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Apparent metabolizable energy and performance of broilers fed selected grain sorghum varieties

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ABSTRACT

Objective: The objective of this study was to determine the nitrogen-corrected apparent ME (AME_n) content of tannin-free red/bronze, white/tan, and US No. 2 varieties of grain sorghum fed to commercial broilers and evaluate its effects on growth performance as an alternative to corn in poultry diets.

Materials and Methods: Nitrogen-corrected apparent ME content of red/bronze, white/tan, and US No. 2 grain sorghum varieties was determined using a dextrose control diet as the standard fed to 112 mixed-sex Cobb 500 female × Hubbard male broilers. Weekly measures of mean BW and feed consumption were used to calculate BW gain, feed intake, and feed conversion ratio. Analyses were based on a 2 × 4 factorial arrangement of treatments with age (grower and finisher phases) and grain types (corn-dextrose, red/bronze, white/tan, and US No. 2) defining the treatments. Cage was the experimental unit with data analyzed using JMP Pro version 15.2.0 (SAS Institute Inc.).

Results and Discussion: Mean AME_n values of modern grain sorghum varieties for broilers in the grower diet phase were determined as 3,336 (red/bronze), 4,000 (white/tan), and 3,341 (US No. 2) kcal/kg and, in the finisher-diet phase, as 3,001 (red/bronze), 3,599 (white/tan), and 3,599 (US No. 2) kcal/kg ($P = 0.0155$). No significant differences among treatments for growth performance (BW gain, feed intake, feed conversion ratio) in the grower- and finisher-diet phases were observed.

Implications and Applications: Responses indicate the potential for grain sorghum to replace corn without suboptimal effects on broilers. Growth performance trials with the full substitution of corn in feed formulation will be necessary to validate AME_n values and evaluate additional performance parameters.

Key words: alternative feedstuff, apparent metabolizable energy, tannin free, grain sorghum, broiler chicken

INTRODUCTION

Grain sorghum is an alternative feedstuff to corn due to its similar nutritional composition and its adaptations to drought and varying soil types, enabling it to be grown in locations coinciding with poultry production in the southeastern United States (**US**). Previous studies with commercial broiler diets indicated that low-tannin grain sorghum was an effective partial or complete replacement for corn, whereas high-tannin grain sorghum negatively affected feed intake, protein digestibility, and growth (Gualtieri and Rapaccini, 1990). The combination of antinutritional factors, including tannin, phytate, and karafin compounds in grain sorghum, resulted in decreased nutritive value and palatability, affecting feed intake (**FI**) and, thus, reduced growth of broilers. Rodrigues et al. (2007) evaluated broiler performance in Australian grain sorghum–based diets and concluded a negative relationship between grain sorghum tannins and apparent ME (**AME**) values. Correspondingly, nitrogen-corrected AME (**AME_n**) values have been lower in red grain sorghum varieties than in white grain sorghum varieties due to an increased tannin content in the red varieties (Mandal et al., 2006). Dykes and Rooney (2006) indicated that, of the tannin-free grain sorghum varieties, red grain sorghum had a greater total of phenol compounds than white grain sorghum, resulting in adverse effects on performance. Low-tannin and tannin-free varieties may be potential replacements for corn as they are similar in nutritive value (Gualtieri and Rapaccini, 1990). Overall, these inconsistencies have invoked a negative per-

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ception of using grain sorghum as an alternative; however, evaluation of low-tannin grain sorghum varieties proved to be effective relative to high-tannin grain sorghum varieties fed to broilers (Hulan and Proudfoot, 1982).

Today, modern varieties of grain sorghum in the US are tannin free for animal feed use; however, limited data are available to support modern varieties as an alternative feedstuff to corn in broiler diets. Validating the nutritional effects of modern grain sorghum varieties on the growth, health, and product quality of broilers is necessary to support the use of these varieties in poultry feed. In addition, validating the nutrient profile of tannin-free grain sorghum is important due to the variability of its nutrient content and previous data lacking comparable characterization of grain types, form, and processing methods (Taylor and Kruger, 2019). Failure to accommodate for variations in energy values when formulating a diet can significantly affect the cost of feed and production. As a result, evaluating the nutritional composition of modern grain sorghum will provide commercial poultry nutritionists with up-to-date specifications for practical use in feed formulation, which is currently limited based on outdated or nonexistent nutritional profiles for tannin-free grain sorghum.

