THE INFLUENCE OF VARYING INCLUSION LEVELS OF WHOLE GRAIN SORGHUM ON PERFORMANCE AND GUT MORPHOLOGY OF INDIGENOUS BOSCHVELD CHICKENS

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Abstract. Maize has long been the preferred ingredient in animal feeds due to its high yield, energy content, and positive impact on animal production. However, its use as the main source of energy in poultry is subjected to competition. This study aimed to explore the influence of incorporating whole grain sorghum on the performance and gut histomorphology of Boschveld chickens. The total of 112-day-old Boschveld chickens were distributed into four groups, each consisting of 28 birds per treatment., for the duration of 90 days. The sorghum concentrations were at 0% (control), 25%, 50% and 75% inclusion. The data were subjected to GLM and Duncan's multiple range test to separate the means. BWG was significantly higher ($p<0.05$) in chickens fed WGS diet. FI showed both linear ($p=0.000$) and quadratic ($p=0.0181$) effects from 1-42 days period. Chickens on the 75% WGS diet exhibited significantly better FCR ($p<0.05$) compared to control. Measurements of organs (weight, length, pH) indicated significant treatment effects ($p<0.05$). However, chickens fed a diet comprising 75% WGS had significantly higher ($p<0.05$) gizzard weight compared to concentration with 0%, 25% and 50%. Incorporating varying amounts of WGS in the diet did not adversely affect the performance. Therefore, it is concluded that up to 75% WGS can be included in chicken feeds without a negative consequence.
Keywords: *inclusion, effect, poultry, breed, cereal*

Introduction

A perfect balance in nutrients and high cost of feed has been a challenge in animal production. Around 70% of the costs of producing chicken is related to feeding expenditures (Willems et al., 2013). Maize stands out as the preferred energy grain in chicken feed formulations, primarily attributed to its high energy content, low fiber content, essential fatty acids, and minimal pigments. Serving as a crucial element in poultry diets, maize contributes significantly, providing approximately 60 to 70 percent of the necessary nutrients and fulfilling the protein requirements for chickens (Prakash, 2013). To mitigate feed cost concerns, the concept of whole grain feeding was conceived, facilitating the utilization of alternative grains as animal feed. This method has demonstrated benefits, resulting in a decrease in the handling and processing costs associated with feed by eliminating milling steps (Bennett et al., 2002; Singh et al., 2014). Consideration of whole feeding techniques aims to improve intestinal integrity and is based on the assumption that

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they benefit animal health (Truong et al., 2017). Increasing concern over the high cost of conventional feed has driven the exploration of alternative grains for animal nutrition, with sorghum emerging as a viable option in response to this challenge.

The sorghum variety is regarded as a great source of nutrients and has a wide range of phenolic compounds (Nemukondeni et al., 2022). Sorghum's nutrient profile is similar to that of maize. The amount of protein (21.09%) in sorghum is higher than that of maize but the quality of the protein is lower (Fagundes et al., 2019; Farahat et al., 2021). Proteins are essential, physiologically active substances that aid in the creation of bodily tissue and promote the renewal and development of the body (Beski et al., 2015). Whole-grain feeding has been linked to heavier and more functional gizzards (Liu et al., 2015). More recently, the whole-grain feeding system has been studied, revealing that whole sorghum grains can constitute up to 50% of the chicken diet without affecting performance when offered from hatch (Mabelebele et al., 2020). While maize traditionally serves as the primary energy source in poultry diets, sorghum can be leveraged as a potential alternative, particularly in instances of maize scarcity or price escalation due to climate change or armyworm infestations impacting maize crop yields (Tuleun et al., 2013).

Boschveld chickens scavenge for insects, wild seeds, maggots, and ticks around the cowshed, providing biological pest control (Brazier, 2020). Consequently, the utilization of whole grain sorghum can potentially reduce scavenging. One particular advantage is that local farmers can cultivate the grains for animal feeding, capitalizing on the environment conducive to sorghum crop growth. The use of whole grain sorghum has an influence on the performance and gut histo-morphology of Boschveld chickens. Therefore, feeding birds whole grain sorghum directly benefits their performance. The aim of the study was to determine the influence of varying inclusion levels of whole grain sorghum on the performance and gut morphology of Indigenous Boschveld chickens.

Materials and methods

The study was conducted at Dreamland AH, located at Plot No. 60, Sebokeng Municipality, Evaton Road, Gauteng Province, Republic of South Africa, with precise geographic coordinates of 26.6071 S, 27.8473 E. Sebokeng experiences an average annual temperature of 25°C, with winter temperatures around 15°C, and an average annual rainfall of 729 mm. Ethical approval for the research was obtained from the University of South Africa, with reference number 2020/CAES AREC/111. The study adhered to all protocols and guidelines for the ethical use of research animals in South Africa.

To maintain hygiene, the poultry house was thoroughly cleaned and disinfected with paraformaldehyde prior to the arrival of birds. Wood-shaved sawdust served as bedding for chickens. All equipment, including feeders and drinkers, were cleaned with disinfectants. Drinkers were washed and cleaned daily in the mornings, while feeders were cleaned weekly. The chickens had continuous access (*ad libitum*) to feed and water. Vaccination against Gumboro and Newcastle diseases was performed at two weeks and three weeks of age, administered via drinking water. Biosecurity measures included a footbath with disinfectants installed. Chicks were closely monitored at 4-hour intervals up to 21 days of age.

A total of 112 Indigenous Boschveld chicks, each averaging 40.11 ± 0.428 g/bird, were procured from a local hatchery. These chicks were randomly assigned to four groups based on whole grain sorghum (WGS) inclusion levels, utilizing a completely randomized design. Each group comprised four replicates with 28 birds in each treatment. The WGS

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inclusion levels were set at 0% (Control), 25%, 50%, and 75%. Throughout the 1–90-day experiment, performance metrics such as Body Weight Gain (BWG), Feed Intake (FI), and Feed Conversion Ratio (FCR) were accuretely measured on a weekly basis. The BWG of the birds were recorded weekly and analysed in three distinct periods: 1-42 days, 42-60 days, and 60-90 days. Additionally, the amount of feed consumed and leftovers were recorded weekly. To determine feed intake, the consumed feed was calculated by subtracting the leftovers from the total feed provided. This comprehensive approach allowed for a detailed assessment of the chickens' growth and feeding patterns over the course of the study.

