	74.2	74.0	73.2

[a]Geometric mean particle size (d_{gw}) was determined from 100 g samples according to AOAC procdures (1990)

Table 2.3. Growth performance and carcass characteristics of broiler chicks fed imported corn and domestically produced sorghums in West Africa[a]

Item	Treatment			SE	P value	
	Corn	Local sorghum	Improved sorghum		C vs S[b]	LS vs IS[c]
d 0 to 21						
ADG, g	13	12	10	1	0.001	0.09
ADFI, g	20	19	17	1	0.01	0.02
G:F, g/kg	647	635	592	24	0.09	0.11
d 0 to 42						
ADG, g	28	25	22	1	0.01	0.01
ADFI, g	51	48	43	1	0.01	0.01
G:F, g/kg	547	533	514	12	0.01	0.07
d 0 to 60						
ADG, g	37	35	31	1	0.001	0.001
ADFI, g	77	72	65	1	0.001	0.001
G:F, g/kg	478	488	484	10	0.28	0.73
Carcass measurements						
Carcass yield, %	76.0	76.6	74.7	0.6	0.18	0.001
Gizzard weight, g	51	51	49	2	0.56	0.97
Liver weight, g	52	47	49	2	0.16	0.12
Fat weight, g	25	19	21	2	0.15	0.23

[a]A total of 840 chicks (280/treatment)

[b]Corn vs sorghum

[c]Landrace sorghum vs agronomically improved sorghum

CHAPTER 3 -

Effects of Sorghum Variety on Growth Performance and Subsequent Egg Production of Layer Chicks Reared in West Africa

ABSTRACT

A total of 450 1-d-old layer chicks (Harco line with an initial BW of 29 g) were used in an 18-month experiment to determine the effects of sorghum variety on growth and egg production. There were 50 chicks/pen and three pens/treatment with feed and water consumed on an ad libitum basis. The control diet was corn-based with fishmeal and peanut meal used as the primary protein supplements. Sorghum was used to replace corn on a wt/wt basis so that treatments were: 1) a corn (imported from Nigeria)-based control; 2) a locally adapted landrace variety of sorghum (Mota Galmi) with red seed, purple plant, and 0.3 mg catechin equivalents/100 mg of grain DM; and 3) an agronomically improved variety of sorghum (IRAT 204) with white seed, tan plant, and no detectable tannins. For d 0 to 126, there were no differences ($P > 0.13$) in ADG and G:F among birds fed the corn and sorghum treatments. However, the numerical advantage in ADG for birds fed the agronomically improved sorghum resulted in a 78 g advantage in BW ($P < 0.001$) at the beginning of the laying period compared to birds fed the locally adapted sorghum. For the laying period, birds fed the sorghum grains took fewer days ($P < 0.01$) to come into production than birds fed the corn-based diet. Egg production and feed intake tended to be greater ($P < 0.1$) in layers fed sorghum-based diets, however there were no differences in average egg weight ($P > 0.85$) and feed conversion ($P > 0.16$) among birds fed corn and the sorghums.

Keys words: Corn, Chicks, Layers, West Africa, Niger

INTRODUCTION

Because of corn importation, high production costs are the main constraint to poultry production in Niger (Maizama et al., 2003). In experiments undertaken in India, sorghum varieties developed by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) were equal to corn in nutritional value for broilers and layers (Parthasarathy et al., 2005). Additionally, Hancock et al. (2000) proposed that adequate processing improved the nutritive value of sorghum in poultry and swine to levels similar to that of corn. Consequently, with selection of good varieties and proper processing, sorghum could play an important part in diets fed to livestock and poultry in West Africa. However, poultry producers and extension personnel in the Sahel of West Africa have concerns about using sorghum in layer feeds because of perceived low nutritional value of domestically produced sorghum grain. Thus, a layers experiment was completed to determine the nutritional value of layer diets formulated with either imported corn or locally produced sorghum grain.

MATERIALS AND METHODS

A total of 450 1-d-old layer chicks (Harco line with an average BW of 29 g) were used in an 18-month experiment to determine the effects of diets with imported corn vs locally produced sorghums on growth performance and egg production. There were 50 chicks/pen (3.9 m^2 from d 1 to 21 and 12.5 m^2 after d 21) having rice hulls as eddings. Birds were vaccinated for Newcastle HB1/Lasota (NVD-I2) and Gumboro (nobilis gumboro 228E). Temperature inside the naturally-ventilated house averaged 21 to 32°C and 35 to 42°C at 8:00 am and 4:00 pm, respectively. Birds were allowed to consume water and feed on an ad libitum basis. The control diet (Table 3.1) was corn-based with fishmeal and peanut meal used as the primary protein supplements. The diet was formulated to exceed recommendations for all nutrient concentrations as suggested in the 1994 NRC for poultry. Sorghum was used to replace the corn on a wt/wt basis so that treatments were: 1) a corn (imported from Nigeria)-based control; 2) a locally adapted landrace variety of sorghum (Mota Galmi) with red seed, purple plant, and 0.3 mg catechin equivalents/100 mg of grain DM; and 3) an agronomically improved variety of sorghum (IRAT 204) with white seed, tan plant, and no detectable tannins.

Cereal grains were ground through a hammermill equipped with a screen having 1.5 mm openings. The ground cereals had particle sizes of 598, 615, and 611 μm for corn, local sorghum, and improved sorghum, respectively. Ingredients and experimental diets were analyzed for proximate components (DM, CP, crude fat, crude fiber, and ash), tannins (catechin equivalents), and particle size (Table 3.2). Response criteria were live weight at d 0, 42, 84, and 126, average daily gain (ADG), average daily feed intake (ADFI), gain to feed ratio (G:F), age at 20% of birds laying, egg weight, egg production, and g egg/g feed.

Data were analyzed as a randomized complete block design using the Proc Mixed procedure of SAS. Means were separated using the orthogonal contrasts of: 1) corn vs sorghums, and 2) local landrace vs agronomically improved sorghum.