Energy is arguably the most expensive and physiologically important component of a poultry diet. It is also the first parameter to consider in diet formulation due to its multifaceted functions for metabolism, maintenance, growth, and heat production in animals (Wu et al., 2020). The energy provided from a feed and its availability to the bird can be measured by evaluating the ME of feedstuffs in a diet. Measures of FI and excretory output are the basis for quantitatively determining ME (Bedford et al., 2016). A more recent study in broilers by Khalil et al. (2021) suggests that AME_n is affected by age, and in a study by Bartov (1995), AME_n of corn and sorghum diets decreased with increasing age. Therefore, determining the AME_n value of each of these modern grain sorghum varieties is a critical factor in diet formulation for the full replacement of corn in poultry feed. The objective of this study was to determine the AME_n content of red/bronze, white/tan, and US No. 2 varieties of tannin-free, grain sorghum for feeding commercial broilers and evaluate its effect on growth performance.

MATERIALS AND METHODS

Animal Care and Use

All experimental policies and procedures were reviewed and approved by the Clemson University Institutional Animal Care and Use Committee (AUP #2017-051).

Birds and Husbandry

A trial was conducted during a 1- to 47-d-of-age grow-out period to evaluate the AME_n response of 112 mixed-sex Cobb 500 female × Hubbard male commercial broilers from 22 to 24 d of age and 43 to 45 d of age. At 1 d of age, birds were housed in a solid-sided research house and randomly distributed (4 birds per cage) in heated battery brooder cages, 34 cm × 98 cm, and transferred at 21 d of age to grower battery cages, 61 cm × 71 cm (Petersime). Each grower battery cage was the experimental unit, with a metal trough feeder and water unit. The temperature of the cage was 35°C at placement and gradually decreased to reach 27°C, and a lighting program of 16 h of light to 8 h of dark (16L:8D) was followed throughout the study.

Tannin Analysis

Varieties of grain sorghum used in this experiment were analyzed for tannin content to ensure zero tannin content before use in experimental diets. An acid-butanol assay (Hagerman, 2002) for proanthocyanidins was conducted on red/bronze, white/tan, and the US No. 2 grain sorghum varieties. In this assay, acid was added to a sample of each grain to yield a colored product (known as cyanidin) or a colorless product (known as catechin) if tannins were present or absent, respectively (Hagerman, 2002). The colored product has an absorbance peak at 550 nm and is characteristic of a high-tannin grain (Hagerman, 2002).

Experimental Diets

Three modern varieties of grain sorghum commonly grown in the southeastern US, red/bronze, white/tan, and US No. 2, were obtained from the states of Florida and North Carolina and used for all diets. The red/bronze and white/tan grain sorghum varieties were identity preserved, whereas US No. 2 was a red/bronze-based variety that may have contained other mixed grain sorghum varieties. Nutrient and GE analyses of grain sorghum used in the experimental diets are shown in Table 1. All whole grain sorghum was ground through a hammer mill (Premier 1 Supplies) with a 4-mm sieve. The trial included 4 cages for the dextrose/control diet and 8 cages for each of the 3 treatments with a grain sorghum variety; therefore, cage was the experimental unit. Diets were fed as mash *ad libitum* and formulated based on an industry-standard supplied by a commercial nutritionist. All birds were fed a corn-based acclimation diet on d 1 to 3. On d 4, birds were randomly assigned 1 of 4 corn basal diets with 20% of the calories for the GE of corn replaced by the equivalent calories of the respective GE of grain sorghum (red/bronze, white/tan, or US No. 2; Table 1) or dextrose for the dextrose/control diet. Dextrose was used as a reference ingredient due to its known GE content. The classical basal substitution method (Sibbald et al., 1960) was modified in this study to target a more practical approach and for evaluation for future use by commercial nutritionists. The ingredient composition, nutrient analyses, and AME_n for the basal and complete test diets are shown in Tables 2, 3, 4, and 5.

Excreta Collection and Measurements

Excreta collection and other measurements for AME_n determination of grain sorghum were determined in the grower- and finisher-diet phases for broilers from 22 to 24 d of age and 43 to 45 d of age during a 72-h total excreta collection period. At the end of each collection period, feed disappearance and total excreta weight were measured. A 30-g sample of feed and excreta was analyzed, on a DM basis, for GE with a bomb calorimeter and nitrogen content with a combustion N analyzer at the University of Georgia Feed, Environmental and Water Laboratory. Feed intake, excreta weight, GE, and nitrogen content results were used to calculate the AME_n of grain sorghum using the difference method by MacLeod et al. (2008):

$$\text{Diet AME}_n\text{: AME}_n = \{(\text{GEI} - \text{GEE}) - [8.73 \times (\text{NI} - \text{NE})]\}/\text{FI}, \quad [1]$$

$$\text{Sorghum AME}_n\text{: AME}_{n\ \text{grain sorghum}} = [\text{AME}_{n\ \text{basal}} + (\text{AME}_{n\ \text{diet}} - \text{AME}_{n\ \text{basal}})]/\text{proportion of grain sorghum in diet}, \quad [2]$$

where GEI = GE intake; GEE = GE output in excreta; NI = nitrogen intake from the diet; NE = nitrogen output from excreta; and 8.73 = nitrogen correction factor from previous research (Titus et al., 1959).

