

Assessment of Black Soldier Fly Larvae Meal as a Dietary Protein Source for Enhancing Broiler Meat Quality

Odetha Lawrence Mchunguzi

Sokoine University of Agriculture

Isack I. Kerario

Sokoine University of Agriculture

Whitefrank M. Frank

COSTECH: Tanzania Commission for Science and Technology

Charles Moses Lyimo

`charles@sua.ac.tz`

Sokoine University of Agriculture <https://orcid.org/0000-0002-8739-0253>

Research Article

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Abstract

This study evaluated the effects of different inclusion levels of black soldier fly larvae meal (BSFLM) on slaughter characteristics, meat quality, and fatty acid profiles of broiler chickens. A total of 360 one-day-old chicks were randomly assigned to six dietary treatments, including a commercial feed (TCOM) as a positive control, a formulated feed with 0% BSFLM (negative control), and experimental diets containing 25%, 50%, 75% and 100% BSFLM as a replacement for soybean meal. The findings revealed that 25% BSFLM inclusion resulted in the highest slaughter weight (2964.33 g), dressing percentage (80.72%), and carcass weight (2404.20 g), whereas higher inclusion levels (75% and 100%) led to reductions in these parameters. Body parts' weights (breast, thigh and drumstick) and viscera organ weights were significantly influenced, with optimal performance observed at moderate BSFLM levels (25%-50%). Proximate analysis showed significant variations in dry matter (DM), crude protein (CP), and ether extract (EE) among treatments. The highest CP (50.49%) was recorded in 100% BSFLM, while 75% BSFLM had the highest EE (1.95%). Fatty acid composition (total fatty acids, oleic acid, and linoleic acid) did not differ significantly across treatments. Meat lightness and yellowness varied in drumsticks, while shear force values were highest in 50% BSFLM. Cooking loss decreased with increasing BSFLM inclusion, with the lowest loss at 100% BSFLM (9.14%). No significant differences were observed in meat temperature and pH across treatments. The study concludes that BSFLM can serve as a viable protein alternative in broiler diets, with 25%-50% inclusion levels recommended to optimize growth performance and maintain desirable meat quality for consumers.

1.0 Introduction

Broiler chickens play a pivotal role in food security and economic development in many developing countries, including Tanzania. Nevertheless, broiler production faces significant challenges, particularly regarding nutrition and feed quality. The feeding practices of broiler chickens are faced with inadequate nutrient composition, high competition for conventional feed sources, inconsistent feed availability (Makkar et al., 2014) and low-quality feed ingredients. Consequently, this can negatively impact broiler chickens' growth, slaughter characteristics and overall meat quality. These issues (slaughter characteristics and meat quality) have impacts on broiler chickens' productivity, the economy of farmers and consumers' satisfaction.

Nutritional deficiencies can lead to poor feed conversion efficiency, lower carcass weights and undesirable meat quality traits such as meat pH, poor texture, reduced juiciness, tenderness, and inconsistent color (Choi *et al.*, 2023; Pečjak et al., 2022). Additionally, inadequate feeding may increase the cost of production, mortality rates and susceptibility to diseases. Consequently, this may affect the sustainability of broiler and/or poultry production (Heita et al., 2023). The growing demand for poultry meat in Tanzania necessitates the exploration of sustainable and cost-effective feed ingredients to improve broiler production.

Conventional protein sources such as soybean meal and fishmeal are often expensive and subject to supply fluctuations (Heita et al., 2023; Abou-Elezz et al., 2011). This prompts the need for alternative protein sources, such as leaf meals, insects, maggots, larvae, etc. In this regard, black soldier fly larvae (BSFLM) meal has emerged as a promising substitute due to its high protein content, essential amino acids, and favorable fat profile (Sumbule et al., 2021). Additionally, BSFLM can be produced using organic waste, contributing to environmental sustainability while minimizing the overdependence of the poultry industry on conventional protein feed sources. Various studies in different areas of Africa and beyond have been done on the use of BSFLM as a replacement for conventional feed sources, such as fish meals, soybean meal, etc (Renna et al., 2017; Heita et al., 2023; Nampijja et al., 2023; Fruci et al., 2023).

Despite its potential, in Tanzania, there is a paucity of information on the effects of BSFLM meal inclusion on broiler performance, specifically regarding slaughter characteristics and meat quality. Recent work from Tanzania has demonstrated the growth and economic advantages of BSFLM in broiler production; however, evidence on carcass and meat quality responses remains limited (Mchunguzi et al., 2025). Thus, this study intended to assess the effects of different inclusion levels of BSFLM meal on broiler slaughter characteristics and meat quality. The findings will provide valuable insights into the feasibility of BSFLM meal as a sustainable feed ingredient for poultry production. Moreover, information from this study is crucial for optimizing feed formulations and ensuring the production of high-quality poultry meat in Tanzania.

