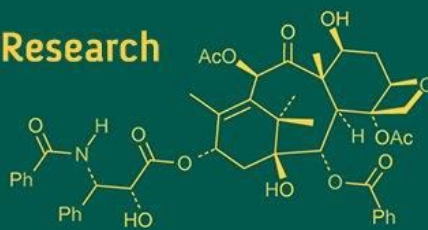
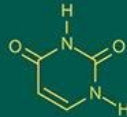


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
 ISSN Online: 2617-4707
 NAAS Rating (2026): 5.29
 IJABR 2026; 10(1): 1014-1019
www.biochemjournal.com
 Received: 21-10-2025
 Accepted: 23-11-2025

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Effect of feeding black soldier fly larvae meal on colour parameters, structural attributes and Sensory evaluation scores of breast meat in commercial broilers

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DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i1m.7169>

Abstract

The increasing global demand for poultry meat has led to challenges especially with respect to availability of quality and sufficient quantity protein such as soybean and fish meal for inclusion in broiler diets. The inclusion of insects or insect meal in poultry feeding could also be justified by the fact that birds generally dig in and scratch the ground for insects as a part of their natural diet. Insect meals are also good source of protein, energy, essential amino acids, fats, vitamins and minerals. An attempt was made to incorporate and evaluate the effect of inclusion of black soldier fly larvae meal in broiler diet on carcass characteristics etc. Birds up to 6 weeks were fed diet with 5, 10 and 15 Percent of black soldier fly larvae meal and all the diets will be formulated to meet isocaloric and nitrogenous by manipulating the diet inclusion level in the basal diet. At the end of the 6th week, birds were slaughtered and evaluated for carcass colour analysis, structural attributes and Sensory evaluation scores in breast meat. The increase in level of inclusion of BSF larvae meal there was a linear increase in redness (a*) values, decreases yellowness (b*) and chroma value. A linear increase in myoglobin content was observed with increase in level of inclusion of BSF larvae meal in the diet. There was no significant difference in appearance, juiciness, tenderness, flavor and overall acceptability of breast muscles between different treatments.

Keywords: Black soldier fly larvae meal, colour, structural, sensory attributes, broilers

Introduction

Insects and their meal prepared contain high nutritive value in terms of crude protein, fats, minerals and essential vitamins. It has been well documented that larvae and pupae of insects such as house fly, black soldier fly have crude protein comparable to that of soyabean meal used in poultry diets (40-60%) and hence can be used as a potential and sustainable alternative protein source in broilers, pigs and fish farming (Kareem *et al.*, 2018) [15]. Schiavone *et al.* (2016) [26] observed that the meal prepared from the BSF larvae had higher metabolizable energy and opined that it can be used as a potential source for replacement of maize in diets of broiler chicken. An attempt was made to incorporate and evaluate the effect of inclusion of black Soldier fly larvae meal in broiler diet on carcass colour analysis, structural attributes and Sensory evaluation scores of breast meat in commercial broilers.

Materials and Methods

A total of one hundred and twenty (120) day old commercial broiler chicks were procured from Venkateshwara Hatcheries Pvt. Ltd. Bengaluru and all the chicks were weighed and wing banded individually. The study was carried out with permission from Institutional Animal Ethics Committee, Veterinary College, Hebbal, Bangalore. The chicks were allocated to four different treatment groups each consisting of three replicates with 10 chicks each (30 chicks per treatment). Each of the treatment groups were fed with different types of experimental diets. The control group T₁ was fed with soyabean meal based basal diet as per BIS (2007) standards. Black Soldier Fly Larvae meal was procured from Sri Kalleshwari feeds Pvt Ltd, Kerala. The composition of BSF larvae meal is presented in Table 1. Birds in treatment groups T₂, T₃, T₄ were fed diet with 5, 10 and 15 Percent of black soldier fly

larvae meal respectively and all the diets will be formulated to meet isocaloric and nitrogenous by manipulating the diet inclusion level in the basal diet. (Table 2, 3 and 4). The chicks were reared in deep litter system and will be maintained under standard managerial practices till 6th weeks of age. Feed and water will be provided *ad libitum* throughout the experimental period. At the end of the 6th week, six (6) birds from each treatment will be slaughtered as per standard protocol to studied Colour parameters, structural attributes and Sensory evaluation scores of breast meat

Colour Analysis

Colour of the sample was tested using Hunter lab Mini scan XE plus Spectrocolorimeter (HunterLab, Model No: MSEZ-4500L, Reston, Virginia, USA) with geometry of diffuse/80 (sphere-8 mm view) and an illuminant of D65/10 deg (Bindu *et al.*, 2007) [11].

