Agroforest Syst (2024) 98:245–254
https://doi.org/10.1007/s10457-023-00902-7

Dose-related responses of broiler chickens to black velvet tamarind (*Dialium guineense*) stem bark supplementation: carcass characteristics, organ weight and intestinal biometry

Ifeanyichukwu P. Ogbuewu · **Christian A. Mbajiorgu**

Received: 18 January 2023 / Accepted: 30 August 2023 / Published online: 14 September 2023

Abstract Carcass characteristics, organ weights, and intestinal biometry of broiler chickens fed diets supplemented with black velvet tamarind (*Dialium guineense*) stem bark (BSB) were assessed. Two hundred, day-old Ross 308 broilers were divided into 4 groups of 50 chickens, and each group replicated five times. Each group were assigned to one experimental diet in a completely randomised design designated T0 (0), T1 (0.5), T2 (1.0) and T3 (1.5 g BSB/kg feed). Data obtained on carcass characteristics, organ weights, and intestinal biometry were analysed statistically. Results showed that BSB was low in crude protein (6.42%) and high in crude fibre (30.65%) and ash (9.35%). Broiler chickens fed diet T1 had significantly higher ($P < 0.05$) breast and drumstick weights than those offered the other 3 diets. There were significant differences ($P < 0.05$) in the abdominal fat pad, liver, proventriculus, gizzard weight, and intestinal biometry of broiler chickens in all the groups. Results also showed that dietary BSB supplementation level had a quadratic effect ($P < 0.05$) on breast, drumstick, liver, proventriculus weight, abdominal fat pad, and intestinal biometry of broiler chickens. In contrast, dietary BSB supplementation levels had linear effect ($P < 0.05$) on gizzard weight. It can be concluded that BSB is rich in ash and fibre, and is suitable as a feed additive in broiler chicken diets at a level not beyond 0.5 g/kg feed for best organ weight, carcass yield, intestinal biometry. Thus, there is potential to utilize BSB for improved productivity of broiler chickens.

Keywords Black velvet tamarind · Carcass traits · Organ weights · Gut biometry · Broiler chickens · Quadratic function

I. P. Ogbuewu (✉)
Department of Animal Science and Technology, Federal University of Technology, Imo State, P.M.B. 1526, Owerri, Nigeria
e-mail: dr.ogbuewu@gmail.com

I. P. Ogbuewu · C. A. Mbajiorgu
Department of Agriculture and Animal Health, University of South Africa, Florida Science Campus, Private Bag X6, Florida 1710, South Africa

Introduction

High performance and productivity are the needs of the modern broiler chicken industry which to a certain extent could be achieved by the use of specific feed additives. Antibiotic growth promoters (AGPs) were continually included in animal diets at sub-therapeutic doses to improve animal performance and health by reducing the activity of destructive microbes in the digestive tract (Dibner and Richards 2005). However, the routine use of AGPs in animal diets was associated with the development of bacterial resistance toward several antibiotic substances (Marshall and Levy 2011). Given the global trend to restrict or reduce the use of AGPs in animal production, there are an increasing number of studies on the use non-therapeutic alternatives such as prebiotics, enzymes, probiotics, immunostimulants, organic acids, and phytogenic feed additives (PFAs) as an alternative to AGPs in chicken nutrition. Phytogenic feed additives have also been reported to be relatively safe, effective and cheaper. It is also the most preferred because it contains several phytochemicals (terpenes, saponins, flavonoids, tannins, alkaloids, phenol, and glycosides) of pharmacological importance in animal production (Dhan et al. 2012). There are several species of tropical plants with high therapeutic value. Some of these plants are still underutilised; one such potential plant is black velvet tamarind (*Dialium guineense*), which is rich in essential nutrients and phytochemicals (Ogbuewu et al. 2023).

Black velvet tamarind is a tropical fruit-bearing tree in the flowering plant family Fabaceae and subfamily Caesalpinioideae. It is also a woody plant with a densely hairy leafy crown, smooth greyish bark, and whitish flowers that bear thick black fruits. The tree grows up to 30 m tall and thrives well in the rainforest region of West Africa (Akinpelu et al. 2011). The pulp is edible and may be eaten raw or soaked in water and consumed as a beverage. The stem bark leaves, and fruits are utilised in traditional medicines to treat a variety of diseases (Arbonnier 2004; Akinpelu et al. 2011). The use of black velvet tamarind stem bark as an alternative to AGPs in chicken production seems logical because of their proven anti-microbial activity in vitro (Olajubu et al. 2012; Gideon et al. 2013). Besides that, black velvet tamarind bark is high in fibre, which may have a significant impact on gastrointestinal tract (GIT) development, enzyme production, and digestive physiology of avian species (Jha and Mishra 2021). On the same hand, the addition of black velvet tamarind stem bark (BSB) to chicken feed is expected to maintain the integrity of the intestine by strengthening mucosal structure and functions and increasing the population and diversity of microbiota in the GIT.

Based on the literature available to date, there is limited information on the effects of BSB on broiler chicken productivity and no recommendations for the optimum supplementation level in their diet. To bridge the observed knowledge gap, this experiment aimed to provide baseline information on the effect of diets with and without BSB supplementation on carcass characteristics, organ weights, and intestinal biometry of broiler chickens broiler chickens.