Birds were group weighed (kg/cage), and feed disappearance was measured weekly on d 1, 8, 15, 22, 29, 36, 43, and 47. Mortality was recorded daily for birds that died over the grow-out period. Weekly measures of group BW and feed disappearance were used to calculate BW gain (**BWG**), FI, and feed conversion ratio (**FCR**) per treatment (15 to 22 d of age and 36 to 43 d of age):

$$\text{Grower-phase FCR}_{15\text{–}22\text{ d of age (not adjusted for mortality)}} = \text{mean FI}_{15\text{–}22\text{ d of age}} \div \text{mean BWG}_{15\text{–}22\text{ d of age}}, \quad [3]$$

$$\text{Finisher-phase FCR}_{36\text{–}43\text{ d of age (not adjusted for mortality)}} = \text{mean FI}_{36\text{–}43\text{ d of age}} \div \text{mean BWG}_{36\text{–}43\text{ d of age}}. \quad [4]$$

Statistical Analysis

The analyses were based on a completely randomized design with a 2 × 4 factorial arrangement of treatments with age (grower phase and finisher phase) and grain types (dextrose/control, red/bronze, white/tan, and US No. 2) defining the treatments. Cage represented the experimental unit, and ANOVA followed by Fisher's LSD procedure was used to determine specific differences among the grain type means. P-values ≤ 0.05 were considered evidence of statistical significance. All statistical calculations were performed using JMP Pro version 15.2.0 (SAS Institute Inc.).

RESULTS AND DISCUSSION

Tannin Analysis

The absorbance measured for each grain sorghum variety for this experiment yielded no product at 550 nm compared with the pure sorghum with spectra at 550 nm; thus, no tannins were present in the varieties used for this experiment. Additional confirmation for the presence of tannins in the red/bronze variety, which is more commonly known to contain greater tannin content, was tested at a high and low concentration of tannin to ensure that there were no traces of tannins in larger sample sizes. Results showed similar spectra for both concentrations with no peak at 550nm, indicating no tannin traces in any of the samples.

Table 1. Nutrient and GE analyses of sources of corn and modern varieties of grain sorghum (red/bronze, white/tan, and US No. 2)

Item	Dextrose	Corn	Grain sorghum variety: Red/bronze	Grain sorghum variety: White/tan	Grain sorghum variety: US No. 2
DM[1] (%)	—	84.58	87.48	89.93	84.44
GE, as fed[2] (kcal/kg)	3,376	3,926	3,752	3,686	3,653
Ash[1] (%)	—	1.07	0.90	1.10	1.39
Crude fat[1] (%)	—	3.13	2.89	2.46	2.93
Crude fiber[1] (%)	—	1.50	1.80	1.70	2.20
CP[1] (%)	—	7.52	8.87	9.33	8.65
Methionine (%)	—	0.15	0.15	0.17	0.14
Lysine (%)	—	0.26	0.24	0.24	0.23
Threonine (%)	—	0.26	0.30	0.31	0.28

[1]Proximate analysis and AA were determined using the AOAC International methods (Novus International Inc. Laboratory Services).

[2]Determined by the University of Georgia Feed, Environmental and Water Laboratory.

Table 2. Ingredient composition of basal broiler diet (as fed) in phases of a 1- to 47-d grow-out for complete test diets (as fed)

Item	Basal diet phase		
	Starter (1–11 d)	Grower (12–24 d)	Finisher (25–47 d)
Ingredient (%)			
Corn	49.45	58.60	63.11
Soybean meal, 47.5% CP	42.05	33.55	28.81
Fat, vegetable	3.59	2.96	3.47
Mono-dicalcium phosphate	1.89	1.83	1.73
Limestone	1.57	1.56	1.50
Sodium chloride	0.55	0.59	0.60
DL-Methionine	0.33	0.28	0.24
L-Threonine	0.00	0.005	0.01
Biolys[1]	0.05	0.10	0.11
Choline chloride, 60%	0.18	0.19	0.12
Vitamin and mineral premix[2]	0.22	0.23	0.20
BMD 50[3]	0.06	0.06	0.06
Saccox 60[4]	0.06	0.05	0.04
Calculated composition[5]			
ME (kcal/kg)	2,983	3,039	3,125
CP (%)	23.62	20.38	18.51
Crude fat (%)	6.11	5.68	6.27
Calcium (%)	1.02	0.98	0.94
Sodium (%)	0.24	0.25	0.26
Lysine (%)	1.52	1.30	1.17
Methionine (%)	0.71	0.62	0.55
Methionine + cysteine (SAA[6]; %)	1.11	0.97	0.88
Total phosphorus (%)	0.82	0.77	0.73
Available phosphorus (%)	0.47	0.45	0.43
Analyzed composition			
CP[7] (%)	25.28	20.91	18.78
Crude fat[7] (%)	5.88	4.75	5.74
Calcium (%)	1.04	2.71	1.17
Sodium (%)	0.20	0.13	0.13
Lysine (%)	1.76	1.15	1.19
Methionine (%)	1.32	0.38	0.47
Methionine + cysteine (SAA; %)	0.99	0.65	0.77
Total phosphorus (%)	0.82	0.92	0.98