The instrument was calibrated with black and white tile ($L^* = 94$, $a^* = 1.10$ and $b^* = 0.6$) every time before the colour measurement was taken. The colour was expressed as L^* (brightness), a^* (redness) and b^* (yellowness). The hue (relative position of colour between redness and yellowness) and chroma (colour intensity) was calculated as follows.

$$\text{Hue} = \frac{\tan^{-1}(b^*/a^*)}{\sqrt{(a^*)^2 + (b^*)^2}}$$

Average value for each colour parameter was determined by taking observation from six different areas of the same sample.

Myoglobin and Met-Myoglobin content: Myoglobin was extracted from meat sample using a procedure as detailed by Warris (2007) [31] with slight modifications (Trout, 1989) [28].

Rigor value estimation (R-Value): Rigor value was estimated as per the method outlined by (Honikel and Fischer, 1977) [12]. The R-value of the meat samples were estimated at 2 and 24 hours after slaughter.

Collagen content: Hydroxyproline content of the meat sample was estimated based on the procedure of Nueman and Logan (1950) [22] with few modifications as recommended by Naveena *et al.* (2004) [21]. The collagen content was calculated by multiplying hydroxyproline content with 7.14 (Dransfield *et al.*, 1983) [9] and was expressed in mg/g tissue.

Collagen solubility: Collagen solubility was assessed using the method described by Mahendrakar *et al.* (1989) [18]. HP content was calculated using the below formula.

$$\% \text{ Collagen solubility} = 7.14 \times \% \text{ HP solubilized}$$

Myofibrillar fragmentation index: Myofibrillar fragmentation index was estimated by following the method given by Davis *et al.* (1980) [7] with slight modifications as suggested by Hawkins *et al.* (1987) [10].

Warner-Bratzler shear force: Warner-Bratzler shear force (WBSF) of each muscle sample was determined by the method outlined by Wheeler *et al.* (1997) [32].

Muscle fibre diameter: Fibre diameter was measured as per the method outlined by Jeremiah and Martin (1977) [14].

Sarcomere length: Sarcomere length of each muscle sample was measured as per the method outlined by Hostetler *et al.* (1972) [13].

Sensory Evaluation: The meat samples were cooked at 100 °C in a water bath for 30 minutes. The cooked meat chunks were served to semi-trained panelists and evaluated for appearance, flavor, juiciness, tenderness and overall acceptability using an 8-point descriptive scale in a score sheet (Where, 8 = extremely desirable, 1 = extremely undesirable) (Keeton, 1983) [16].

Statistical analysis: The descriptive statistics for the different types of data were determined as per Snedecor and Cochran (1994) [28] and the SPSS 20 statistical software. The differences between the mean values were evaluated using Tukey's Range Test at a significance level of 0.05 ($P \leq 0.05$).

Results

Meat colour

The Mean $\pm$ SE of lightness, redness, yellowness, hue, chroma, myoglobin and met-myoglobin values of breast meat from commercial broilers fed with Black soldier fly larvae meal are presented in the Table 5.

Lightness (L^*): The Mean $\pm$ SE of the lightness of breast meat in T₁, T₂, T₃ and T₄ were 54.73 $\pm$ 0.72, 55.11 $\pm$ 0.29, 55.23 $\pm$ 0.40 and 55.97 $\pm$ 0.19, respectively. No significant differences in lightness value were recorded between all the four treatments groups. In the present study, no significant difference could be observed in the lightness values between the different treatments and the value ranged from 54.73 to 55.97.

Redness (a^*): The Mean $\pm$ SE of the redness of breast meat in T₁, T₂, T₃ and T₄ were 2.70 $\pm$ 0.11, 2.97 $\pm$ 0.14, 2.98 $\pm$ 0.07 and 3.20 $\pm$ 0.11, respectively. Statistical analysis revealed a significant ($p < 0.05$) difference in redness (a^*) values between the treatment groups. It was observed that T₄ has the highest redness and was not significantly different from T₂ and T₃, similarly no significant difference in redness value could be observed between T₁, T₂ and T₃. The redness values increased linearly with increase in inclusion levels of BSF larvae meal. The results of the redness (a^*) values revealed that with the increase in level of inclusion of BSF larvae meal there was a linear increase in redness (a^*) values, with higher values being observed in 15 Percent level of inclusion compared to other groups. This could be attributed to higher myoglobin concentration in 15 Percent inclusion level in this study. No significant difference could be observed between the three levels of inclusion of BSF larvae meal.