Materials and methods

Ethical approval, study site and black velvet tamarind powder preparation and analysis

Permission for the use of animal and animal protocol was approved by the Animal Ethics Committee of the Federal University of Technology Owerri (FUTO), Imo state, Nigeria (Reference number: 2021–0264). This study was performed at the Teaching and Research farm, FUTO (Latitude 4° 4′ and 6° 3′ N and Longitude: 6° 15′ and 8° 15′ E). This experiment was conducted from November 2021 to January 2022.

Fresh stem barks were harvested from black velvet tamarind trees in the Botanical garden of the Department of Forestry and Wildlife Technology, FUTO. The stem barks were chopped into smaller pieces with the sharp stainless knife and thereafter spread lightly on tarpaulin under the shed to air-dry for about 14 days and thereafter milled using hammer mill to produce black velvet tamarind stem bark (BSB) powder following the procedures Moronkola et al. (2017). Thereafter, powdery mass BSB was stored in an unused feed bag for feed supplementation. The AOAC (2008) method was used to analyse BSB samples in triplicates to determine the dry matter value (method no 930.15), crude fibre (method no 978.10), ash (method no 924.05), ether extract (method 954.02) and nitrogen content (method no 984.13). Crude protein was computed by multiplying N content by 6.25. The values were reported in percentages (%).

Experimental diets

Two standard diets (Table 1) were formulated for the starter phase (1–21 days) and finisher phase (22–47 days) to meet the minimum requirement of Ross 308 broiler chicken (NRC 1994; Aviagen 2019). The rationale to formulate the diets was to enhance experimental design. At each phase, the standard diets were divided into four equal portions and labelled diets T0 to T3. Diet T0 contained 0 g BSB/kg feed supplementation, diet T1 was supplemented with 0.5 g BSB/kg feed, while diets T2 and T3 were supplemented with 1.0 and 1.5 g BSB/kg feed, respectively. The chemical analysis was done as per AOAC (2008).

Table 1 Ingredient and nutrient composition of basal-diet fed to broiler chickens* and BSB

Ingredients	Starter (up to 3 weeks)	Finisher (3–7 weeks)	BSB	Quantity (%)
Maize	52.00	60.00	Dry matter (%)	86.54 ± 0.13
Soybean meal	30.00	26.00	Moisture (%)	13.46 ± 0.26
Wheat offal	3.50	2.00	Crude protein (%)	6.42 ± 0.15
Palm kernel cake	4.00	3.00	Ether extract (%)	0.47 ± 0.04
Spent grain	3.50	1.00	Crude fibre (%)	30.65 ± 0.41
Fish meal	3.00	3.00	Total ash (%)	9.35 ± 0.02
Bone meal	2.50	3.00		
Limestone/oyster shell	0.50	1.00		
Common salt	0.25	0.25		
Mineral-vitamin premix**	0.25	0.25		
Lysine	0.25	0.25		
Methionine	0.25	0.25		
Total	100.00	100.00		
Calculated values				
Crude protein (%)	23.90	20.39		
ME (Kcal/kg)	3003	3100		
Crude fibre (%)	4.08	4.08		
Crude fat (%)	4.44	4.44		
Ash (%)	1.66	1.66		
Calcium (%)	1.63	1.63		
Phosphorus (%)	1.14	1.14		
Analysed values				
Crude protein (%)	23.98	20.43		
ME (Kcal/kg)	3003	3100		
Crude fibre (%)	4.18	4.21		
Crude fat (%)	4.45	4.43		
Ash (%)	1.67	1.66		
Calcium (%)	1.64	1.65		
Phosphorus (%)	1.15	1.13		

*Formulated according to Ross 308 nutrition specifications (2019) (Aviagen 2019)

**To provide the following per kg feed: vitamin A: 12,000 IU; vitamin B_1: 1.43 mg; vitamin D_3: 3500 IU; vitamin B_3: 40.17 mg; vitamin E: 44.7 IU; vitamin B_2: 3.44 mg; pantothenic acid: 6.46 mg; vitamin B_6: 2.29 mg; biotin: 0.05 mg; folic acid: 0.56 mg; vitamin B_{12}: 0.05 mg; vitamin K_3: 2.29 mg; iron: 120 mg; zinc: 120 mg; copper: 15 mg; manganese: 150 mg; cobalt: 0.4 mg; selenium: 0.3 mg; iodine: 1.5 mg

$^+$Chemical analysis was done using the method of AOAC (2008)

Chickens, housing and experimental design

Two hundred-day-old Ross 308 broiler chicks (mean live weight: 40 ± 1 g) purchased from a commercial hatchery were used for the experiment. Broiler chickens were distributed to four dietary groups (50 broiler chickens/group; 10 broiler chickens/replicate) in a completely randomized design. Broiler chickens were housed in a deep litter system (replicate pen dimension: 2.0 m × 2.0 m). Wood shavings were spread on the floor of the pen to a depth of 3 cm. Drinkers and feeders were cleaned daily in the morning before being used. The feeding schedule consisted of a mash starter diet until 21 days and a mash finisher diet until 47 days of age. Feeds and water were given ad libitum throughout the 47 days of the feeding trial. The vaccination programme was implemented following Ross broiler management guide (Aviagen 2019). The temperature of the house was regulated and maintained within 31 °C ± 2 from day 1 to 7 and reduced by 2 °C after each consecutive 7 days until the house temperature was 26 °C ± 2. From the 8th day till the end of the study, the broiler chickens were provided with light having an intensity of 10 lx for 18 h with 6 h of darkness. All experimental diets for each starter and finisher phase were prepared with the same batch of ingredients and all diets within a period had the same composition.

