Ciência Rural, Santa Maria, v.53:8, e20210466, 2023
http://doi.org/10.1590/0103-8478cr20210466
ISSNe 1678-4596
ANIMAL PRODUCTION

Whole and ground sorghum replacing corn on the performance of carcass parts and relative weight of 28-day-old turkey offal

Alexandre Ambrósio[1*] Evandro de Abreu Fernandes[2] Fernanda Heloisa Litz[2] Naiara Simarro Fagundes[2] João Paulo Rodrigues Bueno[2] Leticia Misturini Dalla Costa[1]

[1]Brasil Foods BRF S.A., 85603-025, Francisco Beltrão, PR, Brasil. E-mail: ale_ambrosio@hotmail.com. *Corresponding author.
[2]Programa de Pós-graduação em Ciências Veterinárias, Universidade Federal de Uberlândia (UFU), Uberlândia, MG, Brasil.

ABSTRACT: The study evaluated the effects of replacing corn with whole and ground sorghum on the zootechnical performance of turkeys fed from one to 28 days of age. A total of 3,960 male Nicholas turkeys were used, divided into six treatments: A) Whole sorghum (100%Sw); B) Ground corn (100%Cg); C) 75% Ground Corn + 25% Ground Sorghum (75%Cg/25%Sg); D) 50% Ground Corn + 50% Ground Sorghum (50%Cg/50%Sg); E) 25% Ground Corn + 75% Ground Sorghum (25%Cg/75%SG) and F) Ground Sorghum (100%Sg). At seven days, live weight was the same between treatments (164 g per bird). At 28 days, the percentage of breast, thigh-drumstick, and wings remained constant in the corn-based diet or partial and total replacements by ground or whole sorghum grain. The length of the small intestine was shorter in treatments B and C. The digestibility of the lipid fraction of the diet (DEE) was significantly higher in the diet with ground sorghum. The treatment based on ground sorghum grain showed the same result for ground corn in the dry matter (DM) and mineral matter (MM DM%) composition of the turkey carcass at 28 days. Ground sorghum influenced the lipid portion of the carcasses (EE DM%). Thus, it is concluded that whole sorghum grain presented the same results as ground sorghum and ground corn for zootechnical performance, carcass muscle mass, and viscera morphometry in turkeys at 28 days of age.
Key words: performance, grain, *Meleagris*, nutrition, *sorghum bicolor*.

Sorgo integral e moído em substituição ao milho no desempenho, de partes da carcaça e peso relativo de vísceras de perus de 28 dias

RESUMO: Objetivou-se avaliar os efeitos da substituição do milho pelo sorgo inteiro e moído sobre o desempenho zootécnico de perus fornecido no período de um a 28 dias de idade. Foram utilizados 3.960 perus machos da linhagem Nicholas, divididos em seis tratamentos: A) Sorgo inteiro (100%Si); B) Milho moído (100%M); C) 75% Milho moído + 25% Sorgo moído (75%M25%S); D) 50% Milho moído + 50% Sorgo moído (50%MS); E) 25% Milho moído + 75% Sorgo moído (25%M/75%S) e F) Sorgo moído (100%Sm). Aos sete dias de idade o peso vivo foi igual entre os tratamentos (média de 164 g por ave). Aos 28 dias a percentagem de peito, coxa-sobrecoxa e asas mantiveram-se constantes na dieta a base de milho, ou substituições parciais e totais pelo sorgo grão moído ou inteiro. O comprimento do intestino delgado foi menor no tratamento B e C. A digestibilidade da fração lipídica da ração (DEE) foi significativamente maior na ração com o sorgo moído. O tratamento base sorgo grão moído mostrou o mesmo resultado para milho moído na composição de matéria seca (MS) e de matéria mineral (MM MS) da carcaça dos perus aos 28 dias. O sorgo grão moído influenciou a parcela lipídica das carcaças (EE MS). Desta forma, conclui-se que o grão de sorgo inteiro apresentou os mesmos resultados do que sorgo moído e milho moído para desempenho zootécnico, massa muscular da carcaça e morfometria das vísceras em peruzinhos do alojamento a 28 dias de idade.
Palavras-chave: conversão alimentar, grão inteiro, *Meleagris*, nutrição, consumo de ração.

