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Growth performance and meat quality of Cobb 500 broilers fed phytase- and tannase-treated, sorghum-based diets

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Abstract

This study aimed to evaluate the effects of phytase and tannase addition in broiler diets on the growth performance and meat quality of broilers fed sorghum-based diets. Twelve experimental diets were formulated at three sorghum levels (0, 50, and 100%) and four enzyme levels (no enzyme, 5000 FTU phytase, 25 TU tannase, and a combination of 5000 FTU phytase + 25 TU tannase). Data on voluntary feed intake, average weekly weight gain, and feed conversion ratio were recorded and used to assess growth performance. Technical and nutritional parameters were used to determine meat quality. Broilers fed total sorghum diets with phytase and tannase enzyme combination had the highest feed intake in the first (24.4 ± 0.04 g/bird/day) and second weeks of life (23.0 ± 1.06 g/bird/day), respectively. Complete sorghum diets with phytase (83.0 ± 0.88 g/bird/day) and tannase (122.0 ± 0.88 g/bird/day) showed the highest feed intake in the third and fourth weeks, respectively. Broilers fed 50% sorghum diets with tannase (135.3 ± 0.05 g/bird/day) and complete maize diets with phytase (158.1 ± 0.88 g/bird/day) had the highest feed intake during weeks five and six, respectively. Broilers fed a 50% sorghum diet without enzymes showed the highest weight gain in the final week (606.5 ± 32.39 g). Comparable feed conversion was observed in birds fed complete maize and 50% sorghum diets. Dietary treatment substantially influenced the live body, carcass, liver, kidneys, abdominal fat pad weight, and intestinal length. However, it did not affect nutritional and technical parameters or *Pectoralis major* meat.

Key words: Carcass, exogenous enzymes, feed efficiency, sorghum
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Introduction

Maize is the chief energy source used in feed formulations, with inclusion rates greater than 50% in most feeds (Baurhoo *et al*., 2011). Over the past few years, maize has become increasingly less available and is marketed at high prices. This has necessitated the need to evaluate potential grains that can be used in broiler diets instead of maize, while sustaining the economic feasibility of feed and poultry enterprises (Baurhoo *et al*., 2011).

Sorghum is a crucial animal feed ingredient and good energy source (Kaufman *et al*., 2013). Its chemical composition is comparable to that of maize (Abah *et al*., 2020). However, sorghum diets

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fed to broilers resulted in inferior growth compared to maize diets (Selle *et al*., 2010). This is attributed to the effects of sorghum antinutrients, such as phytate and tannins. Phytate chelates minerals, including phosphorus and calcium, and binds to starch and protein through binary and ternary complexes (Nissar *et al*., 2017; Brouns, 2022). Tannins complex with starch and proteins, including digestive enzymes, and lower nutrient digestion and utilization (Hargrove *et al*., 2011; Barros *et al*., 2012). Additionally, tannins have astringent properties that cause dryness in the mouth and lower feed intake (Ashok and Upadhyaya, 2012). Suboptimal nutrient utilisation and performance in broilers fed sorghum diets can be attenuated by the inclusion of exogenous phytase and tannase. These facilitate enzymatic degradation of phytate and tannins, thus improving the digestibility and utilisation of minerals, starch, and protein (Schons *et al*., 2011).

The global demand for poultry meat is projected to increase by 41% by 2030 (OECD and FAO, 2022). However, consumers prefer lean meat that has highly digestible protein and is free of cardiovascular risk factors (Donma & Donma, 2017; Mustasim *et al*., 2019). Feed plays an important role in determining the quality of meat and meat products (Narrod *et al*., 2012). For example, energy determines the physiological processes and reactions that occur in meat after slaughter (Zhang *et al*., 2005). The addition of exogenous enzymes to feed improves nutrient utilisation and growth rate and indirectly affects meat water holding capacity, texture, and flavour (Escobedo del Bosque *et al*., 2022). A high growth rate results in an imbalance ratio between oxidants and antioxidants and ensures a limited supply of oxygen to meet the demand required for fast growth, leading to oxidative stress and hypoxia, respectively. This results in lipid peroxidation and woody breast meat (Panda & Cherian, 2014; Choi *et al*., 2020; Emami *et al*., 2021).

Many studies have reported that the use of phytase in broiler diets influences growth without adversely affecting on meat quality (Hao *et al*., 2018; Wang *et al*., 2019; Hakami *et al*., 2022). Data on the effects of using a combination of phytase and tannase enzymes in sorghum diets on growth performance and broiler meat quality are still unavailable. Hence, the current study aimed to evaluate the effects of adding phytase and tannase enzymes to sorghum-based broiler diets on voluntary feed intake, feed conversion ratio, weight gain, meat yield, and quality of Cobb 500 broiler chickens.

Materials and Methods

All procedures followed in the current study complied with the national standards for the good care and management of research animals. Animal ethics approval was granted by Zimbabwe's National Animal Research Ethics Committee (Reference Number: 013/22).

The study was conducted at Henderson Research Station, Poultry Section in Mazowe District, Zimbabwe. It is in agroecological region IIb characterised by an annual rainfall range of 750–1000 mm (Mavhura *et al*., 2021). The latitude and longitude of the area are 17.35° E and 300.58° S, respectively and the altitude is 1300 m above the mean sea level. The temperature range for this area is 15–29 °C. The area is suitable for all farming systems, including dairy, piggery, horticulture, poultry, beef, and crop production (Mavhura *et al*., 2021).

Maize and sorghum were purchased from the local market in Harare, Zimbabwe and were milled and analysed for dry matter, gross energy, crude protein, ash, crude fat, calcium, and phosphorus composition according to AOAC standards (AOAC, 1995). Condensed tannins in sorghum were quantified using the method of Folin–Denis (Pratik *et al*., 2016). Ultra Soyabean Meal (solvent extracted), manufactured by Global Industries Limited, Zambia, was used as the protein source. Maxipacks (starter, grower, and finisher premixes of mineral, vitamin, amino acids) and limestone flour were purchased from Capital Foods Limited, Zimbabwe. The feed formulation was performed using the IDT Feed Formulation software. For the energy fraction of the diets, maize was substituted with sorghum through substitution by weight at three levels (0, 50, and 100%). There were four enzyme inclusion levels (no enzyme, 5000 FTU Phytase, 25 TU Tannase, and 5000 FTU phytase + 25 TU tannase) for each sorghum inclusion level. Microbial phytase and tannase were imported from Xi'an Tian Guangyuan Biotechnology Company, China, and had activity of 100 000 U/g and 500 U/g, respectively.

