

EFFECTS OF DIFFERENT SORGHUM VARIETIES FED TO BROILER CHICKENS ON GROWTH PERFORMANCE, DAILY ENERGY BALANCE, AND ENERGY CONCENTRATION

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ABSTRACT

This study evaluated growth, daily energy balance, and energy parameters in broilers fed with sorghum (varieties—Australian Red, US Red, Indian White, and locally developed IPB Cosor 5) and compared with those fed with corn and wheat. Male broilers (Ross 308 n=70) were assigned, using a completely randomized design, to 7 dietary treatments (10 replicates each), consisting of a 60% corn-soybean meal basal diet and 40% test ingredient. Individually housed in metabolic cages, broilers were fed on days 13-22, with excreta collected on days 21-23. All sorghum diets had comparable body weight gain and feed intake ($p=0.06$) to corn and wheat. Feed-to-gain ratio (F/G) of birds fed Australian Red, US Red, and Indian White were similar to corn and wheat, but those fed IPB Cosor 5 had poorer ($p<0.001$) F/G. On a DM basis, apparent metabolizable energy (AME) values of the sorghum grains ranged from 3,337-3,845 kcal/kg, which is comparable ($p=0.04$) to corn (3,575 kcal/kg) and wheat (3,677 kcal/kg). Nitrogen-corrected AME (AMEn) in sorghum grain ranged from 2,985-3,382 kcal/kg DM, similar ($p=0.11$) to corn (3,149 kcal/kg) and wheat (3,230 kcal/kg). In conclusion, comparable energy concentration results regardless of varietal differences indicate good replacement potential of sorghum for corn and wheat in broiler diets.

Keywords: apparent metabolizable energy, broiler, corn, IPB Cosor 5, sorghum

INTRODUCTION

Feeds account for 70% of livestock production expenses (Makkar, 2018), making grain prices a key factor influencing animal performance and the broader poultry industry. Corn, wheat, and sorghum are among the most common cereal grains used in global livestock feed, providing highly digestible carbohydrates essential for broiler diets. However, corn availability faces challenges from rising and volatile prices, supply constraints, and increased demand, impacting the Philippines' local corn production and feed industry, due to climate events and pest infestations from both local and global disruptions—resulting in higher costs and reduced agricultural growth (Kocak *et al.*, 2022; Westcott & Hoffman, 1999; USDA, 2024a; Gomez, 2024; Statista, 2024; Ceballos *et al.*, 2017). The country also relies heavily on wheat imports, which have fluctuated amid global economic disruptions,

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leading to increased wheat prices and heightened economic vulnerability (Mottaleb *et al.*, 2022). These circumstances emphasize the importance of reducing dependence on corn and wheat by exploring alternative energy sources.

Sorghum emerges as a promising alternative, serving as a staple livestock feed in leading producers such as the United States and Nigeria. Global sorghum production has shown more stable year-over-year fluctuations over the past decade than corn, yet exhibits less stability than wheat (USDA, 2024b). Sorghum is distinguished by its superior drought tolerance and adaptability relative to maize and wheat (Rooney, 2016). The yields of maize and wheat decline under conditions of drought (Nguyen *et al.*, 2023) and water stress (Zhao *et al.*, 2020). Conversely, sorghum, which flourishes with minimal water requirements, can survive for several weeks without irrigation (Bi *et al.*, 2022) and adapts well to low-water conditions (Hossain *et al.*, 2022). Its ratooning capability—permitting multiple harvests within a single season (Rosentrater and Evers, 2018)—coupled with its shorter maturation period relative to maize and wheat, renders it particularly suitable for the Philippines' typhoon-prone climate (Chisi and Peterson, 2019; Sun *et al.*, 2007; Wcislo & Szarlej-Wcislo, 2014). These characteristics collectively position sorghum as a resilient alternative grain to maize and wheat.

