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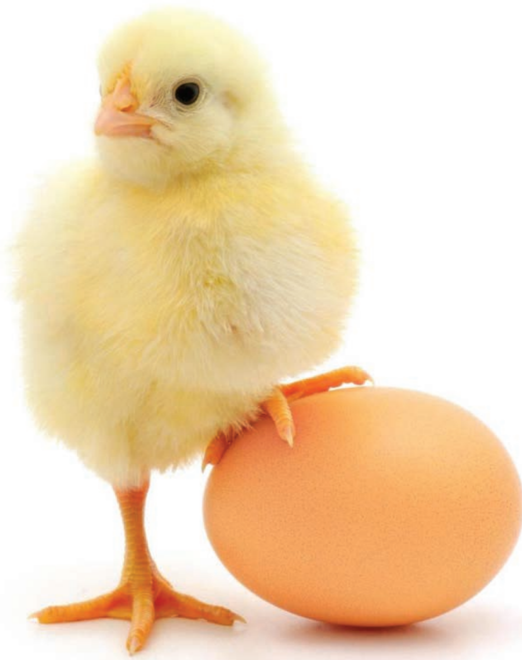

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Research Article

Effect of Replacing Dietary Corn by Sorghum on The Growth Performance, Shank Skin Pigmentation, Carcass Traits, Caecal Microflora and Nutrient Digestibility of Broiler Chickens

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Abstract

Objective: A six weeks trial was conducted to investigate the effect of using different levels of grain sorghum in the broiler chicken diets as a replacement for corn on the growth performance, shank skin pigmentation score, carcass traits, caecal microflora and nutrient digestibility. **Materials and Methods:** Isocaloric/isonitrogenous diets were formulated where sorghum replaced corn at rates of 0% (control), 10, 25, 50 and 100% making 5 dietary treatments with 5 replicate pens per treatment. A total of 250-day-old-chicks (Cobb500) were randomly allocated into 25 pens with 10 birds per pen. **Results:** The obtained results revealed no significant differences in the body weight (BW), average daily gain (ADG) and feed conversion ratio (FCR) when sorghum replaced corn at levels up to 50%. The ADG was decreased and the FCR was increased when sorghum replaced corn at 100%. The average daily feed intake was not impacted by sorghum inclusion. The measured carcass traits and caecal microflora were not impacted by sorghum inclusion. The shank skin pigmentation score was significantly decreased by sorghum inclusion at 50-100%. The protein digestibility was significantly decreased when sorghum inclusion replaced corn at 100%. **Conclusion:** It can be concluded that sorghum is a good partial alternative for corn at levels up to 50% without negative impacts on the broiler chicken productivity.

Key words: Corn, sorghum, growth performance, nutrient digestibility, broiler chickens

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Utilizing alternative energy rich feed ingredients in poultry nutrition is one of the ongoing interesting topics among poultry nutritionists and feed producers. Although, corn is the main traditional energy source in poultry diets, sorghum can be utilized as a potential alternative especially when there is a scarcity or a price increase in corn due to climatic changes or infestation by fall armyworm that impacts corn crop yield or due to maize competition with human diet[1].

Sorghum bicolor L. was originated from northeastern Africa approximately 5000 years ago[2]. It is the fifth most important global cereal crop after corn, rice, wheat and barley[3]. Compared to corn, sorghum can grow under various conditions (wet/dry climate; clay/sandy soil; wide pH and salinity ranges) thus making it a perfect crop to grow in drought prone areas where many other crops would fail[4]. Globally, the area planted with sorghum has been increased by 60% and the yield has improved by 233% over the past 50 years[5]. The current total annual production of sorghum ranges from 40-45 million tons from approximately 40 million hectares[6]. Approximately 52% of grain sorghum is used for human food while the rest is used in animal feed[7].

