Final Report

for

United Sorghum Checkoff Program (USCP)

USCP Contract Number: MD012-22

Project Title: Validation of apparent metabolizable energy (AME) values of selected U.S. No. 2 grain sorghum for feeding commercial broilers chickens

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Executive Summary

Sorghum has not enjoyed the penetration of the Southeastern U.S. feedstuffs market that corn has experienced for decades. Early research with sorghum in broiler diets indicated that birds did not grow as well on grain sorghum as a corn-based diet due to the presence of antinutritional factors. Recent genetic improvements in grain sorghum have reduced tannin levels to essentially zero, and utilization of phytases has helped remove the negative effects of phytates in sorghum and other grains. However, there are limited data concerning the nutritional value of the new modern grain sorghum varieties to gain wide acceptance of the grain as a full replacement for corn in broiler diets.

Controlled research studies showing both the nutritional value and the impact on growth and livability are needed. Further, this information must be provided to poultry integrators on how to best utilize grain sorghum as an additional resource for their operations. The original objective of this work was to validate the apparent metabolizable energy (AME) value of U.S. No. 2 grain sorghum for feeding commercial broiler chickens. These AME values were expected to be determined in a previous USCP project (RG 006-21). Despite the fact that all field and laboratory work was conducted in a timely manner, an unexpected response in the variables assessed rendered no practical AMEn values. Therefore, the objectives for the present project were modified to reflect the need for information for poultry nutritionists and producers. The modified objectives were:

1. To determine the effect of grain sorghum-based diets on the performance of broiler chickens
2. To determine the effect of sorghum-based diets with phytase superdosing on the performance of broiler chickens

To address the research objectives above, we conducted a grow-out trial using a commercial bird cross commonly used by poultry integrators. We evaluated two high-quality U.S. #2 sorghum samples (mixed in a 1:1 ratio; dietary treatment 2) versus corn (dietary treatment 1) as a standard. Also, a third treatment with a sorghum-based diet and phytase superdosing (dietary treatment 3) was evaluated. All diets were formulated to be isonitrogenous and isocaloric. Feed intake, body weight, body weight gain, and feed efficiency were assessed weekly from 0 to 42 days of age.

It was evident that the sorghum samples used in this trial were virtually tannin-free, with an average tannin content of 0.67 mg/g epicatechin equivalent. During the first week, no significant differences in performance were observed among treatments. However, at 14, 21, and 28 days of age, birds fed the sorghum diet with phytase superdosing tended to perform better than the other two treatments. By the end of the trail, no significant differences were observed in any of the variables assessed.

We concluded that under the conditions of this study, commercial broiler chickens fed tannin-free sorghum-based diets would have a similar performance to those fed corn-based diets. The effective formulation of broiler diets will require the analyzed nutrient composition of grains and accurate information about micro-ingredients and additives composition and inclusion rates. In addition, diets need to be formulated based on digestible amino acids. The metabolizable energy (ME) values assigned for corn and sorghum were 3,939 and 3,700 kcal/kg of dry matter. Since poultry diets are routinely formulated "as is", ME values must be adjusted accordingly. The lack of significant differences between treatment 1 and treatment 2 on broiler performance validates the energy values used in this trial. Also, the results from this trial suggested that the amount of methionine combined with the superdose of phytase might have helped birds to achieve a better uptake of nutrients earlier in life. Further research should be done to clarify the effect of phytase superdosing in sorghum-based diets on broiler performance and explore the mechanism related to this response.

Technical Objective

Goal: *To continue our efforts at Clemson University to enhance the marketing opportunities for grain sorghum varieties through a better understanding of the nutritional benefits for use in poultry production enterprises.*

Objective (original): To validate previously obtained apparent metabolizable energy (AME) values of U.S. No. 2 grain sorghum in commercial broiler chickens.

Objectives (modified):

3. To determine the effect of grain sorghum-based diets on the performance of broiler chickens.
4. To determine the effect of sorghum-based diets with phytase superdosing on the performance of broiler chickens.

Hypotheses (modified):

1. Commercial broiler chickens fed tannin-free sorghum-based diets would have a similar performance to those fed corn-based diets.
2. Tannin-free sorghum-based diets with phytase superdosing would have similar or better results on broiler performance than those fed corn-based diets.

Background (original)

Alternative feedstuffs may reduce the competition between human, animal, and industrial uses while minimizing the dependence on corn by the poultry industry. Categorized as one of the top five cereal grains, sorghum is a potential alternative feedstuff to corn and lends itself to a variety of uses for animals, including poultry. Not only is it nutritionally equivalent to corn, but it is tolerant to dry, sandy soils (Buchanan et al., 2005; Goche et al., 2020). This characteristic allows it to grow successfully in the Southeastern U.S. Sorghum is highly desirable for production because of its potential to alleviate the production pressure of growing other cereal grains like corn that are less tolerant to variable climate and soil types.