A precision scale (RADWAG, MODEL PS 750/C/2) was used to measuring body weight gain, while a measuring tape, five meters in length, was employed to measure the length of organs. Subsequently, the feed conversion ratio (FCR) was calculated using the following formula:

$$\text{Feed Conversion Ratio (FCR)} = \text{Feed intake (g)/Body weight gain (g)} \quad \text{(Eq.1)}$$

At 60 and 90 days, three chickens per treatment were randomly chosen and humanely slaughtered using the cervical dislocation method, in accordance with the ethical guidelines outlined by the University of South Africa. Following the slaughter, the birds were immersed in hot water to facilitate feather removal, after which were cleaned and dissected to harvest the internal organs for analysis. At 60 days, the following organs were measured: small intestine, gastrointestinal tract (GIT), liver, gizzard, pancreas, proventriculus, heart, and spleen. At 90 days, a more extensive evaluation was conducted, including measurements of the small intestine, large intestine, crop, and caeca. Additionally, the pH levels of the gut organs were measured using a digital pH meter (Crison, Basic 20 pH meter). At the conclusion of the 90-day experiment, an assessment of bone weight, length, and diameter was conducted. Post-slaughtered, samples from the tibial and femoral bones were collected, ensuring they were free from any debris, and subsequently stored at -20°C for preservation. A calliper was employed to determine the tibial and femoral length and width of the bones. Following the measurements, the bones were placed in plastic bags, frozen, and preserved for further analysis in the laboratory.

Statistical analysis

Statistical analysis conducted using one-way analysis of variance (ANOVA) within a general linear model (GLM) procedure (SAS, 2012). The data were analysed using a completely randomized design. Mean values were differentiated using Duncan's multiple range test. ANOVA was employed to assess significant differences among the means, with a significance threshold set at $P<0.05$. Regression analyses were performed to explore the relationships between various parameters (such as body weight gain, feed intake, feed conversion ratio, organ weight, meat characteristics, and bone measurements) and the dietary supplement of WGS. Both simple linear regression models ($Y=a+bx$) and quadratic models ($Y=a+b1x+b2x2$) were utilized. The quadratic model, chosen for its superior fit, was used to determine optimal responses, with specific coefficients (*a, b1, and b2*) and the dietary supplement of whole grain sorghum (x) being factors in the analysis.

The ingredient and nutrient composition of the dietary formulations used in the study are shown in *Table 1*. The chicken diet was formulated to meet the requirements as recommended in the specifications of indigenous chicken (Kingori et al., 2003).

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Table 1. *Formulation of a diet incorporating whole grain sorghum*

Whole grain sorghum DIET (%)				
Ingredients	0	25	50	75
Yellow maize	51.33	38.49	25.66	12.83
Sorghum	-	12.83	25.66	38.49
Soya bean	33.03	20.01	25.91	25.22
Soya oil cake	-	19.12	13.52	10.62
Limestone powder	12.30	7.80	7.10	9.70
Potassium carbonate	1.20	0.50	0.90	1.00
Mono calcium phosphate	0.98	0.10	0.10	0.99
Salt	0.30	0.30	0.30	0.30
Premix	0.40	0.40	0.40	0.40
Lysine	0.18	0.17	0.17	0.17
Methionine	0.28	0.28	0.28	0.28
Total	100	100	100	100

† The active ingredients contained in the vitamin–mineral premix was as follows (per kg of diet): vitamin A 12000 IU, vitamin D3 3500 IU, vitamin E 30.0 mg, vitamin K3 2.0 mg, thiamine 2 mg, riboflavin 6 mg, pyridoxine 5 mg, vitamin B12 0.02 mg, niacin 50 mg, pantothenate 12 mg, biotin 0Æ01 mg, folic acid 2 mg, Fe 60 mg, Zn 60 mg, Mn 80 mg, Cu 8 mg, Se 0Æ1 mg, Mo 1 mg, Co 0Æ3 mg, I 1 mg

Results

Analysed nutrient composition of WSG diet

The examination of the feed's nutrient composition revealed significant differences among the treatments ($p < 0.05$). Specifically, the inclusion of 75% WGS resulted in the highest ($p<0.05$) dry matter content compared to the other treatments. Similarly, feeds with 50% inclusion exhibited higher ($p<0.05$) gross energy (GE) compared to other treatment levels. Notably, the feed containing 75% WGS displayed the highest crude protein content ($p < 0.05$), as delineated in *Table 2*.

Table 2. *Analysed composition of the diet and amino acid digestibility*

Parameters	**0%**	**25%**	**50%**	**75%**
Dry Matter (%)	91.50	91.02	91.60	92.65
Gross Energy (MJ/Kg)	11.08	13.45	14.14	11.78
Crude Protein (%)	24.07	19.53	23.01	28.67
His	0.21	0.11	0.17	0.16
Arg	0.49	0.52	0.66	0.48
Ser	0.60	0.60	0.75	0.62
Gly	0.87	1.12	1.17	1.11
Asp	0.90	0.90	1.11	0.93
Glu	1.35	1.55	1.79	1.41
Thr	0.72	0.64	0.78	0.72
Ala	0.67	0.75	0.99	0.73
Pro	0.74	0.62	0.83	0.77
Lys	0.32	0.39	0.45	0.35
Tyr	0.43	0.56	0.68	0.53
Met	0.19	0.20	0.25	0.24
Val	0.52	0.61	0.73	0.59
Ile	0.40	0.48	0.58	0.46
Leu	0.73	0.85	1.05	0.75
Phe	0.60	0.76	0.95	0.71

0%=control (No sorghum), 25%=WGS inclusion on the diet, 50%=WGS inclusion on the diet, 75%=WGS inclusion on the diet. WSG=whole grain sorghum

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Growth performance of Indigenous Boschveld chickens fed graded levels of WGS

The influence of WGS inclusion on the growth performance of Indigenous Boschveld chickens aged 1-90 days is summarized in *Table 3*. Chickens fed 75% WGS exhibited significantly higher ($p<0.05$) BWG during the first 1-42 days compared to other treatment levels, with a quadratic effect observed ($p=0.01$). FI was higher ($p<0.05$) in birds fed 25% WGS, showing both linear and quadratic significance ($p=0.000$). At 60 days, chickens on the 75% WGS diet had higher ($p<0.05$) BWG, while those on the 50% WGS diet exhibited the highest ($p<0.05$) BWG at 90 days. Maize-based diet outperformed WGS in relation to FI, with the 50% WGS diet scores higher ($p<0.05$) values than other sorghum levels. FCR varied, with significant associations detected in different treatment levels. Specifically, the 75% WGS diet resulted in higher ($p<0.05$) FCR values at 1-42 and 60-90 days. However, there were no significant FCR differences between linear or quadratic associations among the treatments.