[1]50.7% lysine, Biolys (Evonik).

[2]Vitamin premix per kilogram of diet: vitamin A = 16,435.29 IU; vitamin D_3 = 3,582,452; 25-hydroxyvitamin D_3 = 0.08 mg; vitamin E = 156.53 IU; vitamin B_{12} = 0.05 mg; biotin = 0.47 mg; menadione = 7.04 mg; thiamine 4.23 mg; riboflavin = 14.09 mg; d-pantothenate = 23.48 mg; vitamin B_6 = 7.44 mg; niacin = 93.92 mg; folic acid = 3.13 mg. Trace mineral premix per milligram per kilogram of diet: manganese = 113.59%; zinc = 107.90%; iron = 0.22%; copper = 5.68%; iodine = 3.41%; cobalt = 1.70%; selenium = 0.34%.

[3]Bacitracin methylene disalicylate (Zoetis).

[4]Salinomycin sodium (Huvepharma).

[5]Phase-fed basal diet formulation based on an industry standard supplied by a commercial nutritionist.

[6]SAA = sulfur AA.

[7]Proximate analysis, AA, and minerals were determined using the AOAC International methods (Novus International Inc. Laboratory Services).

Table 3. Ingredient composition and nutrient analyses of complete starter-phase test diets (as fed) for 4 to 11 d of age (dextrose/control, red/bronze, white/tan, and US No. 2)

	Starter treatment			
Item	Dextrose control	Red/bronze	White/tan	US No. 2
Ingredient[1] (%)				
Basal starter diet[1]	87.12	88.40	88.16	89.35
Grain sorghum	0.00	11.60	11.84	10.65
Dextrose	12.88	0.00	0.00	0.00
Calculated composition[1]				
ME (kcal/kg)	3,066	3,035	3,000	3,000
CP (%)	20.47	21.99	21.83	22.00
Crude fat (%)	5.11	5.50	5.45	5.52
Calcium (%)	1.16	1.18	1.17	1.19
Sodium (%)	0.19	0.19	0.19	0.20
Lysine (%)	1.20	1.24	1.24	1.23
Methionine (%)	0.59	0.62	0.62	0.63
Methionine + cysteine (SAA[2]; %)	0.91	0.97	0.96	0.97
Total phosphorus (%)	0.71	0.76	0.76	0.76
Available phosphorus (%)	0.46	0.48	0.48	0.49
Analyzed composition				
CP[3] (%)	22.05	21.73	25.43	22.64
Crude fat[3] (%)	5.55	6.36	5.35	5.76
Calcium (%)	1.13	1.14	1.12	0.94
Sodium (%)	0.18	0.17	0.14	0.13
Lysine (%)	1.19	1.22	1.40	1.33
Methionine (%)	0.69	0.68	0.66	0.62
Methionine + cysteine (SAA; %)	0.98	0.99	1.00	0.96
Total phosphorus (%)	0.76	0.82	0.82	0.76

[1]Phase-fed basal diet (Table 2) and complete diet formulation based on an industry standard supplied by a commercial nutritionist.

[2]SAA = sulfur AA.

[3]Proximate analysis, AA, and minerals were determined using the AOAC (Association of Official Analytical Chemists) methods (Novus International Inc. Laboratory Services).

AME$_n$ Determination

Determined AME$_n$ for grain sorghum in the grower phase (22 to 24 d of age) presented in Table 6 were 3,336 (red/bronze), 4,000 (white/tan), and 3,341 (US No. 2) kcal/kg. White/tan had the greatest AME$_n$, and US No. 2 was intermediate ($P = 0.0387$). In the finisher phase (43 to 45 d of age), shown in Table 6, the determined AME$_n$ was 3,001 (red/bronze), 3,599 (white/tan), and 3,705 (US No. 2) kcal/kg, respectively. The US No. 2 had the greatest AME$_n$, and white/tan was intermediate ($P = 0.0387$). Relative to AME$_n$ determination, FI was greatest in the finisher phase ($P = 0.0123$).