For 2020, the National Chicken Council (NCC, 2020) reported the use of more than 1.4 billion bushels of corn for broiler, pullet, and breeder feed production. However, despite the high demand for cereal grains in poultry diets, sorghum comprises a limited fraction of the industry's total grain. This phenomenon could be attributed to some factors such as (1) misconception about the tannin content of modern variates of grain sorghum, (2) transportation costs from sorghum growers (most located west of the Mississippi River) to broiler growers (mainly located in the Southeastern U.S.), and (3) lack of current nutritional information relevant to poultry nutritionists and formulators to use grain sorghum in diets for modern broilers.

The energy of feedstuffs is not considered a nutrient but "*a property of the energy-yielding nutrients when they are oxidized during metabolism*" (NRC, 1994). The AME value of a feedstuff can be influenced by the species fed, age of the animal (Khalil et al., 2021), the methodology used to determine the value (Losada et al., 2010), and most importantly, the nutrient content and quality of the feedstuff (Zhou et al., 2010). To the best of our knowledge, the information available about the AME value of U.S. tannin-free sorghum is limited and was published more than 10 years ago. This is an important aspect for nutritionists, considering that today's average broiler is 13% heavier and 12 points more efficient than an average broiler in 2009 (NCC, 2020). The USCP has been investing resources to establish a current database of the nutritional value of the U.S. #2 sorghum. In collaboration with Southern Poultry Research, PI Arguelles-Ramos will be working to determine the AME of two U.S. #2 sorghum samples as part of Project R.G. #006-21. As a follow-up, the AME values must be validated in a pen trial. The information generated in this research will help build a strong dossier to make poultry nutritionists confident to switch from the convenience of a long-known grain as corn to a new alternative.

The proposed work aligns with the USCP's mission "*to reveal the potential and versatility of sorghum through increased shared value*" by improving the knowledge about the nutritional makeup of grain sorghum and validation of values obtained in previous trials. Information about sorghum's nutrient composition and energy value for poultry will help broiler feed formulators, and nutritionists enrich their reference value database. Also, it will help to confirm and update AME_n values used on feed formulation. This is key for broiler nutritionists, as energy content affects many aspects of the formulation, including cost, plus significantly impacts the bird's performance. The work proposed will address the research needs under the topics "*other project concepts that have the best opportunity for commercial application.*"

To address the research objectives above, we plan to conduct an AME validation trial using a commercial bird cross commonly used by poultry integrators. We will evaluate two high-quality U.S. #2 sorghum samples versus corn as a standard. Our team will establish an advisory committee to review our progress data and provide advice. Our Industry Advisory Board will comprise highly competent and influential nutritionists from the broiler production and feed additive industries and academics in the animal nutrition field. The board and collaborators will work closely with the P.I. to ensure the proposed research has full applicability and benefit for stakeholders.

Modifications: Due to the result of project R.G. #006-21, the objectives for the current project changed.

Phytate is found in plant-source feedstuffs such as sorghum, and its antinutritive effect is not restricted to poor phosphorus availability. Research has shown that phytate affects energy, amino acids, Ca, and trace mineral digestibility (Selle et al., 2010). On the other hand, phytase is an enzyme added to poultry diets that catalyzes the removal of phosphate groups from phytate, making phosphorus and other nutrients more available for the bird (Selle et al., 2010). Shirley and Edwards (2003) conducted a study assessing graded levels of phytase (from 0 to 12,000 FTU/kg) on broiler performance, and results showed that higher doses of phytase increased phytate disappearance, nutrient bioavailability, body weight, and feed intake (Selle et al., 2010).

To address the research objectives above, we conducted a grow-out trial using a commercial bird cross commonly used by poultry integrators. We evaluated two high-quality U.S. #2 sorghum samples (mixed in a 1:1 ratio) versus corn as a standard. Also, a third treatment with a sorghum-based diet and phytase superdosing was evaluated.

Materials and Methods

All procedures were approved by Southern Poultry Feed and Research, Inc. (Protocol: Clemson-0722) under an Interinstitutional Agreement with Clemson University.

Birds and husbandry. A research study was conducted from 1 to 42-d-of-age to evaluate broiler performance using sorghum-based diets with or without phytase superdosing. This research took place over the summer of 2022 at Southern Poultry Feed and Research (SPFR), Inc., in Athens, GA. At 1-d-of-age, 1,500 Ross 708 male chicks were housed and randomly distributed (50 birds per pen; 10 pens per treatment) in floor pens. Each pen had an area of 1.5 m x 3 m = 4.5 m^2, dirt floors, built-up wood shavings with fresh, top dressing as bedding, and curtain sidewalls. The environment of the poultry house was kept as close as possible to the birds' temperature comfort zone using fans and wet panels. A lightning program of 18 hours of light to 6 hours of dark (18L:6D) was followed throughout the study.

Ingredients. Tannin-free, animal feed-grade U.S. No. 2 grain sorghum was obtained from Kansas and Texas suppliers, while corn was from U.S. origin. Sorghum, corn, and soybean meal samples were sent to the Agricultural Experiment Station Chemical Laboratories to be analyzed for proximates, amino acids profile, and phytic acid. Other sorghum grain sub-samples were sent to the Department of Food Science and Human Nutrition laboratory at Iowa State University for phenolic compounds analysis by spectrophotometry. Results are shown in Table 1. All the data from the analysis were used to formulate iso-caloric and iso-nitrogenous treatment diets.