Table 3. *The influence of WGS inclusion on body weight gain (BWG), feed intake (FI, g) and feed conversion ratio (FCR) in Indigenous Boschveld chickens aged 1 to 90 days*

	Day 1-42			Day 42-60			Day 60-90		
Treatment	**BWG**	**FI**	**FCR**	**BWG**	**FI**	**FCR**	**BWG**	**FI**	**FCR**
0	246.59^{b}	158.97^{d}	0.64^{d}	336.64^{d}	187.57^{d}	0.55^{c}	599.88^{b}	358.38^{a}	0.59^{b}
25	223.50^{c}	222.57^{a}	0.99^{b}	393.24^{b}	279.46^{b}	0.70^{a}	543.13^{d}	338.16^{ab}	0.61^{b}
50	122.20^{d}	197.16^{b}	1.61^{a}	367.76^{c}	241.71^{c}	0.65^{b}	633.75^{a}	288.70^{c}	0.45^{c}
75	258.70^{a}	191.10^{c}	0.73^{c}	426.85^{a}	280.78^{a}	0.65^{b}	561.38^{c}	275.32^{c}	0.79^{a}
SEM	0.847	9.721	0.052	7.421	12.384	0.057	16.189	12.945	0.021
P-value									
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Linear	0.098	0.000	0.972	0.008	0.286	0.002	0.657	0.005	0.376
Quadratic	0.0181	0.000	0.844	0.007	0.87	0.008	0.065	0.000	0.35

a; b; c; d; Means in the same column not sharing a common superscript are different ($p < 0.05$). SEM=standard error of the means. 0=control (No sorghum), 25%=WGS inclusion on the diet, 50%=WGS inclusion on the diet, 75%=WGS inclusion on the diet. WSG=whole grain sorghum, BWG=body weight gain, FI=feed intake, FCR=feed conversion ratio

Optimum level of WGS inclusion for the growth performance in indigenous Boschveld chicken

The optimal inclusion level of WGS in the diet for Indigenous Boschveld chickens' growth performance is outlined in *Table 4*. The regression model identified FI ($p < 0.001$), BWG ($p < 0.001$), and FCR ($p < 0.001$) to be significantly influenced by the treatment and its quadratic effects, with Cohen's f-squared for this analysis indicating a large effect (3.92). It was observed that the optimal solution was achieved for BWG ($y = 162.85$, $x = 39.44$), FI ($y = 214.70$, $x = 42.39$), and FCR, which exhibited a negative correlation with the treatment ($y = 0.1307$, $x = -20.5$) during the 1–42-day period. Conversely, during the 42–60-day period, the WGS diet exhibited a negative correlation with the growth parameters, as indicated; BWG ($y = 139.76$, $x = -453$), FI ($y = 275.42$, $x = -60.76$), and FCR ($y = -0.934$, $x = -500$). Furthermore, the regression analysis revealed that the optimal solution for BWG occurred at $y = 622.52$ when the treatment was $x = 22.95$, while FI reached its optimal level at $y=198.31$ when the treatment was $x=233.3$. Additionally, FCR exhibited a negative association ($y = -2.04$).

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***Table 4.** The optimum inclusion level of WGS diet on the growth performance of indigenous Boschveld chicken from 1-90 days*

Factor	Formula	Optimal X value	Optimal Y value	r^2	P
1-42 days					
BWG (g/kg)	$Y=262.395-5.048x+ 0.064x^2$	39.44	162.85	0.846	0.0001
FI (g/kg)	$Y=164.4+2.37x --0.028x^2$	42.39	214.70	0.79	0.001
FCR (g; g)	$Y=0.551+0.041x+-0.001x^2$	-20.5	0.1307	0.846	0.001
42-60 days					
BWG (g/kg)	$Y=344.97+0.906x – 0.001x^2$	-453	139.76	0.825	0.001
FI (g/kg)	$Y=197.89 + 2.552x - 0.021x^2$	60.76	275.42	0.685	0.016
FCR (g; g)	$Y=0.566+0.006x+0.000006x^2$	-500	-0.934	0.578	0.071
60-90 days					
BWG (g/kg)	$Y=573.53-4.269x- 0.093x^2$	22.95	622.52	0.838	0.00001
FI (g/kg)	$Y=361.64-1.4x --0.003x^2$	233.33	198.31	0.835	0.00001
FCR (g; g)	$Y=0.625-0.008x +-0.0000006x^2$	666.67	-2.04	0.735	0.006

X=Inclusion level for optimal value, Y= Optimal Y-level, r2= regression coefficient, P= Probability, BWG=body weight gain, FI=feed intake, FCR=feed conversion ratio

The influence of WGS on the length and weight of the visceral organs in Boschveld chickens at 60 days

The influence of WGS on the lengths and weights of visceral organs in Boschveld chickens at 60 days is summarized in *Table 5*. Chickens on a 75% WGS diet exhibited significantly higher ($p<0.05$) small intestine weight, with a significant quadratic effect found ($p=0.005$). The intestinal length of chickens fed 75% WGS was longer ($p<0.05$) compared to other treatments, with a significant treatment effect ($p=0.001$). Furthermore, inclusion of 75% WGS resulted in better ($p < 0.05$) GIT weights with a significant quadratic association ($p = 0.008$). In relation to other organs, the 75% WGS diet led to higher ($p<0.05$) gizzard weight compared to maize-based diet and increasing WGS inclusion levels correlated with increased gizzard weight. Quadratic ($p=0.05$) influence for heart, with 25% WGS resulting in heavier ($p<0.05$) weight.

***Table 5.** The influence of WGS on the length and weight of the visceral organs in Boschveld chickens at 60 days*

	Treatment				P-value			
Parameters	0	25	50	75	SEM	Treatment	Linear	Quadratic
Small intestine Weight (g)	23.50^{d}	43.50^{ab}	34.50^{c}	47.50^{a}	0.500	<.0001	0.903	0.005
Small intestine Length(cm)	103.50^{b}	92.50^{c}	96.50^{c}	120.30^{a}	0.559	<.0001	0.748	0.365
GIT Weight (g)	86.50^{d}	128.50^{ab}	101.50^{c}	130.50^{a}	0.500	<.0001	0.49	0.008
Liver (g)	14.50^{c}	21.50^{a}	18.50^{b}	21.50^{a}	0.500	<.0001	0.201	0.038
Gizzard (g)	18.50^{b}	17.50^{b}	18.50^{b}	30.50^{a}	0.500	<.0001	0.159	0.133
Pancreas (g)	2.00^{a}	2.00^{a}	2.50^{a}	2.00^{a}	0.144	<.0001	0.553	0.148
Proventriculus (g)	2.00^{c}	4.50^{a}	3.50^{ab}	4.50^{a}	0.408	0.0004	0.942	0.024
Heart (g)	2.50^{c}	7.50^{a}	5.50^{ab}	6.00^{a}	0.456	0.0001	0.581	0.05
Spleen (g)	1.00^{a}	1.00^{a}	0.00^{b}	0.00^{b}	0.144	1.0000	0.685	0.003

a; b; c; d; Means in the same row not sharing a common superscript are different ($p < 0.05$). SEM=standard error of the means. 0=control (No sorghum), 25%=WGS inclusion on the diet, 50%=WGS inclusion on the diet, 75%=WGS inclusion on the diet. WSG=whole grain sorghum, g=grams, cm=centimetres