INTRODUCTION

Corn is the primary energy source in poultry nutrition, comprising 60 to 70% of feeds (REECE et al., 1986; LOTT et al., 1992). The growing demand for corn for human consumption, combined with limited supplies at certain times of the year, encourages companies and producers to search for alternative foods to formulate poultry diets (CÓRDOVA-NOBOA et al., 2018).

One of the alternatives reported by the industry is the use of sorghum varieties without tannin, which have a nutritional value very close to corn; in addition, sorghum can be produced in semi-arid areas and adapt to low-quality soils (TORRES et al., 2013; CÓRDOVA-NOBOA et al., 2018). This has been stimulating the sorghum grain production sector with a growing market supply and prices that can vary from 10 to 20% lower than corn, constituting the most promising energy source for feeds, especially for monogastric animals (ROCHA et al., 2008). An essential aspect of sorghum in the feeding of broilers and laying hens is the possibility of including the whole grain in the diet of birds, which can reduce the final cost of feed production (SILVA et al., 2015). Studies showed that sorghum in the diet of chickens

Received 06.14.21 Approved 09.26.22 Returned by the author 11.29.22
CR-2021-0466.R1
Editors: Rudi Weiblen Wagner Araújo

and hens does not compromise the zootechnical performance compared to the traditional corn-based diet and competes with the final cost of production (FAGUNDES et al., 2017; SALEH et al., 2019).

Grain sorghum has a prominent position in the broiler segment, given that large companies have purchased large volumes in the harvest; however, there is a lack of information and research in the area of turkey production; however, the expectation is that its presence in nutrition has the same performance demonstrated in birds. Thus, the study evaluated the replacement of corn with the ground or whole sorghum on the zootechnical performance of turkeys in the period from one to 28 days of age.

MATERIALS AND METHODS

Site description and turkey management

He experiment was conducted at the Experimental Farm, located at Fazenda do Glória, Faculty of Veterinary Medicine, UFU, from October to November 2012. One-day-old male turkeys (Nicholas strain) were housed, supplied by the BRF company. The birds were vaccinated against avian poxvirus disease in the hatchery and were housed with an average weight of 60.4 grams. The experiment lasted 28 days, coinciding with the initial production phase.

The experiment was conducted in a 60 x 10 m masonry shed, previously disinfected with quaternary ammonia, covered with a metallic structure and fiber-cement tiles, sides with a masonry wall, and mesh screen of four square centimeters, internal and external aviary curtains, and concrete floor. It was equipped with 72 boxes (1.90 x 1.60 m each). The boxes were composed of 20 kg tubular feeders and a pendular drinker.

Housing density was 18 birds m². The water was from a deep well, chlorinated, and available in poultry drinkers. The birds were debeaked at 17 days, following the procedure recommended in the strain manual. In the first week of life, the temperature inside the shed was controlled with heaters and curtains. In the subsequent period, thermal comfort was maintained by adjusting the height of the curtains, ventilation, sprinkling of microdroplets of water, and natural and artificial lighting.

Experimental design

The experiment was carried out in a completely randomized design, using 3,960 turkeys divided into six treatments: A) Whole sorghum (100%Sw); B) Ground corn (100%Cg); C) 75% Ground Corn + 25% Ground Sorghum (75%Cg/25%Sg); D) 50% Ground Corn + 50% Ground Sorghum (50%Cg/50%Sg); E) 25% Ground Corn + 75% Ground Sorghum (25%Cg/75%Sg); F) Ground sorghum (100%Sg). Each treatment consisted of 12 replications of 55 birds.

Experimental diets

The mash feeds were provided from housing to 28 days of age, formulated according to the recommendations of the strain, and produced on the farm. The food program consisted of pre-starter food throughout the experiment phase. The feeds were based on corn grain, sorghum grain, soybean meal, degummed soybean oil, dicalcium phosphate, limestone, table salt, DL-Methionine, L-Lysine, L-Threonine, vitamin premix, mineral, and additives. (Table 1). All macro ingredients were submitted to bromatological analysis in the Laboratory of Analysis of Raw Material and Feed (Laboratório de Análise de Matéria Prima e Ração - LAMRA) of the Faculty of Veterinary Medicine of UFU.