2.0 Materials and methods

2.1 Study location

The study was conducted at the Lower Farm, part of the Department of Animal, Aquaculture, and Range Sciences at Edward Moringe Campus, Sokoine University of Agriculture (SUA), situated in Morogoro Municipality. SUA is positioned at 6°52" S latitude and 37°38'59" E longitude at an elevation of 660 meters above sea level. The municipality experiences an annual average rainfall ranging from 500 to 1800 mm, with daytime temperatures between 27°C and 31°C, and the coolest months record minimum night temperatures of 14°C.

2.2 Source of experimental units and their management

A total of 360 one-day-old broiler chicks were obtained from OGANIA Company Limited. Upon arrival, the chicks were weighed and placed in a sanitized brooding area, where they were kept for 14 days. The brooding temperatures were maintained at 35°C during the first week and 32°C in the second week, aligning with standard brooding practices. The chicks were fed a commercial broiler starter feed from Alvines Company Limited during these two weeks. After the brooding period, the chicks were moved to grow-out pens and provided with formulated experimental diets (Tables 2 & 3) for the subsequent four weeks (weeks 3 to 6). During the study, feed and water were supplied ad libitum using appropriate feeders and drinkers. Vaccinations were administered according to the recommended schedule.

2.3 Ethical clearance

Before experimentation, handling of animals and all experimental protocols were carried out according to the guidelines of the Animal Ethics, established by the Sokoine University of Agriculture Research and Ethical Committee.

2.4 Experimental design and treatments

A total of 360 broiler chicks were randomly assigned to six dietary treatments during the grower and finisher phases, following a completely randomized design with three replicates per treatment. The treatments included a commercial feed (Tcom) and five experimental diets in which soybean meal was partially or fully replaced with black soldier fly larvae meal (BSFLM) at inclusion levels of 0% (T0), 25% (T25), 50% (T50), 75% (T75) and 100% (T100). Each replicate contained 20 chicks (Table 1).

Table 1
Experimental layout/design

Treatments							
Replicate	Tcom	T0	T25	T50	T75	T100	Total
R1	20	20	20	20	20	20	120
R2	20	20	20	20	20	20	120
R3	20	20	20	20	20	20	120
Total	60	60	60	60	60	60	360

2.5 Source of the feedstuffs and feed formulation

Black soldier fly larvae meal was sourced from the CAF Company in Dar es Salaam, while other feed ingredients were obtained from Morogoro Agro-inputs suppliers. After gathering the ingredients, samples were sent to the Tanzania Veterinary Laboratory Agency (TVLA) for proximate analysis (Table 2) using a near-infrared reflectance spectrophotometer (NIRS) instrument (NIRS Systems 5000, Firmware Version 156 and USA). The NIRS instrument was specifically calibrated for concentrate mixed rations (tmrgpfe.eqa) following the procedures outlined by Berglund *et al.* (1990) and Aufrere and Michalet-Doreau (1988). The metabolizable energy (ME) content of the concentrate diet was also analyzed using the NIRS Systems 5000 at TVLA, Temeke. Black soldier fly larvae meal (BSFLM) was used to replace soybean meal (SBM) in broiler grower and finisher diets (14–42 days) at inclusion levels of 0% (30% SBM), 25% (22.5% SBM), 50% (15% SBM), 75% (7.5% SBM) and 100% (0% SBM), with the commercial feed serving as positive control. The grower diets were formulated to contain 12 MJ ME and 220 g CP per kg DM, while the finisher diets contained 13 MJ ME and 190 g CP per kg DM. The formulation included BSFLM, soybean meal, hominy meal, rice polish, sunflower seed cake, cottonseed cake, bone meal, mineral premix, limestone, and salt (Tables 2 & 3). All diets, including the starter feed, were

prepared in pellet form. Finely ground feed samples were then sent to TVLA for proximate analysis (Table 2).

Table 2
Physical composition (% as fed) of the experimental grower diets

Ingredient	Diets with different inclusion levels of BSFLM (Treatment)				
	T0	T25	T50	T75	T100
BSFLM	0	7.5	15	22.5	30
Soya Bean Meal	30	22.5	15	7.5	0
Maize Meal	34	34	34	34	34
Hominy Meal	9	9	9	9	9
Rice polish	2	2	2	2	2
Sunflower cake	7	7	7	7	7
Cotton Seed Cake	13	13	13	13	13
Limestone	1	1	1	1	1
Bone meal	2	2	2	2	2
Broiler premix	1.5	1.5	1.5	1.5	1.5
Salt	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100
Calculated composition in (%)					
CP (%)	22	22	22	22	22
ME(MJ/Kg DM)	12	12	12	12	12

Table 3
Physical composition (% as fed) of the experimental finisher diets

Diets with different inclusion levels of BSFLM (Treatment)					
Ingredient	T1	T2	T3	T4	T5
BSFLM	0	7.5	15	22.5	30
Soya Bean Meal	30	22.5	15	7.5	0
Maize Meal	40	40	40	40	40
Hominy Meal	6	6	6	6	6
Rice polish	5	5	5	5	5
Sunflower cake	4	4	4	4	4
Cotton Seed Cake	10	10	10	10	10
Limestone	1	1	1	1	1
Bone meal	2	2	2	2	2
Broiler premix	1.5	1.5	1.5	1.5	1.5
Salt	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100
Calculated composition in (%)					
CP (%)	19	19	19	19	19
ME (MJ/Kg DM)	13	13	13	13	13