The nutrient profile of sorghum is very similar to corn. The protein quantity in sorghum is higher than corn but the quality of the protein is lower (protein digestibility of sorghum is approximately 95% of that of corn). The fat content and energy value are slightly lower in sorghum as compared to corn. Compared to yellow corn, sorghum contains reduced quantities of yellow xanthophyll that provide yellow coloring for skin pigmentation in broilers and egg yolk in layers. Tannins content is a concern in sorghum; red sorghum is rich in tannins while white/yellow sorghum is of lower or free tannin content. Tannins interfere with nutrients metabolism and absorption plus their bitter taste which reduces feed palatability. Low-tannins white sorghum is similar to corn in its nutritional value for poultry[7,8]. Limited published studies confirmed that low tannin sorghum can be a successful alternative energy source for corn in broiler chicken diets without negatively impacting the performance parameter[9-11]. The objective of this study was to examine the effect of substituting yellow corn with white sorghum on the growth performance, shank skin pigmentation, carcass traits, caecal microflora and nutrient digestibility of broilers.

MATERIALS AND METHODS

Experimental birds and management: A total of 250 day-old-broiler chicks (Ross 308 strain) were purchased from a local hatchery. Once arrived, they were leg banded and randomly allocated into 5 experimental dietary treatments. Each treatment contained 5 replicate pens with 10 birds in each pen. The average BW difference of the day old chicks between the pens was less one g. The pens were equipped with fresh wood shaving as a bedding material. The chicks were reared in an environmentally controlled house. They were incubated at a temperature of 33°C during the first week of age then the temperature was gradually reduced by 2°C every week till 25°C was reached then maintaining this temperature for the rest of the trial period. The average relative humidity was 65%. The lighting program was 23 h light.

All the birds were vaccinated against Newcastle and Avian Influenza diseases at d 7 using dead vaccine (Volvac® B.E.S.T AI+ND, Boehringer Ingelheim Company, Germany; S/C injection) and against Newcastle disease using live attenuated vaccine at d 14 (Nobilis® ND Clone 30, Intervet, The Netherlands; ocular route). The birds were also vaccinated against Gumboro disease at d 12 and 22 (Nobilis® GUMBORO D78, Intervet, The Netherlands; drinking water).

The trial was carried out at the Poultry Experimental Station of the College of Veterinary Medicine, Zagazig University, Egypt. All the experimental procedures followed the guidelines of the local experimental animal care and use committee of Zagazig University.

Experimental diets: The experimental diets were formulated to meet the breed recommendations[12] with adjustment of the age and to be isocaloric and isonitrogenous. The feeding program was divided into three feeding phases: starter (0-14 days of age), grower (15-28 days of age) and finisher (29-42 days of age). There were 5 dietary treatments; in treatment 1 (control), the birds were fed on the corn based diet while in treatments 2-5, the birds were fed on diets where sorghum replaced corn at 10, 25, 50 and 100% respectively. The feed was provided in mash form on ad-libitum basis. No synthetic antimicrobials were included in the experimental diets. White sorghum was obtained from a local trader.

Samples of white sorghum and yellow corn were submitted to the Regional Center for Food and Feed, Agriculture Research Centre, Giza, Egypt for proximate composition (dry matter, crude protein, ether extract, crude fiber, ash, calcium and phosphorus) according to the standard procedures cited by AOAC[13] and amino acid analysis using ion exchange chromatography according to European Commission[14] (Table 1 and 2). Other feed ingredients and diets were analyzed for dry matter, crude protein, ether extract, crude fiber and ash according to the standard procedures cited by AOAC[13]. The analyzed values were in close agreement with the calculated values. The experimental diets and their composition are presented in Table 4.

Table 1: Chemical composition of yellow corn and white sorghum (as is basis)[1]

Items	Corn (yellow)	Sorghum (white)
Moisture (%)	11.60	11.00
Dry matter (DM, %)	88.40	89.00
Crude protein (CP, %)	7.80	9.10
Ether extract (EE, %)	4.00	3.00
Crude fiber (CF, %)	2.05	1.80
Nitrogen free extract (NFE, %)[2]	73.15	73.65
Ash (%)	1.40	1.45
Calcium (%)	0.01	0.02
Phosphorus (%)	0.22	0.24
AMEn (kcal kg^{-1})[3]	3350.00	3288.00
Yellow xanthophyll (mg kg^{-1})[4]	23.00	0.00

[1]Analyzed; [2]NFE: 100-(% moisture+% CP+% EE+% CF+% ash); [3]Nitrogen corrected metabolizable energy was calculated according to Janssen[15]:
Corn: 36.2×CP+85.44×EE+37.26×NFE
Sorghum: 31.02×CP+77.03×EE+37.67×NFE. [4]INRA-CIRAD-AFZ feed tables