Measurements of carcass traits, organ weight, and intestinal biometry

On the 47th day of the study, three broiler chickens per replicate were selected, tagged and weighed. The broiler chickens were fasted for 12 h and slaughtered via the cervical dislocation method. After scalding, feather picking and evisceration were performed and different cut parts and organs were weighed following the guidelines of USDA (1989). Carcass and organ weight values were expressed as a percentage of the mean live weight. The lengths and weights of the intestines were measured following the procedures outlined by Maoba et al. (2021) and Ahiwe et al. (2022).

Statistical analysis

Data on carcass traits, organ weights and intestinal biometry were analysed using General Linear Model procedure of the statistical analysis system of SAS Institute using one-way analysis of variance (SAS 2010). The differences among means were determined ($P<0.05$) by Duncan's multiple range test of the same package. The statistical model used was as follows: $Y_{ijk}=\mu+\alpha_i+\beta_{ijk}$, where Y_{ijk}=overall observation (carcass characteristics, organ weights, lengths and weight of the intestines), μ=population means, α_i=effect of ith treatment (i=diets T0, T1, T2 and T3) and β_{ijk}=residual effect. The responses in carcass traits, organ weight and lengths and weights of the gastro intestines tract to dietary BSB supplementation levels were modeled using the following quadratic equation (Eq. 1) (SAS 2010):

$$Y = a + b_1x + b_2x^2 \quad (1)$$

where y=carcass traits, organ weight, length and weights of the intestines; a=intercept on the y-axis; b_1 and b_2=coefficients of the quadratic equation; x=dietary BSB supplementation level and $-b_1/2b_2$=x value for optimum response. The basis for using a quadratic equation was used because it gave the best fit.

The relationship between optimal responses in gizzard weight and dietary BSB supplementation level was modeled using a linear regression equation (Eq. 2) (SAS 2010) of the form:

$$Y = a + bx \quad (2)$$

where y=optimal gizzard weight; a=intercept, b=coefficient of the linear equation and x=dietary BSB supplementation level. The model was fitted to the experimental data using the non-linear model (NLIN) procedure of SAS (SAS 2010). The model was used because it gave the best fit.

Results

Proximate composition, carcass yield and cut-part weight

The calculated and analysed chemical composition of experimental basal diets for starter and finisher phases and the composition of BSB are shown in Table 1. The result of the carcass characteristics of broiler chickens is presented in Table 2**.** There were no significant differences ($P>0.05$) in live, kill-out, and

Table 2 Carcass characteristics of broiler chickens fed diets supplemented with BSB

Parameters	T0	T1	T2	T3	Mean	SEM	*p*-value
Live weight (kg)	2.52	2.57	2.55	2.50	2.54	0.03	0.695
Kill out weight (kg)	2.38	2.43	2.39	2.36	2.40	0.05	0.141
DFW (kg)	2.24	2.31	2.27	2.24	2.27	0.96	0.891
Dressed weight (kg)	1.87	1.93	1.86	1.84	1.88	0.05	0.785
Dressing percentage	74.31	75.06	73.00	73.68	74.01	1.84	0.283
Breast (% live weight)	16.82[c]	20.54[a]	17.33[b]	18.03[b]	18.18	1.06	0.015
Drumstick (% live weight)	8.60[b]	9.33[a]	8.27[b]	8.68[b]	8.72	0.34	0.044
Thigh (% live weight)	12.78	11.29	11.03	11.51	11.65	1.18	0.134

[a–c]Means within a row with different superscripts are significantly different ($P<0.05$) according to the Duncan's multiple range test; *T0* standard diet + 0 g BSB/kg feed; *T1* standard diet + 0.5 g BSB/kg feed; *T2* standard diet + 1.0 g BSB/kg feed; *T3* standard diet + 1.5 g BSB/kg feed; *DFW* de-feathered weight*; SEM* standard error of the mean, *p* probability value de-feathered weights among the treatment groups. On the same hand, there were no significant differences ($P > 0.05$) in the dressed weight and dressing percentage for broiler chickens offered diet T1 with those offered the other three diets,. Breast weight recorded for broiler chickens in T1 group was significantly heavier ($P < 0.05$) than those in the other three dietary groups. In addition, there were no significant differences ($P > 0.05$) in the breast weight for broiler chickens on diets T2 and T3; however, the breast weights of broiler chickens on diets T2 and T3 differed significantly ($P < 0.05$) from those on diets T0 and T1. There was significant difference ($P < 0.05$) between T1 and those on diets T0, T2 and T3 in the drumstick weight; however, broiler chickens on T1 recorded significantly higher ($p < 0.05$) drumstick weight. There was no significant difference ($P > 0.05$) in the thigh weight among treatment groups, with broiler chickens on diet T2 recording the lowest value.