RESULTS AND DISCUSSION

Cereal grains and diets (Table 3.2) had similar particle sizes, DM, ash, ether extract, and crude fiber, but corn had greater nitrogen free extract and sorghums had greater crude protein. From d 84 to 126 ADG for pullets fed the improved sorghum was greater ($p > 0.01$) by 1.3 g compared to birds fed either corn or local sorghum. However, Average daily gain was similar (P > 0.25) for pullets fed corn vs sorghums from d-1 to 126 (Table 3.3).

Body weight from d 0 to 126 reported by Parthasarathy et al. (2005) was 1,208 g for white Leghorn pullets, whereas our average BW at d 126 was 1,841 to 1,919 g. This difference in weight could be explained by the fact that Leghorns are light BW strains whereas Harco layers are heavy strains. As for the effect of our treatments, the low content tannins (0.3 CE/100 g DM) did not affect growth. This is in agreement with results reported by Balla (1999) and Monge (2007) who also reported that low tannin sorghum did not depress growth performance.

Overall ADFI to d 126 was not affected (P > 0.17) by treatment for birds fed corn and the sorghums. However, birds fed sorghum-based diets consumed more (P < 0.01) feed to d 84. Our ADFI to d 126 (41 g) was lower than 49 g for white Leghorn layers fed sorghum-based diets in India (Parthasarathy, 2005). The low feed intake for both corn- and sorghum-based diets in our experiment may have been caused by heat stress. Between 30 and 35°C, a 1°C increase induces four times as much decrease in feed intake as a change of 1°C between 10 and 20°C (McDonald, 1978). Thus, with the temperature experienced by our birds (average of 32°C), one could expect a decrease in ADFI.

Gain:feed among birds fed the corn and sorghum treatments were similar (P > 0.14) from d 0 to 84. However, birds fed the agronomically improved sorghum had the best G:F for d 84 to 126 (P < 0.01). Butler (1978), Carré (2000) and Hancock (2000) reported that low tannin content in sorghum grain and adequate milling (particles sizes 598 to 615 µm) contributed to sorghum-based diets supporting similar efficiencies to those for birds fed the corn-based diets.

The numerical advantage in ADG for birds fed the agronomically improved sorghum resulted in a 78 g advantage in BW at the beginning of the laying period compared to birds fed the locally adapted sorghum ($P < 0.001$). Consuming the sorghum-based diets resulted in earlier entry into laying and greater egg production compared to consuming the corn-based diet. This observation supports the use of sorghum to feed layers in warm and dry environments which also are more suitable for production of sorghum vs corn. Birds fed the sorghum grains took fewer days ($P < 0.01$) to come into production and during the laying period ate more feed ($P < 0.01$) and produced more eggs ($P < 0.01$) than birds fed the corn-based diet. There were no differences ($P > 0.85$) in average egg weight among birds fed corn and the sorghums.

Age at 20% egg production was 133 to 154 for commercial layers in data reported by Ryan et al. (1998) and ours was 133 to141 d. Sell et al. (1984) reported low egg production in layers fed high-tannin (47%) vs those fed low-tannin sorghum-based diets (69%). However, feed intake was similar for birds fed the two sorghums. Jacob et al. (1996) reported egg production of 71% for layers fed corn-based diets vs 65% for birds fed high-tannin sorghum. Egg production did not decrease when layers were fed diets with sorghum as 32 to 50% of the diet (Nakhede et al., 1981; Gowda et al., 1984; Thakur et al., 1985) or when sorghum was the sole cereal in the diet (Rama Rao et al., 1995; Ambula et al., 2003; Partharathy et al., 2005).

Smith and Olivier (1972) reported egg production of 82, 79, 70, and 53% when building temperatures were 27, 29, 32 and 35°C, respectively. In addition, Mashaly et al. (2004) reported feed intake, egg production and egg weight at 87, 87 and 56 at thermo-neutral conditions (24ºC); 67 83 and 54 at cyclic conditions (24 to 35ºC); and 42, 56, and

47 during heat stress (35ºC) in commercial laying hens. Thus, our egg production data would be considered typical for birds exposed to heat stress.

In our experiment, egg weight and feed efficiency were similar in layers fed corn- and sorghum-based diets (P > 0.16). Previous research reports have suggested similar egg weight and feed efficiency in layers fed sorghum vs corn (Rama Rao et al., 1995; Ambula et al., 2003; Partharathy et al., 2005). However, feed efficiency has been reported to be lower in layers fed high-tannin sorghum compared to those fed low-tannin sorghum or corn (Sell et al., 1984; Jacob et al., 1996).

From d 0 to 126, there were no differences (P > 0.80) among treatments for mortality. Mortality averaged 5% during wk 1, 1% for wk 1 to wk 12, 4% wk 12 to wk 18 and these results are in agreement with the results reported by Balnave and Brake, (2005).

IMPLICATIONS

In summary, sorghum grain was equal (if not superior) to corn as a feedstuff in diets for layers reared in West Africa. Consequently, in the Sahel, poultry producers should not hesitate to use locally produced sorghum grain in layer diets if it helps to cheaper their cost of production.

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Table 3.1. Corn- and sorghum-based diets fed to layer chicks in West Africa (as fed basis)

Ingredient	d 0 to 42	d 42 to 84	d 84 to 126	Laying period
Cereal[a]	66.55	71.25	68.65	66.65
Wheat bran	10.00	10.00	10.00	10.00
Peanut meal	8.00	5.00	5.00	5.00
Fish meal	8.00	5.00	5.00	5.00
Blood meal	2.50	4.00	2.50	2.50
Bone meal	4.00	4.00	8.00	10.00
D,L-methionine	0.10	0.00	0.00	0.00
L-lysine HCl	0.10	0.00	0.10	0.10
Salt	0.50	0.50	0.50	0.50
Premix[b]	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00
Calculated Analysis				
ME_n, kcal/kg	2,856	2,896	2,767	2,767
Total Ca, %	1.22	1.17	2.20	2.67
Available P, %	0.75	0.67	0.75	0.75
CP, %	17.6	16.1	15.0	14.9
Lys, %	0.95	0.82	0.78	0.78
Met, %	0.42	0.28	0.26	0.26
Thr, %	0.70	0.58	0.50	0.50
Trp, %	0.17	0.16	0.14	0.14
DEB, mEq/kg[c]	156	149	152	156