Sorghum contains tannins, which are significant anti-nutritional factors that reduce energy digestibility in poultry feed (Hariprasanna *et al.*, 2015). Sorghum grains are categorized into three types based on tannin concentration. Type 1 grain sorghum, characterized by an unpigmented pericarp, is tannin-free, although the average recorded tannin concentration is 0.28 g/kg; Type 2 sorghum has condensed tannins in the pigmented testa of approximately 4.48 g/kg; and Type 3 sorghum contains tannin in both testa and pericarp, roughly around 11.95 g/kg (Asquith *et al.*, 1983; Dykes and Rooney, 2006). High-tannin sorghum decreases nitrogen-corrected apparent metabolizable energy (AMEn), as chickens fed high-tannin sorghum tend to exhibit lower AMEn values compared to those on corn diets (Nyachoti *et al.*, 1996). Conversely, low-tannin sorghum does not impair growth performance in birds from days 1 to 21 (Torres *et al.*, 2013), enhances gut health and digestion in broilers (Moritz *et al.*, 2022a; Huang *et al.*, 2017), and can be incorporated into approximately 50% of starter and finisher diets without adverse effects (Hulan and Proudfoot, 1982; Scott *et al.*, 1998). Consequently, low-tannin sorghum presents a viable alternative to corn and feed wheat in broiler nutrition.

This study examined low-tannin sorghum varieties IPB Cosor 5, Australian Red, US Red, and Indian White. While previous research found that red and white sorghum have lower energy levels than corn and wheat (Moss *et al.*, 2020), data on growth performance or energy values for these varieties, including IPB Cosor 5, are lacking. This study aimed to evaluate their effects on broiler growth performance (weight gain, body weight, feed intake, and feed-to-gain ratio), daily energy balance (apparent total tract digestibility (ATTD) of dry matter (DM) and gross energy (GE), and AME/AMEn concentrations, compared to corn and wheat.

MATERIALS AND METHODS

The protocol for this study was approved by the Institutional Animal Care and Use Committee of the University of the Philippines Los Baños (approval number UPLB-2024-028). Day-old Ross 308 chicks were sourced from a commercial hatchery (San Miguel

Foods, Inc., Candelaria, Quezon) and brooded conventionally until day 12 at the University Animal Farm, Putho-Tuntungin, Los Baños, Laguna. They were housed in open-sided grow-out pens before being individually transferred to a 50 x 60 cm cage in a metabolism room maintained at approximately 24-26°C, with 24-hour fluorescent lighting provided from days 13 to 23.

On day 13, n=70 male chicks were randomly selected and assigned to 7 dietary treatments using a completely randomized design. Each treatment had 10 replicates. A corn-soybean meal diet served as the basal diet, while the other 6 treatments consisted of 60% basal diet and 40% (as-fed basis) of the test ingredients: yellow corn, feed wheat, and any one of the four low-tannin sorghum varieties (IPB Cosor 5, Australian Red, US Red, and Indian white), respectively (Table 1).

Feed intake and refusals were recorded from days 13 to 23, while the birds were fasted and weighed on day 21 to calculate body weight gain and feed efficiency (F/G). Excreta were collected every 24 hours from days 21 to 23, then cleaned, weighed, frozen at -4°C, homogenized, oven-dried at 75°C, and ground. Test ingredient samples were analyzed for tannin content. Diet, test ingredients, and excreta gross energy (GE) were measured using a bomb calorimeter (Model 6400, Parr Instruments, Moline, IL) at the Animal Nutrition Analytical Service Laboratory, University of the Philippines Los Baños, Laguna. The apparent metabolizable energy (AME) of each diet was calculated using Equation 1.

The energy value of the basal diet was determined using the direct method. In contrast, the energy values of the test ingredients were determined and calculated using the difference method. Nitrogen-corrected AME (AMEn) is corrected for zero N retention to account for factors such as the gross energy value of uric acid at 0.034 MJ/kg (Hill & Anderson, 1958) or the gross energy of nitrogen-containing compounds in chicken urine at 0.037. The correction factor is valued at 8.22 kcal per g of N retained in the body (Sauvant *et al.*, 2004). It was calculated using Equation 2:

Lastly, the AME and AMEn of the cereal grains were determined to evaluate their individual effects without the other energy-providing ingredients in the formulation. It was calculated using Equations 3 and 4:

Data were analyzed using the Mixed Procedure of SAS (SAS Inst., Cary, NC, USA), with individual birds as the experimental unit. The model included diet as the fixed effect and replicate as the random effect. When diet is a significant source of variation, least-squares means were compared using the PDIFF option of SAS with the Tukey-Kramer Test at a 5% significance level.