3.0 Data collection

3.1 Carcass characteristics

At the end of the 6-week experimental period, a total of 30 chickens, 5 from each treatment group, were randomly selected for slaughter. The chickens were fasted for 12 hours before slaughter and then weighed to determine their slaughter weight. After bleeding for five minutes, the chickens were de-feathered and reweighed, with the weight difference recorded as feather weight. On the same day, the carcasses were dissected and eviscerated, and the various carcass parts were weighed. Post-evisceration, the weights of the carcass, intestines, breasts, drumsticks, thighs, liver, gizzard, heart and spleen were recorded. Moreover, the abdominal fat weight was also recorded. The dressing percentage was calculated as a proportion of the pre-slaughter body weight using the following formula:

$$\text{Dressing Percentage (\%)} = (\text{Carcass weight} / \text{Pre-slaughter body weight}) \times 100 \dots \dots \dots (1)$$

3.2 Measurement of meat color

The inner surfaces of the breast, drumstick and thigh were used to determine the color of the meat. A portable colorimeter (MINOLTA CR-200b, Osaka, Japan), operating on the CIELAB system, was used to measure relative lightness (L^*), redness (a^*) and yellowness (b^*) of the meat.

3.3 Measurement of pH and Temperature

The pH and temperature of the breast muscle were determined 45 minutes after slaughter using a spear-end digital portable pH meter (Knick Portamess® 910, Germany) and thermometer, respectively.

3.4 Determination of cooking loss and shear force value (tenderness)

Cooking loss percentage and meat tenderness were determined according to the method described by Honikel (1998). Meat samples from the breast, thigh and drumstick were weighed and sealed in polyethene plastic bags, then cooked in a water bath set at a constant temperature of 70 °C for one hour. After cooking, the samples were cooled under running cold water for two hours and weighed to obtain the weight loss. Cooking loss was calculated using the following formula:

$$\text{Cooking loss (\%)} = ((\text{Weight before cooking} - \text{Weight after cooking}) / \text{Weight before cooking}) \times 100 \dots (2)$$

For shear force determination, meat strips measuring approximately 2×2×1 cm were cut parallel to the muscle fibres from the breast samples. These strips were tested using a Weaner-Bratzler shear blade attached to a Zwick/Roell instrument (Z2.5, Germany). Shear force values were expressed in Newtons (N).

3.5 Carcass chemical composition analysis

Muscle and fat portions were mixed, and each sample was finely minced using a meat grinder with a 5 mm plate, then frozen at -4°C for further analysis. The chemical composition of the minced meat was determined using wet proximate analysis to assess the dry matter, ash, crude protein and fat content. The dry matter content was determined using the oven-drying method at 105°C. (AOAC, 2005). Ash content was determined by incinerating the samples in a muffle furnace at 550 °C for three hours (AOAC, 2012). Crude protein was examined using the Kjeldahl technique with a 2200 Foss Tecator Kjeltex distillation unit (Foss, Höganäs, Sweden) (AOAC, 1990). Fat content was determined using the Soxhlet extraction method with a Soxtec system 2050 (Foss, Höganäs, Sweden) (AOAC, 2000).

3.6 Statistical analysis

Before analysis, data normality was evaluated using the Shapiro-Wilk test. To correct skewness, slaughter weight, carcass weight, and breast shear force data were log-transformed. A one-way analysis of variance (ANOVA) was then performed to determine the effects of dietary treatments on carcass traits and meat quality parameters in broiler chickens. Where significant differences were detected, treatment means were compared using Tukey’s post hoc test at a significance level of $p < 0.05$. Results are expressed as mean $\pm$ standard error of the mean (SEM). All statistical analyses were conducted using R statistical software (version 4.3.2, 2023). The general linear model used for ANOVA was as follows:

$$Y_{ij} = \mu + T_i + e_{ij} \dots\dots\dots(3)$$

Where;

Y_{ij} = Response (such as thigh, drumstick weight) of the j^{th} replicate of the i^{th} treatment level,

μ = overall mean effect,

T_i = Effect due to different levels of BSFLM,

E_{ij} = Error term.

4.0 Results

4.1 The laboratory analyses of the experimental raw materials and feeds

The laboratory results for the composition of the raw materials (ingredients), as well as the BSFLM-based starter, grower and finisher diets are shown in Table 4. The findings indicated nutritional variations (e.g., differences in Crude protein, crude fiber, ash, etc.) among different diet levels across the starter, grower and finisher feeds.