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Optimum level of WGS inclusion on weight and length of visceral organs in indigenous Boschveld chicken at 60 days

Table 6 demonstrates the optimal WGS inclusion levels for visceral organ weight and length in Indigenous Boschveld chickens at 60 days. The study yielded significant effects on the small intestine ($p<0.00$), gizzard ($p<0.00$), and spleen ($p<0.02$) in response to varying levels of WGS. The regression coefficients ranged between 0.41 and 1.00. For small intestine length, gizzard weight, and spleen, the optimal values were observed (y=138.43, y=61.49, and x=39.x=69), respectively. In response to the sorghum diet, there was a negative association for pancreas weight (x=-28.33, y=-55.22).

Table 6. *Optimum level of WGS inclusion on the visceral organs weight and length for indigenous Boschveld chicken at 60 days*

Factor	Formula	X	Y	r^2	P
GIT (g)	$Y=92.75-0.81x – 0.01x^2$	81.00	320.36	0.66	0.24
Small intestine (g)	$Y=26.05 – 0.46x – 0.002x^2$	77.00	215.62	0.79	0.09
Small intestine (cm)	$Y=103.75-0.83x+0.001x^2$	29.64	138.43	1.00	0.00
Liver (g)	$Y=15.30+0.19x+0.0003x^2$	48.00	120.52	0.77	0.11
Gizzard (g)	$Y=18.95-0.24x+0.01x^2$	24.20	61.49	0.98	0.00
Pancreas (g)	$Y=1.93-0.02x+0.00051x^2$	-28.33	-55.22	0.41	0.63
Proventriculus (g)	$Y=2.28-0.07x-0.01x^2$	3.55	9.63	0.74	0.14
Heart (g)	$Y=2.98-0.17x+0.0061x^2$	42.25	94.62	0.79	0.09
Spleen (g)	$Y=1.10-0.02x+0.0031x^2$	20	39.69	0.89	0.02

X=Inclusion level for optimal value, Y= Optimal Y-level, r2= regression coefficient, P= Probability, g=gram, cm=centimetre

The influence of WGS on length, weight and pH in Boschveld chickens at 90 days

The study's findings regarding the influence of WGS on the weight, length, and pH of visceral organs at 90 days are summarized in *Table 7*. The GIT exhibited greater weight ($p < 0.05$) in the control diet as compared to the sorghum treatment, with a linear effect observed in the regression analysis ($p = 0.029$). Increasing WGS inclusion resulted in longer GIT, with the longest ($p < 0.05$) length recorded in birds fed 75%. Regression analysis predicted both linear ($p = 0.022$) and quadratic ($p = 0.014$) effects on GIT length. Small intestine weight was lower ($p > 0.05$) in birds fed 25% WGS diet. The pH in the small intestine was higher ($p < 0.05$) in birds fed maize compared to sorghum, with significant linear ($p = 0.012$) and quadratic ($p = 0.007$) effects detected. The pH value in the large intestine exhibited significant linear and quadratic effects ($p=0.00$), with the 75% WGS group displaying the highest ($p<0.05$) pH level. Liver organ weight increased as the level of inclusion increased; however, maize-fed birds exhibited better ($p < 0.05$) liver weight. Maize-fed birds also displayed superior ($p < 0.05$) gizzard weight and pH compared to all WGS treatments. The pancreas weight in Boschveld birds fed 75% WGS increased ($p < 0.05$) in response to the WGS diet, showing both linear and quadratic relationships. Maize-fed birds exhibited larger ($p < 0.05$) hearts, spleen and crop weight compaed to graded WGS diet. Futheremore, regression analysis indicated a significant linear ($p = 0.042$) and quadratic ($p = 0.015$) effect on caeca length.

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***Table 7.** The influence of WGS on the length, weight and pH of visceral organs of Boschveld chicken at 90 days*

Parameters	Treatment				P-value			
	0	25	50	75	SEM	Treatment	Linear	Quadratic
GIT (g)	262.00[a]	172.00[d]	215.00[b]	211.00[bc]	7.257	<.0001	0.029	0.080
GIT (cm)	149.00[c]	136.00[d]	156.00[b]	168.00[a]	5.093	<.0001	0.022	0.014
Small intestine (g)	70.63[a]	54.39[b]	72.07[a]	71.85[a]	3.42	<.0001	0.208	0.269
Small intestine (cm)	139.5[ab]	125.50[c]	146.50[a]	148.50[a]	3.777	<.0001	0.967	0.718
Small intestine pH	6.48[a]	5.27[c]	5.91[b]	6.08[b]	0.891	<.0001	0.012	0.07
Large intestine (g)	19.42[a]	9.07[c]	12.47[b]	12.19[b]	1.767	0.0002	0.031	0.025
Large intestine pH	5.74	5.60	5.92	6.23	0.790	<.0001	0.00	0.00
Large intestine(cm)	12.50	11.50	12.50	11.50	1.252	<.0001	0.615	0.195
Liver (g)	40.81[a]	29.06[c]	31.63[b]	34.33[b]	1.610	<.0001	0.635	0.352
Gizzard (g)	56.81[a]	22.12[c]	46.61[b]	47.62[b]	6.225	0.0040	0.802	0.613
Gizzard pH	6.00[a]	5.80[c]	5.97[ab]	5.64[d]	0.110	<.0001	0.410	0.328
Pancreas (g)	3.85[b]	3.67[c]	3.42[d]	4.36[a]	0.065	<.0001	0.309	0.224
Pro-Vent (g)	8.56[a]	7.43[c]	8.35[ab]	8.66[a]	0.261	<.0001	0.059	0.066
Pro-Vent pH	5.98[b]	5.44[bc]	5.79[b]	6.66[a]	0.285	<.0001	0.001	0.001
Heart (g)	13.92[a]	8.46[b]	8.36[bc]	9.57[b]	0.564	<.0001	0.017	0.021
Spleen (g)	4.38[a]	2.58[c]	2.71[c]	3.34[b]	0.250	<.0001	0.074	0.257
Crop (g)	18.75[a]	12.56[c]	13.26[b]	13.26[b]	0.559	<.0001	0.503	0.534
Crop pH	3.60[c]	3.41[d]	3.70[b]	4.00[a]	0.022	<.0001	0.55	0.25
Caeca (g)	7.89[c]	10.51[b]	10.81[b]	12.27[a]	1.419	0.0001	0.089	0.145
Caeca pH	5.98[b]	6.02[b]	6.01[b]	6.14[a]	0.112	<.0001	0.257	0.207
Caeca (cm)	18.50[b]	18.50[b]	17.50[bc]	20.50[a]	0.523	<.0001	0.042	0.015