Twelve diets were formulated, comprising a starter, grower, and finishing diet. Diets were formulated to meet broiler nutrients requirements (NRC, 1994). The diets were analysed for dry matter, crude protein, gross energy, fat, calcium, and phosphorus using AOAC procedures (AOAC, 1995), and

the analysed nutrient compositions are shown (Tables 1–3). Diets 1–4 were complete maize-based diets with different enzyme treatments (Diet 1 had no enzyme, Diet 2 had 500 FTU phytase, Diet 3 had 25 TU tannase and Diet 4 had a combination of 5000 FTU phytase + 25 TU tannase). Additionally, diets 5–8 were formulated by 50% substitution of maize with sorghum on a weight basis, and they had different enzyme levels (Diet 5 had no enzyme, Diet 6 had 5000 FTU phytase, Diet 7 had 25 TU tannase, and Diet 8 had a combination of 5000 FTU phytase + 25 TU tannase). Diets 9–2 were complete sorghum-based diets with variations in enzyme levels (Diet 9 had no enzyme, Diet 10 had 5000 FTU phytase, Diet 11 had 25 TU tannase, and Diet 12 had a combination of 5000 FTU phytase + 25 TU tannase).

Table 1 Ingredients and chemical composition of starter diets

Ingredient (gkg^{-1})	**Percentage inclusion level of sorghum**											
	0%				**50%**				**100%**			
Diet	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Maize meal	560	560	560	555	289	286	286	282	0	0	0	0
Sorghum meal	0	0	0	0	289	286	286	282	585	585	585	580
Soya meal	400	395	395	395	382	383	383	386	375	370	370	370
Limestone flour	12	12	12	12	12	12	12	12	12	12	12	12
Broiler maxipack	28	28	28	28	28	28	28	28	28	28	28	28
Phytase	0	5	0	5	0	5	0	5	0	5	0	5
Tannase	0	0	5	5	0	0	5	5	0	0	5	5
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Proximate composition (%)											
DM	92.9	92.9	92.9	92.9	93.0	93.0	93.0	93.0	91.8	91.8	91.8	91.8
CP	22.0	21.9	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0	22.0
Fat (EE)	2.20	2.20	2.20	2.20	1.99	1.99	1.99	1.99	2.14	2.14	2.14	2.14
CF	2.73	2.73	2.73	2.73	3.88	3.88	3.88	3.88	4.21	4.21	4.21	4.21
Ca	0.88	0.88	0.88	0.88	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
P	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
CT	0.02	0.02	0.02	0.02	0.65	0.65	0.65	0.65	1.02	1.02	1.02	1.02
GE(MJ/Kg)	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7

Note: *DM = Dry Matter, CP = Crude Protein, EE = Ether Extract, CF = Crude Fibre, Ca = Calcium, P = Phosphorus, CT = Condensed Tannins, GE = Gross Energy*

Table 2 Ingredients and chemical composition of grower diets

Ingredient (gkg^{-1})	Percentage inclusion level of sorghum											
	0%				50%				100%			
Diet	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Maize meal	644	644	644	640	324	322	322	320	0	0	0	0
Sorghum meal	0	0	0	0	324	322	322	320	644	644	644	640
Soya meal	316	311	311	310	312	311	311	310	316	311	311	310
Limestone flour	16	16	16	16	16	16	16	16	16	16	16	16
Broiler maxipack	24	24	24	24	24	24	24	24	24	24	24	24
Phytase	0	5	0	5	0	5	0	5	0	5	0	5
Tannase	0	0	5	5	0	0	5	5	0	0	5	5
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Proximate composition (%)											
DM	93.0	93.0	93.0	93.0	92.5	92.5	92.5	92.5	92.9	92.9	92.9	92.9
CP	19.0	19.0	19.0	19.0	19.5	19.5	19.5	19.5	20.0	20.0	20.0	20.0
Fat (EE)	2.81	2.81	2.81	2.81	2.39	2.39	2.39	2.39	2.12	2.12	2.12	2.12
CF	3.61	3.61	3.61	3.61	4.04	4.04	4.04	4.04	4.39	4.39	4.39	4.39
Ca	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.84	0.84	0.84	0.84
P	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.41	0.41	0.41	0.41
CT	0.02	0.02	0.02	0.02	0.69	0.69	0.69	0.69	1.11	1.11	1.11	1.11
GE(MJ/kg)	17.4	17.4	17.4	17.4	17.1	17.1	17.1	17.1	17.1	17.1	17.1	17.1

Note: *DM = Dry Matter, CP = Crude Protein, EE = Ether Extract, CF = Crude Fibre, Ca = Calcium, P = Phosphorus, CT = Condensed Tannins, GE = Gross Energy*

Table 3 Ingredient and chemical composition of finisher diets

Ingredient(g/kg)	Percentage inclusion level of sorghum											
	0%				50%				100%			
Diet	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Maize meal	700	700	700	697	361	358	358	356	0	0	0	0
Sorghum meal	0	0	0	0	360	358	358	357	721	716	716	711
Soya meal	264	259	259	257	243	243	243	241	243	243	243	243
Limestone flour	12	12	12	12	12	12	12	12	12	12	12	12
Broiler maxipack	24	24	24	24	24	24	24	24	24	24	24	24
Phytase	0	5	0	5	0	5	0	5	0	5	0	5
Tannase	0	0	5	5	0	0	5	5	0	0	5	5
Total	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
	Proximate composition (%)											
DM	93.0	93.0	93.0	93.0	95.4	95.4	95.4	95.4	94.3	94.3	94.3	94.3
CP	17.17	17.17	17.17	17.17	17.0	17.0	17.0	17.0	17.8	17.8	17.8	17.8
Fat (EE)	2.32	2.32	2.32	2.32	2.42	2.42	2.42	2.42	2.13	2.13	2.13	2.13
CF	3.56	3.56	3.56	3.56	3.50	3.50	3.50	3.50	4.05	4.05	4.05	4.05
Ca	0.77	0.77	0.77	0.77	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
P	0.37	0.37	0.37	0.37	0.38	0.38	0.38	0.38	0.37	0.37	0.37	0.37
CT	0.02	0.02	0.02	0.02	0.73	0.73	0.73	0.73	1.38	1.38	1.38	1.38
GE(MJ/Kg)	17.77	17.77	17.77	17.77	17.8	17.8	17.8	17.8	17.6	17.6	17.6	17.6

Note: *DM = Dry Matter, CP = Crude Protein, EE = Ether Extract, CF = Crude Fibre, Ca = Calcium, P = Phosphorus, CT = Condensed Tannins, GE = Gross Energy*

Three hundred and sixty, unsexed Cobb 500-day old chicks were randomly allocated to thirty-six 1 m × 2 m pens. The experiment followed a completely randomized design, with 12 dietary treatments replicated three times. There were ten birds in each pen. A 10-cm-thick layer of dry grass was placed on the floor as bedding in all pens. Heat and lighting were provided using 75 W infra-red lamps. The starter diet was fed from days 1–14, whereas the grower and finisher diets were offered from days 15–28 and 29–42, respectively. Feed and water were provided *ad libitum* throughout the feeding trial. Vitamins C and E as well as biotin (Stress Pac®, Irvine's, Zimbabwe) were administered in drinking water on day-old chick arrival to combat the stress experienced during transportation. A foot bath drenched with disinfectant (Virukill®, Veterinary Distributors, Pvt, Ltd, Zimbabwe) was placed at the entrance to the brooding house. Any mortalities were recorded, as they occurred, during the entire experimental period.

