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Feed intake, growth performance and carcass traits of broilers fed diets with various inclusion levels of baobab seed oilcake

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Abstract

The effects of increasing dietary inclusion levels of baobab seed oilcake (BSOC) on the growth performance, carcass characteristics, and yield in Ross 308 broiler chicks were assessed. Dietary treatments (T) consisted of four levels of BSOC: T1, control (0% BSOC); T2, 5% BSOC; T3, 10% BSOC; and T4, 15% BSOC. Birds on T2 and T1 had the highest bodyweight (BW) on days 14 and 28, respectively. Feed intake (FI) was highest during the periods of 1 to 7 days and 15 to 21 days in T2 birds. From 15 to 21 days, Feed conversion ratio (FCR) was highest in T3 birds. Significant differences were noted in slaughter and carcass weights among the treatments. Although no significant differences were observed in dressing percentages among treatments, birds in T1 had a higher dressing percentage, followed by those on T2. There were no statistical differences in carcass yield among the treatments. Calculations for revenue and gross margin showed that feed costs were lower in T4 and higher in T2 in the starter phase. In in the grower phase, feed costs were lower in T4 and higher in T3. The gross margin was higher in T1 and lower in T2 in the starter phase. During the grower phase it was higher in T1 and lower in T4. It was concluded that the inclusion of 5% BSOC at most could improve growth performance. Additionally, increasing levels of BSOC reduced feed costs, with a reduction in the gross margin in the grower stage of broilers.

Keywords: Baobab, broiler performance, carcass yield, protein utilization efficiency, revenue
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Introduction

Globally, there is increasing demand for poultry products. This may be attributed to the alleged healthiness of chicken, higher profit margins over a short period, and high acceptability of poultry products in many culinary traditions (Rao *et al*., 2006; Sola-Ojo *et al*., 2013). According to Vadivel & Pugalenthi (2010) and Bampidis & Christodoulou (2011), there has been high competition for the consumption of traditional protein sources between human beings and the livestock industry in the last two decades, which has resulted in an inadequate supply of dietary proteins. As such, soybean has been the primary dietary source of plant protein, although currently its production has not been sufficient to meet the protein demands of the increasing human population and expanding livestock industry (Saulawa *et al*., 2014). Fishmeal and soybean now occupy central roles in poultry feeds. Nevertheless, their inadequate supply has led to a rise in the price of poultry feed. Ultimately this has affected the growth of the poultry industry, particularly in developing countries (Peron *et al*., 2005; Bello *et al.*, 2011). Hence, to meet the protein demands, recent research trends have focused on finding alternatives to dietary protein in poultry diets. Baobab seed oilcake (BSOC) has proved to have such potential (Amerah *et al*., 2007; Melesse *et al*., 2013).

Nutritional composition of baobab (*Adansonia digitata* L.) seeds shows a high level of crude protein (CP) that is essential in poultry productivity (Osman, 2004; De Caluwé *et al.*, 2010). The seeds have a protein value that ranges from 20 to 36% CP and an energy level of 4.19 to 16.75 kJ/kg, which is comparable with sunflower meal (24.4–36.7 CP and 19.1–20.2 kJ/kg) and soybean hulls (10.5–19.2 CP and 17.5–18.7 kJ/kg) (Feedipedia, 2014). As for the amino acids (AA), two of the 17 observed AA in baobab seeds are categorized as essential, namely lysine (5.0 g/100 g) and methionine (1.0 g/100 g), and they are in moderately appreciable amounts (Osman, 2004). Even though studies on the use of BSOC on broiler

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production are few (Chimvuramahwe *et al*., 2011; Saulawa *et al*., 2014), there is a scarcity of studies on its effects on growth performance and efficiency of protein utilization in broilers. Thus, the purpose of this study was to investigate the growth performance, the effectiveness of protein utilization, carcass characteristics and feed implications in broiler chickens as affected by the inclusion of BSOC in broiler diets. Looking at the availability of essential AA in the baobab seeds, it could be hypothesized that the processed oilcake would provide some of these AA for broiler growth.