Tannin analysis. Approximately 100 mg of crude sorghum powder was suspended in 1.5 mL of 70% acetone solution containing 0.05% trifluoroacetic acid) and extracted by ultrasonication for 30 min (FB11203, Fisherbrand). The ultrasonic frequency was 80 kHz. After extraction, the solvents were evaporated using a CentriVap (Labconco) at 35°C for 30 min and centrifuged at 16,200 g for 5 min (accuSpin Micro 17, Thermo Fisher Scientific, Waltham, MA). 1 mL of 13% alcoholic acidic solution was added in each dry sample and vortex prior to analysis of tannins content by methylcellulose precipitation method. The content is expressed in mg/g of dry powder, as (-)-epicatechin equivalent. (Warerlot Lab, Iowa State University, Ames, IA).

Experimental treatments. Whole-grain sorghum was ground through a hammermill with a 3-mm sieve and corn with 4-mm sieve. Starter, grower, and finisher diets were formulated for each treatment. All experimental starter diets were offered as crumbled feed, while the other diet phases were pelletized. Birds were fed ad-libitum, and each phase lasted 14 days (starter: 0-14; grower: 14-28; finisher: 28-42 days). The ingredients composition, calculated and analyzed nutrient composition for the experimental starter, grower, and finisher diets are shown in tables 2, 3, and 4, respectively. The trial used two inclusion levels of phytase: a standard dose of 550 FTU/kg (reflecting typical commercial inclusion) and a superdose of 2,000 FTU/kg (Quantum Blue phytase, AB Vista). The resulting treatments were the following, treatment 1 (T1) consisted of a corn-based diet with 550 FTU/kg and serving as a standard; treatment 2 (T2), a sorghum-based diet with 550 FTU/kg (standard dose); and treatment 3 (T3), a sorghum-based diet with 2,000 FTU/kg (superdose).

Performance Measurements. During the study, mortality was checked daily, pen body weight, feed placement, and rejected feed were measured weekly. The data recorded were used to calculate cumulative body weight (BW), body weight gain (BWG), feed intake (FI), and feed conversion ratio adjusted to mortality (AdjFCR) using the following equation:

$$\text{AdjFCR}=(\text{Total FI})/(\text{BWG} + \text{mortality BW})$$

Experimental Design and Statistical Analysis. Each pen was considered the experimental unit. The three treatment diets were replicated in 10 blocks and randomized within each block (3 pens defined for each block). The location of the pens in the facility was used as the blocking factor. To compare the treatments, one-way ANOVA followed by Fisher's LSD method to assess significant differences between treatments. The statistical analysis was performed using JMP Pro version 16 (SAS Institute Inc., 2021) using a significant level of P-value ≤ 0.05.

Results

Tannin Analysis. The average tannin content for the Kansas and Texas grain sorghum samples was 0.63 and 0.71 mg/g epicatechin equivalent, respectively (Table 1).

Performance

Body Weight and Mortality. During the first week, no significant differences among treatments were found on BW (table 5). At 14 and 21-d-of-age, birds fed the T3 diet tended to be heavier than birds fed the T1 diet (table 5; $P = 0.063$ and $P = 0.072$, respectively). No significant differences in BW were observed at 28, 35, and 42-d-of-age ($P > 0.1$). Also, mortality was similar for all treatments throughout the trial ($P>0.1$; table 5).

Cumulative BWG, FI, and AdjFCR. No differences in performance were observed during the first week of age. At 14-d-of-age, birds fed T3 tended to gain more weight and be more efficient than birds fed T1 (table 6; $P < 0.10$). Similarly, by 21 d-of-age, birds fed the T3 diet had a better AdjFCR ($P < 0.05$) and showed a numerically higher BWG than broilers fed T1 (table 6; $P < 0.10$). By 28 d-of-age, birds under T3 were more efficient than T1 ($P < 0.05$) without a significant effect of the diet on BWG. After 28-d-of-age, performance parameters were similar among dietary treatments (Table 6). As shown in table 6, FI was not affected by the type of diet consumed throughout the experimental period ($P > 0.1$)

Even though there is a limited body of research concerning bird performance under tannin-free sorghum-based diets with phytase superdosing, previous studies considered this grain as a potential alternative to corn due to their nutritional similarities (Gualtieri and Rapaccini, 1990), therefore, T1 and T2 were expected to have similar outcomes throughout the study. This hypothesis was confirmed as sorghum or corn-based diets with a standard dose of phytase (550 FTU/kg) did not show significant differences in BW, BWG, FI, and AdjFCR during the experiment. However, previous research from Torres et al. (2013) showed discrepancies with our results. As part of the experiment, they tested a full replacement of corn with low-tannin sorghum on broilers, and the results indicated a negative impact on performance compared to corn. It should be noteworthy that the latter study illustrated the outcomes of low-tannin sorghum-based diets on bird performance parameters, while the grains tested in this experiment were virtually tannin-free varieties. Thus, the higher content of tannins from the sorghum varieties used by the Torres et al. (2013) study may have been responsible for the inferior performance.