[a]Sorghum replaced corn on a wt/wt basis

[b]Supplied (per kg of diet):500 mg of Zn; 600 mg of Fe; 600 mg of Cu; 5 mg of I; 100,000 IU of Vit A; 20,000 IU of Vit D; 1150 IU of Vit E; 0.25 mg of Vit B_{12}; 20 mg of menadione; 8 mg of folic acid; and 5,000 mg of choline

[c]DEB (diet)= sodium + potassium – chloride (% in diet x valence x 10,000/atomic weight)

Table 3.2. Physical and chemical characteristics of imported corn and domestically produced sorghums fed to layer chicks in West Africa (as fed basis)[a]

Item	Corn	Landrace sorghum	Improved sorghum
Particles size, µm[a]	598	615	611
Moisture, %[b]	9.8	8.0	7.5
Crude protein, %[b]	8.0	10.7	11.7
Ether extract, %[b]	4.8	3.6	3.6
Crude fiber , %[b]	1.9	2.2	1.9
Ash, %[b]	1.2	1.5	2.2
Nitrogen free extract, %[b]	74.2	74.0	73.2

[a]Geometric mean particle size (d_{gw}) was determined from 100 g samples according to ASAE (1983)

[b]AOAC (1990)

Table 3.3. Growth and laying performance of poultry fed imported corn and domestically produced sorghums in West Africa[a]

	Treatment				P value	
Item	Corn	Local sorghum	Improved sorghum	SE	C vs S[c]	LS vs IS[d]
d 0 to 42						
BW, g[a]	363	363	360	6	0.92	0.72
ADG, g	8.0	8.0	7.9	0.2	0.60	0.43
ADFI, g	16.0	16.7	16.0	0.4	0.51	0.28
G:F, g/kg	503	473	483	16	0.81	0.25
d 42 to 84						
BW, g	1,119	1,102	1,114	6	0.16	0.17
ADG, g	18.0	17.7	17.7	0.3	0.64	0.43
ADFI, g	38.7	40.3	42.3	1.0	0.04	0.15
G:F, g/kg	467	440	427	15	0.12	0.16
d 84 to 126						
BW, g	1,854	1,841	1,919	10	0.03	0.01
ADG, g	17.7	17.7	19.0	0.3	0.05	0.05
ADFI, g	55.3	56.3	56.3	0.8	0.61	0.39
G:F, g/kg	317	310	340	4	0.05	0.28
d 0 to 126						
BW, g	1,854	1,841	1,919	10	0.01	0.01
ADG, g	14.7	14.3	15.0	0.3	0.15	0.37
ADFI, g	39.7	40.7	41.1	0.6	0.09	0.52
G:F, g/kg	397	380	393	6	0.43	0.07
Mortality d 0 to 126, %	9.9	10.5	12.5	2.0	0.51	0.52
20% egg production, d	141	133	135	2	0.01	0.43
ADFI, g	70	79	77	7	0.02	0.54
Laying rate, %	46.6	56.2	55.1	4.7	0.01	0.65
Egg weight, g	49	49	49	2	0.85	0.98
FC, feed/egg	3.28	3.05	2.96	0.45	0.16	0.23

[a]A total of 450 chicks (150/treatment)

[b]BW = Live body weight

[c]Corn vs sorghums; [d]Locally adapted sorghum vs the agronomically improved sorghum

CHAPTER 4 -

Effects of Sorghum and Particle Size on Growth and Carcass Characteristics of Broiler Chicks Reared in West Africa

ABSTRACT

A total of 2,000 1-d-old chicks (with an average BW of 41 g) were used in a regional experiment to determine the effects of cereal grain and particle size on growth and carcass characteristics. There were 25 chicks/pen and four pens/treatment at five stations (Senegal, Mali, Burkina Faso, Niger, and Nigeria) with feed and water consumed on an ad-libitum basis. For Senegal, Mali, Burkina Faso, and Niger, Cobb 500 broiler chicks were used. In Nigeria, Arbor Acres broiler chicks were used. The control diet was corn-based with fish meal, peanut meal, cotton seed meal, and soybean meal as the primary protein supplements. The diet was formulated to 1.30 and 1.07% Lys for d 0 to 21, and d 21 to 42, respectively, with all other nutrients at or above NRC (1994) recommendations. Sorghum was used to replace corn on a wt/wt basis so that treatments were cereal (corn and sorghum grain) and particle size (the cereals ground through a 6.4-mm vs 2-mm screen). There was no cereal*particle size interaction ($P > 0.56$) for growth performance. Also, ADG ($P > 0.20$), ADFI ($P > 0.15$), and F:G ($P > 0.36$) were not affected by particle size treatment. However, average daily gain ($P < 0.001$), and gain:feed ratio ($P < 0.001$) were greater for birds fed corn-based diets vs those fed the sorghum-based diets. Carcass weight and yield were similar for all birds ($P > 0.38$). In conclusion, local sorghum had comparable nutritional value to corn in broiler chicks and in West Africa local sorghums are a good alternative for poultry feeds when priced on expected difference in rate and efficiency of grain

Keys words: Sorghum, Corn, Particle Size, Poultry, West Africa

INTRODUCTION

Corn is the main cereal used for poultry diets in West Africa (Abdoulaye, 2006). Yet, sorghum is produced extensively in Sahelian countries like Senegal, Mali, Burkina Faso, Niger, and Nigeria and could play an important role in poultry feed (Parthasarathy et al., 2005; Issa et al., 2007). Many studies have demonstrated that tannin-sorghums reduce feed intake, rate of gain, and efficiency in broilers (Sell et al., 1985; Douglas et al., 1990; Hancock, 2000). Butler et al. (1992) suggested that these negative effects resulted from the ability of tannins to bind and precipitate proteins including grain proteins and digestive enzymes. Yet, it is well established that cereal type (e.g. corn vs sorghum) does not affect gastrointestinal tract or intestinal morphology measurements in poultry (Donald et al., 2008). Furthermore, sorghum can be used as the sole grain source in either broiler or layer diets without compromising performance (Cramer et al., 2003; Parthasarathy et al. 2005; Travis et al., 2006; Nyannor et al., 2007).