$$AME = \frac{GE \text{ input} - GE \text{ output}}{DM \text{ intake}} \quad \text{Equation 1}$$

$$AMEn = AME - \left[\frac{N \text{ gain} \times 8.22}{DM \text{ Intake}} \right], \text{ where } N \text{ gain} = \frac{(BW \text{ Gain} \times 0.2)}{6.235} \quad \text{Equation 2}$$

$$AME \text{ grain} = \frac{AME \text{ diet} - (AME \text{ basal diet} \times \text{Inclusion Rate basal})}{\text{Inclusion Rate grain}} \quad \text{Equation 3}$$

$$AMEn \text{ grain} = AME \text{ grain} - N \text{ correction} \quad \text{Equation 4}$$

Table 1. Ingredient composition of experimental diets (as-fed basis).

Item	Treatment					
	Corn-Soy Basal Diet	Corn	Wheat	IPB Cosor 5 Sorghum	Australian Red Sorghum	US Red Sorghum
Basal	-	60	60	60	60	60
Corn	61.77	-	-	-	-	-
Soybean Meal	32.70	-	-	-	-	-
Coconut Oil	1.24	-	-	-	-	-
Corn	-	40.0	-	-	-	-
Wheat	-	-	40.0	-	-	-
IPB Cosor 5 Sorghum	-	-	-	40.0	-	-
Australian Red Sorghum	-	-	-	-	40.0	-
US Red Sorghum	-	-	-	-	-	40.0
Indian White Sorghum	-	-	-	-	-	40.0
L-lysine HCl	0.23	-	-	-	-	-
L-methionine	0.32	-	-	-	-	-
L-threonine	0.11	-	-	-	-	-
L-isoleucine	0.02	-	-	-	-	-
L-valine	0.07	-	-	-	-	-
Monocalcium phosphate	1.52	-	-	-	-	-
Limestone	1.14	-	-	-	-	-
Salt	0.45	-	-	-	-	-
Vitamin Premix ¹	0.06	-	-	-	-	-

Table 1 continued . . .

Item	Treatment						
	Corn-Soy Basal Diet	Corn	Wheat	IPB Cosor 5 Sorghum	Australian Red Sorghum	US Red Sorghum	Indian White Sorghum
Trace Mineral Premix ²	0.17	-	-	-	-	-	-
Choline Chloride 60%	0.20	-	-	-	-	-	-
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DM, %	88.35	88.09	88.74	88.89	88.89	88.73	88.72
Gross Energy, kcal/kg	3,926	3,920	4,088	4,104	4,054	4,072	4,024

¹ Provided the following vitamins and quantities per kg of complete diet: Vitamin A: 56,000,000 IU; Vitamin D3: 12,500,000 IU; Vitamin E: 150,000 IU; Vitamin K: 10,000 mg; Vitamin B1 10,000 mg; Vitamin B2: 30,000; Vitamin B6: 20,000; Vitamin B12: 125,000 mcg; Niacin: 200,000 mg; Pantothenic acid: 60,000 mg; Folic acid 5,000 mg and; Biotin 750,000 mcg.

² Provided the following minerals and quantities per kg of complete diet: Iron: 100 g; Copper: 10 g; Cobalt: 100 g; Zinc 75 g; Iodine 1 g; Selenium: 0.120 g and; Carrier: 1 kg.

Table 2. Growth performance of Ross 308 broiler chickens during the starter phase (D13 to D23) given diets supplied with corn, wheat, and different sorghum varieties at 40% inclusion.¹

Item	Experimental Diet							SEM	P-value
	Basal	Corn	Wheat	IPB Cosor 5	Australian Red	US Red	Indian White		
Initial BW, g	381.76	340.82	336.05	375.49	339.68	325.79	379.91	19.95	0.22
Final BW, g	810.02 ^a	712.01 ^{bc}	761.28 ^{ab}	661.28 ^c	688.67 ^{bc}	703.56 ^{bc}	705.67 ^{bc}	17.44	<0.001
Body Weight Gain, g	212.15 ^a	158.58 ^b	184.81 ^{ab}	151.13 ^b	170.36 ^b	155.89 ^b	167.88 ^b	7.94	<0.001
Feed Intake, g	292.72 ^{ab}	269.55 ^b	320.15 ^a	291.78 ^{ab}	294.08 ^{ab}	278.31 ^{ab}	285.19 ^{ab}	10.86	0.06
F/G	1.40 ^c	1.71 ^b	1.73 ^b	1.99 ^a	1.73 ^b	1.79 ^{ab}	1.70 ^b	0.057	<0.001

¹Values are least-square means of 10 replicates per treatment.