Table 2: Amino acid composition of yellow corn and white sorghum

Amino acid (%)	Corn (yellow)	Sorghum (white)
Lysine	0.24	0.22
Arginine	0.37	0.35
Methionine	0.17	0.16
Cystine	0.18	0.16
Threonine	0.29	0.30
Leucine	0.95	1.15
Isoleucine	0.27	0.36
Valine	0.38	0.44
Phenylalanine	0.37	0.44
Tyrosine	0.28	0.39
Histidine	0.23	0.22
Glycine	0.31	0.32
Alanine	0.57	0.80
Glutamic acid	1.37	1.80
Aspartic acid	0.51	0.60
Serine	0.37	0.43
Proline	0.68	0.75

Measurements

Growth performance parameters: Individual bird weights and feed consumption were measured at the end of each feeding phase. The following performance parameters were determined: average body weight (BW), average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR; feed/gain). Birds were checked twice daily for mortality and any dead birds were weighed and the data were used to correct the FCR to mortality and to calculate the livability percentage.

Shank skin color score: At day 42, 15 birds per treatment (three bird per pen) showing no signs of abnormalities were randomly selected and individually evaluated for pigmentation coloring of their shanks using DSM broiler color fan. The fan score is ranged from 101 (pale yellow/creamy) to 108 (deep orange). The color evaluation was done by one person for consistency of measurement[16].

Carcass traits: At the end of the trial (day 42), five birds per treatment (one bird per pen representing the pen average weight) were collected, individually weighed and sacrificed by bleeding the jugular veins. The carcasses were defeathered and eviscerated then weighed to determine the hot carcass weight. The dressing percentage was calculated by dividing the hot carcass weight on the live weight and multiplying by 100. The weights of the breast, thigh plus drumstick, abdominal fat and liver were measured and expressed as a ratio of the carcass weight.

Caecal microflora count: The left caecum of the sacrifice birds (5 birds per treatment) were excised and placed into the sterile labelled bags and stored at -80°C till analyzed. The frozen caeci were thawed and transferred into sterile tubes to determine the counts of coliforms and lactobacilli. Each sample was serially diluted from initial 10^{-1} to 10^{-9}, then 100 µL of the diluted samples were plated on agar media (MacConkey for coliforms and MRS for lactobacillus) and incubated at 37°C for 24 and 48 h under aerobic and anaerobic conditions, respectively. The results are shown as $\log_{10}$ colony forming unit (CFU) per gram of caecal digesta[17].

Apparent total tract nutrient digestibility: At end of the trial (42 days of age), two birds having the average weight of the pen were kept in their pens (10 birds/treatment) and fed on the same type of feed they consumed in the finisher stage but with the addition of 0.5% titanium dioxide as an indigestible marker for 7 days. The first 3 days were kept as an adaptation period, followed by the collection period in the last four days. During the collection period, a plastic sheet was laid under the birds and over the bedding materials in each pen. Samples from the excreta (free from feather and feed) voided by the tested birds in each pen were collected twice daily in airtight bags and stored at -18°C till analyzed. Samples from the offered feed were collected and stored until analyzed. The frozen excreta collected from each pen were thawed, pooled, dried in a hot air oven at 55°C for 72 h and then ground to pass through a 0.5 mm sieve.

Titanium dioxide concentration in the diets and excreta was measured according to Short *et al.*[18]. The proximate analysis of dry matter, crude protein and ether extract of diets and excreta was conducted according to the standard procedures cited by AOAC[13]. Uric acid content of the excreta was determined according to Marquardt[19]. The apparent total tract nutrients digestibility was determined using the following equation described by Schneider and Flatt[20].