a; b; c; d; Means in the same row not sharing a common superscript are different ($p < 0.05$). SEM=standard error of the means. 0=control (No sorghum), 25%=WGS inclusion on the diet, 50%=WGS inclusion on the diet, 75%=WGS inclusion on the diet. WSG=whole grain sorghum, g=grams, cm=centimetres

Optimum level of WGS inclusion on weight, length and pH of visceral organs in indigenous Boschveld chicken at 1-90 days

Table 8 show the optimal level in relation to visceral organs at 90 days. A quadratic relationship was observed between GIT weight ($p < 0.000003$) and length ($p < 0.00513$), small intestine weight ($p < 0.01279$), length ($p < 0.052839$), and pH ($p < 0.027687$), large intestine weight ($p < 0.043860$), length ($p < 0.04982$), pH ($p < 0.043313$), gizzard weight ($p < 0.034574$), pancreas ($p < 0.027016$), proventriculus ($p < 0.013164$), heart weight ($p < 0.028421$), and caeca weight ($p < 0.05350$). The optimization of organs varied across each case, yielding the following values: $y = 186.72$ (GIT weight), $y = 142.07$ (GIT length), $y = 61.94$ (small intestine weight), $y = 5.98$ (pH small intestine), $y = 133.56$ (large intestine length), $y = 5.50$ (pH large intestine), $y = 9.80$ (large intestine weight), $y = -237.50$ (large intestine length) Large intestine length and pancreas exhibited negative responses to the sorghum diet ($y = -237.50$; $x = -0.08$). The regression coefficient fell within the range of 0.55 and 0.89.

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Table 8. *The optimum inclusion of WGS on the visceral organ weight, length and pH for indigenous Boschveld chicken at 90 days*

Factor	Formula	Optimal X value	Optimal Y value	r^2	P
GIT (g)	$Y=350-59.25x+5.375x^2$	5.51	186.72	0.834	0.000003
GIT (cm)	$Y=164.25 – 11.775x – 1.563x^2$	3.77	142.07	0.664	0.00513
Small intestine (g)	$Y=81.93- -8.946x+1.0001x^2$	4.47	61.94	0.798	0.01279
pH small intestine	$Y=6.618-0.031x+0.0001x^2$	4.45	5.98	0.788	0.027687
Small intestine (cm)	$Y=148-7.6x+1x^2$	3.80	133.56	0.554	0.052839
pH large intestine	$Y=7.8-0.89x+0.086x^2$	5.17	5.50	0.835	0.043313
Large intestine (g)	$Y=30.45-7.208x+0.629x^2$	5.73	9.80	0.664	0.043860
Large intestine (cm)	$Y=12.5-0.01x+0.00001x^2$	5000	-237.50	0.661	0.04982
Liver (g)	$Y=56.24-9.875x+0.903x^2$	5.47	29.24	0.616	0.074019
Gizzard (g)	$Y=88.969-22.467x+2.231x^2$	5.04	32.13	0.553	0.034574
pH Gizzard	$Y=5.918-0.036x-0.000801x^2$	2.25	5.96	0.589	0.054159
Pancreas (g)	$Y=0.791-0.159x+0.95x^2$	-0.08	0.78	0.898	0.027016
Proventriculus (g)	$Y=9.755-0.84x+0.09x^2$	4.67	7.80	0.55	0.013164
pH Proventriculus	$Y=7.133-0.76x+0.08x^2$	4.75	5.33	0.661	0.037933
Heart (g)	$Y=21.714-0.031x+0.0001x^2$	5.79	7.73	0.688	0.028421
Spleen (g)	$Y=7.04-1.668x+0.152x^2$	5.49	2.46	0.887	0.07758
Crop (g)	$Y=26.13-4.65x+0.387x^2$	6.01	12.14	0.664	0.088532
pH Crop	$Y=3.918-0.232x+0.0321x^2$	3.74	3.48	0.837	0.06510
Caeca (g)	$Y=5.56-1.397x-0.072x^2$	9.70	12.34	0.565	0.05350
pH Caeca	$Y=6.03-0.0331x+0.006x^2$	2.75	5.99	0.798	0.08416
Caeca (cm)	$Y=21.25-1.625x+0.188x^2$	4.32	17.74	0.891	0.09910

X=Inclusion level for optimal value, Y= Optimal Y-level, r2= regression coefficient, P= Probability, g=gram, cm=centimetre

The influence of WGS on the carcass and meat characteristics at 60 and 90 days

The influence of WGS on carcass and meat characteristics at 60 and 90 days is summarized in *Table 9*. All traits showed significant differences among treatments ($p < 0.0001$) at 60 days. Chickens subjected to graded WGS diets demonstrated higher ($p < 0.05$) carcass weights compared to those fed control, with the 75% WGS group displaying the highest weight. Linear and quadratic trends varied by trait, with significant linear trends in carcass, breast, and thigh weights, and significant quadratic trends in all traits. At 90 days, all traits showed significant differences among treatments ($p < 0.0001$). Linear trends were significant for carcass, drumstick, and wing weights. Similarly, quadratic trends were significant for carcass ($p = 0.001$), breast ($p = 0.002$), drumstick ($p < 0.001$), and wing weights ($p = 0.001$).

Optimum level of WGS inclusion on carcass characteristics in indigenous Boschveld chicken at 60 and 90 days

Table 10 illustrates the optimum inclusion levels on carcass characteristic in Boschveld chickens. At 60 days, drumsticks ($p<0.00$) showed a significant effect, while at 90 days, carcass ($p<0.01$), breast ($p<0.00$), and drumsticks ($p<0.00$) were significant. The optimal levels for carcass characteristics varied: carcass at y=762.10, breast at y=2.80, and drumstick at y=92.51. At 90 days, there was a negative relationship between carcass (x=-0.33) and thigh (y=-15.93). The highest regression coefficient of 1.00 was detected for drumsticks portion.