Yellowness (b^*): The Mean $\pm$ SE of the yellowness values of breast meat in T₁, T₂, T₃ and T₄ were 11.03 $\pm$ 0.14, 10.38 $\pm$ 0.24, 10.18 $\pm$ 0.40 and 9.68 $\pm$ 0.23, respectively. Analysis of variance revealed a significant ($p < 0.05$) difference in yellowness (b^*) values between the treatment groups. It was observed that T₄ has the lowest yellowness value and was not significantly different from T₂ and T₃.

There was also no significant difference in yellowness value between T₁, T₂ and T₃. A linear decrease in yellowness value could be observed with the increasing levels of BSF larvae meal inclusion in this study. The Mean $\pm$ SE of the hue of breast meat of T₁, T₂, T₃ and T₄ were 0.51 $\pm$ 0.003, 0.52 $\pm$ 0.004, 0.50 $\pm$ 0.005 and 0.51 $\pm$ 0.005, respectively. No significant difference could be observed in hue values between the treatment groups. The Mean $\pm$ SE of the chroma of breast meat in T₁, T₂, T₃ and T₄ were 3.32 $\pm$ 0.02, 3.22 $\pm$ 0.03, 3.18 $\pm$ 0.06 and 3.11 $\pm$ 0.03, respectively. The ANOVA revealed significant ($p < 0.05$) difference in chroma value among different treatment groups. T₄ had the highest chroma values and was significantly different for T₁ and no significant difference could be observed between T₄, T₂ and T₃ and between T₁, T₂ and T₃.

Myoglobin (mg/g) and Met-myoglobin (%): The Mean $\pm$ SE of the myoglobin value of breast meat in T₁, T₂, T₃ and T₄ were 0.88 $\pm$ 0.01, 0.94 $\pm$ 0.03, 0.93 $\pm$ 0.05 and 1.06 $\pm$ 0.05, respectively. A significant ($p < 0.05$) difference in myoglobin content was recorded between the treatment groups. T₄ had the highest myoglobin content and was significantly different from control, whereas no significant difference could be observed between T₂, T₃ and T₄. Similarly, no significant difference could be observed with respect to myoglobin content between T₁, T₂ and T₃. A linear increase in myoglobin content was observed with increase in level of inclusion of BSF larvae meal in the diet. The Mean $\pm$ SE of the met-myoglobin value of breast meat in T₁, T₂, T₃ and T₄ were 66.17 $\pm$ 1.12, 68.28 $\pm$ 2.65, 68.60 $\pm$ 1.11 and 65.87 $\pm$ 2.55, respectively. No significant differences in met-myoglobin value were recorded between all four treatments. The results of the study indicated that there was a significant difference in concentration of myoglobin between different treatment groups with higher concentration being recorded in 15 Percent inclusion level. No significant difference could be observed with respect to met-myoglobin concentration between the treatment groups in this study. A linear and non-significant increase was evident with increase in level of inclusion of BSF larvae meal.

Structural characteristics

The Mean $\pm$ SE of shear force, muscle fiber diameter, sarcomere length, collagen content, collagen solubility and myofibrillar fragmentation index values of breast meat from commercial broilers fed with Black soldier fly larvae meal are presented in the Table 6

Shear force (kg/cm²): The Mean $\pm$ SE of the shear force value of breast meat in T₁, T₂, T₃ and T₄ were 5.50 $\pm$ 0.11, 5.48 $\pm$ 0.08, 5.43 $\pm$ 0.11 and 5.32 $\pm$ 0.07 respectively. No significant differences in shear force value were recorded between all four treatments. However, shear force value increased with increase in the inclusion levels of BSF larvae meal.

Muscle fiber diameter (μ m): The Mean $\pm$ SE of the muscle fiber diameter of breast meat in T₁, T₂, T₃ and T₄ were 54.69 $\pm$ 0.77, 56.05 $\pm$ 1.5, 55.52 $\pm$ 0.34 and 54.73 $\pm$ 1.4 respectively. No significant differences in muscle fiber diameter were recorded between all four treatments.