Organ weight

The effect dietary BSB supplementation on organ weights of broiler chickens is presented in Table 3. The results showed that heart, lungs, spleen, pancreas and bursa of Fabricius weights of broiler chickens fed diet T0 was not significantly ($P > 0.05$) different from those offered the treatment diets. The liver weight of broiler chickens fed diet T1 was not significantly different ($P > 0.05$) from the value obtained in broiler chickens fed diet T3, but differed significantly ($P < 0.05$) from broiler chickens fed diets T0 and T2. Broiler chickens on diet T0 had significantly ($P < 0.05$) lower weight of gizzard than broiler chickens offered diets T1, T2 and T3. Similarly, broiler chickens on diet T0 had significantly lower ($p < 0.05$) proventriculus weight than those on diets T2 and T3, but were not significantly different ($P > 0.05$) from those on diet T1. In contrast, broiler chickens that received diet T0 had significantly higher ($P < 0.05$) abdominal fat pads than those fed diets T1, T2 and T3. However, broiler chickens fed diet T3 had the lowest abdominal fat pad when compared to those on other two treatment diets (T1 and T2).

Intestinal biometry

The results of the lengths and weights of the intestines are shown in Table 4. There were no significant differences ($P > 0.05$) in the weights and lengths of the large intestine. Broiler chickens on diets T2 and T3 had significantly higher ($P < 0.05$) duodenal weight than those on the control diet but were not significantly different ($P > 0.05$) from those on diet T1. In addition, broiler chickens on diets T2 and T3 had significantly heavier ($P < 0.05$) jejunal than those in groups fed diets T0 and T1. Broiler chickens on the control diet had significantly lower ($P < 0.05$) ileal weight than those on diets T1 and T3. On the other hand, there was no significant difference ($P > 0.05$) between broiler chickens offered diets T0 and T2 in ileal weight. Broiler chickens in groups fed the control diet had significantly reduced ($P < 0.05$) caecal weight compared to those on diet T3. However, there was no significant difference ($P > 0.05$) among broiler chickens fed diets T0, T1 and T2 in caecal weights.

Table 3 Organ weights of broiler chickens fed diets supplemented with BSB

Weight	T0	T1	T2	T3	Mean	SEM	*p*-value
Liver (% LW)	1.59^{c}	2.34^{b}	2.59^{a}	2.21^{b}	2.18	0.07	0.024
Heart (% LW)	0.52	0.42	0.52	0.53	0.50	0.61	0.106
Lungs (% LW)	0.59	0.58	0.60	0.58	0.59	0.14	0.247
Spleen (% LW)	0.11	0.08	0.10	0.09	0.10	0.03	0.154
Pancreas (% LW)	0.12	0.22	0.22	0.23	0.20	0.05	0.126
Bursa of Fabricius (% LW)	0.12	0.12	0.10	0.10	0.09	0.06	0.093
Proventriculus (% LW)	0.45^{b}	0.49^{ab}	0.52^{a}	0.53^{a}	0.45	0.04	0.023
Gizzard (% LW)	1.72^{c}	1.77^{b}	1.85^{a}	1.89^{a}	1.71	0.02	0.019
Abdominal fat pad (% LW)	2.29^{a}	2.12^{c}	2.06^{b}	1.84^{a}	2.05	0.01	0.013

$^{a-c}$Means within a row with different superscripts are significantly different ($P < 0.05$) according to the Duncan's multiple range test; *LW* live weight; *T0* standard diet + 0 g BSB/kg feed; *T1* standard diet + 0.5 g BSB/kg feed; *T2* standard diet + 1.0 g BSB/kg feed; *T3* standard diet + 1.5 g BSB/kg feed; *SEM* standard error of the mean, *p* probability value

Table 4 Intestinal biometry of broiler chickens fed diets supplemented with BSB

Parameters	T0	T1	T2	T3	Mean	SEM	*p*-value
Weight							
Duodenum (g)	15.67[b]	18.67[ab]	21.33[a]	21.00[a]	19.17	0.92	0.046
Jejunum (g)	36.67[c]	47.67[b]	55.00[a]	55.00[a]	48.67	3.32	0.036
Ileum (g)	25.33[b]	33.67[a]	28.00[b]	32.33[a]	29.83	1.10	0.024
Large intestine (g)	5.00	3.00	3.67	5.00	4.17	0.44	0.068
Caecum (g)	14.00[bc]	14.00[bc]	17.33[ab]	18.33[a]	15.67	1.13	0.013
Length							
Duodenum (cm)	28.70[b]	34.83[a]	35.33[a]	35.33[a]	33.55	1.36	0.044
Jejunum (cm)	85.93[b]	94.27[a]	86.47[b]	96.42[a]	90.77	3.01	0.017
Ileum (cm)	76.67[b]	81.66[ab]	84.67[a]	86.67[a]	82.42	2.08	0.045
Large intestine (cm)	11.70	9.37	10.06	10.77	10.61	0.55	0.066