Table 3: Comparison between the essential amino acid composition of yellow corn and white sorghum

	Corn (yellow)		Sorghum (white)		
Total amino acid (TAA)	TAA[1]	TAA relative to CP (%)	TAA[1]	TAA relative to CP (%)	Difference (%)[2]
Crude protein	7.8.0		9.1		
Lysine	0.24	3.08	0.22	2.42	21.43
Arginine	0.37	4.74	0.35	3.85	18.92
Methionine	0.17	2.18	0.16	1.76	19.33
Cystine	0.18	2.31	0.16	1.76	23.81
Threonine	0.29	3.72	0.3	3.30	11.33
Leucine	0.95	12.18	1.15	12.64	-3.76
Isoleucine	0.27	3.46	0.36	3.96	-14.29
Valine	0.38	4.87	0.44	4.84	0.75
Phenylalanine	0.37	4.74	0.44	4.84	-1.93
Histidine	0.23	2.95	0.22	2.42	18.01

[1] Analyzed data. [2]Level of increase or decrease in the percentage of TAA relative to CP of sorghum compared to corn

$$100 - [\{(\%) \text{ indicator in feed} / (\%) \text{ indicator in feces}\} \times \{(\%) \text{ nutrient in feces} / (\%) \text{ nutrient in feed}\}\} \times 100]$$

Statistical analysis: The obtained results were statistically analyzed using Statistix®9[21]. The pen served as the experimental unit for the growth performance data while individual bird was served as the experimental unit for other data. ANOVA was conducted to determine the treatment effect and LSD was used to determine if significant differences exists among treatments. All statements of statistical significance were based on p<0.05.

RESULTS

Proximate and amino acid composition of white sorghum: Results indicated that sorghum has 1.30% higher crude protein than yellow corn. The NFE is approximately similar between the two cereal grains. White sorghum containing 62 kcal kg^{-1} less apparent metabolizable energy and 1% less ether extract than yellow corn. Values of calcium and phosphorus are very close among corn and sorghum. White sorghum is lacking xanthophyll pigment while yellow corn is rich in it (Table 1).

Both corn and sorghum have the same limiting essential amino acids (lysine, tryptophan, arginine, methionine and cystine) while being rich in leucine, proline and glutamic acid (Table 2). The percentage of total amino acid relative to crude protein in white sorghum was found to be lower for lysine, arginine, methionine, cystine, threonine and histidine and higher for leucine and isoleucine, while very close for valine and phenylalanine when compared to yellow corn (Table 3).

Performance parameters: Substituting up to 50% of the corn by sorghum did not result in significant difference in the average BW. At 100% substitution, the final average BW was significantly decreased by 5.25% compared to broilers fed on corn diet (p<0.050; Table 5). During the feeding periods of 0-14, 15-28 and 0-42 days of age, the ADG was not significantly impacted by including sorghum at 50% of the corn but it was significantly decreased (p<0.05) by approximately 5.5% when sorghum replaced corn at 100%. The ADG was not significantly (p>0.05) affected by sorghum inclusion during the feeding period of 29-42days of age (Table 5). The ADFI was not affected by sorghum inclusion during different feeding periods (p>0.05, Table 6). The FCR was not impacted when sorghum substituted corn at levels up to 50% during different feeding period. However, at 100% sorghum substitution, the FCR was significantly increased by levels up to 8% during 15-28 (p<0.05), 29-42 (p<0.05) and 0-42 (p<0.01) days of age (Table 6).

Shank skin pigmentation score: Addition of sorghum as a substitute for yellow corn at 50 and 100% resulted in a significant decrease in the shank skin pigmentation score (p<0.01). Substitution of corn by sorghum at levels below 50% did not significantly impact the shank skin pigmentation score (Table 8).

Carcass traits: The measured carcass traits were not affected by substitution of corn by sorghum at different levels (p>0.05; Table 7).

Caecal microflora: Neither coliforms nor lactobacilli were significantly affected by substitution of corn by sorghum (p>0.05, Table 8).

Total tract nutrient digestibility: As shown in Table 9, the digestibility coefficient of crude protein was significantly (p<0.05) decreased by 5.25% when sorghum replaced corn at 100% compared to 100% corn diet. The digestibility of crude protein did not significantly influence when the replacement level was up to 50% (p>0.05). Corn replacement by sorghum at different levels did not significantly (p>0.05) impact the digestibility coefficient of dry matter or crude fat.