Physical kernel characteristics (eg., seed size and texture), production environment, and processing are major factors recognized to induce variation in sorghum-based diets for poultry (Wondra et al., 1992; Hancock, 2000, Oria et al., 2000). Research results are consistent in showing that sorghum grain, when ground finely, has similar nutritive value to that of corn (Healy et al., 1994; Hancock, 2000) and wheat (Mikkelson et al., 2008; Perez-Maldonado et al., 2008). Unfortunately, data from comparisons of corn vs sorghum, especially when processed differently to maximize nutrient digestibility of the two cereals, are not available in West Africa. Thus, the goal of the experiment reported herein was to determine the nutritional merits of diets based on corn and locally produced (non-tannin) sorghums when the cereals were milled to different particle sizes.

MATERIALS AND METHODS

A common protocol was used in experiments at five sites that included the Regional College of Science and Veterinary Medicine (EISMV), Dakar, Senegal; the Institute of Rural Economy (IER), Bamako, Mali; the National Institute for Environment and Agricultural Research (INERA) Bobo-Dioulasso, Burkina Faso; the Abdou Moumouni University (UAM) Niamey, Niger; and the University of Maiduguri (UNIMAID) Maiduguri, Nigeria. At each site, 400 1-d-old broiler chicks were randomly allocated to 16 pens (25 birds/pen) with four pens per treatment and four treatments for a total of 2,000 birds. The control diet was corn-based with fish meal, peanut meal, cotton seed meal, and soybean meal used as protein supplements (Table 4.1). It was very important that the diets were as similar as possible across locations with the only differences being the cereal grain treatments. Thus, a supplement of all ingredients except the cereal grain was made in Senegal. Allotments of this supplement were transported to each experiment station and mixed with the appropriate amount of cereal grain to form the finished diets. The supplement was based on the 1994 NRC for poultry with essential amino acids at least 115%, vitamins at least 150%, Ca, available P, Na, and Cl at leat 115%, and other minerals at least 115% of NRC recommendations. Also, electrolyte balance (Na + K – Cl) was adjusted to 240 mEq/kg and a coccidiostat and antibiotic were added to all diets.

To produce the cereal grain treatments, corn and sorghum were ground through a hammermill equipped with 6.4 vs 2 mm screens. The corn was white, and the local sorghum was white and tannin free (purchased at the local market in Burkina Faso and Senegal, *Niatitema* in Mali, *Sepon 82* in Niger, and *Chakara white* in Nigeria). In Senegal, Mali, Burkina Faso, and Niger Cobb-500 broiler chicks were used. Arbor Acres broiler chicks were used in Nigeria. Birds were vaccinated for Newcastle HB1/Lasota (NVD-I2) and Gumboro (nobilis gumboro 228E). The birds were bedded on deep litter in open-sided buildings with 12-m^2/pens. The buildings were naturally ventilated while temperature and humidity ranged from 24 to 29°C and 76 to 91% in the mornings, and from 31 to 37°C and 56 to 70% during the afternoons (Figure 1).

The control diet was formulated to 1.29 and 1.15% Lys for d 0 to 21 and d 21 to 42, respectively. Sorghum was used to replace the corn on a wt/wt basis so that treatments were cereal source corn vs sorghum and particle size (cereals ground through 6.4 vs 2-mm screens). The birds were allowed to consume feed and water on an ad-libitum basis. They were weighed at d 0, 21, and 42 with ADG, ADFI, and G:F as response criteria. At the end of the experiment, 12 birds per pen were randomly chosen and killed for carcass evaluation. Weights of the live bird, carcass, gizzard, liver, mesenteric fat and empty intestines were recorded. Additionally, gizzards were opened and scored for lesions on a scale of 0 (none) to 5 (severe). Samples of the cereals and diets were analyzed for dry mater, ash, crude fat, crude fiber, and crude protein using AOAC (1990) procedures (Table 4.2). Additionally, the cereal grains were evaluated for kernel diameter, weight, and hardness (Bean et al., 2006) and tannins (Butler et al., 1978).

All growth and carcass data were analyzed as a randomized complete block with a 2x2 factorial arrangement of treatments using the Proc Mixed procedure of SAS. Live weight was used as a covariate for carcass data analysis.

RESULTS AND DISCUSSION

The present study is the first regional project in West Africa conducted through a network representing the combined effort of EISMV, IER, INERA, UAM, INRAN, UMAID, and KSU. The objective especially was to evaluate local sorghums fed to broiler chicks. Sorghum grain was bought at local markets in Burkina Faso and Senegal while they were chosen by scientists at IER in Mali, INRAN in Niger, and UNMAID in Nigeria. The cereal grains (Table 4.2) were similar for dry mater, ash, and crude fiber, but corn had greater nitrogen free extract and fat, and sorghums had greater crude protein. The corn used at various sites was white and had similar seed weight (24.9 ± 1.7g/100 seeds), DM (89.7 ± 0.3%), CP (7.6 ± 0.2), and NFE (74.8 ± 0.2). At all sites sorghum grain was white, tannin-free, and with seeds weighing 2.3 g/100 seeds, and with a seed diameter of 1.9 mm. Other sorghum characteristics included DM of 89.6 ± 1.1%, CP of 9.1 ± 0.5%), fat of 2.5 ± 0.2%, CFof2.4 ± 0.2, ash of 2.0 ± 0.1, NFE of 74.0 ± 0.7%), and hardness of 92 ± 13).

No cereal*particle size interactions were observed ($P > 0.67$) for ADG, ADFI, or G:F. Also, ADG, ADFI and G:F were not affected by particle size ($P > 0.15$). However, ADG was greater ($P < 0.001$) in birds fed corn-based diets than for birds fed sorghum-based diets. Average daily gains at d 21, (31 g for corn and 29 g sorghum) were similar to data from Donald et al. (2008) who reported ADG of 33 g for corn-based, 31 g for wheat-based, and 30 g for sorghum-based diets. The resulting ADG for birds fed sorghum in our experiment were similar to those reported by Cramer et al. (2003) with ADG of 32 g at d 21 for birds fed mash, crumbled and pelleted sorghum-based diets.