The nutritional composition of grain sorghum in the present study (Table 1) was similar to published reports for low-tannin grain sorghum containing 8 to 10% CP (Douglas et al., 1990). Grain sorghum has comparable DM, protein, and limiting AA (lysine, methionine, and threonine) content to that of corn despite the major difference in composition reported as grain sorghum having slightly greater protein and less fat (NASEM, 1994). Variations in nutrient composition of an ingredient can be attributed to the region, environment, and season in which it is grown (Scott et al., 1998). Therefore, due to these existing variations, it is necessary to determine the energy content of feedstuffs to adequately formulate a diet, especially when considering alternative feed ingredients (Sibbald, 1980).

Researchers, nutritionists, and grain producers are most familiar with tannin-containing or “bird-proof” grain sorghum and its suboptimal effects on digestibility and growth performance in broilers (Selle et al., 2013). In this present study, grain sorghum varieties were acquired in the US and analyzed as tannin free. Although more red grain sorghum, known as a high-tannin variety, is grown and used in broiler feed worldwide due to its bird-resistant and high-yield attributes, white sorghum–based diets have been shown to outperform red grain sorghum–based diets because of lower tannin content (Mandal et al., 2006; Liu et al., 2016).

Table 4. Ingredient composition, nutrient analyses, and calculated treatment nitrogen-corrected apparent ME (AME_n)[1] of complete grower-phase test diets (as fed) for 12 to 24 d of age (dextrose/control, red/bronze, white/tan, and US No. 2)

Item	Grower treatment			
	Dextrose control	Red/bronze	White/tan	US No. 2
Ingredient[2] (%)				
Basal grower diet[2]	85.04	86.54	86.30	86.18
Grain sorghum	0.00	13.46	13.70	13.82
Dextrose	14.96	0.00	0.00	0.00
Calculated composition[2]				
ME (kcal/kg)	3,126	3,090	3,050	3,052
CP (%)	17.10	18.80	18.63	18.62
Crude fat (%)	4.64	5.07	5.03	5.06
Calcium (%)	1.05	1.06	1.06	1.06
Sodium (%)	0.20	0.20	0.20	0.20
Lysine (%)	1.01	1.05	1.05	1.05
Methionine (%)	0.50	0.54	0.53	0.53
Methionine + cysteine (SAA[3]; %)	0.78	0.85	0.84	0.84
Total phosphorus (%)	0.66	0.71	0.71	0.71
Available phosphorus (%)	0.43	0.45	0.45	0.45
Analyzed composition				
CP[4] (%)	20.47	19.52	20.53	20.17
Crude fat[4] (%)	4.50	4.63	4.92	4.91
Calcium (%)	0.92	1.04	1.02	0.97
Sodium (%)	0.16	0.18	0.16	0.17
Lysine (%)	1.00	1.09	1.10	1.14
Methionine (%)	0.55	0.53	0.59	0.54
Methionine + cysteine (SAA; %)	0.80	0.82	0.87	0.31
Total phosphorus (%)	0.70	0.76	0.76	0.73
GE[5] (kcal/kg)	4,025	4,266	4,303	4,340

[1]Calculated AME_n of each complete test diet determined using the following equation: $AME_n = \{(GEI - GEE) - [8.73 \times (NI - NE)]\}/FI$, where GEI = GE intake; GEE = GE output in excreta; NI = nitrogen intake from the diet; NE = nitrogen output from excreta; FI = feed intake; and 8.73 = nitrogen correction factor from previous research (Macleod et al., 2008).

[2]Phase-fed basal diet (Table 2) and complete diet formulation based on an industry standard supplied by a commercial nutritionist.

[3]SAA = sulfur AA.

[4]Proximate analysis, AA, and minerals were determined using the AOAC International methods (Novus International Inc. Laboratory Services).

[5]Determined by the University of Georgia Feed, Environmental and Water Laboratory.