Table 4: Diet composition and nutrient content (% as fed)

	Starter					Grower					Finisher				
Ingredients	S0	S10	S25	S50	S100	S0	S10	S25	S50	S100	S0	S10	S25	S50	S100
Corn, ground yellow	53.06	47.88	40.10	27.13	0.00	57.73	52.09	43.62	29.41	0.00	60.86	54.90	45.97	31.12	0.00
Sorghum, ground white	0.00	5.30	13.26	26.53	54.29	0.00	5.77	14.43	28.87	59.05	0.00	6.08	15.22	30.43	62.25
Soybean meal, 46% CP	37.25	37.08	36.82	36.40	35.51	32.23	32.06	31.76	31.31	30.34	28.48	28.28	27.99	27.50	26.48
Corn gluten meal, 60% CP	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Limestone	1.49	1.49	1.48	1.48	1.48	1.34	1.34	1.34	1.43	1.34	1.19	1.19	1.19	1.19	1.19
Monocalcium phosphate	1.67	1.68	1.68	1.69	1.71	1.48	1.49	1.49	1.50	1.52	1.28	1.29	1.29	1.30	1.33
Premix[1]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Sodium chloride	0.29	0.29	0.29	0.30	0.30	0.29	0.29	0.30	0.30	0.31	0.29	0.30	0.30	0.30	0.31
Sodium bicarbonate	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
DL. Methionine	0.33	0.33	0.34	0.34	0.36	0.29	0.29	0.30	0.31	0.32	0.28	0.29	0.29	0.30	0.32
L. Lysine HCl	0.28	0.28	0.30	0.32	0.36	0.26	0.26	0.28	0.30	0.35	0.26	0.27	0.28	0.30	0.35
L. Threonine	0.10	0.10	0.11	0.11	0.12	0.09	0.09	0.10	0.10	0.11	0.08	0.08	0.09	0.09	0.10
Choline chloride 60%	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Vegetable oil	2.98	3.02	3.07	3.15	3.32	3.74	3.77	3.83	3.92	4.11	4.73	4.77	4.83	4.92	5.12
Nutrient composition															
Crude protein,	23.00	23.00	23.00	23.00	23.00	21.00	21.00	21.00	21.00	21.00	19.50	19.50	19.50	19.50	19.50
AME (kcal kg^{-1})	3000.00	3000.00	3000.00	3000.00	3000.00	3100.00	3100.00	3100.00	3100.00	3100.00	3200.00	3200.00	3200.00	3200.00	3200.00
Calcium	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.80	0.80	0.80	0.80	0.80
Available phosphorus	0.50	0.50	0.50	0.50	0.50	0.45	0.45	0.45	0.45	0.45	0.40	0.40	0.40	0.40	0.40
Lysine	1.44	1.44	1.44	1.44	1.44	1.29	1.29	1.29	1.29	1.29	1.19	1.19	1.19	1.19	1.19
Methionine	0.71	0.71	0.71	0.71	0.72	0.65	0.65	0.65	0.65	0.66	0.62	0.62	0.62	0.62	0.63
Methionine+cystine	1.08	1.08	1.08	1.08	1.08	0.99	0.99	0.99	0.99	0.99	0.94	0.94	0.94	0.94	0.94
Sodium	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18

S0: Control with 0% sorghum, S10: Sorghum replaced 10% of dietary corn, S25: Sorghum replaced 25% of dietary corn, S50: Sorghum replaced 50% of dietary corn, S100: Sorghum replaced 100% of dietary corn.
[1]Supplied the following per kg of diet; Vitamin A: 12000 IU, Vitamin D3: 3000 IU, Vitamin E: 10 mg, Vitamin K3: 1 mg, Vitamin B1: 1 mg, Vitamin B2: 5 mg, Vitamin B6: 1.5 mg, Pantothenic acid: 10 mg, Vitamin B12: 0.01 mg, Niacin: 30 mg, Folic acid: 1 mg, Biotin: 0.05 mg, Zn: 60 mg, Mn: 60 mg, Fe: 30 mg, Cu: 4 mg, I: 0.3 mg, Co: 0.1 mg and Se: 0.1 mg

Table 5: Effect of replacing dietary corn by sorghum on the average BW and ADG of broiler chickens