Birds were offered feed at *ad libitum* for the entire feeding period and feed refusals were weighed and recorded every morning. Broilers were weighed at 7-day intervals (days 7, 14, 21, 28, 35, and 42) using a Mettler PE 2000 digital scale with an accuracy of ± 0.1 g. Voluntary feed intake (VFI), weekly weight gain (WWG) and feed conversion ratio (FCR) were calculated as follows:

$$\text{VFI} = \text{Feed offered} - \text{Feed refusals} \quad (1)$$

$$\text{WWG} = \frac{\text{Final weight} - \text{Initial weight}}{\text{Initial weight}} \quad (2)$$

$$\text{FCR} = \frac{\text{Total feed consumed}}{\text{Total weight of product produced}} \quad (3)$$

At day 42, seventy-two birds from each dietary treatment comprising 2 birds/replicate were randomly selected for ileal villi morphology analyses. Birds were fasted overnight to limit intestinal throughput. The birds were weighed individually using Salter Model 250-6S™, a digital scale weighing 500 g in 20 g increments. The birds were humanely slaughtered using the neck dislocation method and the carcasses were scalded in hot water at 60 °C for approximately 63 s. Manual plucking was performed to remove all the feathers. The neck was cut between the occipital condyle and atlas bone to separate the head from the carcass; the carpal joint was the marked region at which the feet were separated from the carcass. Carcasses were eviscerated, and the internal organs, including the giblets (heart, liver, lungs, kidneys, spleen, total intestines, and gizzard) and abdominal fat pad (AFP), were weighed on a digital scale (Mettler PE 2000). For intestinal length determination, a flexible tape (± 1 mm accuracy) was used. The carcass was cut into prime cuts of economic importance, namely the wings, legs (thigh and drumstick), and breasts. The cuts were weighed using a digital scale. All carcass measurements were expressed relative to the live body weight (g/kg BW), whereas the length of intestines was recorded in cm/kg BW.

The breast of each bird was cut off the carcass, deboned, packed in polyethylene bags, and then placed in iced cooler boxes prior to transportation. The breast meat samples were then transported to the University of Zimbabwe, Department of Livestock Sciences, where they were kept chilled pending further analyses. *Pectoralis major* muscle samples were collected from the left breast muscle and chilled for 24 h until further analyses. Muscle DM, CP, fat, ash, shear force, and cooking loss were determined.

The AOAC procedure (AOAC, 1995) was used to determine muscle nutrient composition. A portable digital pH meter (CRISON pH25, CRISON Instruments SA, Alella, Spain) with a piercing electrode was used to measure muscle pH at 45 min (initial pH; pHi) and 24 h post-slaughter. The pH meter was calibrated using a buffer solution of pH 7. Shear force was determined using breast muscle strips. Meat strips measuring 1.5 × 1.5 cm and 0.5 cm thick were heated in plastic bags at 96 ºC for 10 min and cooled at room temperature (20–25 °C). The shear force of the cooked breast meat strip samples was determined using a Warner–Bratzler instrument (G-R Electrical Mfg Co., Manhattan, KS 66502; Model 5565, Instron Ltd, Buckinghamshire, UK) according to the method described by Warner *et al*. (2021)

For the determination of cooking loss, breast meat strips of 2.5 × 2.0 × 5.0 cm were boiled until the temperature of the meat reached 90 °C. A hot water bath at 92 °C was used to cook the meat. The cooked samples were cooled at room temperature for 5 min and reweighed. The temperatures of the water-bath and meat samples during cooking were monitored using a handheld digital thermometer. Cook loss was determined using the formula (Galobart and Moran, 2014).

$$\%\ \text{Cook loss} = [100 \times \frac{(W1-W2)}{W1}] \quad (4)$$

where: W_1 is weight of raw meat samples before cooking and W_2 is the post cook weight of the samples cooled.

The data were tested for normality using the Shapiro–Wilk test and $\log_{10}$-transformed wherever necessary. The General Linear Models (GLM) procedure of the Statistical Analysis System, ver. 9.4 (SAS Institute Inc., 2011) was used to analyse the data. Tukey's tests were performed to separate means. All tests were done at 5% level of significance. Two separate statistical models were used for measurements made during the live phase and all measurements made after slaughter.

$$Y_{ijk} = \mu + T_i + W_j + (T + W)_{ij} + \varepsilon_{ijk} \quad (5)$$

where:
Y_{ijk} = response variable (feed intake, weekly weight gain, feed conversion ratio),
μ = general mean common to all observations,
T_i = effect of the i^{th} dietary treatment (0, 50, 100% sorghum level with no enzyme or phytase only or tannase only or phytase + tannase enzyme),
W_j = effect of j_{th} week (weeks 1 to 6),
$(T + W)_{ij}$ = the interaction of week and treatment,
ε_{ijk} = random error term.

$$Y_{ijk} = \mu + T_i + P_j + \varepsilon_{ijk} \quad (6)$$

where:

Y_{ijk} = response variable (live weight, carcass weight, internal organs weight, intestinal length, meat dry matter, CP, EE, ash, pH, shear force, cooking loss),
μ = general mean common to all observations,
T_i = effect of the i^{th} dietary treatment (0, 50 and 100% sorghum level with no enzyme or phytase only or tannase only or phytase plus tannase enzyme combination),
P_j = effect of time postmortem (45 minutes and 24hours post-mortem)
ε_{ijk} = random error term.

Results

The levels of significance for fixed effects on voluntary feed intake (VFI), average weekly weight gain (AWWG), and feed conversion ratio (FCR) are shown Table 4. Week by treatment interactions for VFI, AWWG, and FCR were observed (P <0.05).