[a–c] Means within a row with different superscripts are significantly different ($P<0.05$) according to the Duncan's multiple range test; *T*0 standard diet + 0 g BSB/kg feed; *T*1 standard diet + 0.5 g BSB/kg feed; *T*2 standard diet + 1.0 g BSB/kg feed; *T*3 standard diet + 1.5 g BSB/kg feed; *SEM* standard error of the mean, *p* probability value

Table 5 BSB supplementation levels for optimal carcass and organ weight of broiler chickens

Variables	Quadratic equation	r^2	Optimal x-level	Optimal y-level	*p*-value
Breast (% LW)	$Y = 14.3 + 3.817x - 0.755x^2$	0.28	2.53	19.12	0.037
Drumstick (% LW)	$Y = 7.995 + 0.53x - 0.08x^2$	0.19	3.31	8.87	0.021
Liver (% LW)	$Y = 0.2425 + 1.6235x - 0.2825x^2$	0.99	2.87	2.58	0.044
Proventriculus (% LW)	$Y = 0.3925 + 0.0645x - 0.0075x^2$	0.99	4.30	0.53	0.035
Abdominal fat pad (% LW)	$Y = 2.1425 + 0.0765x - 0.0375x^2$	0.98	1.02	2.18	0.018

X level optimal BSB supplementation level, *Y* value optimal carcass and organ weight, r^2 coefficient of determination, *p* value probability value

There was a significant increase ($P<0.05$) in the duodenal lengths of broiler chickens fed diets T1, T2 and T3 when compared to those fed the control diet. Broiler chickens on diets T0 and T2 had significantly shorter ($P<0.05$) jejunum length than those on the other two diets. Similarly, the ileal length of broiler chickens fed diet T0 was significantly shorter ($P<0.05$) than those fed diets T2 and T3. However, there was no significant difference ($P>0.05$) on ileal length in broiler chickens on diets T0 and T1.

Optimisation model

Results of the effect of BSB supplementation level on optimal cut-part (i.e. breast and drumstick) weights, organ (liver, gizzard, and proventriculus) weights and abdominal fat pad in broiler chickens are presented in Table 5. Breast and drumstick weights were optimised at 2.53 and 3.31 g BSB/kg feed, respectively.

Table 6 Relationship between BSB supplementation levels and gizzard in broiler chickens

Variable	Formular	r^2	*p*-value
Gizzard (% LW)	$Y = 1.66 + 0.059x$	0.90	0.019

r^2 coefficient of determination, *p* probability value

Similarly, liver and proventriculus weights were optimised at 2.87 and 4.30 g BSB/kg feed, respectively. Results also indicated that dietary BSB supplementation level had a quadratic effect ($P<0.05$) on the abdominal fat pad and was optimised at 1.02 g BSB/kg feed. The result of optimal gizzard weights of broiler chickens fed BSB-supplemented diets as presented in Table 6 revealed that BSB supplementation level had a linear effect ($P<0.05$) on gizzard weight.

The results of BSB supplementation level on the weights and lengths of the intestines are presented in Table 7. Results indicated that BSB supplementation had a quadratic effect ($P<0.05$) on weights and lengths of the intestines in broiler chickens. Duodenal, jejunal, ileal and caecal weights were optimised at 3.62, 3.63, 3.83 and 0.76 g BSB/kg feed, respectively. Duodenal, jejunal, ileal and caecal lengths of broiler chickens were optimised at BSB supplementation levels of 3.17, 0.44 and 4.71 g/kg feed, respectively.

Discussion

The use of herbal products in animal production has gained a lot of research because of their several mechanisms of action which include improvement in nutrient digestibility and gut health (Hippenstiel et al. 2011). Positive effects of herbal products on chicken performance for example are postulated to stabilise the proliferation of gut microbiota leading to a reduction in the levels of microbial metabolites in the digestive tract, hence modulating the immune system and increasing energy available for muscle accretion (Hippenstiel et al. 2011). In the present study, the heavier breast and drumstick among broilers fed 0.5 g BSB/kg feed when compared to those fed the other diets indicate that the T1 diet is suitable and could be recommended for cut parts development in broiler chickens. Hong et al. (2012), also, reported that medicinal plant-based products had a positive effect on breast meat in broiler chickens. Similarly, Javan et al. (2012) observed that the addition of medicinal plants to the diets of broiler chickens influenced their breast meat quality. The heavier breast and drumstick values observed in broiler chickens on diet T1 could be attributed to the anti-oxidative activities of the beneficial bioactive compounds contained in the test feed additive (Ogbuewu et al. 2023). Broiler chickens on the control diet had similar de-feathered weight with those on other diets. This indicates dietary BSB supplementation did not promote feather growth and development, as Abu et al. (2020) reported that BSB is deficient in sulphur-containing amino acids like methionine, lysine and cysteine which are required for feather development.