	Average BW[1] (g)			ADG (g)			
	Day 14	Day 28	Day 42	0-14 days of age	15-28 days of age	29-42 days of age	0-42 days of age
TRT 1	400.500[a]	1251.400[a]	2174.000[a]	25.660[a]	60.78[a]	65.90	50.76[a]
TRT 2	394.500[a]	1229.600[a]	2147.000[a]	25.240[a]	59.64[a]	65.52	50.12[a]
TRT 3	393.000[ab]	1242.000[a]	2164.000[a]	25.100[ab]	60.64[a]	65.84	50.52[a]
TRT 4	394.800[a]	1238.300[a]	2168.000[a]	25.240[a]	60.26[a]	66.40	50.62[a]
TRT 5	380.100[b]	1177.900[b]	2060.000[b]	24.180[b]	56.98[b]	63.02	48.06[b]
p-value	0.049	0.006	0.011	0.048	0.013	ns	0.011
Pooled SEM	4.460	13.000	22.720	0.320	0.770	0.94	0.540

BW: Body weight, ADG: Average daily gain, ns: No significant effect ($p>0.05$). [a,b]Means in a column with no common superscript letter differ significantly ($p<0.05$)
[1]The average initial body weight of day-old chicks was 42.0±1.5

Table 6: Effect of replacing dietary corn by sorghum on the ADFI and FCR of broiler chickens

	Days of age							
	ADFI (g)				FCR (g g^{-1})			
	0-14	15-28	29-42	0-42	0-14	15-28	29-42	0-42
TRT 1	31.90	96.54	140.2	89.54	1.24	1.590[b]	2.13[b]	1.760[b]
TRT 2	31.40	98.76	142.0	90.74	1.25	1.660[ab]	2.17[ab]	1.810[b]
TRT 3	31.64	98.56	140.8	90.36	1.26	1.630[b]	2.14[b]	1.790[b]
TRT 4	31.52	97.74	139.8	89.68	1.25	1.620[b]	2.11[b]	1.770[b]
TRT 5	31.74	97.70	142.2	90.56	1.31	1.720[a]	2.26[a]	1.880[a]
p-value	ns	ns	ns	ns	ns	0.012	0.04	0.006
Pooled SEM	0.22	0.31	0.42	0.37	0.02	0.020	0.03	0.020

ADFI: Average daily feed intake, FCR: Feed conversion ratio, ns: No significant effect ($p>0.05$). [a,b]Means in a column with no common superscript letter differ significantly ($p<0.05$)

Table 7: Effect of replacing dietary corn by sorghum on the carcass traits (%) of broiler chickens at 42 days of age

	Dressing	Breast	Thigh+drumstick	Abdominal fat	Liver
TRT 1	73.84	27.08	31.96	1.788	3.36
TRT 2	75.20	26.68	31.84	1.718	3.34
TRT 3	72.84	26.26	30.60	1.636	3.25
TRT 4	72.94	25.82	31.42	1.600	3.19
TRT 5	73.46	26.46	31.86	1.812	3.48
p-value	ns	ns	ns	ns	ns
Pooled SEM	0.73	0.30	0.35	0.060	0.10

ns: No significant effect ($p>0.05$)

Table 8: Effect of replacing dietary corn by sorghum on the caecal microflora and shank skin pigmentation score of broiler chickens at 42 days of age

	Coliforms count*	Lactobacilli count*	Shank skin pigmentation score
TRT 1	6.42	7.52	105.0000[a]
TRT 2	5.30	7.72	105.4000[a]
TRT 3	5.84	8.64	104.4000[ab]
TRT 4	5.14	8.16	103.4000[b]
TRT 5	5.90	8.66	103.6000[c]
P-value	ns	ns	0.0001
Pooled SEM	0.48	0.68	0.3800

ns: No significant effect ($p>0.05$). [a,b,c]Means in a column with no common superscript letter differ significantly ($p<0.05$). *Bacterial counts are expressed as log10 CFU g^{-1} of caecal digesta

Table 9: Effect of replacing dietary corn by sorghum on the nutrient digestibility coefficient (%) of broiler chickens

	Dry matter	Crude protein	Crude fat
TRT 1	74.26	75.88[a]	83.77
TRT 2	76.53	76.87[a]	86.54
TRT 3	74.26	76.88[a]	83.97
TRT 4	75.97	77.46[a]	86.61
TRT 5	74.06	71.89[b]	84.94
p-value	ns	0.05	ns
Pooled SEM	1.45	1.32	1.94

ns: No significant effect ($p>0.05$). [a,b]Means in a column with no common superscript letter differ significantly ($p<0.05$)

DISCUSSION

The obtained results revealed that sorghum can safely replace half of the dietary corn and that complete replacement resulted in poor performance. The poor performance observed at 100% sorghum inclusion could be attributed to presence of kafirin (the dominant protein fraction), phytate and non-tannins phenolic compounds in white sorghum which could compromise the quality of protein and starch[22].