Data collection and atatistical analyses

The performance variables were obtained during the experiment by weighing the feed and all live birds in the experimental units at 7, 14, 21, and 28 days of age.

From these data, the zootechnical performance was calculated. Feed consumption (FC) - the difference between the initial weight of the feed available in the tube feeder at the beginning of each week and the weight of the leftovers. The average live weight (LW) - the weight of all the birds in the box was calculated and divided by the number of birds. The birds that died during the experiment were also weighed.

To calculate the feed conversion ratio (FCR) the following equation was used: FCR = (average feed intake) / ((average live weight + dead birds' weight) – (bird initial weight)). Traditional food conversion was determined by TFC = (feed intake) / (mean live weight). Viability (V%) was determined by V = (number of live birds) / (number of birds housed) x 100.

Body performance

At 28 days of age, a sample of five birds from each treatment was selected based on the average live weight (± 5%) of the treatment to determine the variables of body conformation and relative weight of parts of the carcass and viscera. After 8 hours of fasting, the birds sampled were

Table 1 - Ingredients and percentage composition of sorghum and corn-based diets for turkeys in the initial production phase (from 1 to 28 days) according to each treatment.

	----------Feed (%) / Treatments----------				
Ingredients	A and F	B	C	D	E
Soybean meal 46.5%	45.07	45.89	45.68	45.47	45.27
Corn grain 7.6	0.00	39.54	29.59	19.63	9.66
Sorghum 8.6	39.24	0.00	9.88	19.76	29.65
Corn meal (Gluten 60%)	5.00	5.00	5.00	5.00	5.00
Soybean oil	4.62	3.52	3.79	4.08	4.35
Dicalcium phosphate	3.28	3.35	3.33	3.32	3.30
Limestone	1.18	1.14	1.15	1.16	1.17
L-Lysine HCL	0.47	0.44	0.45	0.45	0.46
PX INI PC1	0.43	0.43	0.43	0.43	0.43
DL- Methionine	0.34	0.33	0.34	0.34	0.34
Common salt	0.33	0.33	0.33	0.33	0.33
L- Threonine	0.04	0.03	0.03	0.03	0.03
TOTAL	100	100	100	100	100

[1]Initial premix (kg): VitA 12.000,00UI, VitB1 4.00mg, VitB12 0.03mg, VitB2 10.00mg, VitB6 6.00mg, VitD3 4.000.00UI, VitE 100.00UI, VitK 4.00mg, Zn 160.00mg, Cu 20.00mg, Se 0.30mg, Fe 100.00mg, I 3.00mg, Mn 160.00mg, Folic acid 4.00mg, Pantothenic acid 28.00mg, Mo 0.50mg, Biotin 0.20mg, Choline 1600.00mg, Ac. Nicotinic 80.00mg.

taken to the abattoirs and submitted to the ethical slaughter procedure. The small intestine and gizzard were separated in the evisceration, and the food residue was removed. The carcass parts were cut according to the procedures used in industrial abattoirs, being arranged, breast (%Br), thigh and drumstick (%TD), weighed on a precision scale of 0.01g and the percentages of the cuts were calculated based on the live weight of the bird.

The gizzard was weighed separately, and relative weight was calculated concerning live weight. The length of the small intestine was measured with the aid of a measuring tape (0.1 cm precision), and then weighing was performed.

Food digestibility and carcass chemical composition

At 21 days of age, a metabolic test of digestibility of protein fractions and ether extract was carried out in cages, with birds of average live weight (± 5%) of three treatments under development in the performance test, to compose the experimental design thus distributed: A) Ground corn (100%Cg); B) Ground sorghum (100%Sg) and C) Whole sorghum (100%Sw), composed of three treatments and ten replications with four birds each.

After being randomly housed in the cages, the birds were adapted for three days, and the complete collection of excreta took place in the following five days. The amount of food ingested (the difference between the amount of feed offered minus the leftovers) was calculated to conduct the test daily. The excreta collection in the trays of each cage was performed twice a day, stored in identified plastic bags, weighed, and frozen for later analysis. Feed labeled with iron oxide was used to determine the beginning and end of the period and ensure the correct evaluation between the feed ingested and the excreta produced.