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Table 9. *The influence of WGS on carcass and meat cut weights at 60 and 90 days*

Treatment	Carcass (g)	Breast(g)	Thighs(g)	Drumsticks(g)	Wings(g)
Carcass Day 60					
0	301.50^{c}	48.50^{b}	50.50^{b}	46.50^{b}	45.50^{b}
25	360.00^{ab}	60.50^{a}	67.50^{a}	57.50^{a}	55.50^{a}
50	317.50^{c}	35.50^{d}	47.50^{c}	57.50^{a}	48.50^{b}
75	362.50^{a}	43.50^{c}	51.50^{b}	60.50^{a}	54.50^{a}
SEM	0.478	0.500	0.500	0.500	0.500
P-value					
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001
Linear	0.015	0.003	0.008	0.056	0.007
Quadratic	0.001	0.016	0.012	0.000	0.003
Carcass Day 90					
0	752.00^{a}	113.00^{a}	115.00^{ab}	117.00^{c}	110.00^{a}
25	756.00^{a}	88.00^{c}	125.00^{a}	125.00^{a}	117.00^{a}
50	711.00^{c}	81.00^{d}	100.00^{cd}	122.00^{ab}	107.00^{a}
75	701.00^{b}	104.00^{b}	110.00^{c}	111.00^{cd}	109.00^{a}
SEM	34.584	6.091	5.592	3.597	4.760
P-value					
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001
Linear	0.006	0.294	0.256	0.004	0.001
Quadratic	0.001	0.002	0.183	0.000	0.001

a; b; c; d; Means in the same column not sharing a common superscript are different ($p < 0.05$). SEM=standard error of the means. 0=control (No sorghum), 25%=WGS inclusion on the diet, 50%=WGS inclusion on the diet, 75%=WGS inclusion on the diet. WSG=whole grain sorghum, g=grams

Table 10. *The optimum inclusion of WGS on carcass characteristic in indigenous Boschveld chicken at 60 and 90 days*

Factor	Formula	X	Y	r^2	P
Carcass 60 days					
Carcass (g)	$Y=283.375+30.925x-3.375x^2$	4.58	434.22	0.61	0.32
Breast (g)	$Y=52 + x - x^2$	0.50	53.50	0.51	0.48
Thigh (g)	$Y= 42.25 - 14.55x - 3.25x^2$	2.24	79.30	0.48	0.52
Drumsticks (g)	$Y=35 + 14.2x - 2x^2$	3.55	92.51	0.95	0.00
Wings (g)	$Y= 47.75 + 2.35x - 0.25x^2$	4.70	68.20	0.38	0.68
Carcass 90 days					
Carcass (g)	$Y=762 - 2.3x - 3.5x^2$	-0.33	762.10	0.92	0.01
Breast (g)	$Y=165 - 63.4x + 12x^2$	2.64	2.80	0.99	0.00
Thigh (g)	$Y= 122 - 4x - 0.029x^2$	68.97	-15.93	0.50	0.49
Drumsticks (g)	$Y=100.25+21.65x-4.75-x^2$	2.28	154.15	1.00	0.00
Wings (g)	$Y=107.75 + 4.95x - 1.25x^2$	1.98	121.51	0.51	0.47

X=Inclusion level for optimal value, Y= Optimal Y-level, r2= regression coefficient, P= Probability, g=gram

The influence of WGS on tibia and femur bone weight, length and diameter at 60 and 90 days

Table 11 presents the results related to the weight, length, and diameter of the tibia and femur bones in Indigenous Boschveld chickens fed varying levels of WGS. A general linear model analysis revealed significant treatment interactions for all tibial and femoral characteristics at both 60 and 90 days. At 60 days, bone weight in birds fed a 75% diet was higher ($p < 0.05$) than in other treatments. Both linear ($p = 0.001$) and quadratic

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($p = 0.000$) effects were significant for tibia weight. No significant effects were detected for tibia length ($p > 0.05$). For tibia diameter, both linear ($p = 0.033$) and quadratic ($p = 0.043$) effects were significant. At 90 days, tibia weight showed significant linear ($p = 0.045$) and quadratic ($p = 0.000$) effects. Additionally, a significant quadratic effect ($p = 0.002$) was observed for tibia length, and a significant linear effect ($p = 0.03$) was noted for tibia diameter. Regarding femoral bones, at 90 days, femoral bone length was higher ($p < 0.05$) in Boschveld chickens fed a 0% diet. Femur weight demonstrated significant linear ($p = 0.002$) and quadratic ($p = 0.000$) effects.

Table 11. *The influence of WGS on tibia weight, length and diameter bones in Boschveld chickens at 60 and 90 days*

	Day 60			**Day 90**		
Tibia bone analysis						
Treatment	**Weight (g)**	**Lengths (cm)**	**Diameter**	**Weight (g)**	**Length (cm)**	**Diameter**
0	7.09^{c}	7.50^{ab}	0.51^{c}	17.00^{a}	10.00^{ab}	3.30^{a}
25	9.50^{ab}	8.30^{a}	0.62^{b}	16.50^{ab}	10.70^{a}	2.76^{b}
50	8.50^{ab}	7.75^{ab}	0.53^{c}	17.00^{a}	10.65^{ab}	2.64^{b}
75	11.95^{a}	8.00^{ab}	1.72^{a}	13.00^{ab}	10.15^{ab}	2.20^{b}
SEM	1.103	0.290	0.132	1.190	0.375	0.229
P -value						
Treatment	0.0002	<.0001	0.0025	<.0001	<.0001	<.0001
Linear	0.001	0.674	0.033	0.045	0.15	0.03
Quadratic	0.00	0.559	0.043	0.00	0.002	0.782
Femur bone analysis						
0	5.95^{c}	5.20^{a}	0.65^{b}	14.00^{a}	7.40^{a}	3.32^{ab}
25	8.08^{a}	5.95^{a}	0.34^{d}	14.00^{a}	7.00^{b}	3.61^{a}
50	6.52^{ab}	5.65^{a}	0.74^{b}	11.00^{c}	6.75^{c}	1.72^{d}
75	8.47^{a}	5.45^{a}	3.11^{a}	12.00^{b}	7.00^{b}	2.44^{c}
SEM	0.563	0.389	0.141	0.000	0.102	0.191
P -value						
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001	<0.001
Linear	0.862	0.613	0.002	0.192	0.018	0.38
Quadratic	0.468	0.428	0.000	0.507	0.039	0.693

a; b; c; d; Means in the same column not sharing a common superscript are different ($p < 0.05$). SEM=standard error of the means. 0=control (No sorghum), 25%=WGS inclusion on the diet, 50%=WGS inclusion on the diet, 75%=WGS inclusion on the diet. WSG=whole grain sorghum, g=grams, cm=centimetre