Elkin et al. (2002) reported ADG at d 21 of age of 38 g for corn and 38 g for experimental sorghum. Similarly, Nyannor et al. (2007) reported ADG of 34 g for chicks fed corn vs 35 g for birds fed experimental sorghums for 21 d. In addition, Travis et al. (2006) reported ADG of 45 g for chicks fed corn and 45 g for birds fed nine high digestibility sorghum hybrids for 21 d whereas Perez-Maldonado (2008) reported ADG of 44 g for broiler chicks fed wheat-based vs 39 g for those fed sorghum-based diets for 21 d.

In the hot and humid environments of Africa, Kyarissiima et al. (2004) reported ADG of 25 g for chicks fed corn vs 11 g for chicks fed sorghum with 4% tannins for 21 d. Similarly, Nyamambi et al. (2007) reported ADG at 21 d as 15 g for chicks fed corn, 16 g for chicks fed sorghum with 0.07% tannins, and 15 g for chicks fed sorghum with 0.2 to 2.48% tannins. Issa et al. (2007) reported ADGs to d 21 as 13 g for chicks fed corn and 12 g for chicks fed sorghum with 0.3% tannins.

For d 0 to 21, ADFI was not affected by cereal*particle size interactions ($P > 0.70$), or the main effects of corn vs sorghum ($P > 0.33$) or particle size ($P > 0.15$). However, our ADFI for d 0 to 21 were similar to data reported by Elkin et al. (2002) with 53 g for chicks fed corn and 54 g for chicks fed sorghum. Recent research reported feed intakes of 46 g for chicks fed corn and 47 g for chicks fed sorghum (Nyannor et al., 2007), 42 g for chicks fed corn and 38 g for chicks fed sorghum with 4% tannins (Kyarissiima et al., 2004), 39 g for chicks fed corn and 38 g for chicks fed sorghum with 0.2 to 2.48% tannins (Nyamambi et al., 2007); and 20 g for chicks fed corn vs 19 g those fed sorghum with 0.3% tannins (Issa et al., 2007). Travis et al. (2006) reported ADFI of 59 g for chicks fed corn and 62 g birds fed sorghum for 21 d and Perez-Maldonado (2008) reported ADFI of 60 g for birds fed wheat vs 57 g for birds fed sorghum for 21.

The G:F for d 0 to 21 was greater ($P < 0.001$) for birds fed corn vs those fed sorghum. However particle size did not affect G:F ($P > 0.15$). Our G:F for d 0 to 21(605 g/kg for corn and 565 g/kg for sorghum) was lower than those reported by Elkin et al. (2002) of 702 g/kg for birds fed corn and 712 g/kg for birds fed sorghum. Also, Nyannor et al. (2007) and Perez-Maldonado (2008) reported higher G:F (725, 690, and 768 g/kg for birds fed corn, wheat and sorghum) whereas G:F ranging from 393 to 596 g/kg for corn and 357 to 586 for sorghum were reported by Kyarissiima et al. (2004) and Nyamambi et al. (2007).

ADG for d 0 to 42 was greater ($P < 0.001$) for birds fed corn vs those fed sorghum. However, ADG was not affected by particle size ($P > 0.23$). Elkin et al. (2002) reported for d 0 to 42 ADG of 58 g for birds fed corn sorghums for 42 d. Perez-Maldonado (2008) reported similar ADG of (75 vs 73 g) in broilers chicks fed wheat-based and sorghum-based diets, for 42 d. In the hot and dry environments of West Africa, Issa et al. (2007) reported ADG of 28 g for chicks fed corn and 25 g for chick fed sorghum with 0.3% tannin for 42 d.

Particle size did not affect ADG in our experiment. These results are in contrast with those of Healy et al. (1994) who reported ideal particle sizes of 700 and 500 μm for corn and sorghum. However, reducing particle size did not improve ADG in experiment by Reece et al. (1986), Deaton et al. (1995), and Pearson et al. (2006).

In our experiment, ADFI for d 0 to 42 was 89 g for birds fed corn and sorghum. These ADFI are higher than the 61g for corn and sorghum as reported by Nyamambi et al. (2007), the 51 and 48 g for birds fed corn vs low-tannin (0.3%) sorghum as reported by Issa et al. (2007), and 62 g in birds fed mash or hydro-thermally treated sorghum-based diets as reported by Cramer et al. (2003). However, our ADFI were lower than the 100 g for bird fed corn vs 102 g for birds fed sorghum (Elkin et al., 2002).

As for ADG and ADFI, there was no cereal particle size interaction for G:F (P > 0.75). Yet, G:F was greater (P < 0.001) for birds fed corn based-diets vs those fed the sorghum-based diets (P < 0.01). Our sorghum was tannin free. However grain hardness (97) and the large particle sizes in this study may partially be responsible for feed efficiency differences observed in corn and sorghum-based diets. Particle size did not affect G:F (P > 0.67).

Because of the high ADFI in our experiment, G:F for d 0 to 42 was only 532 g/kg for birds fed corn and 505 g/kg for birds fed sorghum-based diets. These values were lower than the 571 g/kg for bird fed corn and 565 g/kg for birds fed sorghum as reported by Elkin et al. (2002) and the 567 g/kg for birds fed corn and 554 for bird fed sorghum as reported by Nyamambi et al. (2007). Furthermore, Cramer et al. (2003) reported G:F of 569 and 575 g/kg for birds fed sorghum crumbles, whereas Perez-Maldonado et al. (2008) reported G:F of 550 g/kg for birds fed wheat and 555 g/kg for those fed sorghum.

Weight of carcass, carcass yield, and weights of fat, gizzard, liver, and intestine were not affected by a cereal*particle size interaction or the main effects of cereal, and particle size (P > 0.14). Also, all gizzards were normal without occurrence of ulceration. In contrast, Parsons et al. (2006) reported improved nutrient retention in broilers fed corn-based diets when corn particles size was increased from 781 to 1,042 μm. However, growth performance and ME were decreased when corn particle size exceeded 1,042 μm because of an increase in size and maintenance requirements for the gastrointestinal tract.

IMPLICATIONS

Birds fed corn-based diets had greater growth performance compared to birds fed sorghum-based diets. Carcass characteristics were similar for birds fed the cereals. Thus, tannin free sorghum had nutritional value comparable to that of corn and in West Africa local sorghum is a good alternative for poultry feeds when slight discount are applied for the differences in ADG ad G:F.

