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Effects of Sorghum on Broilers Gastrointestinal Tract

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ABSTRACT

This study aimed at evaluating the effects of whole and ground sorghum, compared with ground corn, on the live weight, feed conversion ratio, organs weight and intestinal biometrics and histomorphometrics. In total, 960 Hubbard Flex broilers were reared until 42-day-old and distributed into 24 pens, according to the three treatments: ground corn, whole-grain sorghum, and ground sorghum. On day 42, five male birds per treatment were selected by similar body weight and sacrificed. Gizzard absolute weight, and proventriculus, liver, pancreas and heart relative weights, and duodenum, jejunum, ileum, ceca, and colon length and relative weight were determined. Villus characteristics and intestinal mucosa absorption surface area were evaluated. Broilers fed sorghum, independently of physical form, were heavier and had greater feed conversion ratio than those fed ground corn. Gizzard showed the highest relative weight in broilers fed whole sorghum compared to corn. Liver and jejunum relative weight was higher in broilers fed ground corn, compared to ground sorghum. Whole small intestine, cecum and colon relative lengths showed no difference among treatments. Deeper crypts were found in the duodenum of broilers fed whole grain sorghum, compared to ground sorghum, as well as in jejunum compared to ground corn; however, intestinal absorption surface area was not different among treatments. Whole or ground grain sorghum may replace corn in the feed of 1- to 42-d-old broilers, since they improve body weight and feed conversion ratio, and not adversely affect intestinal morphometry and organs weight.

INTRODUCTION

The digestive tract of broilers is still not fully developed immediately after hatching, but it quickly matures, considering the short life span of these birds (Uni *et al.*, 1998). Understanding broiler digestive morphology and function is essential to obtain maximum feed efficiency and weight gain.

According to Maiorka *et al.* (2002), small intestine of birds is the main site of nutrients digestion and absorption. An important component in these segments is the intestinal villi, which increase the contact surface with the food, enabling greater absorption of nutrients. The physical-chemical characteristics of feedstuffs influence the anatomy and the histology of digestive organs, and consequently, the process of nutrient absorption. Therefore, the integrity of the intestinal tissue structure is an indication of the functional and nutritional quality of feedstuffs.

The use of sorghum (Sorghum bicolor (L.) Moench), to replace corn in feeds is economically attractive due to the recent increases in corn prices (Garcia *et al.*, 2013). The culture of sorghum has a high potential for grain production per unit area and can be produced in hot dry environment (Carolino *et al.*, 2014). Garcia *et al.* (2005) evaluated the performance and meat quality of broilers, and found no negative effect of corn replacing for sorghum, as well as Morais *et al.* (2002), Pimentel *et al.* (2007) and Rocha *et al.* (2008), who observed that the use of sorghum as an alternative to corn proved advantageous in broilers diets.

In poultry, cereal grains are generally ground prior to incorporation into feed. However, the use whole grain has increased in order to reduce feed costs caused by transport and processing. This mode of feeding has also been shown to improve performance, wich may be due to modifications of the digestive tract of poultry (Gabriel *et al.,* 2008).

Therefore, the objective of the present study was to evaluate the effect of the dietary inclusion of tannin-free whole or ground sorghum, as compared to corn, on the live weight, feed conservion ratio, organs weight and intestinal biometrics and histomorphometrics of 42-day-old broilers.

MATERIALS AND METHODS

Broilers were reared at Glória experimental farm of the Federal University of Uberlândia (UFU), located in Uberlândia, state of Minas Gerais, Brazil. The study was carried out during the second half of 2011, and was approved by the Committee of Ethics on Animal Use of that university under protocol number 077/11.

In total, 960 one-day-old Hubbard Flex broilers were distributed in 24 pens, according to the three treatments. Each pen housed 40 sexed broilers, with 20 males and 20 females, totaling eight pens replicates per treatment.

A four-phase feeding program was applied: 1 to 8 d-old a pre-starter diet (300g/bird), 9 to 21 a starter diet (900g/bird), 22 to 35 a grower diet (2200g/bird), and 36 to 42 a finisher diet (1000g/bird). Feeds were based on soybean meal and tannin-free sorghum or corn, and were formulated according to the nutritional and energy levels recommended by Rostagno *et al.* (2005).