Materials and Methods

The use of animals was approved by the Animal Ethics Committee (AEC) of the University of Fort Hare (Animal Ethics No. NKU07-1SCHI01). The study was conducted at ARC-API (Agricultural Research Council–Animal Production Institute) Irene, Pretoria.

The BSOC was prepared by extracting the seeds from the fruit, then separating the fruit pulp from the seeds. The seeds were then decorticated/dehulled and placed in a screw press to expel the oil from the seeds. The seed oilcake from the expelling process was then ground into a fine powder to pass through a 0.15-mm sieve, tightly packaged in polyethene plastic bags, sealed and kept at room temperature until required.

A total of 200 Ross 308 broiler chicks of mixed sex were purchased from a reliable commercial supplier for use in the study. At placement, birds were weighed and randomly distributed among 20 floor pens with four treatment groups, each with ten birds (males and females in a 1 : 1 ratio), replicated five times. Maize-soya basal diets of iso-nitrogenous and iso-caloric form were formulated with the inclusion of the BSOC at various levels using SpesFeed Formulation software to meet the birds' dietary nutrient requirements (NRC, 1994). Dietary treatments consisted of four levels of BSOC: T1, control (0% BSOC); T2, 5% BSOC; T3, 10% BSOC; and T4, 15% BSOC (Table 1). The cost of each diet was calculated in US dollars (US$1 = ZAR13.50) (Exchange rates, 2016). All birds were under a two-phase feeding system, namely starter (0–21 days) and grower (22–28 days).

Using the methods of the AOAC (Association of Official Analytical Chemists, 2000), a proximate analysis was done on all the experimental diets and BSOC samples (Tables 2 and 3) for CP, ash, ether extract, calcium and phosphorus composition. Quantitative analysis methods were used to analyse AA in BSOC (Table 4) (AOAC, 2000). Techniques designed by Van Soest *et al.* (1991) were used to determine the acid detergent fibre (ADF), acid detergent lignin (ADL) and neutral detergent fibre (NDF) concentrations of the experimental diets. Throughout the experimental period, cool fresh water was provided *ad-libitum* to the birds.

The growth performance parameters were BW, FI and FCR. Feed allocation and BW per pen were recorded at placement, and at weekly intervals, i.e. at 7, 14, 21 and 28 days old. Feed intake (FI) was calculated as feed given during the week minus refusal feed of that week. Feed conversion ratio (FCR) was calculated as bodyweight-gain/feed intake. At the end of the trial period (day 28), protein intake (PI) was calculated as % crude protein in diet x feed intake during that time. Protein efficiency ratio (PER) was calculated as BW divided by PI (Lemme *et al.*, 2006; Kamran *et al.*, 2008).

At day 28, five birds were randomly selected per treatment, weighed individually and fasted for eight hours with *ad-libitum* water supply before slaughter. During slaughter, birds were re-weighed before being sacrificed by cervical dislocation after electrical stunning at 70 volts. The birds were fully bled, scalded, plucked and washed. The head, neck, and feet were removed. Subsequently, the carcasses were manually eviscerated, cutting off the neck and through the respiratory system, and the oesophagus was removed, before they were placed in a chiller (4 °C) overnight for dripping and cooling. Visceral organs (liver, spleen, heart, and bursa) and gizzards were removed by hand through an opening round the vent and sternum. Carcasses and visceral organs were then weighed individually, and expressed as percentages of live BW. The drumsticks, thighs, and wings were cut from the joints of the carcasses and through the shoulder area to remove the backbone from the breast. The cuts were then weighed, and the yields were calculated as percentages of live bodyweight.

Revenue calculations were made for the birds, and gross margin calculations of the four treatment diets were carried out at the end of the trial. The gross margin (GM) was calculated as broiler price per total BW produced minus cost of feed consumed per total FI. The calculations followed the revenue method used by Chimvuramahwe *et al.* (2011). The broiler income price was taken from the SAPA Poultry and Products Annual (2015) for a whole chicken. The gross margin was calculated per bird in all the treatments in the starter phase and the grower phase. Assumptions that were made were that the weight gain was merely from the feed consumption and was uniform across all birds and the costs were done for feed and bodyweight gains, excluding all other costs such as heating, lighting and water.