^{a,b,c}Means followed by different letters are significantly different ($P<0.05$).

Table 3. Apparent total tract digestibility (ATTD, %) of experimental diets and energy concentration of corn, wheat, and different sorghum varieties in broiler chickens.¹

Item	Basal	Corn	Wheat	IPB Cosor 5	Australian Red	US Red	Indian White	SEM	P-value
ATTD of DM, %	74.59 ^{bc}	78.13 ^{ab}	75.72 ^{abc}	72.94 ^c	76.43 ^{abc}	76.37 ^{abc}	79.22 ^a	0.98	<0.001
ATTD of GE, %	76.96 ^{ab}	79.84 ^a	77.97 ^{ab}	74.68 ^b	78.38 ^{ab}	78.03 ^{ab}	80.72 ^a	0.90	<0.001
AME (As-fed basis), kcal/kg	-	3,751 ^{ab}	3,850 ^{ab}	3,490 ^b	3,806 ^{ab}	3,821 ^{ab}	4,021 ^a	105	0.03
AME (DM basis), kcal/kg	-	3,576 ^{ab}	3,678 ^{ab}	3,337 ^b	3,634 ^{ab}	3,654 ^{ab}	3,846 ^a	106	0.04
AMEn (As-fed basis), kcal/kg	-	3,304	3,381	3,122	3,361	3,397	3,537	94	0.08
AMEn (DM basis), kcal/kg	-	3,149	3,230	2,986	3,209	3,249	3,382	94	0.11

¹Values are least-square means of 10 replicates per treatment.

^{a,b,c}Means followed by different letters are significantly different ($P<0.05$).

RESULTS AND DISCUSSION

Body weight gain of birds fed with a corn diet was comparable across all sorghum varieties (Table 2), supporting previous findings that sorghum-based diets perform similarly in broilers fed with corn (Ciurescu *et al.*, 2023). Weight gain in feed wheat was similar to IPB Cosor 5, Australian Red, US Red, and Indian White grain sorghum, supporting findings that 20% whole wheat or sorghum produce comparable weight gain in chicks aged 8 to 21 days (Biggs and Parsons, 2009). Weight gain in birds fed with the basal diet differed significantly ($P<0.05$) from all sorghum diets, while all sorghum-based diets yielded similar body weight gain.

Birds fed with feed wheat had feed efficiency (F/G) similar to those fed with Australian Red, US Red, and Indian White sorghum, while IPB Cosor 5 had poorer F/G. Feed efficiency of birds fed the corn-based diet was also similar to that of birds fed with sorghum, supporting previous findings in broiler chickens from days 0 to 21 (Moritz *et al.*, 2022a). However, this contrasted with findings where broilers fed red sorghum varieties had poorer F/G than those fed with white sorghum varieties (Olorunsola and Jegede, 2023). IPB Cosor 5 only had a similar F/G to US Red but performed inferior to corn, wheat, and other sorghum varieties.

The poorer F/G in broilers fed IPB Cosor 5 was a body weight gain response, which was a likely result of slightly greater tannin content in this sorghum variety or other anti-nutritional factors not determined in the current study. Australian Red, US Red, and Indian White sorghums were comparable to corn and feed wheat in body weight gain and F/G, highlighting their potential as alternatives. Birds fed with IPB Cosor 5 had similar body weight gain, but had an inferior F/G compared to other treatments.

While high tannin levels negatively affect growth performance (Lee *et al.*, 2010), protein digestibility, and amino acid availability (Samtiya *et al.*, 2020), low tannin levels can enhance growth. In the present experiment, the analyzed tannin content (DM basis) of corn, wheat, and US Red was 0.04%, while Australian Red and IPB Cosor 5 contained 0.05% and 0.08%, respectively. The Indian White was not tested for tannin because white sorghum varieties were not known to contain detectable tannins, with an average of approximately 0.02% (Awika *et al.*, 2004; Pan *et al.*, 2018). All tested feed ingredients were considered low in tannin, with contents below 5% (Ochieng *et al.*, 2020). Therefore, the low tannin content of these sorghum varieties likely contributed to their growth performance being comparable to corn and wheat.