Table 4
The Laboratory analyses of the experimental feeds

Ingredients	Dry Matter (%)	Crude Protein (%)	Crude Fiber (%)	Crude Fat (%)	Ash (%)	Starch	ME Kcal/ kgDM
Black Soldier Fly Larvae Meal	88	42		18	6.5		
Soya Bean Meal	93.3	35.9	6.8	21.1	4.8		3677
Hominy Meal							
Maize Meal	87.7	8.7	3.1	3.7	1.5	61.3	3265
Cotton Seed Cake							
Sunflower Seed Cake							
Starter (Commercial)	91.2	23.8	3.3	3.4	9.6	37.8	2837
Grower							
Tcom	90.7	20.8	3.1	3.7	8.9	41	2888
T0	91.9	20.8	5.1	7.7	13.4	23	2493
T25	90.6	21.8	7	7.2	13.1	16.5	2226
T50	90.5	22.2	8.1	6.4	13.7	14.5	2089
T75	89.1	21.8	9.9	5.8	12.9	13.8	2001
T100	88.9	22	9.6	5.9	12.6	15.2	2074
Finisher							
Tcom	89.4	18.1	3.6	3.8	8.4	42.8	2874
T0	91.2	22.1	5.1	7.4	11.7	25.2	2606
T25	90	22	6.6	6.9	13.5	19.9	2342
T50	89	20.4	6.4	6.9	13.7	23.5	2418
T75	88.7	22.7	10.5	5.8	13	14	2085
T100	88.4	21.8	8.5	5.7	12.1	19.7	2232

4.2 Carcass characteristics of broiler chicken

The carcass characteristics of broiler chickens subjected to different dietary treatments are presented in Table 5. The results indicate that treatment significantly influenced slaughter body weight ($p = 0.001$). The highest slaughter weight was recorded in the 25% BSFLM group (2964.33 ± 106.76 g), while the

lowest was observed in the 75% BSFLM group (2554.60 ± 58.83 g). These findings indicate that slaughter weight increased with BSFLM inclusion up to 25%, but declined at higher inclusion levels.

Similarly, carcass weight varied significantly among treatments ($p = 0.000$). The highest carcass weight (2404.20 ± 124.79 g) was obtained at 25% BSFLM inclusion, while the lowest was recorded in the 100% BSFLM group (1835.60 ± 39.27 g). This trend mirrored that of slaughter weight, indicating that moderate BSFLM inclusion (up to 25%) optimizes carcass yield, whereas higher inclusion levels negatively impact carcass weight.

Dressing percentage was also significantly affected across treatments ($p = 0.000$). The highest value was recorded in the 25% BSFLM group ($80.72 \pm 2.06\%$) and the lowest in the 100% BSFLM group ($70.50 \pm 1.36\%$). Viscera organ weights, including heart, caecum, abdominal fat, and liver showed optimal values at 50% BSFLM inclusion, with respective weights of 14.87 g, 19.67 g, 47.87 g, and 63.33 g and were statistically significant (with P- values 0.000, 0.0022, 0.007 and 0.0003, respectively).

Regarding individual body parts, significant differences were observed among treatments. The highest breast and thigh weights were recorded in the 25% BSFLM (760.54 ± 26.28 g and 165.20 g, respectively), while the lowest values were found at higher inclusion levels (e.g., 75% BSFLM: 661.90 ± 15.24 g for breast and 143.77 ± 3.31 g for thigh, and they were significant ($p = 0.002$). No significant differences were observed in drumstick weights across treatments ($p = 0.17$). These findings suggest that moderate inclusion levels of BSFLM (25–50%) enhance carcass characteristics in broiler chickens, whereas higher inclusion levels may negatively affect performance.

Table 5
Effects of replacing soybean with BSFLM on carcass yield, commercial cuts, and viscera organ percentage of broiler chicken