Dietary treatment influenced voluntary feed intake during the starter, grower, and finishing feeding phases. Broilers fed a complete sorghum diet with phytase and tannase enzyme combination showed the highest VFI (24.4 ± 0.04 g/bird/day) in the first week, followed by those on total sorghum diets without any enzyme (23.0 ± 1.06 g/bird/day). During the second week, birds fed complete maize diets with phytase and tannase enzyme combination showed the least VFI (65.5 ± 0.45 g/bird/day), whereas those fed complete sorghum diets with enzyme combination had the highest VFI (68.7 ± 0.45 g/bird/day). During the grower feeding phase, broilers fed a complete sorghum diet with phytase showed the highest VFI in the third week (83.0 ± 0.88 g/bird/day) and those fed complete sorghum diet with tannase had the highest VFI in the fourth week (122.0 ± 0.88 g/bird/day). In the finisher feeding phase, broilers fed 50% sorghum diets with tannase showed the highest VFI (135.3 ± 0.05 g/bird/day) in the fifth week. The highest VFI in the final/sixth week was observed in broilers complete maize diets with phytase (158.1 ± 0.88 g/bird/day). Voluntary feed intake for the starter, grower and finishing feeding phases are as shown in Figure 1.

Table 4 Effects of dietary treatment and week on growth performance parameters

Parameter	Treatment	Week	Week*Treatment
Voluntary feed intake	*	***	*
Feed conversion ratio	**	***	**
Average weekly weight gain	****	***	*****

Note. *** P <0.0001, ** P <0.001, * P <0.05, NS = not significant

Week (P <0.0001) and treatment (P <0.05) influenced average weekly weight gain. In addition, week (P <0.05) and treatment (P <0.0001) influenced FCR. Better feed conversion was observed in birds fed complete maize and 50% sorghum diets with or without the enzymes. However, birds fed complete sorghum diets showed the highest feed conversion ratio, despite the presence of enzymes.

A significant interaction of week and treatment (P <0.001) on average weekly weight gain was observed. Broilers offered 50% sorghum diets with tannase showed the highest weekly weight gain (104.3 ± 32.33 g) in the first week. The lowest average weekly weight gain was observed in broilers fed complete maize diets with phytase (77.3 ± 32.43 g). Complete maize diets without enzyme had the highest average weekly weight gain in the second week 9235.1 ± 32.38 g) and the lowest AWWG was observed in broilers fed 50% sorghum diet without any enzyme (182.1 ± 32.33 g). In the third week, birds fed 50% sorghum diets without enzymes had the highest weight gain (393.0 ± 32.33 g). Broilers fed complete maize diet without enzymes had the highest AWWG in the fourth (464.5 ± 32.43 g) and fifth weeks (599.0 ± 32.39 g). At six weeks, broilers fed 50% sorghum diet without enzymes had the highest average weight gain (606.5 ± 32.39 g), which was similar to birds fed complete maize diets with the phytase + tannase enzyme combination (606.3 ± 32.98 g).

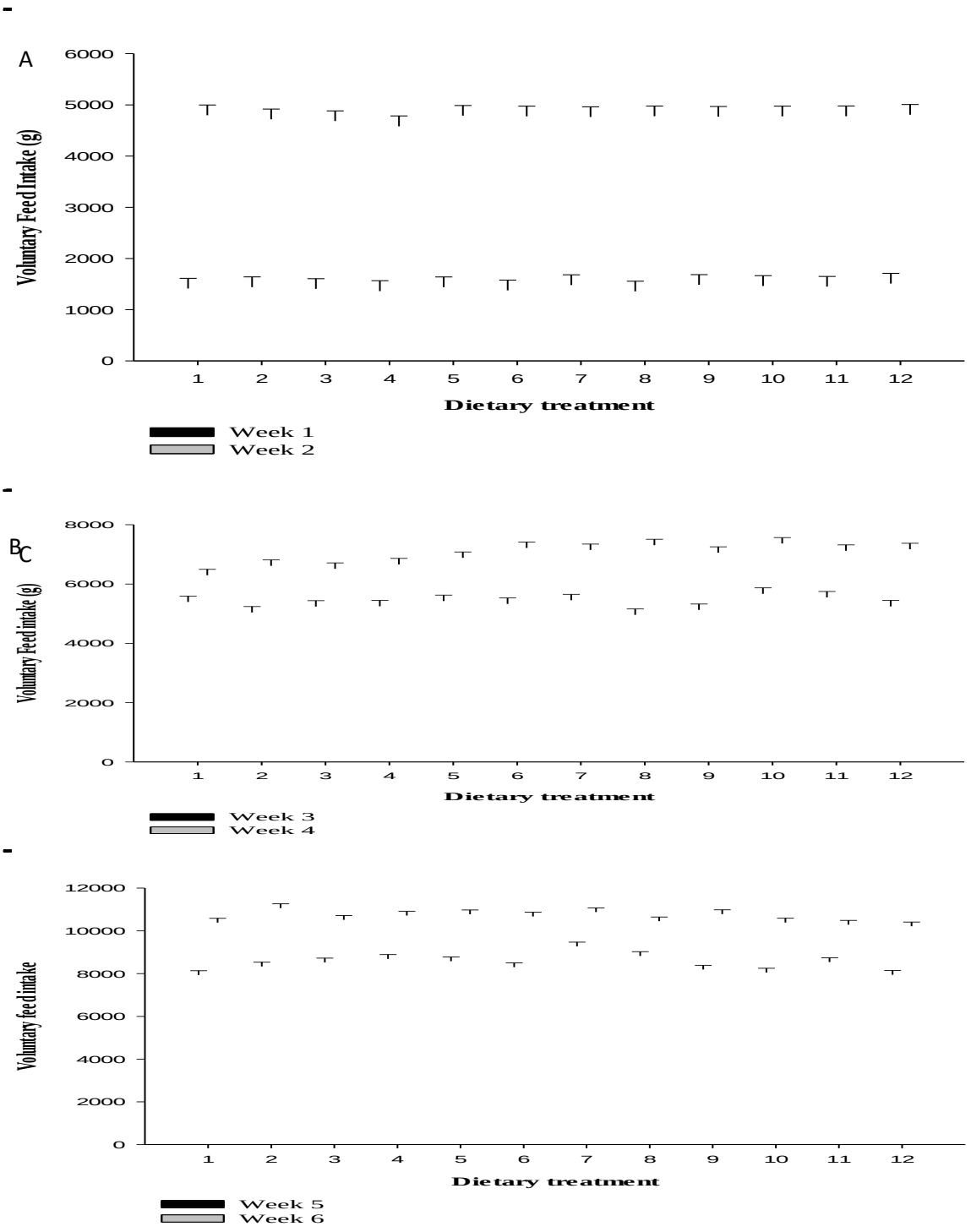

Figure 1 The interaction of treatment and week on voluntary feed intake during the (A) starter, (B) grower, and (C) finisher phases