Table 1 Composition of experimental diets used in the 28 day study period on as fed basis

Feed ingredients, %	Dietary treatments							
	Starter diet				Grower diet			
	T 1	T 2	T 3	T 4	T 1	T 2	T 3	T 4
Baobab seed oilcake	0	5	10	15	0	5	10	15
White maize	66.65	63.20	60.89	58.11	71.51	67.58	64.61	60.46
Soya	24.91	23.37	18.86	14.18	20.08	19.39	15.79	13.96
Sunflower oilcake	4.00	4.00	4.00	4.00	4.33	4.00	4.00	4.00
Fishmeal	0.00	0.00	2.43	5.52	0.00	0.00	2.17	3.51
Soya oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.61
Limestone powder	1.62	1.64	1.42	1.31	1.48	1.51	1.30	0.61
Monocalcium	1.40	1.33	1.09	0.80	1.15	1.09	0.86	0.69
Salt (fine)	0.36	0.35	0.28	0.20	0.37	0.36	0.30	0.25
Methionine DL	0.21	0.21	0.18	0.14	0.20	0.19	0.16	0.14
Tryptophan	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Threonine	0.06	0.06	0.05	0.02	0.06	0.05	0.03	0.02
Bio-lysine	0.41	0.45	0.41	0.33	0.43	0.44	0.39	0.36
Choline chloride	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Vitamin + mineral	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Elancoban	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Olaquindox	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Total	100	100	100	100	100	100	100	100
Cost (Rands/100 kg)	1544	1472	1395	1344	1334	1288	1237	1201
Cost (US$/100 kg)	114	109	103	100	99	95	92	89

BSOC: baobab seed oilcake, T1: 0% BSOC, T2: 5% BSOC, T3: 10% BSOC, T4: 15% BSOC

Table 2 Analysed proximate composition of the baobab seed oilcake on dry matter basis

Constituent	Percentage content (%)
Dry matter	90.86
Moisture	9.14
Ash	4.57
Crude protein (N x 6.25)	22.86
Fat (ether extraction)	8.13
Fibre (crude)	19.97
Total non-structural carbohydrates	6.94
Neutral detergent fibre (NDF)	42.33
Acid detergent fibre (ADF)	35.93
Acid detergent lignin (ADL)	17.16
Calcium	0.24
Phosphorus	0.66
Energy (Kcal/Kg)	0.04

Table 3 Analysed proximate composition of the dietary treatments fed to broilers in the 28 day study period on dry matter basis

Nutrients, %	Dietary treatments							
	Starter diets				Grower diets			
	T1	T2	T3	T4	T1	T2	T3	T4
Crude protein	18.43	19.26	18.94	21.32	13.23	17.66	12.77	20.64
Fat (ether extraction)	2.28	2.96	3.36	3.81	2.56	3.13	3.23	5.03
Fibre (crude)	4.17	5.11	6.79	6.77	4.48	5.60	4.56	8.83
Calcium	0.81	0.81	0.88	1.27	0.56	0.83	0.98	1.15
Phosphorus	0.52	0.60	0.64	0.74	0.38	0.51	0.65	0.75
Energy (MJ/Kg)	16.15	16.45	16.33	16.71	16.46	16.46	16.49	17.13

BSOC: baobab seed oilcake, T1: 0% BSOC, T2: 5% BSOC, T3: 10% BSOC, T4: 15% BSOC

Table 4 Analysed amino acid composition of the baobab seed oilcake on dry matter basis

Analysed amino acids	g amino acid/100 g sample
Arginine	3.33
Serine	0.67
Aspartic acid	1.25
Glutamic acid	3.46
Threonine	0.44
Glycine	0.65
Alanine	0.63
Tyrosine	0.64
Proline	0.56
Methionine	0.26
Valine	0.88
Phenylalanine	0.75
Isoleucine	0.67
Leucine	1.01
Histidine	0.63
Lysine	1.04
Hydroxyproline	0.06

Growth performance, protein utilization, and carcass trait data were subjected to ANOVA using SAS JMP version 11.0.0 (SAS, 2012) under a completely randomized design. When significance of the treatment means was observed, student's t-test was used to separate the means at P <0.05.