The concentration of tannin in grain sorghum used in this study was 42,7mg/kg of sorghum, equivalent to 0.00427% (CBAA method for HPLC with UV detector). This value is so low that classification is tannin-free sorghum. During the experiment the feed average particle size of whole-grain sorghum was 1,815mm, ground corn 0,79mm and ground sorghum 0,82mm. Feeds were chemically analyzed at the Animal Nutrition Laboratory of the School of Veterinary Medicine (LAMRA) of UFU and the results are shown in Tables 1 and 2. Diets supplied in each phase were formulated to contain equal energy and nutrient levels.

Table 1 – Ingredients and calculated nutritional composition of the diets based on sorghum fed broilers during the pre-starter (1 to 7 days), starter (8 to 21 days), grower (21 to 35 days), and finisher (35 to 42 days) phases.

	Quantity (kg)			
Ingredients	pre-starter	Starter	Grower	Finisher
Sorghum – 8.6% CP	54.330	56.630	58.914	61.657
Soybean meal - 46.5% CP	37.217	34.394	31.298	28.557
Soybean oil	4.119	5.112	6.232	6.400
Dicalcium phosphate	1.947	1.582	1.342	1.312
Limestone	0.772	0.823	0.785	0.810
Salt	0.461	0.440	0.420	0.443
L-Lysine HCL	0.323	0.275	0.263	0.253
DL-Methionine	0.210	0.158	0.172	0.206
L-Threonine	0.121	0.088	0.074	0.061
Vitamin and mineral supplement	0.500[1]	0.500[1]	0.500[2]	0.300[3]
TOTAL	100	100	100	100
Calculated nutritional composition				
Crude protein	22.500	21.283	20.027	19.066
Calcium	0.920	0.841	0.758	0.663
Available phosphorus	0.470	0.401	0.354	0.309
Potassium	0.858	0.814	0.764	0.726
Sodium	0.220	0.210	0.200	0.195
Chlorine	0.284	0.271	0.259	0.253
Linoleic acid	3.117	3.659	4.268	4.378
Digestible lysine	1.324	1.217	1.131	1.060
Digestible methionine	0.672	0.607	0.571	0.529
Digestible methionine + cystine	0.953	0.876	0.906	0.774
Digestible threonine	0.861	0.791	0.735	0.689
Digestible tryptophan	0.256	0.242	0.226	0.213
Digestible arginine	1.400	1.315	1.221	1.145
Apparent metabolizable energy	2.9600	3.0500	3.1500	3.2000

[1] Broiler starter premix: Folic acid 140,000 mg/kg, pantothenic acid 1600 mg/kg, Zn bacitracin 11,000 g/kg, biotin 12,000 mg/kg, Cu 1260,000 mg/kg, choline 70 g/kg, Fe 10.5 g/kg, I 252 mg/kg, Mn12.6 g/kg, Met 336.600 g/kg, sodium monensin (exact) 22 g/kg, niacin 6000 mg/kg, selenium 80 mg/kg, VitA 1.600,000 IU/kg, VitB1 600,000 mg/kg, VitB12 2,000 mcg/kg, VitB2 800 mg/kg, VitB6 400,000 mg/kg, VitD3 400,000 IU/kg, VitE 3,000 mg/kg, VitK 400 mg/kg, Zn 12.600 g/kg.

[2] Broiler grower premix: Folic acid 100,000 mg/kg, pantothenic acid 1600 mg/kg, biotin 6,000 mg/kg, Cu 1200,0000 mg/kg, choline 50 g/kg, Fe 10.0 g/kg, Halquinol exact 6000 mg/kg, I 240 mg/kg, Mn12.0 g/kg, Met 267.300 g/kg, niacin 4800 mg/kg, salinomycin exact 13.200 g/kg, selenium 60 mg/kg, VitA 1.280,000 IU/kg, VitB1 400,000 mg/kg, VitB12 1.600 mcg/kg, VitB2 720 mg/kg, VitB6 320,000 mg/kg, VitD3 350,000 IU/kg, VitE 2,400 mg/kg, VitK 300 mg/kg, Zn 12,000 g/kg.