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Table 4.1. Diets fed to broiler chicks in Senegal, Mali, Burkina Faso, Niger, and Nigeria[a]

Ingredient, %	d 0 to 21	d 21 to 42
Cereal grain [b]	57.30	60.56
Peanut meal	5.00	5.00
Fish meal	10.00	5.00
Cottonseed meal	3.00	3.00
Soybean meal	21.55	22.77
D,L-methionine	0.26	0.15
L-lysine HCl	0.00	0.25
L-threonine	0.05	0.10
Salt	0.22	0.15
$CaCO_3$ (38% Ca)	1.00	1.00
Dicalcium phosphate	0.75	1.20
Sodium bicarbonate	0.33	0.37
Vit-min premix[c]	0.34	0.25
Coccidiostat[d]	0.10	0.10
Antibiotic[e]	0.10	0.10
Total	100.00	100.00
Calculated analysis		
MEn, Kcal/kg	2,889	2,888
Total Ca, %	1.15	1.04
Available P, %	0.52	0..40
CP, %	23.78	21.61
Lys, %	1.29	1.15
Met, %	0.64	0.50
Thr, %	0.92	0.86
Trp, %	0.28	0.26
DEB, mEq/kg[f]	244	240

[a]2,000 broiler chicks used (500 chicks/treatment)

[b]Sorghum replaced corn on a wt/wt basis

[c]Supplied (per kg of diet): 220 of mg of Mg; 220 mg of Zn; 110 mg of Fe; 248 mg of Cu; 33 mg of I; 77,105 IU of Vit A; 27,538 IU of Vit D; 165 IU of Vit E; 0.11 mg of Vit B12; 8 mg of menadione; 66 mg of riboflavin; 11 mg of thiamin; 66 mg of d-pantothenic acid; 275 mg of niacin; 14 mg of Vit B6; 7 mg of folic acid; 3,855 mg of choline; and 1.13 mg of biotin

[d]Provided 2 g of Coban per kg of feed

[e]Provided 0.9 g of tylosin per kg of feed.

[f]DEB (diet) = sodium DEB + potassium DEB – chloride DEB (mEq/kg) = % in diet x valence x 10,000/atomic weight)

Table 4.2. Chemical and physical characteristics of cereals and base premix fed to broiler chicks in Senegal, Mali, Burkina Faso, Niger, and Nigeria[a]

		Kernel characteristics					%					
Cereal	Site	Seed color	Diameter[b], mm	Seed wt, g	Hardness[b]	Tannins[c]	DM	CP	EE	CF	Ash	NFE
	Senegal	White		23.03	-	-	89.77	7.49	3.54	2.12	1.94	74.68
	Mali	White	-	28.56	-	-	89.69	7.82	3.43	2.00	1.74	74.70
	Burkina	White	-	25.56	-	-	89.92	7.27	3.60	2.46	1.94	74.66
	Niger	White	-	23.40	-	-	90.48	7.60	3.30	2.83	1.51	75.51
	Nigeria	White	-	34.80	-	-	90.83	7.79	3.50	2.81	1.22	75.50
Corn	*Mean*		-	*26.96*	-	-	*90.14*	*7.59*	*3.47*	*2.44*	*1.67*	*75.01*
Sorghum	Senegal	White	1.94	2.31	106.30	ND	89.48	9.49	2.79	2.26	2.03	72.91
	Mali	White	1.75	1.82	87.41	ND	87.92	8.17	2.50	1.45	1.90	73.90
	Burkina	White	1.74	2.22	112.38	ND	90.07	9.51	2.55	1.81	2.15	74.04
	Niger	White	1.92	1.74	83.32	ND	91.07	9.16	2.19	2.72	2.04	74.96
	Nigeria	White	2.21	3.55	70.65	ND	90.90	9.32	2.22	2.26	2.11	74.98
	Mean		*1.91*	*2.33*	*92.01*	*ND*	*89.89*	*9.13*	*2.45*	*2.10*	*2.05*	*74.16*
Premix[d] d 0 to 21			-	-	-	-	91.52	44.39	4.21	7.32	16.96	18.65
Premix[d] d 21 to 42			-	-	-	-	91.54	41.98	3.12	8.99	14.77	22.69

[a]2,000 broiler chicks used (500 chicks/treatment)

[b]Determined using SKCS (Bean et al., 2006)

[c]Determined using HCl-vanillin method (Butler and Fisher, 1978)

[d]All ingredients in the diet except the cereal

Table 4.3. Growth performance for broiler chicks fed corn- or sorghum-based diets with different particle sizes in Senegal, Mali, Burkina Faso, Niger, and Nigeria[a]

	Corn		Sorghum			P-value		
Item	6.4 mm	2 mm	6.4 mm	2 mm	SE	Cereal (C)	Particle size (P)	C*P
Particle size, μm[b]	934	643	953	729	52	-	-	-
d 0 to 21								
ADG, g	31	30	29	28	2	< 0.001	0.20	0.87
ADFI, g	52	52	52	51	2	0.33	0.15	0.73
G:F, g/kg	590	584	558	551	16	< 0.001	0.36	0.93
d 0 to 42								
ADG, g	47	46	45	45	2	0.001	0.25	0.67
ADFI, g	89	88	89	89	5	0.65	0.23	0.70
G:F, g/kg	522	527	503	502	10	< 0.001	0.67	0.56

[a]A total of 2,000 chicks (400/treatment)

[b]Geometric mean particle size (d_{gw}) was determined from 100 g samples

Table 4.4. Carcass characteristics for broiler chicks fed corn- or sorghum-based diets with different particle sizes in Senegal, Mali, Burkina Faso, Niger, and Nigeria[a]

	Corn		Sorghum			P-value		
Item	6.4 mm	2 mm	6.4 mm	2 mm	SE	Cereal (C)	Particle size (P)	C*P
Particle size, μm[b]	934	643	953	729	52	-	-	-
Carcass, g	1,505	1,510	1,509	1,517	11	0.61	0.56	0.88
Yield, %	73.4	73.8	73.8	74.4	0.6	0.38	0.40	0.83
Fat, g	24	22	23	25	1	0.49	0.87	0.14
Gizzard, g	42	41	40	38	2	0.21	0.25	0.68
Liver, g	44	42	43	42	2	0.67	0.47	0.66
Intestine, g	48	47	46	47	1	0.44	0.86	0.39