Our findings agree with Torres *et al.*[23] who reported that replacing corn by sorghum at 100% resulted in the poor weight gain and feed conversion ratio compared to 100% corn diet or replacing corn by sorghum at 50%. Similarly, Ahmed *et al.*[24] reported poor FCR at 100% sorghum inclusion and the best results were achieved at 100% corn inclusion. Likewise, Mohamed *et al.*[25] did not observe a negative impact on the broiler chicken performance due to replacing corn by sorghum at levels up to 45%. On the other hand, Issa *et al.*[10] successfully replaced corn by low tannin sorghum at 100% without negative impact on the weight gain or FCR.

In agreement with our findings on feed intake, Mohamed *et al.*[25] and Kyarisiima *et al.*[26] did not observe a significant difference in the feed intake due to replacing corn by sorghum. In contrast, Kwari *et al.*[27] reported a significant increase in the feed intake when sorghum replaced corn at various levels (25, 50, 75 and 100%). However, the last researchers (Kwari *et al.*[27]) made the replacement on a weight to weight basis without making adjustment for the energy in the diets containing sorghum. Therefore, the birds consumed more feed to compensate the lower energy in sorghum compared to corn.

Sorghum inclusion as a substitute for corn at 50 and 100% resulted in a significant decrease in the shank skin pigmentation score. This could pose a concern in markets where chickens are sold as live birds as consumers could give preference to birds with much more yellow pigmented shank at the time of purchase. In markets where chickens sold refrigerated/frozen or processed into parts shank skin color should not be a concern. Shelton[28] reported a significant linear decline in the shank pigmentation score due to increasing the sorghum inclusion from 0% to levels up to 100% as a substitution for yellow corn.

No significant differences were observed in the measured carcass traits. Likewise, no significant differences were observed in the carcass yield[10]; dressing, carcass cut up parts (breast, thigh, drumsticks and wings) and liver[27]; carcass yield, gizzard, liver and abdominal fat[29]; dressing, liver and abdominal fat[30] due to corn replacement by low tannin sorghum at levels up to 100%.

The composition of caecal microflora plays an important role in intestinal maturity and protection from colonization with pathogens[17]. Our finding did not reveal significant differences in the coliforms or lactobacilli count due to sorghum inclusion. On the other hand, Shakouri *et al.*[31] reported a significant decrease in the caecal lactobacilli counts due to feeding broiler chickens on sorghum based diet compared to corn based diet.

Complete corn replacement by the sorghum in the current study resulted in a significant drop in the protein digestibility. A substantial proportion of sorghum protein is composed of kafirin, which is a relatively poorly digested protein due to its hydrophobic nature. Furthermore, sorghum contains a considerable amount of phytate which has the capacity to complex proteins in the gut and depress protein digestibility[22,32]. Therefore, the more sorghum inclusion in the diet, the more negative impact will be on protein digestibility though the negative impact of kafirin and phytate can be overcome by protease and phytase enzymes inclusion, respectively.

CONCLUSION

At time of corn scarcity or when it became more expensive, white sorghum can be considered as an alternative and can substitute corn at levels up to 50% in commercial broiler chicken diets without negative impact on the performance parameters and carcass yield. Further studies are recommended on the potential positive impact of phytase and protease supplementation on diets containing sorghum above 50% inclusion.

SIGNIFICANCE STATEMENT

This study investigated the nutritional role of grain sorghum as a partial energy replacement for corn in broiler chicken. The obtained results will help researchers and nutritionists to better understand sorghum nutrient composition and to uncover its impact on shanks skin pigmentation, caecal microflora and nutrient digestibility that many researchers did not explore. Thus, sorghum can be efficiently utilized in broiler chicken nutrition when corn price or availability is a concern.

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