Gizzard and proventriculus can be used to predict chicken performance and health (Lu et al. 1996). The increased proventriculus weights in broiler chickens fed diets T2 (1.0 g BSB/kg feed) and T3 (1.5 g BSB/kg feed) could be attributed to the increased fibre content of the diets, resulting in greater dilatation of proventriculus in terms of size and contents. Besides this, the linearly increased gizzard weight in broiler chickens fed BSB-supplemented diets could be attributed to improved gizzard grinding activity, allowing for the better development of the muscular layers and causing an increase in organ size (Svihus 2011). Similarly, Hetland et al. (2004) found that insoluble fibre modulates gut development, digestive function, and gizzard activity. Some of these effects are a consequence of better gizzard function, with an increase in gastro-duodenal refluxes that facilitate the contact between nutrients and digestive enzymes (Mateos et al. 2012). The significantly high liver weights recorded in broilers offered treatment diets when compared to those fed the control diet could be linked to the anti-nutritional factors contained in *D. guineense* stem bark (Adeleye et al. 2014).

Abdominal fat is the most common way animals accumulate fat, and is positively correlated with total

Table 7 BSB supplementation levels for optimal intestinal biometry of broiler chickens

Variables	Quadratic equation	r^2	Optimal x-level	Optimal y-level	*p*-value
Weight					
Duodenum (g)	$Y=10.343+6.0275x-0.8325x^2$	0.98	3.62	21.25	0.037
Jejunum (g)	$Y=19.255+19.982x-2.75x^2$	0.99	3.63	55.55	0.046
Ileum (g)	$Y=18.153+7.6795x-1.0025x^2$	0.89	3.83	32.86	0.039
Caecum (g)	$Y=13.085+0.382x+0.25x^2$	0.89	0.76	12.94	0.018
Length					
Duodenum (cm)	$Y=20.788+9.7015x-1.5325x^2$	0.96	3.17	36.14	0.035
Jejunum (cm)	$Y=86.868+0.3545x+0.4025x^2$	0.33	0.44	86.79	0.008
Ileum (cm)	$Y=70.428+7.0385x—0.7475x^2$	0.99	4.71	87.00	0.015

X level optimal BSB supplementation level, *Y* value optimal length and weight of intestines, r^2 coefficient of determination, *p* probability value fat. Increased abdominal fat content connotes inefficient use of energy in the feed. The significantly lower abdominal fat pad of broiler chickens on 0.5, 1.0 and 1.5 g BSB/kg feed may be associated with the inhibition of lipid synthesis in the liver and abdominal tissue due to high concentrations of fibre and phytochemicals in the test feed additive (Moronkola et al. 2017; Ogbuewu et al. 2023). Similar observations were reported by Chukwukaelo et al. (2018), confirming the potential positive effect of fibrous diets on the abdominal fat pad, which could be attributed to the ability of fibre intake to modify the serum and tissue lipid levels (Mumford et al. 2011). The significantly high abdominal fat pad in broiler chickens fed a diet with 1.5 g BSB/kg feed supplementation could be related to the fat-forming potential of the diet, which could lead to the rejection of the meat by consumers.

The observed increase in the length and weight of the various segments of the small intestine of broilers fed treatment diets compared to those fed the control diet could be a strategy utilised by the experimental broiler chickens to handle the fibre contained in the test feed additive and diets. This observation may be due to an increase in the absorptive surface area of the villi and the efficiency of digestion and absorption of nutrients (Baurhoo et al. 2007). This implies that fibre contained in the test feed additive and diets has stimulatory effect on gastrointestinal cell proliferation either by increasing cell number (hyperplasia) or cell size (hypertrophy). Studies have shown that dietary fibre increased the absorptive surface area of the villi, feed retention times, and exerts positive effects on nutrient digestibility (Jha and Mishra 2021). The effect of BSB on the histology of the small intestine and feed retention times for broiler chickens was not evaluated in our study and, thus, warrants further research. On the other hand, Mateos et al. (2012) reported a significant decrease in the length of the small intestine in broiler chickens with an increase in dietary fibre level. The disparity in results may be due to differences in the type and form of fibre used, supplementation level of fibre in the feed, as well as the type of diet fed to the broiler chickens (Jha and Mishra 2021).

Avian caeca functions in microbial degeneration of indigestible fibre substances (Zulkifli et al. 2009). The observed increase in the length of caecum of broilers in groups fed diets T2 (1.0 g BSB/kg feed) and T3 (1.5 g BSB/kg feed) suggest an enhanced ability of this organ to degrade the fibre contained in the test feed additive and basal diets. This result is in harmony with Jha and Mishra (2021), who reported that the length and weight of the cecum increased with an increasing level of fibre in the feed. The significantly longer caecum in broilers fed diets T2 (1.0 g BSB/kg feed) and T3 (1.5 g BSB/kg feed) is expected to impact energy metabolism as visceral organs have a high rate of energy expenditure relative to their length and size (Baurhoo et al. 2007).