[3] Broiler finisher premix: Folic acid 100,000 mg/kg, pantothenic acid 1333 mg/kg, biotin 6,670 mg/kg, Cu 2000,000 mg/kg, choline 50 g/kg, Fe 16.60 g/kg, I 400 mg/kg, Mn 20.0 g/kg, Met 230,000 g/kg, niacin 4000 mg/kg, virginiamycin exact 3,666 mg/kg, selenium 60,680 mg/kg, VitA 1,300,260 IU/kg, VitB1 166,000 mg/kg, VitB12 1.667 mcg/kg, VitB2 666.800 mg/kg, VitB6 200,000 mg/kg, VitD3 400,000 IU/kg, VitE 2,167.10 mg/kg, VitK 333.400 mg/kg, Zn 20,000 g/kg.

Table 2 – Ingredients and calculated nutritional composition of the diets based on corn fed to broilers during the pre-starter (1 to 7 days), starter (8 to 21 days), grower (21 to 35 days), and finisher (35 to 42 days) phases.

	Quantity (kg)			
Ingredients	pre-starter	Starter	Grower	Finisher
Corn grain – 8% CP	56.423	58.740	61.598	64.959
Soybean meal - 46.5% CP	37.334	34.579	31.062	28.195
Soybean oil	2.002	2.918	3.864	3.869
Dicalcium phosphate	1.841	1.471	1.228	0.986
Limestone	0.830	0.883	0.850	0.779
Salt	0.447	0.425	0.404	0.394
L-Lysine HCL	0.308	0.258	0.259	0.256
DL-Methionine	0.191	0.137	0.153	0.189
L-Threonine	0.124	0.089	0.082	0.073
Vitamin and mineral supplement	0.500[1]	0.500[1]	0.500[2]	0.300[3]
Total	100	100	100	100
Calculated nutritional composition				
Crude protein	22.400	21.200	19.800	18.749
Calcium	0.920	0.841	0.760	0.663
Available phosphorus	0.470	0.401	0.354	0.309
Potassium	0.856	0.812	0.756	0.714
Sodium	0.220	0.210	0.200	0.195
Chlorine	0.318	0.301	0.290	0.287
Linoleic acid	1.776	2.268	2.776	2.784
Digestible lysine	1.324	1.217	1.131	1.060
Digestible methionine	0.660	0.595	0.559	0.517
Digestible methionine + cystine	0.953	0.876	0.826	0.774
Digestible threonine	0.861	0.791	0.735	0.689
Digestible tryptophan	0.243	0.228	0.209	0.194
Digestible arginine	1.416	1.333	1.228	1.145
Apparent metabolizable energy	2.9600	3.0500	3.1500	3.200

[1] Broiler premix - starter: Folic acid 140,000 mg/kg, pantothenic acid 1600 mg/kg, Zn bacitracin 11,000 g/kg, biotin 12,000 mg/kg, Cu 1260,0000 mg/kg, choline 70 g/kg, Fe 10.5 g/kg, I 252 mg/kg, Mn12.6 g/kg, Met 336.600 g/kg, sodium monensin (exact) 22 g/kg, niacin 6000 mg/kg, selenium 80 mg/kg, VitA 1.600,000 IU/kg, VitB1 600,000 mg/kg, VitB12 2,000 mcg/kg, VitB2 800 mg/kg, VitB6 400,000 mg/kg, VitD3 400,000 IU/kg, VitE 3,000 mg/kg, VitK 400 mg/kg, Zn 12.600 g/kg.