***Description of treatments: 1* = 100% maize with no enzyme, 2* = 100% maize with 5000 FTU phytase, 3* = 100% maize with 25 TU tannase, 4* = 100% sorghum with a combination of 5000 FTU phytase + 25 TU tannase, 5* = 50% maize and 50% sorghum with no enzyme, 6* = 50% maize and 50% sorghum with 5000 FTU phytase, 7* = 50% maize and 50% sorghum with 25 TU tannase, 8* = 50% maize and 50% sorghum with 5000 FTU phytase + 25TU tannase, 9* = 100% sorghum with no enzyme, 10* = 100% sorghum with 5000 FTU phytase, 11* = 100% sorghum with 25 TU tannase, 12* = 100 sorghum with 5000 FTU phytase + 25 TU tannase

Dietary treatment substantially influenced live body weight, cold carcass weight, shank weight, intestinal length, abdominal fat pad, and kidney weight (Tables 5 and 6). However, treatment had no effect on head, legs, heart, lungs, gizzard, wings, breast, and thigh weights (P >0.05). The highest live body weight (LBW) was observed in broilers fed 50% sorghum with no enzyme, whereas while those fed complete maize with tannase had the lowest weights. Broilers fed 50% sorghum supplemented with phytase and tannase had the highest cold carcass weights. The lowest cold carcass weight was observed in birds fed complete sorghum diets with the phytase + tannase combination and this was similar to the other complete sorghum diets with or without single enzymes. Treatment substantially influenced AFP and the highest value was observed in broilers fed complete maize diets with tannase (10.09 ± 0.31 g). The lowest AFP weight was recorded in birds fed complete sorghum with no enzyme (8.0 ± 0.31 g). Overall, AFP tended to decrease with an increase in sorghum inclusion (Figure 2).

Table 5 The level of significance for live body weight and carcass parameters as influenced by dietary treatments

Parameter	Dietary treatment
Live body weight	*
Cold carcass weight	*
Head	NS
Shank	NS
Intestine weight	**
Abdominal fat pad	***
Heart	NS
Liver	*
Lungs	NS
Kidneys	*
Gizzard	NS
Wings	NS
Breast	NS
Thigh	NS

Note: NS = not significant; * = P <0.05; ** = P <0.01; *** = P <0.0001

Table 6 Effect of dietary treatment on live body and cold carcass weight and carcass cuts of economic importance

Treatment	Live body weight	Cold carcass	Wings	Breast	Leg (Thigh + Drumstick)
1	2100.5 ± 63.50 ^{abc}	761.5 ± 6.43 ^{abcde}	90.1 ± 9.92 ^{b}	259.6± 10.85 ^{c}	221.8 ± 6.56 ^{a}
2	1926.5 ± 63.50 ^{cdef}	747.1 ± 6.43 ^{cde}	90.4 ± 9.92 ^{b}	245.0 ± 10.85 ^{d}	220.3 ± 6.56 ^{a}
3	1952.3 ± 63.50 ^{cdef}	754.5 ± 6.43 ^{abcde}	92.6± 9.92 ^{b}	255.4± 10.85 ^{c}	216.6 ± 6.56 ^{a}
4	2096.8 ± 63.50 ^{abcde}	757.0 ± 6.43 ^{abcde}	87.9 ± 9.92 ^{b}	253.9 ± 10.85 ^{cd}	223.5 ± 6.56 ^{a}
5	2159.7 ± 63.50 ^{abc}	767.9 ± 6.43 ^{abcd}	92.7 ± 9.92 ^{b}	259.1± 10.85 ^{c}	221.1 ± 6.56 ^{a}
6	2004.2 ± 63.50 ^{abcdef}	758.4 ± 6.43 ^{abcde}	84.9 ± 9.92 ^{c}	249.9 ± 10.85 ^{d}	223.4 ± ± 6.56 ^{a}
7	1967.5 ± 63.50 ^{bcdef}	756.4 ± 6.43 ^{abcde}	86.8 ± 9.92 ^{b}	257.9± 10.85 ^{c}	216.9 ± 6.56 ^{a}
8	2102.3 ± 63.50 ^{abcd}	764.1 ± 6.43 ^{abcd}	89.4 ± 9.92 ^{b}	270.9± 10.85 ^{b}	216.5 ± 6.56 ^{a}
9	1950.5 ± 63.50 ^{cdef}	747.2 ± 6.43 ^{cde}	91.5 ± 9.92 ^{b}	254.4± 10.85 ^{d}	221.6 ± 6.56 ^{a}
10	1912.8 ± 63.50 ^{cdef}	752.9 ± 6.43 ^{bcde}	122.5 ± 9.92 ^{a}	292.6 ± 10.85 ^{a}	193.6± 6.56 ^{b}
11	1931.2 ± 63.50 ^{cdef}	743.6 ± 6.43 ^{de}	90.3 ± 9.92 ^{b}	250.1± 10.85 ^{d}	218.8 ± 6.56 ^{a}
12	1920.2 ± 63.50 ^{abcdef}	742.6 ± 6.43 ^{de}	88.7 ± 9.92 ^{b}	238.3± 10.85 ^{d}	215.0± 6.56 ^{a}

Note: *Significance tests were performed at P <0.05*

***Description of treatments: 1* = 100% maize with no enzyme, 2* = 100% maize with 5000 FTU phytase, 3* = 100% maize with 25 TU tannase, 4* = 100% sorghum with a combination of 5000 FTU phytase + 25 TU tannase, 5* = 50% maize and 50% sorghum with no enzyme, 6* = 50% maize and 50% sorghum with 5000 FTU phytase, 7* = 50% maize and 50% sorghum with 25 TU tannase, 8* = 50% maize and 50% sorghum with 5000 FTU phytase + 25TU tannase, 9* = 100% sorghum with no enzyme, 10* = 100% sorghum with 5000 FTU phytase, 11* = 100% sorghum with 25 TU tannase, 12* = 100 sorghum with 5000 FTU phytase + 25 TU tannase