The AME_n values for grain sorghum in this study were greater than those reported for tannin-free white and red sorghum varieties (Truong et al., 2016). Truong et al. (2016) determined AME_n values of 2,790 and 2,651 kcal/kg of DM for white and red sorghum varieties, respectively, in broiler chickens from 7 to 28 d of age. Khalil et al. (2021) reported AME_n values of 3,762 kcal/kg at wk 1 and 3,556 kcal/kg at wk 6 for grain sorghum sourced from Australia. Results in the current study show decreased AME_n values for all treatments in the finisher phase. This observation may be similar to previously reported data suggesting that as age increases, FI increases, which can influence the rate of feed passage and digestion, resulting in lower AME_n (Khalil et al., 2021). In fact, a study by Svihus (2011) observed the effect of starch digestibility in wheat and found that it is negatively correlated with increasing FI, which results in reduced AME_n. Therefore, AME_n determination can be extremely variable due to variations in FI and excreta measurements (Dozier et al., 2008). Sibbald et al. (1960) has suggested that lower inclusion rates of a test ingredient may increase AME_n variability, whereas greater inclusion levels may reduce the variability of AME_n values. However, high inclusion levels could be detrimental to performance. As a result, it is practical to choose an inclusion

Table 5. Ingredient composition, nutrient analyses, and calculated treatment nitrogen-corrected apparent ME (AME_n)[1] of complete finisher-phase test diets (as fed) for 25 to 47 d of age (dextrose/control, red/bronze, white/tan, and US No. 2)

	Finisher treatment			
Item	Dextrose control	Red/bronze	White/tan	US No. 2
Ingredient[2] (%)				
Basal finisher diet[2]	84.06	85.66	85.40	85.27
Grain sorghum	0.00	14.35	14.61	14.74
Dextrose	15.95	0.00	0.00	0.00
Calculated composition[2]				
ME (kcal/kg)	3,207	3,171	3,127	3,130
CP (%)	15.26	17.05	16.88	16.87
Crude fat (%)	5.09	5.56	5.51	5.54
Calcium (%)	0.96	0.98	0.98	0.98
Sodium (%)	0.20	0.20	0.20	0.20
Lysine (%)	0.89	0.94	0.94	0.94
Methionine (%)	0.45	0.48	0.48	0.48
Methionine + cysteine (SAA[3]; %)	0.70	0.77	0.76	0.76
Total phosphorus (%)	0.62	0.67	0.67	0.67
Available phosphorus (%)	0.40	0.43	0.42	0.42
Analyzed composition				
CP[4] (%)	18.49	17.63	18.44	18.10
Crude fat[4] (%)	4.95	5.68	5.82	5.80
Calcium (%)	0.90	0.95	1.04	1.07
Sodium (%)	0.13	0.17	0.15	0.21
Lysine (%)	0.95	0.99	1.02	0.91
Methionine (%)	0.35	0.50	0.48	0.44
Methionine + cysteine (SAA; %)	0.62	0.77	0.75	0.70
Total phosphorus (%)	0.67	0.64	0.70	0.70
GE[5] (kcal/kg)	4,249	4,342	4,348	4,423

[1]Calculated AME_n of each complete test diet determined using the following equation: $AME_n = \{(GEI - GEE) - [8.73 \times (NI - NE)]\}/FI$, where GEI = GE intake; GEE = GE output in excreta; NI = nitrogen intake from the diet; NE = nitrogen output from excreta; FI = feed intake; and 8.73 = nitrogen correction factor from previous research (Macleod et al., 2008).

[2]Phase-fed basal diet (Table 2) and complete diet formulation based on an industry standard supplied by a commercial nutritionist.

[3]SAA = sulfur AA.

[4]Proximate analysis, AA, and minerals were determined using the AOAC International methods (Novus International Inc. Laboratory Services).

[5]Determined by the University of Georgia Feed, Environmental and Water Laboratory.

rate that is applicable to the poultry industry in formulation and has a well-characterized nutritional profile. For these reasons, the typical range of inclusion level for a test ingredient in AME_n studies is between 20 and 40% (Alvarenga et al., 2013). In this study, replications for grain sorghum treatments were increased using a lower inclusion range to account for any variation specifically associated with the inclusion level of grain sorghum. Differences in nutrient composition of ingredients and inclusion levels in diets between this present study and previously reported studies using sorghum to replace corn might explain the variation and inconsistencies of determined AME_n values.

Energy is one of the first parameters to consider in feed formulation, but it has been recently reported that there are widely inconsistent values depending on what bioassay is used for the determination of ME (Wu et al., 2020). Dextrose was used for the control diet as a reference ingredient to reduce variability associated with corn for AME_n determination. Typically, glucose represents a baseline for comparison with a known energy content compared with the potential variability of the energy content of other ingredients (e.g., corn) in a basal diet (NASEM, 1994). As a result, it was also more appropriate to use a modified substitution method in this current study because it reflects

Table 6. Mean nitrogen-corrected apparent ME (AME_n) of dextrose/control and grain sorghum varieties (red/bronze, white/tan, and US No. 2), and 72-h feed intake during the grower- and finisher-diet phases of the excreta collection period, 22 to 24 d of age and 43 to 45 d of age, in commercial broilers