At the end of the experiment, the excreta were thawed in the laboratory (LAMRA) of the UFU and homogenized. The samples were pre-dried in a forced air oven at 56 ºC for 72 hours and then ground in a knife mill, as well as the feed samples, for the analysis of crude protein (CP) and ether extract (EE) according to the methodology proposed by the Brazilian Animal Feeding Compendium (BRASIL, 2005). The digestibility was calculated according to: Digestibility = ((Amount of nutrient ingested – Excreted) / Amount of nutrient ingested)*100.

After the collections, five turkeys within the average weight of each of the three treatments were euthanized and plucked to determine the chemical composition of the complete carcasses, ground in an industrial meat mill, and sent to the

laboratory. The carcasses were weighed in aluminum trays and dehydrated in a forced air oven at 56 ºC for 72 hours to obtain the dry matter content (DM%). After dehydration of the material, the concentration of ether extract of the birds (EE DM%) was calculated. From this defatted material, analyses of crude protein (CP DM%) and mineral matter (MM DM%) were conducted, following the methodology proposed by the Brazilian Animal Feeding Compendium (BRASIL, 2005). All these analyzes were performed in duplicate.

For statistical analysis, the homogeneity and normality of variances were evaluated. The data were submitted to analysis of variance and the Tukey test at 5% for comparison of means, using the SAS 9.3 statistical software (SAS Institute Inc., Cary, NC, USA).

RESULTS

At seven days of age, the measured performance of the birds (Table 2) showed that the live weight was the same between treatments, reaching an average of 164 g per bird, similar to the results achieved in industrial rearing. The birds fed with feed with whole sorghum grain had higher feed intake and, consequently, lower feed conversion (FCR and TFC), which can be explained by the presence of whole sorghum grains favoring a loss of feed, visually observed in the litter next to the feeders, due to young birds and selection habits. At this age, no difference was observed in the viability variable.

At 28 days of age (Table 3), the moment in which the birds in an integration system are transferred to the rearing farms until the age of slaughter, no differences were observed between the variables, feed consumption, live weight, feed conversion (FCR and TFC) and viability. This result shows that from housing to 28 days of age, partial or total replacement of corn by sorghum, including whole grain sorghum in the turkey diet, achieved the same zootechnical performance.

It was advocated to compare the development of the carcass of the birds and part of the gastrointestinal tube at 28 days (Table 4), where it is verified that the percentage of breast, thigh-drumstick, and wings concerning the weight of the birds remained constant in the corn-based diet or partial and total replacements by ground or whole sorghum grain. Comparing part of the intestinal gastric tube, it is observed that even using whole sorghum grain, the percentage of gizzard concerning live weight was the same in all treatments. The length of the small intestine in the diet with 25% ground corn and 75% ground sorghum (E) was greater than the treatment with 100% ground corn (B) and 75% ground corn and 25% ground sorghum (C) diet, highlighting a greater presence of whole-grain influencing the size of the small intestine, as well as its weight, where the presence of whole grain was greater than the C treatment.

Comparing the digestibility variables (Table 5), it is observed that the digestibility of the feed (DFD) and crude protein (DCP) of the same were

Table 2 - Zootechnical performance of male turkeys (Nicholas strain) at seven days of age submitted to different diets based on sorghum and corn.

Treatment	Level (Sg%)	FC (g)	LW (g)	FCR	TFC	V (%)
A.100%Sw	-	121a	160	1.224a	0.769a	99.24
B.100%Cg	0	111b	162	1.085b	0.682b	99.39
C.75%Cg25%Sg	25	111b	168	1.032b	0.663b	99.70
D.50%Cg50%Sg	50	106b	164	1.025b	0.649b	98.94
E.25%Cg75%Sg	75	110b	167	1.024b	0.656b	99.54
F.100%Sg	100	109b	163	1.063b	0.669b	99.70
CV (%)		6.24	4.40	8.54	6.93	1.01
P-value		< 0.0001	0.0855	< 0.0001	< 0.0001	0.4065
Regression		ns*	ns*	ns*	ns*	ns*

Means followed by different letters differ from each other by the Tukey test 5% ($P < 0.05$); *not significant for linear, quadratic, and cubic regression ($P > 0.05$).