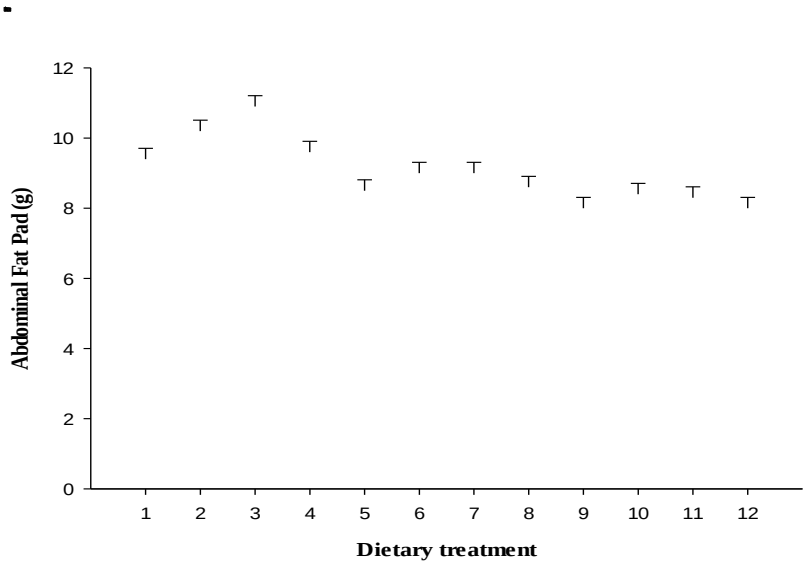

Figure 2 The effect of dietary treatment on abdominal fat pad yield

***Description of treatments: 1* = 100% maize with no enzyme, 2* = 100% maize with 5000 FTU phytase, 3* = 100% maize with 25 TU tannase, 4* = 100% sorghum with a combination of 5000 FTU phytase + 25 TU tannase, 5* = 50% maize and 50% sorghum with no enzyme, 6* = 50% maize and 50% sorghum with 5000 FTU phytase, 7* = 50% maize and 50% sorghum with 25 TU tannase, 8* = 50% maize and 50% sorghum with 5000 FTU phytase + 25TU tannase, 9* = 100% sorghum with no enzyme, 10* = 100% sorghum with 5000 FTU phytase, 11* = 100% sorghum with 25 TU tannase, 12* = 100 sorghum with 5000 FTU phytase + 25 TU tannase

Treatment affected liver weight (P <0.05). Boilers fed complete sorghum diets with phytase had the highest liver weight, whereas those fed complete maize diets with tannase had the lowest liver weight (Table 7). Treatment had no effect on gizzard weight (P >0.05). Broilers fed complete maize diets without enzymes had the heaviest gizzards, whereas the lowest gizzard weight was observed in broilers fed complete sorghum diet without enzymes. Dietary treatment affected intestinal length (P <0.05). Complete sorghum diets with tannase had the longest intestines. This was similar different from birds fed complete maize with either phytase or tannase as single enzymes as well as birds fed complete sorghum diets with or without enzymes (P > 0.05).

Table 7 The effect of dietary treatment on intestinal length, liver, and gizzard weights

Treatment	Liver weight (g)	Gizzard weight (g)	Intestine length (cm)
1	$27.8^{ab} \pm 1.51$	$25.6^{a} \pm 1.80$	$95.3^{defgh} \pm 3.80$
2	$31.0^{a} \pm 1.51$	$23.2^{a} \pm 1.80$	$106.0^{abcdef} \pm 3.80$
3	$26.8^{b} \pm 1.51$	$23.3^{a} \pm 1.80$	$104.0^{abcdefg} \pm 3.80$
4	$30.6^{ab} \pm 1.51$	$21.9^{a} \pm 1.80$	$97.3^{cdefgh} \pm 3.80$
5	$29.4^{ab} \pm 1.51$	$21.4^{a} \pm 1.80$	$93.1^{efgh} \pm 3.80$
6	$27.7^{ab} \pm 1.51$	$22.8^{a} \pm 1.80$	$102.5^{abcdefgh} \pm 3.80$
7	$29.2^{ab} \pm 1.51$	$23.8^{a} \pm 1.80$	$99.7^{bcdefgh} \pm 3.80$
8	$27.3^{ab} \pm 1.51$	$21.2^{a} \pm 1.80$	$94.7^{defgh} \pm 3.80$
9	$29.2^{ab} \pm 1.51$	$21.0^{a} \pm 1.80$	$107.1^{abcdef} \pm 3.80$
10	$31.3^{a} \pm 1.51$	$21.6^{a} \pm 1.80$	$106.0^{abcdef} \pm 3.80$
11	$28.7^{ab} \pm 1.51$	$23.7^{a} \pm 1.80$	$109.7^{abcde} \pm 3.80$
12	$27.3^{ab} \pm 1.51$	$24.1^{a} \pm 1.80$	$104.4^{abcdefg} \pm 3.80$

***Description of treatments: 1* = 100% maize with no enzyme, 2* = 100% maize with 5000 FTU phytase, 3* = 100% maize with 25 TU tannase, 4* = 100% sorghum with a combination of 5000 FTU phytase + 25 TU tannase, 5* = 50% maize and 50% sorghum with no enzyme, 6* = 50% maize and 50% sorghum with 5000 FTU phytase, 7* = 50% maize and 50% sorghum with 25 TU tannase, 8* = 50% maize and 50% sorghum with 5000 FTU phytase + 25TU tannase, 9* = 100% sorghum with no enzyme, 10* = 100% sorghum with 5000 FTU phytase, 11* = 100% sorghum with 25 TU tannase, 12* = 100 sorghum with 5000 FTU phytase + 25 TU tannase

The effects of dietary treatment on breast meat muscle (*Pectoralis major*) dry matter, crude protein, ash, and fat composition are shown in Table 8. Treatment had no effect on dry matter, crude protein, ash, and fat content of meat (P >0.05). Numerically, the highest dry matter composition was

observed in broilers fed complete maize diets with the phytase + tannase enzyme combination but this was not statistically different from the other treatments. Broilers fed complete sorghum diets with phytase + tannase showed the highest CP content although this was not statistically different from the other treatments. The highest ash content was observed in broilers fed complete sorghum diets without any enzyme and this was numerically identical to that of birds fed complete sorghum diets with the phytase + tannase enzyme combination. Broilers fed complete maize without enzymes and broilers fed complete maize diets with tannase had the highest fat content. However, this did not differ substantially from the other treatments. Results of the technical parameters indicated that dietary treatment had no effect on meat pH (45 min and 24 h post-mortem), cooking loss, and shear force (P >0.05).

Discussion

The observations above show that broilers fed total sorghum diets with the phytase + tannase enzyme combination consumed more feed in the first week. Use of the phytase enzyme in either maize or sorghum diets improved feed intake. This result is consistent with previous findings (Shaw *et al*., 2010; Aureli *et al*., 2011) who reported a marked effect of phytase supplementation on feed intake. This is attributed to the role of phytase in releasing phosphorus and making it more available to broilers. Phosphorus deprivation is associated with a loss of appetite (Suttle, 2010), hence a low feed intake. Phytate is an appetite suppressant, hence, the addition of phytase, which breaks down phytate, results in improved feed intake in broilers (Cowieson *et al*., 2011; 2017). The current observations are contrary to those reported by Shaw *et al*. (2011) and van Emmenes *et al*. (2018), who reported that phytase supplementation did not substantially affect voluntary feed intake during the grower or finisher phases. The current findings also contradict previous observations (Torres *et al*., 2013; Sonia *et al*., 2015; Manyelo *et al*., 2019), in which the inclusion level of sorghum inclusion did not affect feed intake in broilers. This can be explained by the fact that taste acuity in chickens is not well developed hence taste of feed plays no role in decreasing feed intake (Mabelebele *et al*., 2018).