Treatment			
Grain type	**Diet phase**	**$AME_{n\ grain}$[1,2] (kcal/kg)**	**72-h Feed $intake_{diet}$[1] (kg)**
Dextrose/control	Grower	3,883 ± 262[ab]	1.55 ± 0.13[d]
Red/bronze	Grower	3,336 ± 185[bc]	1.77 ± 0.09[d]
White/tan	Grower	4,000 ± 185[a]	2.04 ± 0.09[c]
US No. 2	Grower	3,341 ± 198[bc]	1.70 ± 0.09[d]
Dextrose/control	Finisher	2,904 ± 262[c]	2.17 ± 0.13[bc]
Red/bronze	Finisher	3,001 ± 185[b]	2.33 ± 0.09[b]
White/tan	Finisher	3,599 ± 185[ab]	2.81 ± 0.09[a]
US No. 2	Finisher	3,705 ± 198[ab]	2.68 ± 0.09[a]
Main effects means			
Dextrose/control		3,394 ± 185[ab]	1.86 ± 0.11[c]
Red/bronze		3,168 ± 131[b]	2.05 ± 0.08[bc]
White/tan		3,800 ± 140[a]	2.43 ± 0.08[a]
US No. 2		3,523 ± 140[ab]	2.19 ± 0.08[b]
	Grower	3,640 ± 105[a]	1.77 ± 0.05[b]
	Finisher	3,302 ± 105[b]	2.49 ± 0.05[a]
P-value			
Grain type		0.0134	0.0012
Diet phase		0.0277	<0.001
Grain type × diet phase		0.0387	0.0123

[a–d]Means within a column with the same superscript are not significantly different.

[1]Least-squares means ± SEM; each mean represents 4 cages with 4 birds per cage for dextrose/control and 8 cages with 4 birds per cage per treatment of red/bronze, white/tan, and US No. 2.

[2]The AME_n of dextrose and grain-sorghum varieties was calculated by difference using the following equation: $AME_{n\ grain\ sorghum} = [AME_{n\ basal} + (AME_{n\ diet} - AME_{n\ basal})]$/proportion of grain sorghum in diet (Macleod et al., 2008).

how a nutritionist would formulate if only given the GE specification for a test ingredient to determine AME_n in broilers. As a result, it is appropriate to formulate based on the GE of corn and grain sorghum and then equate the calories needed to replace either ingredient rather than a specific inclusion level as the classical substitution method reported in literature. This modified method is much more practical in formulation, allowing for any synergistic or antagonistic interactions in production to happen in commercial formulation (Concept 5, CFC Tech Service Inc.) when other ingredients and their nutrients are contributing alongside the inclusion of grain sorghum.

Kafirin, a common nontannin phenolic compound in grain sorghum, has been shown to negatively affect starch and energy utilization in grain sorghum diets fed to broilers (Truong et al., 2016). White sorghum varieties contain lower polyphenol concentrations, which are associated with lower kafirin concentrations. Truong et al. (2016) found that white grain sorghum was a better option than red sorghum when feeding poultry, which has been correlated with yielding greater AME_n values and better starch and energy utilization compared with those with high kafirin content typically found in red grain sorghum. Results in the present study showed white/tan grain sorghum having the greatest AME_n value compared with previously reported results.

Overall, slight variations in specific parameters including total excreta weight and FI during the excreta collection period have been reported to attribute highly variable AME_n values (Dozier et al., 2008). In this present study, AME_n values were determined for 2 diet phases (grower and finisher) over a 72-h period compared with previous AME_n studies, which typically determined AME_n during the grower phase. Scott et al. (1998) have described the advantage of allowing the broiler chick to adjust its gut capacity and microflora to the diet by providing a 13-d feeding period on a diet before AME_n determination.

In the current study, the modified method also considered AME_n at different ages and diet phases; there was evidence of an age effect on AME_n and 72-h FI. Few published AME_n studies have actually done this, neglecting the fact that diets are formulated with varying energy levels according to the age of the bird (NASEM, 1994; Barzegar et al., 2020). The AME_n determination in 2 different diet phases can explain energy utilization and efficiency in the growing bird. Meat-type birds increase BW with age; thus, greater energy at an older age is necessary to meet demands for maintenance and production as broilers consume feed until their energy requirement for maintenance is met (Sibbald, 1980; Leeson et al., 1996; Gous et al., 2018). Therefore, a feed with greater AME_n may satisfy this energy requirement (Zelenka, 1997). Feed intake is closely related to growth performance and influenced by several factors including energy density of feed, environment, housing, feed form, age, breed, sex, and health status of the bird (Ferket and Gernat, 2006; Dozier et al., 2008; Bedford et al., 2016). As a result, when feed is not consumed to meet the full nutritional requirements of meat-type birds, they will not grow adequately to their genetic potential (Ferket and Gernat, 2006).