Table 3 - Zootechnical performance of turkeys (Nicholas strain) at 28 days of age submitted to sorghum-based diets instead of corn.

Treatment	Level (Sg%)	FC (g)	LW (g)	FCR	TFC	V (%)
A.100%Sw	-	1403	1102	1.341	1.270	96.82
B.100%Cg	0	1411	1089	1.367	1.297	96.97
C.75%Cg25%Sg	25	1400	1086	1.363	1.289	98.64
D.50%Cg50%Sg	50	1410	1121	1.344	1.277	94.85
E.25%Cg75%Sg	75	1407	1098	1.349	1.282	97.57
F.100%Sg	100	1393	1092	1.345	1.276	97.88
CV (%)		3.55	3.50	3.55	3.49	3.47
P-value		0.9449	0.2700	0.6989	0.7231	0.1328
Regression		ns*	ns*	ns*	ns*	ns*

Means followed by different letters differ from each other by the Tukey test 5% ($P < 0.05$); *not significant for linear, quadratic, and cubic regression ($P > 0.05$).

not different between the exclusive feeds of corn, ground sorghum, and/or whole sorghum; however, the digestibility of the lipid fraction of the diet (DEE) was significantly higher in that with ground sorghum. Comparing these results with table 6, there seems to be an explanation if we associate feed and protein digestibility dependent on gizzard activity, whose size was not influenced by the presence of the whole grain.

The chemical composition of the carcass of birds at the end of 28 days of those birds fed with feeds exclusively composed of corn, ground sorghum, and whole sorghum is shown in table 6. No difference was observed in the percentage of crude protein in the carcass between the diets. The ground sorghum-based treatment showed the same result for ground corn in the dry matter (DM) and mineral matter (MM DM) composition of the turkey carcass at 28 days. The whole grain sorghum had significantly lower participation (Table 6). For the lipid portion of the carcasses (EE DM), the difference was in favor of the treatment involving ground sorghum grain (Table 7).

Table 4 - Carcass percentages of the breast (Br), thigh and drumstick (TD), wings (Wn), and gizzard (Gz), and length (LSI) and weight (WSI) of the small intestine of male turkeys (Nicholas strain) slaughtered at 28 days of age submitted different diets based on sorghum and corn.

Treatment	Br (%)	TD (%)	Wn (%)	Gz (%)	LSI (cm)	WSI (g)
A.100%Sw	20.81	19.83	12.32	3.12	137.40ab	36.30a
B.100%Cg	20.75	19.90	12.12	2.94	125.42b	33.30ab
C.75%Cg25%Sg	20.75	20.14	12.41	2.88	124.80b	31.76b
D.50%Cg150%Sg	20.55	19.68	12.36	3.03	138.80ab	35.58ab
E.25%Cg75%Sg	20.49	20.00	12.28	2.95	146.20a	35.12ab
F.100%Sg	20.84	19.82	12.15	2.86	132.20ab	34.30ab
CV (%)	4.64	3.30	3.26	10.33	7.13	5.66
P-value	0.9884	0.9114	0.8411	0.7522	0.0117	0.0158
Regression	ns*	ns*	ns*	ns*	Cubic¹	ns*

Means followed by different letters differ from each other by the Tukey test 5% ($P < 0.05$); *not significant for linear, quadratic, and cubic regressions ($P > 0.05$).

Table 5 - Digestibility of feed (DFD%), crude protein (DCP%), and ether extract (DEE%) in male turkeys at 28 days of age submitted to different diets based on sorghum and corn.

TRAT	DFD (%)ns	DCP (%)ns	DEE (%)ns
A-100%C	73.84	58.85	93.12b
B-100%Sg	73.94	62.00	95.43a
C-100%Sw	73.84	62.75	92.23b
CV (%)	3.71	6.71	1.12
P-value	0.9974	0.3170	0.0012

[ns]not significant by analysis of variance ($P \geq 0.05$).