Results

The effect of the various treatment diets on BW, FI and FCR of broilers for the periods 1 to 7 days, 8 to 14 days, 15 to 21 days, and 22 to 28 days old, respectively, are shown in Table 5. There were no significant differences in BW among treatments at days 7 and 21. However, differences (P <0.05) were noted on days 14 and 28. On day 14, T1 (375.4 g), T2 (394.4 g) and T3 (381.3 g) had similar BW. T4 (358.7 g) was significantly lower than T2, but did not differ significantly from T3 and T1. For day 28, T1 (1266.9 g), T2 (1256.4 g) and T3 (1262.9 g) also had similar BW. T4 (1178.5 g) was significantly lower than T1 and T3, but did not differ significantly with T2. On FI, significant differences were noted only during the periods of 1 to 7 days and 15 to 21 days. On 1 to 7 days, T1 (86.3 g), T2 (92.2 g) and T3 (97.5 g) had similar FI, but T4 (73.1 g) had a significantly lower FI than T2 and T3, but did not differ significantly from T1 (86.3 g). Additionally, during period 15 to 21 days, T2 (594.6 g), T3 (605.9 g) and T4 (572.2 g) had similar FI, but T1 (486.7 g) had a significantly lower FI than T2 and T3, but did not differ significantly from T4 (572.2 g). Differences (P <0.05) in FCR were evident only in the 15 to 21 day period. Treatment 3 (T3) (1.299) birds had a significantly better FCR than birds given T4, but their FCR did not differ significantly from birds given T1 and T2.

Table 5 Bodyweights, feed intake and feed conversion ratio of broilers (1–28 days) fed diets supplemented with or without baobab seed oilcake

Parameters (n = 50)	Dietary treatments				SEM	Significance Level
	T1	T2	T3	T4		
Bodyweight (g)						
0 d	46.00	47.92	49.28	48.04	0.02	NS
7 d	162.58	169.85	152.31	161.95	0.01	NS
14 d	375.44^{ab}	394.42^{a}	381.33^{ab}	358.67^{b}	0.01	*
21 d	728.22	741.19	729.78	687.25	0.02	NS
28 d	1266.89^{a}	1256.36^{ab}	1262.89^{a}	1178.53^{b}	0.03	*
Feed intake (g)						
1–7 d	86.28^{ab}	92.19^{a}	97.52^{a}	73.06^{b}	0.01	*
8–14 d	430.56	458.81	448.28	420.80	0.01	NS
15–21 d	486.69^{b}	594.62^{a}	605.93^{a}	572.24^{ab}	0.03	*
22–28 d	926.10	969.72	1039.48	1026.46	0.06	NS
Feed: gain (g/d:g/d)						
1–7 d	1.884	1.342	2.100	1.742	1.66	NS
8–14 d	1.158	1.098	1.214	1.238	0.07	NS
15–21 d	1.355^{ab}	1.554^{ab}	1.299^{b}	1.651^{a}	0.12	*
22–28 d	1.375	1.517	1.568	1.673	0.10	NS

[ab] Means in the same row with different superscripts differ significantly (P <0.05); NS: not significant (P >0.05); SEM: standard error of mean

Effects of dietary treatments on the PI and PER of the birds from day 1 to day 28 are shown in Table 6. Significant differences were noted from day 8 to day 28 for the PI values. Treatment 4 (T4) had the highest (P <0.05) PI values for 8 to 14 days, 15 to 21 days and 22 to 28 days. For 8 to 14 and 15 to 21 days, T2, T3, and T4 had similar (P >0.05) PI values and T1 had a significantly lower PI than T2, T3 and T4. In the period 22 to 28 days T1 and T3 had similar (P >0.05) PI values, but significantly lower values than T2 and T4. The PER was significantly different for the entire trial period. For the period 1 to 7 days, T1, T2 and T4 had similar PER (P >0.05), but T3 had a significantly lower PER than T4 and did not differ significantly from T1 and T2. For 8 to 14 days, 15 to 21 days and 22 to 28 days, T1 had significantly better PER values than T2, T3, and T4.