In our research, birds fed T3 achieved a numerically higher BW and cumulative BWG at 14 and 21-d-of-age than broilers fed corn or sorghum diets with a standard phytase dose ($P < 0.1$), implying that phytase superdose could explain the better performance.

However, studies have shown that phytase response in sorghum is less pronounced than that in corn grain (Selle et al., 2010; Liu, S. Y. et al., 2014). The reason for the weaker response remains uncertain. Researchers attribute it to a challenging phytate location or a low interaction between phytate and kafirin. The first possibility suggests that the access of phytase to its substrate in sorghum might be restricted by the fibrous texture of the aleurone layer where phytate is located (Doherty and JM, 1982). The second reason corresponds to a low phytate-protein interaction.

In sorghum grain, kafirin represents most of the seed's total protein. This protein is located within protein bodies and contains a scarcity of basic amino acids. Its location impedes a proper interaction with phytate, and the low content of basic amino acids does not create a favorable isoelectric point to create kafirin-protein complexes (Cosgrove, 1966; Selle et al., 2000). Thus, the extra-phosphoric response of phytase is limited in sorghum due to the low affinity of its substrate (phytate) to kafirin. In addition to the interaction with proteins, phytate interacts with other molecules (Csonka et al., 1926; Cosgrove, 1966; Selle et al., 2010). Phytate has the capacity to chelate minerals and form complexes with starch and proteins. Therefore, phytase inclusion in poultry diets can alleviate its antinutritive properties. Adding the enzyme to the diet would increase P digestibility, starch, and protein digestion, and enhance glucose, amino acids, calcium, and trace mineral absorption (Selle et al., 2010; Cowieson et al., 2011; Walk et al., 2013). Even though we think phytase superdosing may have collaborated with bird performance, other variables during those periods could be confounding the result and be responsible for the observed trends.

Table 2 shows the starter diet composition for the three treatment diets. Treatment 3 had 5% more methionine than the other diets, a well-known limiting amino acid in broiler growth performance (Bunchasak, 2009). Additionally, some studies reported that high environmental temperatures influence amino acid requirements. This effect might be caused by reduced amino acid digestibility or a lower feed intake (Howlider and Rose, 1987; Hai et al., 2000). Thus, we suspected that the birds under T3 had a certain advantage by having more methionine to compensate for the inefficient use of amino acids in adverse summer conditions. This advantage would explain the better BW, BWG, and AdjFCR in broilers fed T3 during the starter phase. The results partially agreed with the findings of Ahmed and Abbas (2011). Their study evaluated the effect of sorghum-based diets with different levels of methionine on broiler performance. The research showed that BW, BWG, and FI were significantly affected by methionine levels. One of their treatments used a 110% National Research Council (NRC) recommendation for methionine inclusion in sorghum-based diets, which improved broiler performance (Ahmed and Abbas, 2011). However, in our experiment, FI was not affected by the diets showing inconsistencies with the findings of Ahmed and Abbas (2011) but matching the results from another study conducted by Saki et al. (2007). They evaluated the effect of decreasing broiler crude protein with methionine supplementation and did not find significant differences for FI when methionine was supplemented 10% above NRC recommendations. The inconsistencies between Ahmed and Abbas's research and ours can be explained by the influence of high temperatures on amino acid utilization (Brake, 1998).

Treatment 3 showed a numerically better cumulative AdjFCR than T1 at 14-d-of-age ($P < 0.1$). Moreover, by 21 and 28-d-of-age, AdjFCR of birds fed T3 was significantly better than birds under T1 and T2. The results of the study are in accordance with a trial conducted by Walk et al. (2013) when they evaluated the extra phosphoric effects of superdoses of phytases on broiler diets. They showed that phytase inclusion in balanced or marginally phosphorus-deficient diets might improve FCR due to the extra phosphoric effects of the enzyme. In that trial, they used seven corn-soybean meal dietary treatments with different concentrations of Ca, P, and phytase doses; and found the diet with the highest phytase concentration (1500 FTU/kg) had a better FCR in broilers from 0 to 21-d-of-age. Walk et al. (2013) proposed that the catalysis of phytate by phytase improves FCR and BWG, especially in young broilers, which may be more susceptible to phosphorus deficiency.

Another possible reason for the better cumulative AdjFCR of birds fed T3 at 21 and 28-d-of-age may have been caused by the higher concentration of methionine compared to T1 and T2 diets. Methionine acts as a methyl group donor that methylates gallic acid (hydrolyzed form of tannic acid), enabling it to be excreted in the urine. Then, having extra methionine in diets with tannic acid could potentially explain the improvement in performance (Potter and Fuller, 1968). Also, Armstrong et al. (1973) conducted a study to assess the effects of methionine on chick performance when fed high and low-tannin sorghum varieties. Their result showed that methionine supplementation improved BWG and FCR.