Performance

Growth performance responses including BWG, FI, and FCR are shown in Table 7 for the grower- and finisher-phase diets corresponding to each period for AME_n determination on 22 and 43 d of age. Responses were not negatively affected by grain sorghum treatments compared with dextrose/control, as shown, with no significant differences for both diet phases ($P > 0.05$). The characteristic physiological behavior of a broiler chicken is that they will eat to meet their energy needs (Dozier et al., 2008). Results from this study showed this physiological behavior in birds fed the red/bronze sorghum treatment during the grower phase; birds consumed more feed to meet their energy requirement because red/bronze had the lowest energy. Thus, birds were less efficient as seen in the poorer FCR of 1.53; however, birds in this treatment group were able to compensate for their BW by eating more feed of lower energy compared with the other treatments. No differences in BWG, FI, and FCR among treatments demonstrated similar performance of broilers when not optimally fed diets of equal energy.

Liu et al. (2013) reported that broilers fed white grain sorghum–based diets performed better than broilers fed red grain sorghum–based diets, supporting the data in this study showing no negative effects on growth performance. Dykes and Rooney (2006) also indicated that, of the tannin-free grain sorghum varieties, red grain sorghum had a greater content of phenol compounds than white grain sorghum, resulting in adverse effects on performance. Overall, other studies have shown that using high-tannin grain sorghum varieties would not be feasible. Still, low-tannin and tannin-free varieties may be potential replacements for corn as they are similar in nutritive value (Gualtieri and Rapaccini, 1990). In fact, Hulan and others observed that a lower-tannin grain sorghum variety with an inclusion up to 45% in broiler starter diets and 58% in broiler finisher diets can replace corn without any detrimental effects on BW, FI, and FCR, whereas greater-tannin grain sorghum varieties resulted in decreased BW and FI and poorer FCR (Hulan and Proudfoot, 1982; Scott et al., 1998).

Therefore, current results of AME_n determination for broilers demonstrated that tannin-free modern grain sorghum varieties show potential for replacing corn in diet formulation without sacrificing important performance factors, including BWG, FI, and FCR. Findings from this study further suggest that existing nutrient composition and performance data for grain sorghum fed to broilers is inconsistent and focused on high-tannin varieties associated with their negative influence when fed to poultry. Growth performance trials will be necessary to validate these AME_n values and evaluate additional performance parameters of grain sorghum varieties at the full substitution of corn in feed formulation.

Table 7. Effect of dextrose/control, red/bronze, white/tan, and US No. 2 grain sorghum on growth performance responses (BWG, FI, and FCR)[1] of broilers during the grower- and finisher-diet phases at 15 to 22 d of age and 36 to 43 d of age, respectively

	Diet phase					
	Grower (15–22 d)			Finisher (36–43 d)		
Treatment[2]	BWG (kg/bird)	FI (kg/bird)	FCR (kg/kg)	BWG (kg/bird)	FI (kg/bird)	FCR (kg/kg)
Dextrose/control	0.49 ± 0.03	0.66 ± 0.05	1.35 ± 0.12	0.78 ± 0.14	1.34 ± 0.12	1.72 ± 0.42
Red/bronze	0.48 ± 0.02	0.72 ± 0.04	1.50 ± 0.08	0.90 ± 0.10	1.36 ± 0.08	1.51 ± 0.30
White/tan	0.48 ± 0.02	0.69 ± 0.04	1.44 ± 0.08	0.67 ± 0.10	1.29 ± 0.08	1.92 ± 0.30
US No. 2	0.49 ± 0.02	0.70 ± 0.04	1.43 ± 0.08	0.66 ± 0.10	1.30 ± 0.08	1.97 ± 0.30
P-value	0.9629	0.8342	0.6982	0.3272	0.9106	0.4158

[1]BWG = BW gain; FI = feed intake; FCR = feed conversion ratio.

[2]Least-squares means ± SEM; each mean represents 4 cages with 4 birds per cage (kg/bird) for dextrose/control and 8 cages with 4 birds per cage (kg/bird) per treatment for red/bronze, white/tan, and US No. 2.

APPLICATIONS

Current nutrient composition of grain sorghums and performance results when fed to commercial broilers are inconsistent with previous studies that focused on high-tannin varieties and their negative influence on performance. Results from this study can provide nutritionists with an updated nutrient composition of tannin-free grain sorghum and redefine negative perceptions to give producers confidence in using commercial, tannin-free varieties in broiler production. The AME_n values determined in this study should be used as a reference and not as absolute values due to nutritional variations of grain quality and the region or environment where feedstuffs are grown and sourced.

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