The effects of dietary treatments on slaughter weight, carcass weight, dressing percentage and cut part yield are presented in Table 7. A significant difference among the treatments was noted for slaughter and carcass weights. T1, T3, and T4 had similar slaughter weights (P >0.05). T2 was significantly lower than T1, but did not differ significantly from T3 and T4. Additionally, T1, T3, and T4 had similar carcass weights (P >0.05), but T2 was significantly lower than T1. However, T2 did not significantly differ from T3 and T4. No significant differences were noted in the dressing percentages of the birds. No statistical (P >0.05) differences were observed for the head, wing, thigh, drumstick, and breast among the treatments except for the feet. Nevertheless, the highest percentage yields for the head, thigh, wing, drumstick, and breast were noted in T2, T1, T2, T4, and T3, respectively. For the feet percentage yield, T3 and T4 had significantly higher feet percentage yield than T1 and T2.

Results for dietary treatment effects on feed costs and gross margins for the trial are presented in Table 8. For the starter phase, T4 (US$1.07) had a lower feed cost value than T1, T3, and T2. The highest feed cost value was noted in T2 (US$1.25). On the gross margin for the starter phase, the highest gross margin was observed in birds that were fed T1 (US$2.60), and the lowest was in T2 (US$1.45). Gross margin increased gradually as the BSOC content was increased from T2 to T4. During the grower phase, the lowest feed cost value was noted in birds in T4 (US$0.91), and the highest value was in T3 (US$0.96). For the gross margin, the highest was in birds in T1 (US$0.68), and the lowest in T4 (US$0.54).

Table 6 Protein intake and protein efficiency ratio of broilers fed diets supplemented with graded levels of baobab seed oilcake

Parameters (n = 50)	Dietary treatments				SEM	Significance level
	T1	T2	T3	T4		
Protein Intake (g)						
1–7 d	15.90	18.47	17.75	15.58	0.001	NS
8–14 d	79.35[b]	88.37[a]	84.91[ab]	89.71[a]	0.003	*
15–21 d	89.97[b]	114.52[a]	114.76[a]	122.00[a]	0.006	*
22–28 d	122.52[c]	171.25[b]	132.74[c]	211.86[a]	0.010	*
Protein efficiency ratio (g/g)						
1–7 d	3.41[ab]	3.12[ab]	2.89[b]	3.50[a]	0.187	*
8–14 d	4.75[a]	4.48[ab]	4.51[ab]	4.01[b]	0.179	*
15–21 d	8.41[a]	6.52[b]	6.37[b]	5.64[b]	0.421	*
22–28 d	10.45[a]	7.39[b]	9.60[a]	5.68[c]	0.476	*

[abc] Means in the same row with different superscripts differ significantly (*P* <0.05); NS: not significant (*P* >0.05); SEM: standard error of the mean