Conclusions

Objective 1. It was concluded that under the conditions of this study, commercial broiler chickens fed tannin-free sorghum-based diets would have a similar performance to those fed corn-based diets. The effective formulation of broiler diets will require the analyzed nutrient composition of grains and accurate information of about micro-ingredients and additives composition and inclusion rates. In addition, diets need to be formulated based on digestible amino acids. The metabolizable energy (ME) values assigned for corn and sorghum were 3,939 and 3,700 kcal/kg of dry matter. Since poultry diets are routinely formulated "as is", ME values need to be adjusted accordingly. The lack of significant differences between T1 and T2 on broiler performance validates the energy values used in this trial.

Objetive 2. The results from this trial suggested that the amount of methionine combined with the superdose of phytase might have helped birds to achieve a better uptake of nutrients. Further research should be done to clarify the effect of phytase superdosing in sorghum-based diets on broiler performance and explore the mechanism related to this response.

Impact

Farmers need water-efficient crops to maximize yield during favorable years and minimize losses during dry years. Sorghum is tolerant to dry, sandy soils, which allows it to grow successfully in the Southeastern U.S. Sorghum is highly desirable for production because of its potential to alleviate the production pressure of growing other cereal grains like corn that are less tolerant to variable climates and soil types. Sorghum has been shown to yield more bushels per acre on marginal land in SC, which is due to its inherent water and nutrient use efficiency. Adding sorghum into farm rotations will help to decrease the incidence of important diseases and diversify the use of herbicides.

For 2020, the National Chicken Council reported the use of more than 1.4 billion bushels of corn for broiler, pullet, and breeder feed production. This figure is 3.7 times the number of bushels of grain sorghum produced in the U.S. for the same year. Despite the high demand for cereal grains in poultry diets, sorghum comprises a limited fraction of the industry's total grain. This phenomenon could be attributed to two factors: (1) misconception about the tannin content of modern variates of grain sorghum and (2) transportation costs from sorghum growers (most located west of the Mississippi River) to broiler integrations (mainly located in the Southeastern U.S.). The nutritional information generated from this research provides the producer/nutritionist with valuable information for designing diets containing sorghum in replacement of corn without affecting performance. As such, this represents a positive step towards the acceptance of grain sorghum as an alternative to corn in the U.S., helping to motivate more poultry integrators to include grain sorghum or increase inclusion rates where already in use. This will provide poultry producers with an additional source of energy for production, allowing flexibility from season to season as corn prices fluctuate.

However, more research is needed to provide additional information concerning nutraceutical content and potential beneficial effects, potential anti-quality factor presence and mitigation, nutrient content as affected by environmental growing conditions, as well as storage condition effects. Amassing this type of data in conjunction with that already attained will build a strong dossier of research data needed to improve the confidence of poultry nutritionists in sorghum grain utilization in order to promote increased utilization of sorghum in poultry diets.

Next Steps

1. Recent findings suggest that the abundance of secondary metabolites (nutraceuticals) associated with antimicrobial function may directly impact the control of common poultry intestinal diseases like coccidiosis and necrotic enteritis (N.E.). Therefore, it will be helpful to determine the effectiveness of sorghum hybrids in reducing the incidence and severity of intestinal diseases using a necrotic enteritis challenge model.

2. Following up on item 1, due to the relevance of coccidiosis and N.E. for the poultry industry and potential antimicrobial properties in grain sorghum, further research might be warranted. For example, a floor-pen challenge study with coccidia and N.E. testing different sorghum samples/varieties versus a corn standard.

3. Some secondary metabolites may be beneficial at low rates but not so beneficial at higher rates (anti-quality effect) – thus, understanding the type, content, and beneficial and negative effects of these compounds as well as mitigation strategies when potential issues arise as a result of secondary metabolites is needed to maximize the use of the sorghum in poultry and gamebird diets.

4. As particle size and feed presentation are extremely important for broiler performance, evaluating the particle size of sorghum and its effect on pellet quality will be of interest.

5. Previous research has shown that a portion of the gross energy of grain sorghum is lost in chicken fecal excretions. The main reason for fecal losses is the low digestibility of certain grain components. Enzymes are feed additives that could improve the digestibility of energy-yielding components of the grain, such as structural carbohydrates and proteins, potentially improving the energy value of the grain.

Appendix

Tables

Table 1. Nutrient and anti-nutrient analyses of sources of corn and US No. 2 grain sorghum.

Component (as is)	Corn	Sorghum		Soybean meal
		Texas	Kansas	
Dry matter, %[1]	86.2	87.88	86.51	87.90
Crude fat, %[1]	3.66	1.74	1.52	0.90
Crude fiber, %[1]	2.21	1.57	1.39	3.80
Crude protein, %[1]	7.06	8.88	8.2	45.06
Methionine, %[1]	0.15	0.23	0.18	0.54
Lysine, %[1]	0.16	0.22	0.19	2.44
Threonine, %[1]	0.25	0.29	0.26	1.56
Phytate , %[1]	0.68	0.59	0.48	1.41
Metabolizable energy (kcal/kg DM; estimated)	3,939	3,700	3,700	2,821
Tannins (mg/g)[2]	-	0.71	0.63	-

[1]Proximate analyses, amino acids, and phytate content were determined using the AOAC official methods (University of Missouri Agricultural Experiment Station Chemical Laboratories, Columbia, MO).
[2]Tannin content was expressed in mg/g of dry powder as (-)-epicatechin equivalent.