The determination of optimal inclusion levels of feed additives that gave the best performance parameters in animals has become critical to ensuring the safe and productive use of PFAs in diet formulation to reduce the wastage of feed supplements. As the dietary BSB was increased in the present study, the breast and the drumstick value was also increased until they were optimized at different BSB supplementation levels. In the present study, breast muscle weight was optimised at a BSB level of 2.53 g/kg feed. This value is lower than the value of 3.02 g/kg feed that optimised breast muscle Ross 308 broilers aged 1 to 6 weeks fed Moringa leaf meal (Modisaojang-Mojanaja et al. 2019). The difference might be attributed to the type of PFA used and diet composition. The optimum BSB level required for breast meat weight was lower than the value reported for drumstick weight in the present study. This may indicate low nutrient requirements for breast muscle than drumstick meat in broiler chickens during the growing phase. Similarly, the optimum BSB level required for proventriculus was higher than the value reported for the liver in the current experiment. This is to be expected since the muscular wall of the proventriculus must expand to accommodate the high fibre in the experimental diets prior to digestion.

Few authors have used quadratic optimisation model to determine the supplementation level of medicinal plant-based feed additives that supported optimum production parameters in chickens (Modisaojang-Mojanaja et al. 2019). As reviewed by Ogbuewu et al. (2023), literature depicting the use of the quadratic optimisation model to determine the optimal BSB levels that optimised production traits of broiler chickens is lacking. The findings of the present study are consistent with the results of Modisaojang-Mojanaja et al. (2019), who reported that no single feed additive level optimised all the productive parameters in Ross 308 broiler chickens. This means that dietary PFA levels for optimal productivity will depend on the parameter of interest. Similarly, Maoba et al. (2021) reported that no single feed additive level optimised all the productive variables in Boschveld chickens.

The coefficients of determination (r^2) were positive and ranged from low (0.19) to high (0.99) in the current study. This is an indication that all significant parameters have low to high r^2. The low r^2 recorded for breast meat and drumstick value in the present study suggests that optimal responses in breast and drumstick of broiler chickens fed BSB-supplemented diets could not be predicted using a quadratic model. However, the high r^2 recorded for organ weights in this study indicates that optimal responses in liver, proventriculus, and gizzard of broiler chickens fed BSB-supplemented diets could be predicted using a quadratic and linear model, respectively.

Conclusion

The study revealed that BSB is low in protein, moderate in minerals and high in fibre, and can be added to the diets of broiler chickens at supplementation levels not beyond 4.40, 3.31, 3.82 and 4.71 g BSB/kg feed for best organ weight, carcass yield and lengths and weights of intestines, respectively. The results showed that optimal response trends for different production variables in 1 to 47 days old Ross 308 broiler chickens were influenced by the dietary black velvet tamarind stem bark supplementation. However, dietary black velvet tamarind stem bark supplementation level for optimal response depended on the variable in question, implying that the nutrient requirements of broiler chickens are complex and dynamic, and should be taken into account when compounding their feed. It is recommended that the morphological changes on the gastrointestinal tissues of broiler chickens fed black velvet tamarind stem bark-supplemented diets be investigated to provide further information on the possible benefits to the gastrointestinal tract. Further studies on the gastrointestinal microbiota profiling of broiler chickens fed BSB-supplemented diets are also recommended as we could not perform this aspect in the current experiment.

Conflict of interest

The authors state that they have no conflict of interest to declare.

Authors contributions IPO and CAM designed the study, collected and analysed all the data, and prepared the draft of the manuscript. All authors read the draft and approved the final manuscript.

Funding Open access funding provided by University of South Africa. The study did not attract research grants from funding agencies or research support from organizations that may gain or lose financially through publication of this manuscript.

Data availability The datasets generated in this research will be made available by the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval and consent to participate The study was approved by the Animal Ethics Committee of the Federal University of Technology Owerri.

References

Abu OD, Onoagbe IO, Obahiagbon O (2020) Analyses of metal and amino acid compositions of aqueous and ethanol stem bark extracts of *Dialium guineense*. Open Access J Biogeneric Sci Res 6:1–3

Adeleye AO, Ajiboye TO, Iliasu GA, Abdussalam FA, Balogun A, Ojewuyi OB, Yakubu MT (2014) Phenolic extract of *Dialium guineense* pulp enhances reactive oxygen species detoxification in aflatoxin B_1 hepatocarcinogenesis. J Med Food 17:875–885

Ahiwe EU, Ejiofor I, Oladipupo OA, Ogbuewu IP, Aladi NO, Obikaonu HO, Emenalom OO (2022) Effect of composite enzyme supplementation on production parameters, intestinal segment measurements, and apparent nutrient digestibility of broiler chickens fed low energy and protein diets. Trop Anim Health Prod 54:399

Akinpelu AD, Awotorebo TO, Agunbiade OM, Aiyegoro AO, Okoh IA (2011) Anti-vibrio and preliminary phytochemical characteristics of crude methanolic extracts of the leaves of Dialium guineense (Wild). J Med Plants Res 5:2398–2404

AOAC (2008) Association of analytical chemists, official methods of analysis, 17th ed. Washington

Arbonnier M (2004) Trees, shrubs and lianas of west african dry zones, 2nd edn. Margaraf publishers, GMBH

Aviagen (2019) Ross 308 nutrient specifications. http://eu.aviagen.com/assets/Tech_Center/Ross_Broiler/RossBroilerNutritionSpecs2019-EN.pdf.