Discussion

The aim of this study was to evaluate the influence of feeding BSOC as a protein supplement on growth performance in broilers raised for 28 days. The results are consistent with the findings of Chimvuramahwe *et al.* (2011) who reported that BSOC could be included in broiler diets as a protein source without any adverse effects. These results are also similar to the results of Mwale *et al.* (2008) and Chimvuramahwe *et al.* (2011), who noted a reduction in FI at inclusion levels above 10%. Various studies support the notion of a decline in FI of diets with high energy (Rao *et al.,* 2006; Khajali and Slominski, 2012; Sebola *et al.,* 2015). This is shown in Table 5 as broilers on T3 and T4 had significantly lower feed intake compared with those on T2. This could be attributed to the high fat content of BSOC (Murray *et al.*, 2001; Nkafamiya *et al.*, 2007). The decrease in FI is supported by Veldkamp *et al.* (2005), who noted that FI decreases linearly as dietary energy increases with high energy in diets. Conversely, BSOC diets were consumed by the broiler chicks even at the highest (T4, 15% BSOC) inclusion level, and this may be attributed to the good aroma of the oilcake. This is supported by Mwale *et al.* (2008), Chimvuramahwe *et al.* (2011), and Saulawa *et al.* (2014), who reported that the BSOC has a good aroma that improves FI.

In addition to the high-energy content in broiler diets, the fibre content is noted to have a significant effect on FI in broilers (Sebola *et al.*, 2015). As the fibre content in broiler diets increases, FI tends to decrease. High fibre levels are known to reduce the digestibility of poultry diets (Mikulski *et al.*, 2008; Bampidis & Christodoulou, 2011; Khajali & Slominski, 2012). According to Peron *et al.* (2005) and Sebola *et al.* (2015), the inclusion of insoluble fibre in poultry diets at moderate levels has no detrimental effect on their performance although the nutrient concentration of the diet is reduced. Nevertheless, dilution in fibre beyond the optimal inclusion level causes lower feed intake, probably owing to an increase in the viscosity of the digesta and a longer retention period of the digesta in the gut (Mwale *et al.*, 2008; Sebola *et al.*, 2015). This clarifies the asymptotic response of FI to incremental levels of BSOC that was observed in this trial. The fibre content that was noted for BSOC contradicts that from (Mwale *et al.*, 2008; Chimvuramahwe *et al.,* 2011; Madzimure *et al.*, 2011). This might be because the BSOC used in this study was decorticated/dehulled.

This technique is known to reduce fibre and anti-nutritional factors and increase CP and energy values (Igboeli *et al.*, 1997; Belawu & Ibikunle, 2009; Madzimure *et al.,* 2011; Khajali & Slominski, 2012).

Table 7 Effects of baobab seed oilcake inclusion in broiler feed on carcass characteristics and cut portion yield of broilers at day 28

Yield, % of BW	Dietary treatments				SEM	Significance Level
	T1	T2	T3	T4		
Carcass characteristics						
Slaughter weight (g)	1676.00[a]	1453.33[b]	1550.00[ab]	1457.33[b]	0.66	*
Carcass weight (g)	1230.00[a]	1062.67[b]	1112.67[ab]	1056.67[b]	0.47	*
Dressing percentage (%)	73.39	73.10	71.94	72.49	1.81	NS
Cut portion yield						
Head (%)	2.27	2.62	2.28	2.33	0.11	NS
Thigh (%)	8.80	8.16	6.74	7.43	0.66	NS
Wing (%)	4.02	4.22	3.58	4.01	0.39	NS
Drumstick (%)	5.41	5.11	5.32	5.52	0.39	NS
Breast (%)	24.99	24.09	25.38	21.98	1.83	NS
Feet (%)	3.66[b]	3.68[b]	4.05[a]	4.17[a]	0.10	*

[ab] Means in the same row with different superscripts are significantly different (P <0.05); NS: not significant (P >0.05); SEM: standard error of mean

Table 8 Cost implications and revenue calculations of inclusion of baobab seed oilcake in broiler diets

Description	Dietary treatments			
	T1	T2	T3	T4
Broiler starter feed cost calculations				
Feed cost per kg (US$/kg)	1.14	1.09	1.03	1.00
Total bodyweight gain (g)	1266	911	1263	1208
Total feed intake (g)	1004	1146	1152	1066
Broiler Income @ (US$2.96/kg)	3.75	2.70	3.74	3.58
Cost of total feed consumed (US$/kg)	1.14	1.25	1.19	1.07
Gross margin (US$/bird)	2.60	1.45	2.55	2.51
Broiler grower feed cost calculations				
Feed cost per kg (US$/kg)	0.99	0.95	0.92	0.89
Total bodyweight gain (g)	539	515	533	491
Total feed intake (g)	926	970	1039	1026
Broiler income @ (US$2.96/kg)	1.59	1.52	1.58	1.45
Cost of total feed consumed (US$/kg)	0.92	0.92	0.96	0.91
Gross margin (US$/bird)	0.68	0.60	0.62	0.54