DISCUSSION

Studies on the use of sorghum in turkey diets are still scarce in the literature (LUIS et al., 1982; DOUGLAS et al., 1993; ETUK et al., 2012). The data from the present study showed that, in general, whole sorghum grains positively influenced the zootechnical performance of turkeys. Regarding muscle conformation, higher proportions of sorghum in the diet increased the weight and size of the small intestine (ID) of the animals.

The best results obtained in the present research with 50% Sg are corroborated by ETUK & UKAEJIOFO (2007). The composition of corn and sorghum in the early development stages of birds can influence the results (FAGUNDES et al., 2017). Replacing 50% of corn with low-tannin sorghum can be considered adequate for the diet of broilers. The use of sorghum only negatively affects the intestinal mucosa of birds due to the effect of tannins, which induce greater energy expenditure (epithelial loss) and affect the efficiency of broiler feeding (TORRES et al., 2013).

Table 6 - Calculated nutritional values of sorghum and corn-based diets for turkeys in the initial production phase (from 1 to 28 days) according to levels recommended by the strain guide.

Calculated nutritional composition	
Apparent metabolizable energy (Mcal/kg)	2.900
Crude protein (%)	28.00
Linoleic acid (%)	3.11
Calcium (%)	1.43
Available phosphorus (%)	0.72
Potassium (%)	0.96
Sodium (%)	0.17
Chlorine (%)	0.22
Digestible arginine (%)	1.72
Digestible phenylalanine (%)	1.29
Digestible Phenylalanine+Tyrosine (%)	2.18
Digestible lysine (%)	1.66
Digestible methionine (%)	0.72
Methionine + digestible cystine (%)	1.07
Digestible threonine (%)	0.96
Digestible tryptophan (%)	0.30
Digestible valine (%)	1.14

Table 7 - Bromatological composition in the dry matter (DM) of the carcass of turkeys slaughtered at 28 days of age, submitted to different sorghum-based diets instead of corn.

TRAT	DM (%)	EE DM (%)	CP DM (%)	MM DM (%)
A-100%C	28.76[a]	13.49b	74.16	11.67a
B-100%Sg	28.92[a]	15.71a	72.47	11.42a
C-100%Sw	27.66b	13.62b	73.68	10.10b
CV (%)	1.95	6.40	1.55	4.58
P-value	0.0059	0.0037	0.0904	0.0008

Means followed by different letters differ from each other by the Tukey test 5% ($P < 0.05$).

The results obtained at 28 days show an adaptive capacity of those birds to the gradual inclusion of ground sorghum grain in the diet until its total replacement by corn, or even the granulometry of the diet from the complete replacement of corn by whole sorghum. This result corroborated the hypothesis that ground or whole-grain sorghum can be used in the turkey starter diet without compromising its performance at 28 days.

It should be noted that this experiment was conducted in the most critical and difficult period of turkey farming, especially turkeys for meat production. In addition to the performance result, a very high survival rate (viability) stands out in this study. This result leads us to believe in the possibility of increasing the participation of grain sorghum in the diet of this industrial bird species.

The use of whole sorghum grains increased the size and weight of SI in the present study, highlighting its fundamental importance in animal nutrition since it is responsible for the process of digestion and absorption of nutrients contained in food. The consumption of whole grains can also encourage the muscle development of the gizzard of birds and;consequently, there will be greater development of the small intestine, resulting in greater nutrient absorption capacity (MACLEOD, 2013; SILVA et al., 2015). As observed by LITZ et al. (2020), the better gizzard performance of birds with whole sorghum grain meant that, even with a higher feed intake, they could reach the same live weight and the same feed conversions of the other treatments.

Diets in chickens over nine years of age with whole grain sorghum also had responses in increasing gizzard and small intestine (FERNANDES et al., 2013). The gizzard weight is considered an important observation of the response of the animal organism since this organ can present both hypo and hypertrophy depending on the nutrition to which the animals are submitted (NYACHOTI & ATKINSON, 1996). However, only the small intestine was affected by the different diets in the present study. This fact has already been reported with wheat particles of different sizes, which increased the relative weight and length of the broiler intestine (ENGBERG et al., 2002; YASAR, 2003).