[a]A total of 2,000 chicks (400/treatment)

[b]Geometric mean particle size (d_{gw}) was determined from 100 g samples according to ASAE (1983)

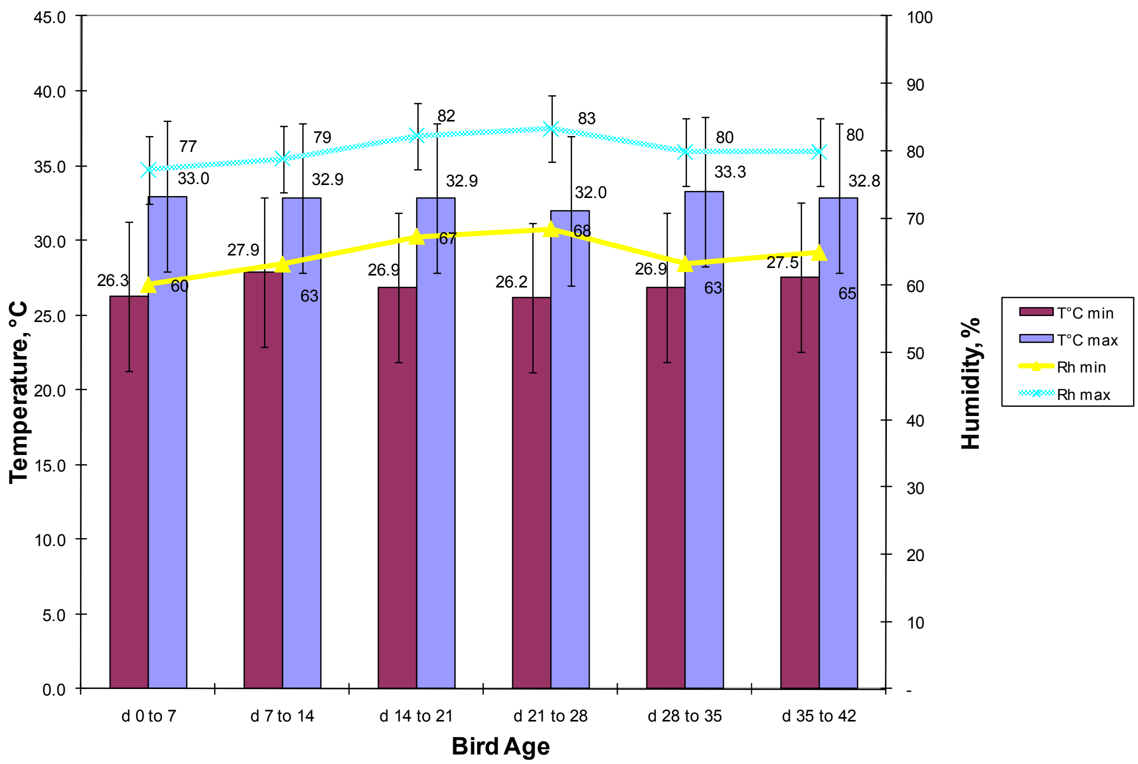

Figure 4.1. Temperature and humidity in naturally ventilated open-sided poultry houses in Senegal, Mali, Burkina Faso, Niger, and Nigeria

Appendix A -
Effects of Abrupt Changes from Corn- to Sorghum-Based Diets on Growth Performance in Finishing Pigs

ABSTRACT

A total of 208 pigs (104 barrows and 104 gilts) were used in a 28-d growth assay to determine the effects of abrupt changes from corn to sorghum and sorghum to corn in diets for finishing pigs. The pigs (average initial BW of 92.0 kg) were allotted by sex, weight, and ancestry to 16 pens (13 pigs/pen and four pens/treatment). All pigs were housed in a modified open-front building and allowed to consume feed and water on an ad libitum basis. Treatments were switching from corn to corn, corn to sorghum, sorghum to corn, and sorghum to sorghum mid-experiment. For d 0 to 14, there were trends ($P < 0.09$) for pigs fed the sorghum-based diet to have better ADG and F:G than pigs fed the corn-based diet. However, for d 0 to 28, ADG, ADFI, and G:F were not affected ($P > 0.15$) by feeding either corn or sorghum. Especially noteworthy was the lack of interactions for d 0 to 14 vs 14 to 28 ($P > 0.15$) suggesting no negative effects of changing cereal at mid-point of the growth assay. In conclusion, pigs fed sorghum-based diets had growth performance that was similar to pigs fed corn-based diets and there was no evidence that abrupt changes from corn to sorghum or sorghum to corn during the finishing phase adversely affected growth rate, feed intake, or efficiency of growth.

Key Words: Corn, Sorghum, Finishing Pigs

INTRODUCTION

Corn continues to be the major cereal fed to pigs in the U.S. and throughout the world. Previous data from our laboratory (Hancock, 2000) suggest that pigs fed sorghum-based diets (when properly milled) have growth performance similar to that of pigs fed corn-based diets. Shelton et al. (2004) reported that pigs fed corn, non-waxy sorghum and, waxy sorghum had similar growth and carcass traits. Finally, Feoli et al. (2007) reported that pigs fed sorghum-based DDGS had greater dressing percentage and lower iodine value than those fed corn-based DDGS. However, there still are concerns about the effects of abrupt changes among corn- and sorghum-based diets (as prices change) on growth performance in pigs. Therefore, the objective of the experiment reported herein was to determine the effects of an abrupt change from corn to sorghum and vice-versa on growth performance in finishing pigs.

MATERIALS AND METHODS

A total of 208 pigs (104 barrows and 104 gilts) were used in a 28-d growth assay. The pigs (average initial BW of 92 kg) were allotted by sex, weight, and ancestry to 16 pens (13 pigs/pen and four pens/treatment). All pigs were housed in a modified open-front building with 2-m x 5-m pens that had half solid and half slatted concrete flooring. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. Diets (Table 1) were 80% cereal for d 0 to 14 and 85% cereal from d 14 to 28 with soybean meal, minerals, vitamins, and amino acids added to meet or exceed all nutrient concentrations suggested by the National Research Council (1998). Treatments were corn- and sorghum-based diets that were switching from corn to corn, corn to sorghum, sorghum to corn, and sorghum to sorghum, on d 14 of the experiment.