According to Axe (1995), particle size and feed form influence bird performance. Avian species are known to pick up the differences in feed particle size by mechanoreceptors that are located in their beaks (Amerah *et al.*, 2007). In general, broilers are known to prefer larger feed particles. This is observed at all ages, and particle size preference is thought to increase with age (Nir *et al.*, 1995; Nir & Ptichi, 2001; Amerah *et al.*, 2007). According to Amerah *et al.* (2007), feed particle size must be increased with age for optimum poultry performance. However, in this study, the performance could have been optimum if the treatment diets had been pelleted since they were fed as mash diets. The literature suggests that grain particle size is more significant in mash diets than in crumbled or pelleted diets (Nir *et al.*, 1995; Nir & Ptichi, 2001; Svihus *et al.*, 2004; Peron *et al.*, 2005). Pelleting of diets is known to improve weight gain, FI and FCR in broilers, regardless of the grain source (Nir & Ptichi, 2001; Kilburn & Edwards, 2004; Gous, 2011). As noted by Amerah *et al.* (2007), the improvements are attributed among other things to higher density, improved starch digestibility from chemical changes during pelleting, increased nutrient intake, changes in physical form, reduced feed wastage and decreased energy spent in eating. The requirements for protein in supplemental feeds is greatly influenced by the levels provided by the natural diet for a targeted production level (Nasr *et al*., 2011; Patience *et al.*, 2015). Consequently, the incorporation of protein in supplemental diets must be formulated to meet the requirements of increasing broiler biomass (Kilburn & Edwards, 2004; Kamran *et al.*, 2008). In this trial, protein intake (P <0.05) differed significantly among the treatments. This may be due to the CP values of the diets and the antinutritional factors in BSOC. BSOC inclusion in the diets resulted in varying levels of CP, thereby affecting PI. Additionally, the inclusion led to diets with different levels of anti-nutritional elements, which might have changed the PER factor of the birds. This can be supported by Nkafamiya *et al.* (2007), who noted that the cumulative effect of anti-nutritional factors to toxic levels with increased inclusion of BSOC in the diets might affect PER owing to reduced FI and digestibility. The body weights also showed that this might have been the cause since there was a linear decrease in BW with the increase of BSOC in the diets. This outcome is also reflected in FI and FCR; which may be explained by the ability of avian species to regulate their FI relative to meet their nutrient requirements, making FCR sensitive to growth responses (Nkukwana *et al*., 2014). The significant treatment effects on PER were similar to those of PI. This can be explained by the findings of Tshorhote *et al.* (2003), who attributed PER to the quality of dietary protein relative to BW and PI. The dressing percentage and cut part yields of broilers at day 28 were not affected by the inclusion of BSOC in the diets, except for the slaughter weight, carcass weight and percentage yield of the feet. The results showed that the inclusion of BSOC in broiler diets produced similar results on carcass characteristics and yield comparable with the control diet. However, the slaughter and carcass weights of birds fed 0% BSOC diet was higher than those fed on 5%, 10%, and 15% BSOC. This can be attributed to the general growth performance of the birds on T1 and the nutritional composition of the 0% BSOC diet relative to the other diets. The poor feed utilization in chickens fed with 15% BSOC explains the observed lower slaughter and carcass weights. Bale *et al.* (2013) noted that a lower FI might be attributed to the increase in the level of residual anti-nutritional factors in BSOC, such as oxalate, phytate, saponins, and tannins. This might have impaired the performance of the birds owing to the incremental levels of fibre and antinutritional factors in the diet (Bampidis & Christodoulou, 2011; Khajali & Slominski, 2012; Sebola *et al.*, 2015).