The use of sorghum in turkey diets can be considered a good alternative to corn, contributing to gains in live weight, feed conversion, and carcass yield, as it promotes an increase in energy use. When used in the form of whole grain, under the conditions in which this experiment was conducted, it showed performance and yield values similar to corn feeds; however, when used in feeds, it generates savings by reducing transport and processing costs (BENNETT et al., 2002).

CONCLUSION

The use of whole sorghum grain showed the same results as ground sorghum and ground corn for zootechnical performance, carcass muscle mass, and viscera morphometry of turkeys at 28 days.

Thus, depending on availability and cost, sorghum is an adequate energy food alternative to replace corn in the turkey diet and contributes to reducing expenses related to the grain grinding process.

BIOETHICS AND BIOSECURITY COMMITTEE APPROVAL

The Ethics Committee on the Use of Animals (CEUA/UFA 082/12) evaluated the experiment.

ACKNOWLEDGEMENTS

The T.R.T. was partial funded by the following Brazilian Federal Agencies: "Coordenação de Aperfeiçoamento de Pessoal de Nível Superior" (CAPES), Brazil – Finance Code 001, and "Conselho Nacional de Desenvolvimento Científico e Tecnológico" (CNPq), Brazil.

DECLARATION OF CONFLICT OF INTEREST

We have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically revised the manuscript and approved the final version.

REFERENCES

BENNETT, C. D. et al. Feeding broiler chickens wheat and barley diets containing whole, ground and pelleted grain. **Poult. Science**, v.81, p.995-1003, 2002. Available from <https://doi.org/10.1093/ps/81.7.995>. Accessed: Feb. 06, 2021. doi: 10.1093/ps/81.7.995.

CÓRDOVA-NOBOA, H. A. et al. Performance, meat quality, and pectoral myopathies of broilers fed either corn or sorghum based diets supplemented with guanidinoacetic acid. **Poultry Science**, v.97, n.7, p.2479–2493, 2018. Available from: <https://doi.org/10.3382/ps/pey096>. Accessed: Jan. 15, 2021. doi: 10.3382/ps/pey096.

DOUGLAS, J. H. et al. Differential Age Response of Turkeys to Protein and Sorghum Tannin Levels. **Poultry Science**, v.72, n.10, p.1944–195, 1993. Available from: <https://doi.org/10.3382/ps.0721944>. Accessed: Jan. 15, 2021. doi: 10.3382/ps.0721944.

ENGBERG, R. M. et al. The influence of grinding and pelleting of feed on the microbial composition and activity in the digestive tract of broiler chickens. **British Poultry Science**, v.43, n.4, p.569-579, 2002. Available from: <https://doi.org/10.1080/00071660220000044 80>. Accessed: Apr. 10, 2014. doi: 10.1080/000716022000004480.

ETUK, E. B.; UKAEJIOFO, U. R. Tannin content and dietary effects of brown coat coloured sorghum on the performance of young local turkey. **Animal Production Research Advances**, v.3, n.2, p.86-90, 2007. Available from: <https://doi.org/10.4314/apra.v3i2.36372>. Accessed: Apr. 10, 2014. doi: 10.4314/apra.v3i2.36372.

ETUK, E. B. et al. Haematological and Serum Biochemical Parameters of Local Turkey Poults Fed Diets Containing Two Varieties of Sorghum. **Journal of World's Poultry Research**, v.2, n.4, p.81–89, 2012. Available from: <https://www.ajol.info//index.php/apra/article/view/36372>. Accessed: Jan. 21, 2021. doi: 10.4314/apra.v3i2.36372.

FAGUNDES, N. S. et al. Replacing corn with sorghum in the diet alters intestinal microbiota without altering chicken performance. **Journal of Animal Physiology and Animal Nutrition**, v.101, n.5, p.e371–e382, 2017. Available from: <https://doi.org/10.1111/jpn.12614>. Accessed: Jan. 21, 2021. doi: 10.1111/jpn.12614.