Parameters (g)	Treatments						P-value
	TCOM	0BSF	25BSF	50BSF	75BSF	100BSF	
Carcass yield							
Slaughter wt	2865.00 ± 56.88 ^{bc}	2748.33 ± 65.71 ^{ab}	2964.33 ± 106.76 ^b	2782.93 ± 68.71 ^{ab}	2554.60 ± 58.83 ^a	2615.60 ± 68.61 ^{ac}	0.001
Carcass wt	2235.47 ± 48.02 ^{ac}	2100.87 ± 52.53 ^{ab}	2404.20 ± 124.79 ^c	2050.80 ± 57.43 ^{ab}	1892.60 ± 44.26 ^b	1835.60 ± 39.27 ^b	0.000
Dressing%	77.99 ± 0.33 ^{ab}	76.42 ± 0.36 ^{ab}	80.72 ± 2.06 ^a	73.62 ± 0.52 ^{b^c}	74.10 ± 0.48 ^{bc}	70.50 ± 1.36 ^c	0.000
Commercial cuts/body parts							
Breast wt	742.32 ± 14.74 ^{bc}	712.09 ± 17.03 ^{ab}	760.54 ± 26.28 ^b	721.06 ± 17.24 ^{ab}	661.90 ± 15.24 ^a	677.70 ± 17.78 ^{ac}	0.002
Thigh wt	161.24 ± 3.20 ^{bc}	154.68 ± 3.70 ^{ab}	165.20 ± 5.71 ^b	156.62 ± 3.87 ^{ab}	143.77 ± 3.31 ^a	147.21 ± 3.86 ^{ac}	0.002
Drumstick wt	138.67 ± 2.75	133.02 ± 3.18	142.07 ± 4.91	134.69 ± 3.33	123.64 ± 2.85	126.59 ± 3.32	0.17
Viscera organ							
Heart wt	11.20 ± 0.33 ^b	11.47 ± 0.39 ^{ab}	12.53 ± 0.61 ^{b^c}	14.87 ± 0.52 ^c	13.73 ± 0.62 ^{ac}	14.60 ± 0.84 ^c	0.000
Gizzard	39.067 ± 1.061 ^{ab}	41.33 ± 1.061 ^b	42.33 ± 1.061 ^b	35.13 ± 1.061 ^a	36.93 ± 1.061 ^a	37.67 ± 1.061 ^{ab}	0.0012
Liver	51.27 ± 2.34 ^{a^b}	48.47 ± 2.34 ^a	59.4 ± 2.34 ^{cb}	63.33 ± 2.34 ^c	54.27 ± 2.34 ^{abc}	59.53 ± 2.34 ^{cb}	0.0003
Caecum	13.93 ± 1.03 ^a	16.4 ± 1.03 ^{ab}	16.93 ± 1.03 ^{ab}	19.67 ± 1.03 ^b	14.93 ± 1.03 ^a	16.93 ± 1.03 ^{ab}	0.0022
Abdominal fat wt	20.99 ± 0.77 ^{ab}	20.89 ± 3.35 ^{ab}	32.18 ± 1.10 ^{a^b}	47.87 ± 4.59 ^b	34.62 ± 2.63 ^{ab}	26.97 ± 3.29 ^a	0.007
a,b,c Means with different superscripts within a row differ significantly at P ≤ 0.001							

Tcom = treatment of commercial feed, T0 = treatment feed with no BSFLM (0% BSFLM + 100% soy bean meal, SBM), T25 = feed with 25% BSFLM (25% BSFLM + 75%SBM), T50 = feed with 50% BSFLM (50% BSFLM + 50%SBM), T75 = feed with 75% BSFLM (75% BSFLM + 25%SBM), T100 = feed with 100% BSFLM (100% BSFLM + 0%SBM).

4.3 Chemical composition of broiler chicken meat

The proximate composition and fat content of broiler meat are presented in Table 6. Our analysis revealed significant variations in dry matter (DM), ash, crude protein (CP) and ether extract (EE) among treatments. Notably, the 50% BSFLM group had the highest DM ($26.14 \pm 0.20\%$) and ash content ($8.17 \pm 0.17\%$), whereas the TCOM and 0% BSFLM groups recorded the lowest DM ($22.73 \pm 0.11\%$) and ($4.40 \pm 0.05\%$), respectively ($p = 0.000$).

The crude protein content peaked at $50.49 \pm 0.08\%$ in the 100% BSFLM group, while the 75% BSFLM group had the lowest CP ($35.96 \pm 0.22\%$). In contrast, ether extract (EE) content was highest in the 75% BSFLM group ($1.95 \pm 0.02\%$) and lowest in the 25% BSFLM group ($0.17 \pm 0.00\%$) ($p = 0.000$). A notable trend was the increase in EE content with higher BSFLM inclusion levels, except for the 25% BSFLM diet, which recorded the lowest EE% among all BSFLM treatments.

Despite these variations, fat composition (total fatty acids, oleic acid, and linoleic acid) showed no significant differences across treatments ($p = 0.445$), indicating that BSFLM inclusion did not alter the fatty acid profile of broiler meat. These findings highlight that moderate BSFLM inclusion enhances crude protein and mineral content, while higher inclusion levels affect ether extract without impacting fatty acid composition.

Table 6: Effect of replacing soybean with BSFLM on the chemical composition of broiler chicken meat							
		Carcass chemical composition					
Parameter (%)	TCOM	0BSF	25BSF	50BSF	75BSF	100BSF	P-value
DM	22.73 ± 0.11 ^d	24.89 ± 0.12 ^{ab}	24.52 ± 0.29 ^b	26.14 ± 0.20 ^c	25.10 ± 0.15 ^{ab}	25.74 ± 0.32 ^{ac}	0.000
Ash	5.09 ± 0.10 ^d	4.40 ± 0.05 ^a	6.98 ± 0.14 ^b	8.17 ± 0.17 ^c	6.64 ± 0.12 ^b	6.96 ± 0.09 ^b	0.000
CP	40.42 ± 0.30 ^e	36.93 ± 0.14 ^a	44.91 ± 0.18 ^c	44.26 ± 0.18 ^c	35.96 ± 0.22 ^d	50.49 ± 0.08 ^b	0.000
EE	0.30 ± 0.01 ^b	1.91 ± 0.00 ^a	0.17 ± 0.00 ^c	0.30 ± 0.01 ^b	1.95 ± 0.02 ^a	0.27 ± 0.01 ^b	0.000
Total fatty acid	34.96 ± 2.41	43.25 ± 5.03	37.20 ± 4.44	42.74 ± 3.39	46.12 ± 3.74	39.81 ± 5.30	0.445
Fatty acid as oleic	24.64 ± 1.70	30.49 ± 3.55	26.23 ± 3.13	30.13 ± 2.39	32.51 ± 2.63	28.06 ± 3.74	0.445
Fatty acid as linoleic	49.04 ± 3.38	60.68 ± 7.05	52.19 ± 6.23	59.96 ± 4.76	64.70 ± 5.24	55.85 ± 7.44	0.445
a,b,c,d,e Means with different superscripts within a row differ significantly at P ≤ 0.001							