[2] Broiler grower premix: Folic acid 100,000 mg/kg, pantothenic acid 1600 mg/kg, biotin 6,000 mg/kg, Cu 1200,0000 mg/kg, choline 50 g/kg, Fe 10.0 g/kg, Halquinol exact 6000 mg/kg, I 240 mg/kg, Mn12.0 g/kg, Met 267.300 g/kg, niacin 4800 mg/kg, salinomycin exact 13.200 g/kg, selenium 60 mg/kg, VitA 1.280,000 IU/kg, VitB1 400,000 mg/kg, VitB12 1.600 mcg/kg, VitB2 720 mg/kg, VitB6 320,000 mg/kg, VitD3 350,000 IU/kg, VitE 2,400 mg/kg, VitK 300 mg/kg, Zn 12,000 g/kg.

[3] Broiler finisher premix: Folic acid 100,000 mg/kg, pantothenic acid 1333 mg/kg, biotin 6,670 mg/kg, Cu 2000,000 mg/kg, choline 50 g/kg, Fe 16.60 g/kg, I 400 mg/kg, Mn 20.0 g/kg, Met 230,000 g/kg, niacin 4000 mg/kg, virginiamycin exact 3,666 mg/kg, selenium60,680 mg/kg, VitA 1,300,260 IU/kg, VitB1 166,000 mg/kg, VitB12 1.667 mcg/kg, VitB2 666.800 mg/kg, VitB6 200,000 mg/kg, VitD3 400,000 IU/kg, VitE 2,167.10 mg/kg, VitK 333.400 mg/kg, Zn 20,000 g/kg.

The treatments consisted of ground corn, whole-grain sorghum and ground sorghum since pre-starter diet. The lighting program adopted during the experiment changed with bird age: 1 to 7 d-old 22 hours of light, 8 to 21 d-old 20 hours and 22 to 42 d-old 23 hours.

To evaluate the gastrointestinal tract, on day 41 birds were weighed, and the males which body weight similar (± 5%) to the average body weight in the same treatment were selected. On day 42, the 15 males selected on the previous day (five per treatment) were fasted for 12 hours, and weighed again at the time of sacrifice in a digital scale (Balmak brand, Brazil line M) with 5-g precision. Birds were then sacrificed by neck dislocation.

After sacrifice, organs and the entire gastrointestinal tube were collected. proventriculus, gizzard, pancreas, liver, heart, and intestines were immediately and individually weighed in a semi-analytical scale (Marte brand, number BL3200H) with 0.01-g precision. Intact small intestine length, i.e., from the beginning of the duodenum to the ileal-cecal junction, was measured using a 0.1-cm scale measuring tape. Tissue samples for morphological measurements were taken from the duodenum (5 cm from the pylorus), jejunum (5 cm posterior to the yolk stalk), and ileum (2 cm anterior to the ileo-cecal valve), as described by Zang *et al.* (2009). The cecum and colon was also collected based on ileo-cecal valve and cloaca.

Fragments measuring approximately 3cm long were collected from the middle portion of the duodenum, jejunum, and ileum per bird. Each fragment was placed in a duly identified flask (50 mL) with a screw cap, containing 10% formaldehyde water solution for fixation. After 72 hours, the flasks were submitted to the Histology Laboratory of UFU, where the material was processed.

Three 0.5cm semi-serial rings were collected from each fragment and placed in a single histological cassette, duly identified and placed in a solution of 70% ethylic alcohol in distilled water. Samples were processed in an automated histology equipment (LUPE TEC, model PT 05), dehydrated in graded series of alcohol, cleared in xylol, and embedded in paraffin.

Serial 5.0-µm thick sections were obtained using a manual microtome, and placed on slides. Tissue sections were then stained, using the routine Harris hematoxylin and eosin procedure (H.E.), and mounted using Entellan® resin and 24 × 60 cover slips (Junqueira & Carneiro, 1982).

The following parameters were evaluated at 42-d-old: live weight; feed conversion ratio; gizzard absolute weight; proventriculus; liver, pancreas, and heart relative weight; intact small intestine, cecum and colon relative lengths; and villus height and width, distance between villus bases, crypt depth, and absorption surface area of the duodenum, jejunum and ileum

The measured parameters were expressed as: grams for live weight and gizzard weight; grams per 100 grams of live weight (g/100g) for organ relative weight, except gizzard; and centimeters per 100 grams of live weight (cm/100g) for relative length of the intestinal segments. Organs relative weights were calculated based on organ weight multiplied by 100 and divided by the live weight. Intestines relative lengths were calculated based on intestine length multiplied by 100 and divided by the live weight.