FERNANDES, E. A. et al. The use of whole grain sorghum in broiler feeds. **Revista Brasileira de Ciência Avícola**, v.15, n.3, p.217-222, 2013. Available from: <https://doi.org/10.1590/S1516-635X2013000300008>. Accessed: May 17, 2014. doi: 10.1590/S1516-635X2013000300008.

LUIS, E. S. et al. Nutritional value of Proso Millets, sorghum grains, and corn in turkey starter diets. **Poultry Science**, v.61, n.2, p.321–326, 1982. Available from: <http://dx.doi.org/10.3382/ps.0610321>. Accessed: Jan. 3, 2021. doi: 10.3382/ps.0610321.

LITZ, F. H. et al. Zootechnical parameters and gizzard development of broilers in sorghum grain diets and the inclusion of carotenoids. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v.72, n.2, p.607-614, 2020. Available from: <http://dx.doi.org/10.1590/1678-4162-11483>. Accessed: Apr. 23, 2020. doi: 10.1590/1678-4162-11483.

LOTT, B. D. et al. The effect of temperature, dietary energy level, and corn particle size on broiler performance. **Poultry Science**, v.71, n.4, p.618-624, 1992. Available from: <https://doi.org/10.3382/ps.0710618>. Accessed: Feb. 23, 2014. doi: 10.3382/ps.0710618.

MACLEOD, M. Nutrition-related opportunities and challenges of alternative poultry production systems. **Lohmann Information**, v.48, n.2, p.23-28, 2013. Available from: <https://www.lohmann-information.com/content/l_i_48_2013_10.pdf>. Accessed: May 13, 2014.

NYACHOTI, C. M.; ATKINSON, J. L. The effect of feeding high-tanning sorghum on digestive organ response and overall performance of broiler chicks. **Poult. Sci.**, v.74, Suppl.1., p.125, 1996. Available from: <https://doi.org/ 10.1093/japr/5.3.239>. Accessed: May 24, 2014. doi: 10.1093/japr/5.3.239.

REECE, F. N. et al. The effects of hammer mill screen size on ground corn particle size, pellet durability, and broiler performance. **Poultry Science**, v.65, n.7, p.1257-1261, 1986. Available from: <https://doi.org/10.3382/ps.0651257>. Accessed: May 24, 2014. doi: 10.3382/ps.0651257.

ROCHA, V. R. R. A. et al. Total replacement of corn by sorghum and poultry slaughterhouse oil in diets for broilers.**Revista Brasileira de Zootecnia**, v.37, n.1, p.95-102, 2008. Available from: <https://doi.org/10.1590/S1516-35982008000100014>. Accessed: May 24, 2014. doi: 10.1590/S1516-35982008000100014.

SALEH, A. A. et al. The effects of replacing corn with low-tannin sorghum in broiler's diet on growth performance, nutrient digestibilities, lipid peroxidation and gene expressions related to growth and antioxidative properties. **Journal of Applied Animal Research**, v.47, n.1, p.532–539, 2019. Available from: <https://doi.org/10.1080/09712119.2019.1680377>. Accessed: Jan. 15, 2021. doi: 10.1080/09712119.2019.1680377.

SILVA, M.C.A. et al. Effects of sorghum on broilers gastrointestinal tract. **Brazilian Journal of Poultri Science**, v.17, p.95-102, 2015. Available from: <http://dx.doi.org/10.1590/1516-635x170195-102>. Accessed: Feb. 06, 2021. doi: 10.1590/1516-635x170195-102.

TORRES, K. A. A. et al. Effects of corn replacement by sorghum in broiler diets on performance and intestinal mucosa integrity. **Poultry Science**, v.92, n.6, p.1564–1571, 2013. Available from: <https://doi.org/10.3382/ps.2012-02422>. Accessed: Jan. 15, 2021. doi: 10.3382/ps.2012-02422.

YASAR, S. Performance, gut size and ileal digesta viscosity of broiler chickens fed with a whole wheat added diet and the diets with different wheat particle sizes**. International Journal of Poultry Science**, v.2, n.1, p.75-82, 2003. Accessed: <http://docsdrive.com/pdfs/ansinet/ijps/2003/75-82.pdf>. Accessed: Apr. 12, 2014. doi: 10.3923/ijps.2003.75.82.