Optimum inclusion of WGS on tibia and femur weight, length and diameter in indigenous Boschveld chicken at 60 and 90 days

Table 12 presents the optimum inclusion levels of WGS in Boschveld chickens, focusing on tibial and femur characteristics. At 60 days, tibia length was significantly influenced, ($p=0.02$) and at 90 days, all tibial characteristics (weight, length, diameter) were significantly affected. Negative correlations were observed between weight ($x=-335.00$) and length (-65.00) at 60 days and for tibial length ($x= -120.00$) at 90 days. The optimal level for bone diameter was achieved at $y=424.66$. Tibia weight at 90 days had the maximum regression coefficient ($r^2=1.00$), indicating a strong influence. For femoral bones, significant differences were found in bone length and diameter at 60 days. The optimal inclusion levels were $y=57.47$ for length and $y=18.55$ for diameter. Femoral bone

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weight showed a negative (x=-0.34) correlation with the WGS diet at 60 days. At 90 days, femoral bone diameter showed significant differences, with the optimal level at y=9.828. Femoral bone weight again showed a negative (x=-0.181) correlation with treatment. The highest regression coefficients for bone length were observed at 60 days (r^2=0.99) and 90 days (r^2=0.86).

Table 12. *The optimum inclusion of WGS on the tibia weight, length and diameter on an indigenous Boschveld chicken from 1-90 days*

Factor	Formula	X	Y	r^2	P
Tibia bone 60 days					
Weight (g)	$Y=7.926 + 0.067x + 0.0001x^2$	-335.00	-684.52	0.54	0.43
Length (cm)	$Y=7.55 + 0.026x – 0.002x^2$	-65.00	-124.14	0.88	0.02
Diameter	$Y= 0.751 – 0.013x – 0.001x^2$	6.50	13.67	0.82	0.06
Tibia bone 90 days					
Weight (g)	$Y=17.05 + 0.062x - 0.001x^2$	31.00	80.97	1.00	0.00
Length (cm)	$Y=10.04 + 0.024x – 0.0001x^2$	-120.00	-232.84	0.96	0.00
Diameter	$Y= 3.268 – 0.017x – 0.001x^2$	212.50	424.66	0.90	0.02
Femur bone 60 days					
Weight (g)	$Y = 6.399 + 0.065x + 0.0966x^2$	-0.34	5.70	0.65	0.26
Length (cm)	$Y = 5.17+ 0.051x – 0.005x^2$	25.50	57.47	0.99	0.00
Diameter	$Y= 0.708 – 0.018x – 0.0003x^2$	9.00	18.55	0.98	0.00
Femur bone 90 days					
Weight (g)	$Y = 8.6 + 4.9x + 13.5x^2$	-0.181	7.348	0.79	0.079
Length (cm)	$Y = 7.417 - 0.025x – 0.002x^2$	6.250	19.761	0.86	0.030
Diameter	$Y= 3.561 – 0.031x – 0.00487x^2$	3.183	9.828	0.66	0.001

X=Inclusion level for optimal value, Y= Optimal Y-level, r2= regression coefficient, P= Probability, g=gram, cm=centimetre

Discussion

Sorghum is ranked fifth among major cereal crops, following maize, rice, wheat, and barley (Bryden et al., 2009). Despite its ranking, sorghum's nutritional value is comparable to that of maize (Hancock, 2000), a primary cereal crop, with a substantial energy content ranging from 50-60% (Ajaja et al., 2002). Notably, sorghum is considered more nutritious than maize due to its high protein content. The energy content of sorghum grain is equivalent to that of maize seeds (Mabelebele and Iji, 2013). It is notable that there exists a dearth of research focused on the utilization of whole grain sorghum specifically in Boschveld chickens. Consequently, most comparative analyses are drawn from studies conducted on broilers. In a recent study by von Schaumburg et al. (2021), white and red sorghum were examined as primary carbohydrate sources in extruded diets for felines. Their findings highlighted a dry matter content of 89.6% in red sorghum, consistent with results observed in our study, albeit lower than diets with 75% sorghum inclusion. Moreover, their research noted lower protein content compared to levels found in our study. Discrepancies in gross energy values, where our study exhibited a lower GE than the reported 17.00±0.007 GE (Nemukondeni et al., 2022), may stem from environmental variations in sorghum cultivation. These observed trends in GE across different sorghum inclusion levels likely result from sorghum's nutritional properties, interactions with other feed components, and analytical variations. For instance, at 25% inclusion, sorghum increases gross energy due to its energy-rich nature, while at 50%, anti-nutritional factors and nutrient dilution effects can reduce gross energy. Conversely,

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the dominance of sorghum at 75% inclusion generally increases measured gross energy, supported by findings indicating certain sorghum varieties have inherently high energy content, rendering them suitable for feed production (Kibalnik et al., 2019).

The application of sorghum at rates of 25% and especially 50% led to a reduction in body weight between days 1-42. However, the highest dose did not result in a change in body weight. Similarly, from days 42-60 and 60-90, the 25% inclusion rate caused a decrease in body weight compared to the control. In contrast, the 50% treatment induced a significant increase in body weight compared to the other treatments, while the 75% inclusion rate again significantly reduced body weight. These growth patterns highlight the chickens' ability to adapt to dietary changes, with early life stages being more sensitive to dietary imbalances that result in initial growth reductions at higher sorghum levels. Over time, chickens may adapt to moderate levels (50%), leading to improved growth due to better nutrient utilization and compensatory growth mechanisms. However, excessively high levels (75%) maintain negative effects, likely due to overwhelming anti-nutritional factors and persistent nutrient imbalances (Ibrahim et al., 2024). Studies by Torres et al. (2013) and Kumar et al. (2005) similarly reported impaired performance and decreased body weight gain with high sorghum levels. The lower growth rates observed between the 1-42 day and 42–60-day intervals can be attributed to initial dietary adaptation challenges, immature digestive systems, and persistent nutrient imbalances, which are known factors affecting chickens fed sorghum (Mohamed et al., 2015; Selle et al., 2017; Kiptui et al., 2024). However, the rapid growth observed between 60-90 days reflects physiological maturation, compensatory growth, and improved metabolic adaptation to the sorghum diet. Notably, Boschveld chickens provided with a diet containing 25% WGS exhibited the highest FI compared to other treatments. FI during the 60–90-day period in the 75% treatment group was observed to be lower than during the 42–60-day period. This suggests that the presence of antinutritional components in the feed may have contributed to poor performance in the growing flock. Similar trends of decreased or fluctuating feed intake have been reported in other studies. For instance, Okoro et al. (2017) noted lower feed intake at week 28 compared to week 24. Kwari et al. (2012) reported a significant increase in feed intake when sorghum replaced maize at various levels (25%, 50%, 75%, and 100%).