Sarcomere length (μ m): The Mean $\pm$ SE of the sarcomere length of breast meat in T₁, T₂, T₃ and T₄ were 1.36 $\pm$ 0.03,

1.30 $\pm$ 0.02, 1.31 $\pm$ 0.02 and 1.32 $\pm$ 0.02, respectively. No significant differences in sarcomere length were recorded between all four treatments.

Collagen content (mg/g): The Mean $\pm$ SE of the collagen content of breast meat in T₁, T₂, T₃ and T₄ were 363.67 $\pm$ 5.18, 367.21 $\pm$ 2.47, 367.57 $\pm$ 4.23 and 362.61 $\pm$ 4.01, respectively. No significant differences in collagen content were recorded between all four treatment groups.

Collagen solubility (%): The Mean $\pm$ SE of the collagen solubility of breast meat in T₁, T₂, T₃ and T₄ were 17.97 $\pm$ 0.39, 18.30 $\pm$ 0.30, 18.38 $\pm$ 0.25 and 18.52 $\pm$ 0.43, respectively. The ANOVA revealed significant no significant difference in collagen solubility between the treatment groups,

Myofibrillar fragmentation index (MFI): The Mean $\pm$ SE of the MFI value of breast meat in T₁, T₂, T₃ and T₄ were 59.18 $\pm$ 0.79, 61.58 $\pm$ 1.75, 60.67 $\pm$ 3.96 and 61.01 $\pm$ 1.13, respectively. No significant differences in MFI value were recorded between the treatment groups.

Sensory evaluation

The Mean $\pm$ SE of appearance, juiciness, tenderness, flavour and overall acceptability of breast meat from commercial broilers fed with Black soldier fly larvae meal are presented in the Table 7. The results of the present study revealed that there was no significant difference in appearance, juiciness, tenderness, flavor and overall acceptability of breast muscles between different treatments. The sensory scores this study corroborates with the results of shear force values and water holding capacity of meat in the present study. The Mean $\pm$ SE of the appearance value of breast meat in T₁, T₂, T₃ and T₄ were 7.23 $\pm$ 0.22, 7.18 $\pm$ 0.30, 7.50 $\pm$ 0.34 and 7.33 $\pm$ 0.33, respectively. No significant difference in appearance scores was recorded between the different treatment groups. The Mean $\pm$ SE of the juiciness value of breast meat in T₁, T₂, T₃ and T₄ were, 7.21 $\pm$ 0.21, 7.00 $\pm$ 0.26, 7.33 $\pm$ 0.33 and 7.17 $\pm$ 0.31, respectively. No significant difference in juiciness scores was recorded between the different treatment groups. The Mean $\pm$ SE of the tenderness value of breast meat in T₁, T₂, T₃ and T₄ were, 6.66 $\pm$ 0.33, 6.67 $\pm$ 0.21, 6.82 $\pm$ 0.31 and 6.60 $\pm$ 0.22, respectively. No significant difference in tenderness score was recorded between the different treatment groups. The Mean $\pm$ SE of the flavour value of breast meat in T₁, T₂, T₃ and T₄ were 7.16 $\pm$ 0.31, 7.50 $\pm$ 0.22, 7.00 $\pm$ 0.37 and 7.05 $\pm$ 0.31, respectively. No significant difference in flavour score was recorded between the different treatment groups. The Mean $\pm$ SE of the overall acceptability value of breast meat in T₁, T₂, T₃ and T₄ were 7.33 $\pm$ 0.21, 7.16 $\pm$ 0.40, 7.33 $\pm$ 0.33 and 7.21 $\pm$ 0.22, respectively. No significant difference in overall acceptability was recorded between the treatment groups.

Discussions

Meat colour remains the main visual parameter assessed by consumers and the most impacting criterion in the meat purchase decision. Indeed, it is an essential parameter in meat industry, in which carcasses should be pink or pale pink, preferred by the consumers, while darker meat is considerably difficult to market (Calnan *et al.*, 2016) ^[3].