Tcom = treatment of commercial feed, T0 = treatment feed with no BSFLM (0% BSFLM + 100% soy bean meal, SBM), T25 = feed with 25% BSFLM (25% BSFLM + 75%SBM), T50 = feed with 50% BSFLM (50% BSFLM + 50%SBM), T75 = feed with 75% BSFLM (75% BSFLM + 25%SBM), T100 = feed with 100% BSFLM (100% BSFLM + 0%SBM), DM = Dry matter, CP Crude protein, EE Ether extract.

4.4 Meat quality traits of broiler chicken

The meat quality parameters are presented in Table 7. The findings indicate significant differences in drumstick lightness and yellowness, while other color attributes remained consistent across treatments ($p = 0.003$ and $p = 0.005$, respectively). Specifically, the 100% BSFLM group had the highest drumstick lightness (66.13 ± 0.87) and yellowness (9.28 ± 0.82), whereas the 0% BSFLM and 50% BSFLM groups recorded the lowest values for lightness (54.26 ± 0.92) and yellowness (5.91 ± 0.42), respectively.

Shear force, a key indicator of meat tenderness, varied significantly among treatments ($p = 0.000$). The highest shear force (47.87 ± 4.59) was recorded in the 50% BSFLM group, while the lowest (20.89 ± 3.35) was observed in the 0% BSFLM group ($p = 0.000$). Particularly, shear force increased with BSFLM inclusion up to 50%, indicating tougher meat at moderate inclusion levels. However, at 100% BSFLM,

shear force declined, suggesting that lower inclusion levels ($\leq 25\%$) may be preferable for achieving tender meat.

Moreover, cooking loss differed significantly among treatments ($p = 0.002$), with the highest cooking loss recorded in the 25% BSFLM group ($15.30 \pm 1.17\%$) and the lowest in the 100% BSFLM group ($9.11 \pm 1.04\%$). However, meat temperature ($p = 0.308$) and pH ($p = 0.809$) did not show significant differences among treatments. These findings indicate that BSFLM inclusion influences meat color, tenderness and cooking loss, with moderate levels ($\leq 50\%$) potentially optimizing meat quality for consumer preference.

Table 7
Effects of replacing soybean with BSFLM on meat quality traits of broiler chicken

Parameters	TCOM	OBSF	25BSF	50BSF	75BSF	100BSF	P-value
Color							
Breast a*	2.06 ± 0.64	2.43 ± 1.21	1.10 ± 0.42	0.65 ± 0.27	0.15 ± 0.05	1.09 ± 0.49	0.139
breast L*	50.36 ± 2.18	47.66 ± 2.81	49.21 ± 0.63	48.75 ± 1.16	50.31 ± 1.73	54.47 ± 3.15	0.33
breast b*	4.92 ± 0.58	6.44 ± 1.10	5.03 ± 0.25	4.11 ± 0.35	5.37 ± 0.57	6.40 ± 0.94	0.178
Drumstick a*	4.34 ± 0.49	3.21 ± 1.12	3.33 ± 0.62	3.35 ± 0.53	2.04 ± 0.36	3.27 ± 0.54	0.323
Drumstick L*	55.86 ± 1.40 ^a	54.26 ± 0.92 ^a	57.68 ± 2.74 ^{ab}	55.34 ± 2.62 ^a	58.36 ± 2.12 ^{ab}	66.13 ± 0.87 ^b	0.003
Drumstick b*	6.04 ± 0.37 ^b	7.07 ± 0.33 ^{ab}	7.32 ± 0.96 ^{ab}	5.91 ± 0.42 ^b	6.45 ± 0.32 ^b	9.28 ± 0.82 ^a	0.005
Thigh a*	8.34 ± 2.02	5.05 ± 1.31	6.02 ± 1.48	8.06 ± 1.09	6.20 ± 1.78	7.15 ± 1.24	0.626
Thigh L*	55.16 ± 2.62	46.69 ± 0.39	55.27 ± 1.99	52.68 ± 1.31	53.94 ± 2.19	54.65 ± 3.74	0.111
Thigh b*	8.22 ± 0.57	7.97 ± 0.62	8.97 ± 0.91	7.67 ± 0.68	8.48 ± 1.24	8.25 ± 0.43	0.898
Other							
Shear force (N)	20.99 ± 0.77 ^a	20.89 ± 3.35 ^a	32.18 ± 1.10 ^b	26.97 ± 3.29 ^{ab}	34.62 ± 2.63 ^b	47.87 ± 4.59 ^c	0.000
Cooking loss (%)	16.15 ± 1.17 ^c	10.91 ± 1.04 ^{ab}	15.30 ± 1.17 ^{cb}	11.04 ± 1.04 ^{ab}	14.02 ± 1.15 ^{bc}	9.11 ± 1.04 ^a	0.002
Temperature (°C)	34.97 ± 0.32	35.63 ± 0.42	35.85 ± 0.44	35.12 ± 0.84	35.57 ± 0.38	36.61 ± 0.59	0.308
pH	6.20 ± 0.79	6.08 ± 0.079	6.13 ± 0.08	6.08 ± 0.89	6.17 ± 0.07	6.12 ± 0.09	0.809
^{a,b,c} Means with different superscripts within a row differ significantly at P ≤ 0.001							