Table 2. Ingredient and nutrient composition of complete starter-phase test diets (as fed) for 1 to 14 d-of-age.

	Starter		
Ingredient, %	T1[1]	T2[1]	T3[1]
Corn	53.53	----	----
Sorghum[2]	----	54.35	54.29
Soybean meal	42.30	39.74	39.75
Dical. Phos.	1.82	1.86	1.86
Ca Carbonate	0.61	0.65	0.65
Salt (NaCl)	0.51	0.52	0.52
Vegetable Oil	0.05	1.47	1.49
L-Lysine	0.33	0.37	0.37
DL-Methionine	0.34	0.35	0.35
L-Threonine	0.18	0.21	0.21
Choline chloride	0.11	0.11	0.11
Mineral premix[3]	0.08	0.08	0.08
Vitamin premix[4]	0.05	0.05	0.05
Amprol[5]	0.05	0.05	0.05
BMD[6]	0.05	0.05	0.05
Phytase[7]	0.01	0.01	0.04
Calculated Composition, %			
ME (Kcal/Kg)[1]	2910	2910	2910
Dry Matter	87.46	88.18	88.18
Crude Protein	24.00	24.00	24.00
Crude Fat	2.39	2.71	2.72
Crude Fiber	2.79	2.32	2.32
Calcium	0.90	0.90	0.90
Phos. Available	0.45	0.45	0.45
Sodium	0.23	0.23	0.23
Dig. Methionine	0.62	0.63	0.63
Dig. Lysine	1.26	1.26	1.26
Dig. Threonine	0.86	0.86	0.86
Dig. Met+Cys	0.88	0.88	0.88
Analyzed composition, %[8]			
Moisture	11.62	11.13	10.78
Crude Protein	25.94	25.99	26.69
Crude Fat	2.77	3.53	3.37
Crude Fiber	2.46	2.30	2.28
Ash	5.43	5.35	5.51
Threonine	1.04	1.04	1.10
Cysteine	0.38	0.37	0.37
Methionine	0.60	0.63	0.63
Lysine	1.70	1.59	1.69

[1]There were 10 replicates for each dietary treatments: T1 = corn+550 FTU/kg; T2 = sorghum+550 FTU/kg; T3 = sorghum+2000 FTU/kg; ME = Metabolizable Energy.

[2] Texas and Kansas sorghum mixed in a 1:1 ratio.

[3] Supplied per kg of diet: manganese ($MnSO_4•H_2O$), 60 mg; iron ($FeSO_4•7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4•5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 0.15 mg; selenium ($NaSe0_3$), 0.3 mg.

[4] Supplied per kg of diet: thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 4.7 mg; D-biotin, 0.11 mg; folic acid, 5.5 mg; menadione sodium bisulfite complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 27.5ug; trans-retinyl acetate, 1,892 ug; all-rac α tocopheryl acetate, 11 mg; ethoxyquin, 125 mg.

[5]Amprolium, Amprol ® 25% (Huvepharma, Peachtree City, GA).

[6]Bacitracin Methylene Disalicylate, BMD 50 (Zoetis, Parsippany, NJ).

[7]Quantum Blue phytase (AB Vista, Marlborough, Wiltshire); added at 0.011% of the diet with 1,650% Ca and 1,500% Avail. P.

[8]Proximate analyses and amino acid content were determined using the AOAC official methods (University of Missouri Agricultural Experiment Station Chemical Laboratories, Columbia, MO).

Table 3 Ingredient and nutrient composition of complete grower phase test diets (as fed) for 14 to 28 d-of-age.

	Grower		
Ingredient	T1[1]	T2[1]	T3[1]
Corn	58.98	----	----
Sorghum[2]	----	59.97	59.91
Soybean meal	34.28	31.41	31.42
Dical. Phos.	1.00	1.04	1.04
Ca Carbonate	0.83	0.88	0.88
Salt (NaCl)	0.52	0.53	0.53
Vegetable Oil	2.52	4.07	4.09
L-Lysine	0.41	0.45	0.45
DL-Methionine	0.39	0.40	0.40
L-Threonine	0.19	0.22	0.22
Choline chloride	0.36	0.36	0.36
Mineral premix[3]	0.08	0.08	0.08
Vitamin premix[4]	0.06	0.06	0.06
Amprol[5]	0.05	0.05	0.05
BMD[6]	0.05	0.05	0.05
Phytase[7]	0.01	0.01	0.04
Calculated Composition			
ME (Kcal/Kg)[1]	3120	3120	3120
Dry Matter	87.63	88.42	88.42
Crude Protein	20.95	20.95	20.95
Crude Fat	4.96	5.29	5.31
Crude Fiber	2.61	2.08	2.08
Calcium	0.75	0.75	0.75
Phos. Available	0.42	0.42	0.42
Sodium	0.23	0.23	0.23
Dig. Methionine	0.64	0.65	0.65
Dig. Lysine	1.15	1.15	1.15
Dig. Threonine	0.77	0.77	0.77
Dig. Met+Cys	0.87	0.87	0.87
Analyzed composition[8]			
Moisture	11.31	10.96	10.50
Crude Protein	23.53	23.56	23.40
Crude Fat	4.21	4.79	5.17
Crude Fiber	2.27	2.28	2.12
Ash	4.86	4.75	4.75
Threonine	1.01	1.00	1.02
Cysteine	0.35	0.31	0.34
Methionine	0.70	0.65	0.68
Lysine	1.52	1.39	1.53

[1]There were 10 replicates for each dietary treatments: T1 = corn+550 FTU/kg; T2 = sorghum+550 FTU/kg; T3 = sorghum+2000 FTU/kg; ME = Metabolizable Energy.