Baurhoo B, Phillip L, Ruiz-Feria CA (2007) Effects of purified lignin and mannan oligosaccharides on intestinal integrity and microbial populations in the ceca and litter of broiler chickens. Poult Sci 86:1070–1078

Chukwukaelo AK, Aladi NO, Okeudo NJ, Obikaonu HO, Ogbuewu IP, Okoli IC (2018) Performance and meat quality characteristics of broilers fed fermented mixtures of grated cassava roots and palm kernel cake as replacement for maize. Trop Anim Health Prod 50:485–493

Dhan P, Charu G, Girish S (2012) Importance of phytochemicals in nutraceuticals. J Chin Med Res Dev 1:70–78

Dibner JJ, Richards JD (2005) Antibiotic growth promoters in agriculture: history and mode of action. Poult Sci 84:634–643

Gideon IO, Joachim E, John ME (2013) Antioxidant and antimicrobial activities of *Dialium guineense* (wild) leaf extract. Pharmaceut Pharmacol Res 1:1–7

Hetland H, Choct M, Svihus B (2004) Role of insoluble non-starch polysaccharides in poultry nutrition. World's Poult Sci J 60:415–422

Hippenstiel F, Abdel-Wareth AAA, Kehraus S, Sudekum KH (2011) Effects of selected herbs and essential oils, and their active components on feed intake and performance of broilers—a review. Arch Geflugelkd 75:226–234

Hong JC, Steiner T, Aufy A, Lien TF (2012) Effects of supplemental essential oil on growth performance, lipid metabolites and immunity, intestinal characteristics, microbiota and carcass traits in broilers. Livest Sci 144:253–262

Javan AJ, Ghazvinian A, Mahdavi A, Vayeghan AJ, Staji H, Khaligh SG (2012) The effect of dietary *Zataria multiflora* boiss. Essential oil supplementation on microbial growth and lipid peroxidation of broiler breast fillets during refrigerated storage. J Food Process Pres 37:881–888

Jha R, Mishra P (2021) Dietary fibre in poultry nutrition and their effects on nutrient utilization, performance, gut health, and on the environment: a review. J Anim Sci and Biotech 12:51

Lu CD, Schoknecht PA, Ellis KJ, Shypailo R, Su DR, Pond WG (1996) Differential compensatory organ growth in young pigs after short-term rehabilitation from protein deficiency. Nutr Res 16:627–637

Maoba S, Ogbuewu IP, Oguttu JW, Mbajiorgu CA (2021) Prediction of responses of indigenous Boschveld chickens to probiotic-yeast additive levels using a quadratic optimization model. Trop Anim Hlth and Prod 53:48

Marshall BM, Levy SB (2011) Food animals and antimicrobials: impacts on human health. Clin Microbiol Rev 24:718–733

Mateos GG, Jimenez-Moreno E, Serrano MP, Lazaro RP (2012) Poultry response to high levels of dietary fibre sources varying in physical and chemical characteristics. J Appld Poult Res 21:156–174

Modisaojang-Mojanaja MMC, Ogbuewu IP, Mokolopi BG, Oguttu JW, Mbajiorgu CA (2019) Mineral composition of *Moringa oleifera* leaf meal (MOLM) and the response of ross 308 broilers to MOLM supplementation. Appl Ecol Environ Res 17:8139–8150

Moronkola DO, Kunle OF, Olaoluwa O, Ogukwe C (2017) Chemical compositions of *Dialium guineense* (Wild) leaf, stem-bark and fruit essential oils. J Complement Alternat Med Res 3:1–8

Mumford SL, Schisterman EF, Siega-Riz AM, Gaskins AJ, Wactawski-Wende J, VanderWeele TJ (2011) Effect of dietary fibre intake on lipoprotein cholesterol levels independent of estradiol in healthy premenopausal women. Am J Epidemiol 15:145–156

NRC (1994) Nutrient requirements of poultry, 9th, Revised. National Academy Press, Washington, DC

Ogbuewu IP, Modisaojang-Mojanaja MMC, Mokolopi BG, Mbajiorgu CA (2023) Nutritional and chemical composition of Black velvet tamarind (*Dialium guineense* Wild) and its influence in animal production: a review. Open Agric 8:2020174

Olajubu F, Akpan I, Ojo D, Oluwalana S (2012) Antimicrobial potential of *D. guineense* (Wild) stem bark on some clinical isolates in Nigeria. Int J Appld Basic Med Res 2:58–62

SAS (2010) Statistical Analysis System. SAS User Guide: Release 9.2. SAS Institute Inc, Cary

Svihus B (2011) The gizzard: function, influence of diet structure and effects on nutrient availability. World's Poult Sci J 67:207–224

USDA (1989) United States Department of Agriculture Poultry Grading Manual. Agriculture Handbook 31. Washington DC: Agricultural Marketing Service, United States Department of Agriculture.

Zulkifli I, Iman Rahayu HS, Alimon AR, Vidyadaran MK, Babjee SA (2009) Gut microflora and intestinal morphology of commercial broiler chickens and red jungle fowl fed diets containing palm kernel meal. Arch Geflugelk 73:49–55