a*= relative redness, L* = relative lightness, b*= relative yellowness, Tcom = treatment of commercial feed, T0 = treatment feed with no BSFLM (0% BSFLM + 100% soy bean meal ,SBM), T25 = feed with 25%

BSFLM (25% BSFLM + 75%SBM), T50 = feed with 50% BSFLM (50% BSFLM + 50%SBM), T75 = feed with 75% BSFLM(75% BSFLM + 25%SBM),T100 = feed with 100% BSFLM (100% BSFLM + 0%SBM).

5.0 Discussion

This study evaluated the effects of graded inclusion levels of Black Soldier Fly Larvae Meal (BSFLM) on slaughter characteristics, carcass traits, meat quality attributes, and fatty acid composition of broiler chickens. The findings provide important insights into the nutritional value, biological responses, and practical limits of BSFLM inclusion in broiler diets under tropical production systems. Overall, the results demonstrate that BSFLM can serve as a viable alternative protein source when included at moderate levels, while excessive inclusion compromises growth performance and certain meat quality traits.

5.1 Nutrient composition of BSFLM-based diets

The proximate composition of the experimental diets revealed that the crude protein (CP) content of BSFLM-based diets was within the range reported by Mwaniki (2019), who documented CP values between 40% and 44%. However, these values were lower than the 55.1% CP reported by Facey et al. (2023). Conversely, the crude fat content in the present study was higher than that reported by Facey et al. (2023), while ash content was lower than the 11–28% range reported by Mwaniki (2019). These variations highlight the inherent heterogeneity of BSFLM nutrient composition.

Differences in feed substrate, larval rearing conditions, processing methods, and agro-ecological environments are well known to influence BSFL nutrient profiles. Substrate composition, in particular, plays a major role in determining larval lipid and protein deposition, while environmental factors such as temperature and humidity influence growth efficiency and nutrient assimilation. These compositional variations are critical when formulating diets, as they affect metabolizable energy, digestibility, and ultimately animal performance.

5.2 Effects of BSFLM inclusion on slaughter weight and carcass yield

The significantly higher slaughter weight, carcass weight, and dressing percentage observed at the 25% BSFLM inclusion level highlight the benefits of moderate BSFLM incorporation. These improvements may be attributed to the relatively higher metabolizable energy content and lower chitin concentration at this inclusion level. Chitin, a structural polysaccharide found in the exoskeleton of insects, is poorly digested by poultry and can interfere with nutrient absorption when present in large quantities.

The improved carcass performance at 25% BSFLM is consistent with the findings of Brown et al. (2017), who reported that low to moderate BSFLM inclusion enhances gut microbiota balance and immune function, thereby supporting better growth performance. In contrast, birds fed 100% BSFLM exhibited significantly lower body and carcass weights, likely due to excessive chitin content impairing protein and

energy utilization. Similar inhibitory effects of high chitin levels on nutrient digestibility have been reported by Marono et al. (2017) and Kawasaki et al. (2019).

Comparable results were reported by Heita et al. (2023), who observed optimal carcass weights at low BSFLM inclusion levels (5%), suggesting that benefits diminish beyond moderate inclusion thresholds. Nampijja et al. (2023) also reported significant differences in carcass yield across BSFLM inclusion levels, further supporting the existence of an optimal inclusion range. However, contrasting results reported by Heita et al. (2023), where no significant differences in slaughter weight were observed, highlight the influence of diet formulation, bird strain, and experimental conditions on performance outcomes.

5.3 Body part yields and visceral organ development

The analysis of individual body parts revealed that birds fed 25% BSFLM had the highest breast and thigh weights, indicating superior muscle accretion at this inclusion level. These findings can be explained by the favorable energy-to-protein ratio and reduced chitin interference, which collectively support efficient muscle protein synthesis. The observed values exceeded those reported by Parmana et al. (2024), who recorded lower breast and thigh weights at BSFLM inclusion levels of 7.5% and 15%, suggesting that moderate increases beyond low inclusion levels can further enhance muscle development.