[2] Texas and Kansas sorghum mixed in a 1:1 ratio.

[3] Supplied per kg of diet: manganese ($MnSO_4•H_2O$), 60 mg; iron ($FeSO_4•7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4•5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 0.15 mg; selenium ($NaSe0_3$), 0.3 mg.

[4] Supplied per kg of diet: thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 4.7 mg; D-biotin, 0.11 mg; folic acid, 5.5 mg; menadione sodium bisulfite complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 27.5ug; trans-retinyl acetate, 1,892 ug; all-rac α tocopheryl acetate, 11 mg; ethoxyquin, 125 mg.

[5]Amprolium, Amprol ® 25% (Huvepharma, Peachtree City, GA).

[6]Bacitracin Methylene Disalicylate, BMD 50 (Zoetis, Parsippany, NJ).

[7]Quantum Blue phytase (AB Vista, Marlborough, Wiltshire); added at 0.011% of the diet with 1,650% Ca and 1,500% Avail. P.

[8]Proximate analyses and amino acid content were determined using the AOAC official methods (University of Missouri Agricultural Experiment Station Chemical Laboratories, Columbia, MO).

Table 4. Ingredient and nutrient composition of complete finisher phase test diets (as fed) for 28 to 42 d-of-age.

	Finisher		
Ingredient	T1[1]	T2[1]	T3[1]
Corn	61.07	----	----
Sorghum[2]	----	61.40	61.35
Soybean meal	31.57	29.48	29.49
Dical. Phos.	0.85	0.89	0.89
Ca Carbonate	0.78	0.82	0.82
Salt (NaCl)	0.52	0.53	0.53
Vegetable Oil	3.79	5.42	5.44
L-Lysine	0.35	0.37	0.37
DL-Methionine	0.34	0.34	0.34
L-Threonine	0.15	0.17	0.17
Choline chloride	0.34	0.34	0.34
Mineral premix[3]	0.08	0.08	0.08
Vitamin premix[4]	0.06	0.06	0.06
Amprol[5]	0.05	0.05	0.05
BMD[6]	0.05	0.05	0.05
Phytase[7]	0.01	0.01	0.04
Calculated Composition			
ME (Kcal/Kg)[1]	3230	3230	3230
Dry Matter	87.66	88.46	88.47
Crude Protein	19.50	19.50	19.50
Crude Fat	6.28	6.63	6.65
Crude Fiber	2.55	2.03	2.03
Calcium	0.75	0.75	0.75
Phos. Available	0.42	0.42	0.42
Sodium	0.23	0.23	0.23
Dig. Methionine	0.58	0.58	0.58
Dig. Lysine	1.05	1.05	1.05
Dig. Threonine	0.70	0.70	0.70
Dig. Met+Cys	0.80	0.80	0.80
Analyzed composition[8]			
Moisture	12.12	11.28	11.22
Crude Protein	21.37	20.97	21.55
Crude Fat	4.72	6.12	6.39
Crude Fiber	2.29	2.11	2.24
Ash	4.55	4.36	4.56
Threonine	0.91	0.83	0.93
Cysteine	0.33	0.30	0.33
Methionine	0.66	0.58	0.62
Lysine	1.44	1.28	1.39

[1]There were 10 replicates for each dietary treatments: T1 = corn+550 FTU/kg; T2 = sorghum+550 FTU/kg; T3 = sorghum+2000 FTU/kg; ME = Metabolizable Energy.

[2] Texas and Kansas sorghum mixed in a 1:1 ratio.

[3] Supplied per kg of diet: manganese ($MnSO_4$•H_2O), 60 mg; iron ($FeSO_4$•$7H_2O$), 30 mg; zinc (ZnO), 50 mg; copper ($CuSO_4$•$5H_2O$), 5 mg; iodine (ethylene diamine dihydroiodide), 0.15 mg; selenium ($NaSe0_3$), 0.3 mg.

[4] Supplied per kg of diet: thiamin•mononitrate, 2.4 mg; nicotinic acid, 44 mg; riboflavin, 4.4 mg; D-Ca pantothenate, 12 mg; vitamin B_{12} (cobalamin), 12.0 µg; pyridoxine•HCL, 4.7 mg; D-biotin, 0.11 mg; folic acid, 5.5 mg; menadione sodium bisulfite complex, 3.34 mg; choline chloride, 220 mg; cholecalciferol, 27.5ug; trans-retinyl acetate, 1,892 ug; all-rac α tocopheryl acetate, 11 mg; ethoxyquin, 125 mg.