According to Fernandes *et al*. (2013), the improvement in carcass characteristics of broiler breeds in recent decades has been pronounced, resulting in substantial genetic gains. Of particular importance is the yield of the breast and legs, since they are the most expensive cuts as they are well paid for on the market (Fernandes *et al.*, 2013). Since the breast is one of the most expensive and valued carcass components in the processing industry, birds given the control diet, T2 and T3 presented a higher yield of this cut, with T3 birds having the highest breast yield. High yields were also noted for thigh, wing, drumstick, and feet in T1, T2, T4 and T4, respectively. This implies that the inclusion of BSOC had a positive effect on carcass yield of the birds. Hence, the inclusion of BSOC in broiler diets improves the carcass yield of broiler chickens.Supplementation of broiler feeds with high protein alternatives such as BSOC is a practical method of decreasing the ever-increasing costs of broiler feeding. The feed cost per kilogram of the formulated starter and grower diets was reduced considerably with the inclusion of BSOC. The lower feed cost per kilogram of BSOC diet compared with the control was as expected since BSOC was cheaper than soybean meal and was readily available locally. This was in agreement with Chimvuramahwe *et al.* (2011), who noted the same decrease with the increased inclusion of BSOC in broiler diets. The inclusion of BSOC in the broiler diets affected the feeding costs significantly. The birds that consumed 0% BSOC and 15% BSOC diets observed higher gross margins compared with those fed T2 and T3. These results are attributed to higher FI of chicks that were on 5% BSOC and 10% BSOC (NRC, 1994). Treatment 1 (T1) and T4 had higher gross margins, which were attributed to lower FI and better FCR than birds fed with T2 and T3. The high gross margin in birds fed with 0% BSOC resulted from the diet, which was formulated following industrial standards This resulted in the chicks performing according to the optimal criteria. They were efficient in converting feed to gain. However, for those fed on 15% BSOC, the low gross margin may have been because of the interaction of their FI and BW. They did not consume much feed owing to the fibre and anti-nutritional content of the diet as a result of incremental levels of these elements from increased inclusion of BSOC (Nkafamiya *et al.*, 2007; Vadivel & Pugalenthi, 2010; Sebola *et al.*, 2015). Nevertheless, they managed to consume enough feed to meet their dietary needs, as shown by their high FCR (Nahashon *et al.*, 1997; Veldkamp *et al.*, 2005). Consequently, the results of this trial contradicted those of Chimvuramahwe *et al.* (2011), who observed a decrease in feeding costs with the inclusion of BSOC in broiler diets. This might be because of the differences in the diet formulations and the ingredients that were used in formulating the diets. Nonetheless, a gradual decrease in feed costs was noted from T2 to T4 in the starter diets, but for the grower diets, it increased from T2 to T3, then decreased from T3 to T4. This was probably due to lower FCR and reduced gains of broilers obtained on those treatment diets (Bello *et al.*, 2011).

Conclusion

The study revealed that baobab seeds consisted of a rich source of protein and other essential nutrients such as lysine, methionine and threonine. The addition of BSOC improved the qualitative and quantitative parameters of growth performance, carcass characteristics and meat yield in broilers. Therefore, it can be concluded that BSOC could be included in broiler diets up to 5% without compromising effects on broiler growth performance. The BSOC could be included in broiler chick rations up to 15% without compromising their carcass yield. The utilization of 5% inclusion level could be the starting point in the use of BSOC in non-ruminant animal feeds. On the other hand, increasing levels of BSOC in broiler diets could result in a decrease in feed costs with a reduction in the gross margin in the grower stage of broilers. Further studies could evaluate the effects of feeding treated BSOC at high inclusion levels in breeder chickens and other older avian species.

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Authors' Contributions

All the authors were directly involved in the design of the experiment. TPM designed the feed formulation of the diets. TTN and JFM provided funding and supervision for the study. All the authors were involved in the preparation of the manuscript.

Conflict of Interest Declaration

No conflict of interest.

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