The apparent total tract digestibility (ATTD) of dry matter (DM) of the basal diet was similar to Australian Red, US Red, and IPB Cosor 5, but lower ($P<0.001$) than Indian White (Table 3). The ATTD of DM in corn was comparable to Australian Red, US Red, and Indian White, but higher ($P<0.001$) than IPB Cosor 5. Indian White had higher ($P=0.001$) ATTD than the basal diet and IPB Cosor 5. The DM digestibility of wheat was similar to that of all sorghum varieties. The ATTD of GE of the basal diet was similar to Australian Red, US Red, and IPB Cosor 5. Corn was comparable to Australian Red, US Red, and Indian White, but not to IPB Cosor 5, with Indian white and corn showing higher ($P<0.001$) GE digestibility than IPB Cosor 5. Wheat had GE digestibility similar to that of all sorghum varieties. Overall, sorghum-based diets had energy balances comparable to those of corn and feed wheat. Indian White occasionally outperformed the standard ingredients, with Australian Red and US Red showing moderate promise. IPB Cosor 5 demonstrated good

viability, comparable to corn in many parameters, and matched wheat's daily energy balance. Therefore, all the sorghum varieties show promise as alternatives, although IPB Cosor 5 may require further improvements in composition or formulation to fully match the performance of corn and wheat.

All sorghum varieties had AME values similar to those of corn and wheat. Indian White had the highest AME at 4,021 kcal/kg (as-fed), while IPB Cosor 5, although the lowest, remained comparable to corn, wheat, Australian Red, and US Red, but was lower ($P=0.03$) than Indian White (Table 3). On a dry matter basis, the AME values of the four sorghum varieties evaluated were comparable ($P=0.04$) to corn and wheat. Indian White's highest AME value of 3,846 kcal/kg exceeded the reported performance of HFQ sorghum at 2,940 kcal/kg (Truong *et al.*, 2016) and Australian sorghum's 3,681 kcal/kg in broilers at week 3 (Khalil *et al.*, 2021). IPB Cosor 5, Australian Red, and US Red had values of 3,337 kcal/kg, 3,634 kcal/kg, and 3,654 kcal/kg, respectively, which are higher than the reported AME of red sorghum at 2,925 to 2,937 kcal/kg (Truong *et al.*, 2016), but lower than Australian sorghum's 3,681 kcal/kg in broilers at week 3 (Khalil *et al.*, 2021). The last three varieties had higher AME than the reported Australian sorghum at 3,436 kcal/kg (Khalil *et al.*, 2021), while IPB Cosor 5 had a lower AME. Differences in nitrogen-corrected apparent metabolizable energy (AMEn) (as-fed) were not significant, indicating all six ingredients had comparable AMEn values. Similarly, AMEn differences on a dry matter basis were not significant, with Indian White reaching 3,382 kcal/kg. Although lower than the reported White/Tan sorghum's AMEn value of $3,800 \pm 140$ kcal/kg (Moritz *et al.*, 2022b), this value is higher than HFQ's 2,827 kcal/kg (Truong *et al.*, 2016). IPB Cosor 5, Australian Red, and US Red had AMEn values of 2,985 kcal/kg, 3,209 kcal/kg, and 3,249 kcal/kg, respectively. Australian Red and US Red had higher AMEn values than red/bronze sorghum ($3,168 \pm 138$ kcal/kg; Moritz *et al.*, 2022b), while IPB Cosor 5 had a lower AMEn but remained comparable to the others. Overall, all four sorghum varieties contained AMEn comparable to those in corn and wheat, indicating similar performance across species (Lopez and Leeson, 2007).

CONCLUSION

All four sorghum varieties are promising alternatives to wheat and corn as feed, with Indian White performing best. Ultimately, the results of this study showed a good indication that any of the four sorghum varieties can serve as a replacement for corn or wheat on a weight-by-weight basis.

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