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[8]Proximate analyses and amino acid content were determined using the AOAC official methods (University of Missouri Agricultural Experiment Station Chemical Laboratories, Columbia, MO).

Table 5. Effect of dietary treatment on broiler body weight and mortality from 0 to 42 d-of-age.

	Variable						
	Body weight						**Mortality**
	Age						
	0	0-14	0-21	0-28	0-35	0-42	0 - 42
Dietary Treatment	(kg)						(%)
T1[1]	0.151	0.384^{y}	0.806^{y}	1.413	2.034	2.696	9.2
T2[1]	0.153	0.396^{xy}	0.824^{xy}	1.412	2.041	2.704	10.6
T3[1]	0.157	0.407^{x}	0.838^{x}	1.442	2.049	2.697	10.8
SEM[2]	0.0031	0.0629	0.0093	0.0156	0.0231	0.0265	0.0116
Source of variation	*P-value*						
Diet	NS	0.063	0.072	NS	NS	NS	NS

x, y Means within the same column lacking a common superscript are significantly different at $P < 0.1$.

[1]There were 10 replicates for dietary treatments: T1 = corn+550 FTU/kg; T2 = sorghum+550 FTU/kg; T3 = sorghum+2000 FTU/kg

[2]SEM for n = 10

Table 6. Effect of dietary treatment on *cumulative* broiler body weight gain, feed intake, adjusted feed conversion ratio.

	Variable																	
	Body weight gain						Feed intake						Adjusted feed conversion					
Dietary treatment	0-7	0-14	0-21	0-28	0-35	0-42	0-7	0-14	0-21	0-28	0-35	0-42	0-7	0-14	0-21	0-28	0-35	0-42
	(kg)						(kg)						(kg:kg)					
T1[1]	0.112	0.346^{y}	0.767^{y}	1.374	1.995	2.658	0.129	0.440	1.007	1.833	3.33	5.119	1.155	1.273^{x}	1.313^{a}	1.324^{a}	1.643	1.825
T2[1]	0.114	0.357^{xy}	0.785^{xy}	1.373	2.002	2.665	0.134	0.449	1.025	1.815	3.29	5.218	1.172	1.254^{xy}	1.305^{a}	1.320^{a}	1.630	1.822
T3[1]	0.119	0.368^{x}	0.799^{x}	1.403	2.01	2.658	0.133	0.452	1.032	1.844	3.331	5.189	1.123	1.230^{y}	1.284^{b}	1.301^{b}	1.636	1.836
SEM[2]	0.003	0.063	0.009	0.016	0.023	0.027	0.003	0.006	0.010	0.017	0.029	0.076	0.023	0.012	0.006	0.005	0.008	0.010
Source of variation	*P-value*																	
Diet	NS	0.06	0.07	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.055	0.01	0.013	NS	NS

[a, b, c] Means within the same column lacking a common superscript are significantly different at the $P < 0.05$.

[x, y] Means within the same column lacking a common superscript are significantly different at $P < 0.1$.

[1]There were 10 replicates for dietary treatments: T1 = corn+550 FTU/kg; T2 = sorghum+550 FTU/kg; T3 = sorghum+2000 FTU/kg

[2]SEM for n = 10

List of Presentations

Presentations:

Sasia, S., M. Arguelles-Ramos. 2023. Effect of sorghum-based conventional diets with or without phytase superdosing on broiler performance. International Poultry Scientific Forum, Atlanta, GA.

Sasia, S., M. Arguelles-Ramos. 2022. Sasia, S., M. Arguelles-Ramos. 2023. Effect of sorghum-based diets with phytase superdosing on broiler performance from 0 – 28 days of age. Arkansas Nutrition Conference, Little Rock, AR.

Arguelles-Ramos, M. 2022. Utilization of sorghum in poultry production. Texas Department of Agriculture Trade Mission - Perú.   Houston, TX.

Publications:

Sasia, S., W. Bridges, B. Lumpkins, and M. Arguelles-Ramos. 2023. Effect of sorghum-based diets with phytase superdosing on broiler performance.
In-progress for submission to Applied Animal Science

List of Abbreviations

Abbreviation	
AdjFCR	Feed conversion ratio adjusted to mortality
AME_n	Nitrogen corrected apparent metabolizable energy
ANOVA	Analysis of variance
AOAC	Association of Official Agricultural Chemists
BW	Body weight
BWG	Body weight gain
FI	Feed intake
FTU	Units of phytase activity; the amount of enzyme that liberates 1 micromole of inorganic phosphorus per minute from 0.0051 mol/l sodium phytate at 37° and pH 5.50 under the conditions of the test
kcal	kilocalories
kg	kilogram
NRC	National Research Council
SE	Southeastern
SEM	Standard error of the mean
SPFR	Southern Poultry Feed and Research, Inc.
T1	Corn + 550 FTU/kg
T2	Sorghum + 550 FTU/kg
T3	Sorghum + 2000 FTU/kg
US	United States of America
USCP	United Sorghum Checkoff Program