Visceral organ weights, including heart, gizzard, liver, caecum, and abdominal fat, were significantly higher at 25% and 50% BSFLM inclusion. Increased liver and heart weights may reflect enhanced metabolic activity and circulatory capacity required to support accelerated growth. These findings align with those of Brown et al. (2017) and Facey et al. (2023), who reported improved organ development with moderate BSFLM supplementation. Heita et al. (2023) also observed higher thigh weights at low-to-moderate inclusion levels, reinforcing the conclusion that BSFLM is most effective when incorporated within a defined optimal range. Collectively, these results suggest that BSFLM inclusion up to 25%–50% enhances carcass yield, body part development, and metabolic organ growth, while excessive inclusion compromises performance due to reduced digestibility associated with high chitin levels.

5.4 Chemical composition and fatty acid profile of broiler meat

The observed increase in ether extract (EE) content with rising BSFLM inclusion (25%–75%) reflects the naturally high lipid content of BSF larvae. Similar trends were reported by Zhou et al. (2018), who attributed increased carcass fat deposition to the protein-sparing effect and energy contribution of insect meals. Renna et al. (2017) observed comparable outcomes in fish, where BSFLM inclusion above 40% increased muscle fat content but negatively affected quality indices.

The carcass CP content observed in this study is consistent with Makokha (2023), who reported the highest protein retention in fish fed 100% BSFLM diets. However, while higher protein retention may be

beneficial in some species, broiler chickens appear to respond optimally at moderate inclusion levels, beyond which muscle development efficiency declines.

Fatty acid composition was largely unaffected by BSFLM inclusion, corroborating findings by Kierończyk et al. (2023), Kawasaki et al. (2019), Fruci et al. (2023), Akbaryan et al. (2019), and Oladokun et al. (2021). The lack of major shifts in fatty acid profiles suggests that BSFLM does not adversely alter the nutritional quality of broiler meat at moderate inclusion levels. However, contrasting findings by Nampijja et al. (2023), who reported significant changes in fatty acid composition, indicate that outcomes may vary depending on larval substrate composition and dietary lipid balance.

5.5 Meat quality attributes: color, tenderness, and cooking loss

Meat color parameters were influenced by BSFLM inclusion level, with higher lightness and yellowness values observed at 100% inclusion. These changes may be attributed to increased lipid and protein deposition, which influence light reflectance and pigment interaction in muscle tissues. Bianchi et al. (2009) reported that animal-based protein sources exert stronger effects on meat color than plant-based feeds, a trend also confirmed by Kierończyk et al. (2023).

Meat tenderness, assessed through shear force, declined at higher BSFLM inclusion levels, particularly at 100%. This may be associated with denser muscle fiber structure resulting from high protein content and altered collagen cross-linking. Murawska et al. (2021) similarly reported increased shear force values at 50% and 100% BSFLM inclusion, indicating reduced tenderness.

Cooking loss was highest at the 25% BSFLM inclusion level, potentially due to lower intramuscular fat and protein levels, which reduce water-holding capacity. Lower fat and protein content increases moisture loss during thermal processing, negatively affecting juiciness. Comparable trends were reported by Murawska et al. (2021), who observed greater cooking losses at lower BSFLM inclusion levels.

5.6 Economic and sustainability implications

The findings of this study are consistent with Mchunguzi et al. (2025), who reported improved broiler growth performance and economic efficiency at moderate BSFLM inclusion levels under Tanzanian production conditions. By partially replacing costly conventional protein sources such as soybean meal and fishmeal, BSFLM reduces feed costs and enhances profitability while contributing to circular bioeconomy principles through waste valorization.

6.0 Conclusion and Recommendations

6.1 Conclusion

This study demonstrates that Black Soldier Fly Larvae Meal is a promising, sustainable alternative protein source in broiler chicken diets. Moderate inclusion levels, particularly 25%–50%, significantly improved slaughter weight, carcass yield, muscle development, and overall meat nutritional quality without adversely affecting fatty acid composition. However, excessive inclusion levels ($\geq 75\%$) negatively impacted growth performance, meat tenderness, and water-holding capacity, likely due to reduced nutrient digestibility associated with high chitin content.

6.2 Recommendations

Based on the findings, it is recommended that BSFLM inclusion in broiler diets be limited to 25%–50% to optimize growth performance, carcass yield, and meat quality. Inclusion beyond this threshold is not advised due to declining performance and undesirable meat texture traits. Future research should focus on long-term feeding trials assessing haematological parameters, immune response, gut health, and consumer sensory acceptance. Additionally, strategies such as chitin reduction, enzymatic supplementation, or defatted BSFLM should be explored to enhance digestibility and broaden the safe inclusion range of BSFLM in poultry production systems.

Declarations

Ethics and consent

All experimental procedures were approved by the Sokoine University of Agriculture Research and Ethics Committee and conducted in accordance with institutional and national guidelines for animal care and welfare.

Competing Interest

The authors declare that they have no known financial, personal, or professional competing interests that could have influenced the research or interpretation of findings reported in this manuscript.

Data Availability

Not Applicable

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