Thirty measures were randomly taken per treatment: villus height and width; distance between villi; crypt depth. The villus height was measured from the tip of the villus to the villus-crypt junction. The villus width was defined as the distance from the outside epithelial edge to the outside of the opposite epithelial edge along a line passing through the vertical midpoint of the villus. The crypt depth was defined as the depth of the invagination between adjacent villi (Wang & Peng, 2008). The distance between villi was measured at the base, taken from the central distance between two villi. Absorption surface area was determined as the times the intestinal mucosa increases, according to the calculations proposed by Kisielinski *et al.* (2002).

Duodenum, jejunum, and ileum section images were captured at 2x magnitude in a light microscope (Olympus Triocular BH2) coupled to a camera (JVC TK-1085U) linked to a computer by a frame grabber (Data Translation 3153). Villus length was measured using the software program HL Image 97 (Western Vision Softwares).

The obtained data were submitted to Shapiro-Wilk normality test and to analysis of variance. Means were compared by the test of Tukey at 5% significance level, using the GLM procedure of SAS statistical package, version 9.2 (Statistical Analysis System, 2008).

RESULTS AND DISCUSSION

Live weight and feed conversion ratio, of 42-d-old broilers fed diets based on whole-grain sorghum or ground sorghum, had better results compared to ground corn (Table 3), proving that regardless of the physical form, sorghum showed better performance results than corn. This results was more interesting than Fernandes *et al.* (2013) that found no difference in the performance characteristics of 42-d-old broilers, by replacing corn by ground or whole sorghum in similar design, as well as Fernandes *et al.* (2008) compared ground corn, broken corn, ground sorghum and whole-grain sorghum (50:50) or Murta *et al.* (2004) with diets based on corn and sorghum with different particle sizes (1.20mm, 4.763mm, 6.350mm, or 9.525mm) or Gualtieri & Rapaccini (1990), where corn was replaced by sorghum (0, 50, and 100%) them did not verify any performance differences in male or female broilers.

Table 3 – Live weight and feed conversion ratio (FCR) of 42-d-old broilers fed diets based on ground corn, whole-grain sorghum or ground sorghum.

Treatments	Live weight (g)	FCR
Ground corn	2206 b	1,695a
Whole-grain sorghum	2309 a	1,652b
Ground sorghum	2323 a	1,646b
CV (%)	2.55	1.87
P value	0.0011	0.0093

Means followed by different letters in the same column are different by the test of Tukey at 5% significance level ($p<0.05$)

Gizzard absolute weight was higher ($p<0.05$) when broilers were fed whole-grain sorghum and lower when fed ground corn, whereas ground sorghum was not different from the other treatments (Table 4). These results are consistent with the hypothesis that coarse feedstuffs promote muscle hypertrophy in the gizzard because of the effort to reduce particle size. Results of Ribeiro *et al.* (2002) corroborate this work to assess the size of food particles in chickens, and it was observed that the gizzard weight also increased when the diet contained large particles, suggesting that gizzard size is related to the development of the longitudinal smooth muscles due to the mechanical work needed to grind the feed. It must be noted that the greater the particle size, the longer the feedstuff needs to remain in the gizzard in order to be reduced (Turk, 1982). This would allow better exposure of the digesta to hydrochloric acid and digestive enzymes, thereby improving feed digestibility, which may explain the higher live weight of the birds fed grain sorghum in the present experiment.

Liver relative weight was higher ($p<0.05$) when 42-d-olf broilers were fed ground corn and lower ($p<0.05$) when ground sorghum was offered, while the whole-grain sorghum treatment was not different from the others (Table 4), suggesting a tendency to equal response of the tested diets . This result was confirmed by Garcia *et al.* (2005), in broilers evaluated at 14, 21, 28, 35, and 42 days of age, did not find any

Table 4 – Absolute gizzard weight, proventriculus, liver, pancreas, and heart relative weights of 42-d-old broilers fed diets based on ground corn, whole-grain sorghum or ground sorghum.