In terms of feed conversion ratio, the diet containing 50% WGS exhibited the highest ratio of 1.61, a notable exception as other treatments maintained FCR values below recorded standards. This aligns with previous findings (Mabelebele et al., 2018), where broiler chickens fed with 50% sorghum from 1 to 35 days also reported similar FCR values. Conversely, the control diet in our study showed the lowest FCR value of 0.64, with slight decreases observed across all treatments during the 42–60-day period. Specifically, chickens fed 50% WGS exhibited decreased FCR compared to previous periods. Throughout all developmental stages, FCR remained low, influenced by various factors such as management practices, feed formulations, and environmental conditions (Aviagen, 2011). However, high tannin content in sorghum could potentially reduce feed intake, thereby affecting weight gain and FCR negatively (Daramola et al., 2020). Nevertheless, studies have shown mixed results on the impact of sorghum on FCR, with some indicating no adverse effects Mohamed et al. (2015), Córdova-Noboa et al. (2018), Liu et al. (2014), Garcia et al. (2013), contrasting with studies reporting decreased performance with high sorghum content (Ahmed et al., 2013). Our study indicates that FCR in Boschveld chickens decreases with age, with this shift occurring more gradually as the chicks mature. Notably, Farahat et al. (2021) obtained results that revealed no

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significant differences in FCR when sorghum replaced maize at levels up to 50%. Similarly, Issa et al. (2015) successfully substituted maize with low-tannin sorghum at 100% without observing negative impacts on FCR. However, a study examining the comparative performance of broiler chickens fed ten equivalent diets based on three sorghum varieties revealed a negative correlation between weight gain and concentrations of 3-deoxyanthocyanins in the diets. Additionally, FCR tended to be correlated with dietary concentrations of luteolin din and 5-methoxy luteolin din (Liu et al., 2016). Variations in the optimization of growth parameters were observed, with BWG (y=622.52, x=22.95), FI (y=198.31, x=233.33), and FCR (y=-204, x=666.67) showing differing regression coefficient values. Similarly, in a study investigating the dietary energy level for optimal productivity and carcass characteristics of indigenous Venda chickens, the growth parameters were optimized at values of x=12.56 (feed intake), x=12.66 (growth rate), and x=12.62 (feed conversion ratio) (Alabi et al., 2013). In a meta-analysis investigating the inclusion of sorghum, millet, and cottonseed meal in broiler diets, a significant relationship was found between the level of sorghum substitution and growth rate (r^2=0.18) (Batonon-Alavo et al., 2015). Additionally, in the current study, performance metrics demonstrated linear and quadratic relationships in FI at 90 days, consistent with Rocha et al. (2022) where chicken varying mixing homogeneity observed linear and quadratic effects for body weight gain and feed consumption in phase three.

The study also investigated the influence of sorghum diets on visceral organ weights, noting significant effects on various organs such as the small intestine, liver, gizzard, and heart. Notably, diets with whole grain sorghum were associated with increased organ weights, consistent with previous findings (Jonkowski et al., 2012). However, in our study, gizzard weight was lower in the sorghum diet at 90 days, in agreement with other studies (Thomas et al., 2008; Arroyo et al., 2012; Pasquali et al., 2016,). A linear relationship was observed between relative gizzard weight at 35 days (Mabelebele et al., 2018), findings contrast with the current study, where no linear relationship was detected (p=0.802). Boschveld chickens fed with sorghum diets displayed higher carcass weights at 60 days compared to those on control maize diets, which differs from some previous reports (Puntigam et al., 2020). This finding also contrasts with studies reporting no significant impact of sorghum inclusion on carcass weights in broiler chickens (Kwari et al., 2012; Torres et al., 2013; Garcia et al., 2013). Moreover, the current study's findings differ from those reporting lower carcass weights in birds fed whole grain sorghum (Carolino, 2012; Masenya et al., 2021). The sorghum diet did not adversely affect the tibia bone weight, length, and diameter of Boschveld chickens throughout the 1–90-day period. This finding aligns with Manyelo et al. (2019), which demonstrated that replacing maize with low-tannin white sorghum did not alter the weight, length, diameter, or ash content of the birds' tibia bones. Notably, in the current study, the tibia weight at 90 days was 17.00 g, surpassing the 13.50 g and 16.69 g weights reported for Venda chickens of both males and females (Mabelebele et al., 2017). However, the femur weight for males in the same study exceeded the recorded weight in the current study, indicating potential of species and diet-related variations. Additionally, research by Świątkiewicz and Arczewska-Wlosek (2012) suggests that diets with reduced calcium and accessible phosphorus may negatively impact various indices of bone health. Moreover, environmental enrichment, such as increased distance between resources or the availability of vertical panels, has been associated with changes in bone properties, potentially leading to larger muscles and bones, thereby enhancing leg health (Pedersen et al., 2020). Thus, it is noteworthy that the findings of this study, along with published

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data, support the notion that whole sorghum diets can effectively substitute maize-based diets in poultry feeding without compromising the performance of Boschveld chickens. The research findings and comparative data support the nutritional viability of sorghum, emphasizing its potential role in sustainable poultry feeding practices (Sadiya et al., 2020).

Conclusion

The aim of the study was to determine the influence of varying inclusion levels of whole grain sorghum on the performance and gut morphology of Indigenous Boschveld chickens at different growth stages. The results suggested that a 75% WGS diet in the initial phase (days 1-42) supported the highest body weight gain and favourable feed conversion ratios, while a 50% WGS diet in the final phase (days 60-90) resulted in optimal body led to weight gain and feed efficiency. Carcass characteristics benefited most from the inclusion of 25% and 75% WGS at 60 days, while the 25% WGS group showed better results at 90 days. WGS also positively influenced bone development at different stages. These results suggest that WGS can be a sustainable feed option for Boschveld chickens, promoting growth and carcass quality without compromising performance, thereby improving food security and nutrient diversity. A sustainable improvement of local chickens could diversify the source of nutrition for the growing human population.

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