Corn, sorghum, and diet samples were collected and analyzed for proximate components (AOAC, 1990) and particle size. All growth data were analyzed as a randomized complete block design using the Proc Mixed procedure of SAS. Orthogonal contrasts were used to separate treatment means with comparison of corn vs sorghum for d 0 to 14, corn vs sorghum for d 14 to 28, and the interaction effect of changing cereal s mid-experiment.

RESULTS AND DISCUSSION

Cereal grains and diets (Table 5-2) had similar particle sizes, dry mater, ash, ether extract, and crude fiber. However, corn and corn-based diets had greater nitrogen free extract while sorghum and sorghum-based diets had greater crude protein. Average daily gain, ADFI and G:F (Table 5-3) indicate similar growth performance from d 0 to 28 for all treatments ($P > 0.10$). For d 0 to 14, there were trends ($P < 0.09$) for pigs fed the sorghum-based diet to have greater ADG and G:F compared to pigs fed the corn-based diet. However, for d 0 to 28, ADG, ADFI, and G:F were not affected by feeding corn vs sorghum ($P > 0.15$). Additionally, there were no interactions among cereals fed for d 0 to 14 vs 14 to 28 suggesting no negative effects ($P > 0.15$) of an abrupt and total change of cereal at mid-point of the finishing phase.

The similar growth performance in our experiment for pigs fed corn and sorghum is in agreement is in agreement with data reported by Shelton et al. (2004). In addition, Hancock (2000) reported that the use of sorghum grains in diets did not decrease body weight gain in finishing pigs. The high performance obtained with pigs fed sorghum can be explained by the relative small particle size of the diets used in our experiment (692 μm for corn-based diet and 663 μm for the sorghum based-diet). O'Quinn et al. (1997) also reported similar ADG, ADFI and F:G in finishing pigs fed sorghum-based diets. In addition, our results are in agreement with data from Nyachoti et al. (1996) who reported similar overall body weight gain, feed intake, and G:F in broilers fed corn and sorghum when broiler chicks were subjected to abrupt changes from corn to sorghum and vice-versa.

IMPLICATIONS

Pigs fed sorghum-based diets had growth performance not different from that of pigs fed corn-based diets. Additionally, there was no evidence that abrupt changes from corn to sorghum or from sorghum to corn during the finishing period adversely affected growth rate, feed intake, or efficiency of growth. Consequently, sorghum grain is a good alternative feedstuff for swine producers at any time when corn is expensive. Producers should not hesitate to make a total substitution.

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Table A.1. Composition of corn- and sorghum-based diets fed to finishing pigs[a]

Ingredient, %	d 0 to 14	d 14 to 28
Cereal[b]	79.54	84.82
Soybean meal, 47.5% CP	17.90	12.90
Monocalcium phosphate	0.72	0.59
Limestone	1.10	1.06
L-lysine HCl	0.24	0.16
D,L-methionine	0.01	-
L-threonine	0.03	-
Salt	0.30	0.30
Vitamins	0.04	0.04
Minerals	0.07	0.07
Vitamin add pack[c]	-	0.01
Antibiotic[d]	0.05	0.05
Total, %	100.00	100.00
Calculated Analyses		
ME	3,274	3,265
Ca, %	0.60	0.55
Total P, %	0.50	0.45
Available P, %	0.21	0.18
CP, %	16.1	13.2
Lysine, %	0.90	0.70
Methionine, %	0.27	0.23
Threonine, %	0.61	0.48
Tryptophan, %	0.20	0.14

[a]A total of 208 pigs (52 pigs/treatment) with an average initial BW of 92 kg

[b]Sorghum replaces corn on a wt/wt basis

[c]Supplied (per kg of diet): 44,060 IU of Vit A; 5,508 IU of Vit D; 176 IU of Vit E; 0.15 mg of B_{12}; 18 mg of menadione; 33 mg of riboflavin; 110 mg of pentatonic acid; and 22 mg of niacin

[d]Provided 0.9 g of tylosin phosphate per kg of feed

Table A.2. Chemical composition of the feeds and ingredients fed to finishing pigs

	Cereal		Diet	
Item	Corn	Sorghum	Corn	Sorghum
Particles size, μm[a]	659	658	692	663
Dry matter, %[b]	86.5	86.5	87.0	87.0
Crude protein, %[b]	7.1	9.3	13.0	14.1
Ether extract, %[b]	2.4	2.6	2.3	2.4
Cellulose, %[b]	1.9	1.7	2.2	1.9
Ash, %[b]	1.3	1.2	3.6	3.6
Nitrogen free extract, %[b]	73.8	71.7	65.9	65.0

[a]Geometric mean particle size (d_{gw}) was determined from100 g samples according to ASAE (1983)

[b]AOAC, 1990

Table A.3. Effects of abrupt changes from corn to sorghum and vice-versa on growth performance in finishing pigs[a]

Item	Treatment[b]				SE	P-value[c]		
	C to C	C to S	S to S	S to C		C vs S d 0 to 14	C vs S d 14 to 28	Cvs S d 0 to 14 * C vs S d 14 to 28
d 0 to 14								
ADG, g	0.99	1.04	1.07	1.11	0.04	0.07	-	-
ADFI, g	3.24	3.24	3.30	3.32	0.17	-	-	-
G:F, g/kg	307	321	330	337	18	-	-	-
d 14 to 28								
ADG, g	1.07	1.12	1.07	1.00	0.03	-	-	-
ADFI, g	3.64	3.70	3.61	3.52	0.14	-	-	-
G:F, g/kg	295	303	298	285	7	-	-	-
d 0 to 28								
ADG, g	1.03	1.08	1.07	1.06	0.03	-	-	-
ADFI, g	3.44	3.47	3.45	3.42	0.15	-	-	-
G:F, g/kg	300	311	313	310	11	-	-	-

[a]A total of 208 pigs (52/treatment).

[b]C = corn and S = sorghum

[c]Dash = Non significant (P > 0.15)