Treatments	Gizzard (g)	Proventriculus (g/100g)	Liver (g/100g)	Pancreas (g/100g)	Heart (g/100g)
Ground corn	36.770 b	0.357	3.020 a	0.231	0.5205
Whole-grain sorghum	47.064 a	0.325	2.650 ab	0.213	0.6114
Ground sorghum	39.504 ab	0.328	2.348 b	0.193	0.5446
CV (%)	12.52	8.34	16.38	13.45	16.18
p value	0.0217	0.0659	0.0202	0.0589	0.2067

Means followed by different letters in the same column are different by the test of Tukey at 5% significance level (p<0.05)

differences in proventriculus, pancreas, or liver relative weights when corn and high- or low-tannin sorghum were fed.

There was no difference (p>0.05) among treatments relative to duodenum, ileum, cecum, or colon relative weights, of 42-d-old broilers (Table 5). However, jejunum relative weight was higher (p>0.05) when broilers were fed ground corn compared with ground sorghum, which was not different from the whole-grain sorghum treatment, possibly a tendency to equal response of the tested diets. Although the jejunum is where most of the digestion and intestinal absorption occur (Vieira, 2002), in spite of the higher value of jejunum relative weight in broilers fed ground corn compared to ground sorghum, there was not a greater live weight and feed conversion ratio.

Table 5 – Duodenum, jejunum, ileum, cecum, and colon relative weights of 42-d-old male broilers fed diets based on ground corn, whole-grain sorghum or ground sorghum.

Treatments	Duodenum (g/100g)	Jejunum (g/100g)	Ileum (g/100g)	Cecum (g/100g)	Colon (g/100g)
Ground corn	0.739	1.599 a	1.280	0.490	0.159
Whole-grain sorghum	0.696	1.461 ab	1.186	0.493	0.177
Ground sorghum	0.715	1.235 b	0.990	0.490	0.132
CV (%)	16.67	18.24	24.88	5.47	25.99
p value	0.8129	0.0441	0.2131	0.9729	0.1625

Means followed by different letters in the same column are different by the test of Tukey at 5% significance level (p<0.05)

The results obtained for the three segments of the small intestine are different from those of Fernandes *et al.* (2008), who found an increase in small intestine relative weight in 42-d-old broilers fed 50 or 100% sorghum in replacement of corn. Those authors did not observe any influence of feed physical form on cecum weight. Although Dahlke *et al.* (2003) and Nir *et al.* (1995) demonstrated that dietary particle size affects intestinal weight and size, Garcia *et al.* (2005), did not observe any effect of the substitution of corn by sorghum on intestinal relative weight, which is consistent with the findings of the present study.

There was no effect of treatment (p>0.05) on entire small intestine, cecum, or colon relative lengths (Table 6). These results are consistent with those reported by Fernandes *et al.* (2008), who compared diets based on ground corn, ground sorghum, ground and whole-grain sorghum (50:50), or whole-grain sorghum for broilers, and did not find any differences in small intestine length. Garcia *et al.* (2005) also found no influence of diets based on corn or low- and high-tannin sorghum on small intestine or cecum length of broilers.

Table 6 – Whole small intestine, cecum and colon relative lengths of 42-d-old male broilers fed diets based on ground corn, whole-grain sorghum or ground sorghum.

Treatments	Small intestine (cm/100g)	Cecum (cm/100g)	Colon (cm/100g)
Ground corn	6.208	1.387	0.286
Whole-grain sorghum	5.863	1.286	0.255
Ground sorghum	5.596	1.239	0.256
CV (%)	11.99	11.69	18.03
p value	0.3380	0.2385	0.5353

Test of Tukey at 5% significance level (p<0.05)

There was no effect of treatment (p>0.05) on villus height and width, villus distance and absorption surface area in the small intestines, of 42-d-old broilers (Table 7). However, broilers fed ground sorghum presented shallower duodenum crypts compared with those fed whole-grain sorghum. The treatment with ground corn was not different from the others. This result may suggest that the duodenum mucosa of birds fed whole-grain sorghum suffered more damage than in the other treatments, because crypt depth increases according to epithelium turnover needs (Macari, 1995; Boleli *et al.*, 2002). Despite the energy losses with cell turnover, this response may be beneficial to the intestine, as shown by the higher live weight of the broilers at 42 days of age. Deeper crypts, suggesting higher cell proliferation in the intestinal epithelium, is a response of the body in an attempt to maintain villus characteristics, that is, to maintain absorption surface area (Uni *et al.*, 1998; Uni *et al.*, 2000).