Table 8 The effects of dietary treatment on breast meat nutritional composition

Treatment	DM	CP	ASH	FAT
1	26.1^{a} ± 1.50	26.8^{a} ± 2.22	2.0^{a} ± 1.08	2.2^{a} ± 0.41
2	25.7^{a} ± 1.50	27.6^{a} ± 2.22	3.8^{a} ± 1.08	1.7^{a} ± 0.41
3	26.2^{a} ± 1.50	26.8^{a} ± 2.22	3.3^{a} ± 1.08	2.2^{a} ± 0.41
4	28.1^{a} ± 1.50	26.7^{a} ± 2.22	3.1^{a} ± 1.08	2.2^{a} ± 0.41
5	26.0^{a} ± 1.50	25.7^{a} ± 2.22	3.0^{a} ± 1.08	2.0^{a} ± 0.41
6	25.3^{a} ± 1.50	26.8^{a} ± 2.22	1.3^{a} ± 1.08	1.0^{a} ± 0.41
7	26.5^{a} ± 1.50	29.1^{a} ± 2.22	3.1^{a} ± 1.08	2.1^{a} ± 0.41
8	28.0^{a} ± 1.50	24.8^{a} ± 2.22	1.3^{a} ± 1.08	1.4^{a} ± 0.41
9	25.4^{a} ± 1.50	25.5^{a} ± 2.22	4.3^{a} ± 1.08	0.7^{a} ± 0.41
10	29.2^{a} ± 1.50	28.2^{a} ± 2.22	2.6^{a} ± 1.08	1.1^{a} ± 0.41
11	26.2a ± 1.50	24.9a ± 2.22	3.0a ± 1.08	1.1a ± 0.41
12	26.0a ± 1.50	29.9a ± 2.22	4.3a ± 1.08	1.3a ± 0.41

***Description of treatments: 1* = 100% maize with no enzyme, 2* = 100% maize with 5000 FTU phytase, 3* = 100% maize with 25 TU tannase, 4* = 100% sorghum with a combination of 5000 FTU phytase + 25 TU tannase, 5* = 50% maize and 50% sorghum with no enzyme, 6* = 50% maize and 50% sorghum with 5000 FTU phytase, 7* = 50% maize and 50% sorghum with 25 TU tannase, 8* = 50% maize and 50% sorghum with 5000 FTU phytase + 25TU tannase, 9* = 100% sorghum with no enzyme, 10* = 100% sorghum with 5000 FTU phytase, 11* = 100% sorghum with 25 TU tannase, 12* = 100 sorghum with 5000 FTU phytase + 25 TU tannase

Better feed conversion was observed in birds fed the complete maize diet and 50% sorghum diet with or without enzymes. This supports previous observations by Ahmed *et al*. (2013), who reported better FCRs in chicks fed 0, 10%, and 20% water-treated sorghum, whereas the poorest FCR was observed in chicks fed high levels of untreated sorghum. Additionally, Mabelebele *et al*. (2018) corroborated our findings and highlighted that birds fed tannin-containing sorghum had poor feed conversion ratios. The observation that complete sorghum diets resulted in the highest FCR is best explained by the fact that sorghum contains tannins. These tannins reduce energy, starch, protein, and amino acid digestion, resulting in low nutrient utilisation, which translates into low weight gain per unit of feed consumed, resulting in a poor FCR (Hassan *et al*., 2003). Conversely, Tandiang *et al*. (2014) reported that FCR of broilers fed a complete maize diet was poor. However, Manyelo *et al*. (2019)

observed that the FCR of birds fed high-sorghum diets (50%, 75% and 100% inclusion levels) was better than that of birds fed low-sorghum diets (0% and 25%). The observation that in the early weeks of life, feeding broilers with 50% sorghum diets resulted in higher body weight is consistent with previous findings (Manyelo *et al*., 2019). They stipulated that body weight was higher for birds fed 50% sorghum diets than for broilers fed 100% maize-based diets during the first three weeks of life. From day 22 to slaughter, weight gain was substantially higher in broilers fed high-sorghum diets (50%, 75%, and 100% sorghum) than in those fed low-sorghum diets (25% and 0% sorghum) (Manyelo *et al* 2019). However, Mabelebele *et al*. (2018) reported that sorghum inclusion had no marked effect on weight gain of growing broiler chickens because they used a tannin-free sorghum cultivar. In contrast, broilers fed maize-based diets showed higher weight gain than those fed with malted sorghum (Manyeula *et al*., 2022).

The observation that phytase addition to sorghum diets resulted in a higher body weight gain in the first week of life agrees with previous findings (Shaw *et al*., 2011; Sousa *et al*., 2015; van Emmenes *et al*., 2018). Supplementation of maize–soyabean diets with phytase resulted in 11.04% increase in body weight compared to broilers fed the same diet without phytase supplementation (Sousa *et al*., 2015). In addition, during the starter phase (1–21 d), the combination of phytase and xylanase showed the best weight gain compared to the treatments containing xylanase only (Dessimoni *et al*., 2019). This indicates that when used in combination with other enzymes, phytase elicits an additional increase in body weight gain.

During the final week of life, the addition of the phytase and tannase enzyme combination resulted in significantly higher weight gain, which conforms to previous observations. In previous studies, the addition of tannase had no significant effect on final body weight gain but led to low feed intake (FI) and improved feed conversion efficiency (Abdulla *et al*., 2016). The addition of tannase to maize-soybean-grape pomace diets had no significant effect on weight gain during the growing (days 11–24) and finishing feeding phases (days 25–42 (Ebrahimzadeh *et al*., 2018). The use of tannase in wheat straw diets resulted in a 1.8-fold reduction in tannin content (Raghuwanshi *et al*., 2014). They also highlighted that a 0.1% tannase concentration resulted in an approximately double increase in lactase and xylanase activities. This clearly indicates that tannase can synergistically work with other enzymes to improve their efficiency. However, owing to a lack of knowledge on the catalytic activities and mode of action of tannase, its use is still low. There is very little published data on the use of tannases in livestock diets.

The observation that dietary treatment had a marked effect on live and carcass weights corroborates previous findings (Yunusa *et al*., 2014). In their study, Yunusa *et al*. (2014) observed that broilers fed red sorghum had the lowest live and carcass weights compared to those fed pearl millet, maize, and white sorghum. However, these results contradict previous observations by Carolino *et al*. (2014) and Silveira *et al*. (2017), who observed that sorghum-based feed had no marked effect on carcass yield. Additionally, Mabelebele *et al*. (2018) reported that there was no substantial difference in carcass, breast, thigh, and drumstick weights among broilers fed different sorghum varieties at 21 d of age. The results are also in agreement with previous observations by van Emmenes *et al*. (2018) and Dessimon *et al*. (2019), who found that phytase supplementation had no effect on carcass component yield.