Broilers fed ground corn presented the shallowest crypts in jejunum ($p<0.05$) compared to those fed whole-grain sorghum. This may be explained by the fact that whole-grain sorghum may have been more aggressive to the epithelium, leading to higher cell proliferation in the crypts, which, therefore, were deeper (Macari, 1995; Boleli *et al.*, 2002). However, absorption surface area in the jejunum was not different among treatments ($p>0.05$), indicating that the tested feedstuffs, in particular free-tannin sorghum, did not interfere in the absorption mechanisms at this intestinal segment as observed in the duodenum.

There was no effect of treatment ($p>0.05$) on morphometric characteristics of the ileum. These results suggest that, independently of treatment, the digesta arriving at the ileum had already been submitted to maximum enzyme activity and maximum absorption in the previous intestinal segments. Due its stable pH and lower availability of nutrients for absorption, digesta is less aggressive towards the intestinal mucosa, and therefore, it does not influence the structure of the epithelium, and consequently, absorption surface area.

When evaluating the effect of corn replacement by low-tannin sorghum in the diet of one- to 42-d-old broilers, similar to this study, Campos (2006) did not observe any influence on villus height in any of the intestinal segments; however, villus height continuously increased with bird age.

Consistent with the results of the present study, Uni *et al.* (1998), Oliveira *et al.* (2000), and Geyra *et al.* (2001) reported that the duodenum and the jejunum present high cell proliferation and migration rates, as well as high villi and deep crypts, because they are submitted to stronger aggression and stimuli. Ribeiro *et al.* (2002) did not find any effects of increasing corn particle size on duodenal morphology (villus number and height) in 21- to 42-d-old male broilers, but that villus number and height increased with age.

CONCLUSIONS

Whole or ground grain sorghum may replace corn in the feed of 1- to 42-d-old broilers, since they improve body weight and feed conversion ratio, and not adversely affect intestinal morphometry and organs weight.

Table 7 – Villus height and width, distance between villus bases, crypt depth, and absorption surface area of the duodenum, jejunum and ileum of 42-d-old male broilers fed diets based on ground corn, whole-grain sorghum or ground sorghum.

Treatments	Height (µm)	Width (µm)	Distance (µm)	Crypt (µm)	Absorption surface area
			Duodenum		
Ground corn	1736.648	204.110	134.594	274.823 ab	12.986
Whole-grain sorghum	1596.992	218.259	117.297	332.305 a	12.896
Ground sorghum	1821.906	217.068	133.633	263.152 b	13.727
CV (%)	14.73	11.01	25.59	12.97	24.05
p value	0.3947	0.6331	0.6559	0.0288	0.9027
			Jejunum		
Ground corn	1318.410	148.818	82.231	239.261 b	15.263
Whole-grain sorghum	1618.780	166.941	94.705	315.722 a	16.482
Ground sorghum	1505.330	169.524	86.758	263.323 ab	16.173
CV (%)	18.08	20.35	22.26	15.21	9.37
p value	0.1500	0.5709	0.6070	0.0361*	0.4338
			Ileum		
Ground corn	993.308	181.132	83.054	199.394	10.946
Whole-grain sorghum	1157.130	182.774	77.277	233.119	12.460
Ground sorghum	1131.632	180.078	83.427	231.519	11.328
CV (%)	18.25	9.66	8.03	11.57	19.29
p value	0.4052	0.9704	0.3406	0.1033	0.5539

Test of Tukey at 5% significance level ($p<0.05$)

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