The result that dietary treatment had no marked effect on cuts of economic importance agrees with previous observations. Carcass yield of cuts of economic importance in broiler chickens were not substantially different among the various dietary treatments (Garcia *et al*., 2013; Torres *et al*., 2013). The results of the current study indicate that abdominal fat pad was substantially lower in birds fed complete sorghum diets. Medugu *et al*. (2010) highlighted that the abdominal fat pad was lower in birds fed millet diets than in those fed maize- and high-tannin, sorghum-based diets.

Lung, kidney, liver, and heart weights were not substantially different among treatments (Yunusa *et al*., 2014). However, the authors observed that gizzard weights were substantially higher in birds fed maize–soyabean diets than in those fed sorghum and millet diets. The current results showed that dietary treatment substantially influenced intestinal length. These results corroborate those of Momtazan *et al*. (2010), who observed that the inclusion of phytase and carbohydrase enzyme complexes resulted in a reduction in jejunum length. This is ascribed to the breakdown of antinutrients which reduces the viscosity of the digesta, and consequently, has a negative effect on intestinal length (Momtazan *et al*., 2010). The finding that dietary treatment had no marked effect on other digestive organ weights is surprising, because it was hypothesised that sorghum diets promoted muscle hypertrophy in the gizzard (Manyelo *et al*., 2019) to reduce particle size and improve the efficiency of

digestion. The increase in gizzard weight leads to an increase in the efficiency of digestion and metabolism, thus increasing oxygen and blood supply demand. The high demand for blood supply results in an increase in heart weight (Khanyile *et al*. 2017). In addition, the catabolism of nitrogenous compounds increases the level of waste in the blood, and thereby increasing the workload of the kidneys. This subsequently leads to an increase in kidney weight and size (Khanyile *et al*., 2017). These results are similar to previous findings (Thomas & Ravindran, 2008; Melingasuk *et al*., 2012; Ahmed *et al*., 2013; Silva *et al*., 2015), who found no marked difference in digestive tract organ weight in broilers fed sorghum or maize diets.

The current results, however, contradict those of Fernandes *et al*. (2013), who observed that the inclusion of 50% or 100% whole sorghum grain resulted in a substantially high gizzard and small intestine weight. Complete replacement of maize by sorghum also resulted in higher liver, gizzard, and small intestine absolute and relative weights of broilers aged 1–21 d (Manyelo *et al*., 2019). Similar findings were observed by Zhu *et al*. (2014), who found that addition of exogenous enzymes resulted in low digestive organ weight. It was anticipated that complete sorghum diets would result in lower liver and gizzard weights. This is because sorghum tannins and phytate can reduce the interaction between digestive enzymes and their respective substrates, thus altering the structure and function of digestive organs (Martinez-Gonzalez *et al*., 2017). The inclusion of tannase and phytase enzymes could have counteracted this response (Pasquali *et al*., 2016), thus no negative effect of sorghum diets on digestive tract organs was observed.

The eating quality of meat is a function of its flavour, juiciness, and tenderness (Verbeke *et al*., 2010). The pH range shows the amount of glycogen stored in the breast muscle before slaughter and how rapidly it was converted to lactic acid post-mortem (Dyubele *et al*., 2010). The meat pH recorded in this study falls within the ranges cited in previous studies of 5.84–6.05 (Le Bihan-Duval *et al*., 2008; Fernandes *et al*., 2016; Abubakar *et al*., 2021) indicating that the pH value of the meat was good. As anticipated, the pH of breast meat 24 h after slaughter was slightly lower than that of meat 45 min post-mortem. This is because post-mortem oxygen deficit facilitates anaerobic glycolysis of glycogen, leading to the formation of lactic acid from pyruvate, thus decreasing muscle pH (Brossi *et al*., 2009). A reduction in pH is required for correct maturation of meat during the muscle–meat conversion stage (Brossi *et al* 2009). The observation that dietary treatment had no marked effect on meat pH is in agreement with previous observations by Moses *et al*. (2022). In their study, Moses *et al*. (2022) observed that the pH of meat of broilers fed red and white sorghum was 5.6 and 5.5, which is comparable to 5.5 of maize diets. Thus, the inclusion of sorghum in broiler diets did not affect glycogen levels or meat maturation. However, there are external factors that influence meat pH, such as environmental temperature, handling of broilers before slaughter, and storage temperature (Lawrie, 2003).

The finding that dietary treatment had no effect on cooking loss and shear force is similar to previous results (Córdova-Noboa *et al*., 2018), who observed that partial and complete replacement of sorghum for maize had no effect on shear force and cooking loss. Masenya *et al*. (2021) found that the use of whole or crushed sorghum in broiler diets had no marked effect on shear force and cooking loss. The shear force, and hence meat tenderness, is influenced by myofibrillar integrity, sarcomere length, connective tissue cross-linking, collagen content of the intramuscular connective tissue, protein denaturation during cooking, and ultimate meat pH (Schönfeldt & Strydom, 2011; Yamauchi & Sricholpech, 2012; Hughes *et al*., 2014; Warner *et al*., 2021).

Moisture content is an important parameter that influences meat palatability, colour, texture, and flavour (Rabia *et al*., 2018). The results of the current study corroborate those of Bogosavljevic-Boskovic *et al*. (2010) and Mohammed (2020). They found meat moisture, fat, and crude protein ranges of 72.8–77.9, 2.26–6.74 and 20.02–26.07%, respectively. A meat fat content less than 10% is classified as lean (Williamson *et al*., 2005) and is good for heart health. High levels of fat, particularly saturated fat and cholesterol, increase the risk of cardiovascular diseases, hence the preference for lean meat (Bronzato & Durante, 2017).

Conclusion

Sorghum can be used in broiler diets (up to 50% inclusion) with no adverse effects on VFI, weight gain, and FCR. The use of phytase and tannase enzymes, alone or in combination in sorghum-based diets, results in better feed intake, weight gain and feed efficiency. It was also concluded that sorghum has no adverse effects on carcass and cut-part yields, nutritional composition, or meat physical parameters.

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Authors' contributions

R.P Magaya conducted the research, collected data, and wrote the draft manuscript; T. Mutibvu analysed the data and provided mentorship and supervision during the planning and execution of the research, proofread and corrected the manuscript; E.T. Nyahangare supervised during the planning and execution of the research, proofread and corrected the manuscript; S. Ncube supervised during the planning and execution of the research, proofread and corrected the manuscript.

Conflict of interest

The authors declare that there are no conflicts of interest attached to this work.

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