The values Lightness (L^*) are well within the normal range of lightness values as reported by Van Laack *et al.* (2000) [30] who stated that the normal values of lightness in broiler muscle ranged from 50 and 56. The findings of the Redness (a^*) study are in line with Cullere *et al.* (2016) [5] who observed that inclusion of BSF larvae meal significantly affected the redness (a^*) value in the breast meat of broiler quails and they reported that higher redness value in birds fed 10 Percent BSF meal (1.13). Similar increase in redness values have been reported by Schiavone *et al.* (2019) [27], Daszkiewicz *et al.* (2022) [6] and Murawska *et al.* (2021) [20] in broilers fed different levels of BSF larvae meal. The increase in redness values could be attributed to the fact that BSF larvae contain higher concentrations of minerals, including Fe, than other edible insects used as animal feed. Hence, higher supply of Fe, which is present in the heme group of heme pigments, may be linked with the concentration of heme pigments in meat (Dierenfeld and King, 2008) [8]. In the present experiment, it was observed that there was a significant linear decrease in yellowness (b^*) and chroma value with increase in levels of BSF larvae meal. The findings are in alignment with Murawska *et al.* (2021) [20] who observed a decrease in yellowness and saturation (chroma) values in breast muscle in broiler supplemented with HI larvae meal as compared to that of control. Popova *et al.* (2020) [24] also reported that both breast and thigh muscle of broiler fed with BSF larvae meal had a significantly lower yellowness (b^*) and chroma value. However, contrary to the findings of this study Heuel *et al.* (2022) [11] observed a significant increase in yellowness in birds fed with BSFL meal as compared to control and Leiber *et al.* (2017) [17] who did not find any significant difference in meat colour of broilers fed BSF larvae meal.

The findings of Myoglobin (mg/g) and Met-myoglobin (%) were in line with Daszkiewicz *et al.* (2022) [6] who also reported a linear and quadratic increase in total concentration of heme pigments in the muscles of broiler chickens with increasing HI meal levels, with a maximum concentration in diet with 75 Percent meal. In addition, the present findings cannot be compared with the results of other studies investigating BSF larvae meal because none of the researchers have studied the implication of BSF meal on muscle pigments. The results of the present Structural characteristics study revealed no significant difference in shear force value, sarcomere length, muscle fibre diameter, collagen content, solubility and Myofibrillar fragmentation index between the treatment groups indicating no negative influence of BSF larvae meal inclusion in broiler diets. It has been documented earlier that there is a strong positive relationship between sarcomere length and meat tenderness and muscles with the sarcomere length shorter than 2.0 μm are found to be tender (Wheeler *et al.*, 2000) [33]. The values in the present study fall within this range and hence meat from all the treatments had similar shear force values. However, studies related to collagen content and solubility in broilers is very limited since the birds are slaughtered relatively in early stage of physiological development when intramuscular collagen is not significantly cross-linked (Purslow, 2018) [25] and there is paucity of data or information related to the effect of insect meal on structural characteristics in the meat of broiler chickens.

The findings of the present Sensory evaluation study are in agreement with Cross *et al.* (1986) [4] who concluded that BSF larvae meal did not cause any adverse effect on the eating quality attributes such as juiciness, tenderness and flavor as compared to that of control group. Similarly, Mohammed *et al.* (2017) [19] observed that the sensory panel scores did not reveal any significant differences in color, aroma, tenderness, flavor or overall acceptability in birds fed up to 33 Percent BSF meal. BSF larvae meal inclusion did not cause any significant influence on the aroma, flavour, initial and sustained juiciness and tenderness of cooked broiler breast muscles as that of soyabean fed broilers (Pieterse *et al.*, 2018) [23]. However, contrary to the findings of this study, Murawska *et al.* (2021) [20] opined that the taste panelists could notice a slight but steady decrease in flavor of the meat as the inclusion level of BSF meal increased in the feed. They also reported that chickens fed the highest amount of BSF insect meal (100%) was tougher and had less desirable flavor compared to other groups.

Table 1: The proximate composition of BSF larvae meal as under:

Proximate	Value
Metabolizable energy (kcal/kg)	3970.1
Crude protein (%)	59.7
Calcium (%)	2.3
Phosphorus (%)	1.6
Lysine (g/100 g)	2.8
Methionine (g/100 g)	1.0

Table 2: Percent ingredient and nutrient composition of Pre-starter diet

Ingredient	T ₁	T ₂	T ₃	T ₄
Yellow Maize	54.2	56.15	58	59.8
Soyabean meal	39.1	33.3	26.5	20
BSF larvae meal	0	5	10	15
Oil	3	2	1.5	1.5
Salt	0.5	0.5	0.5	0.5
Limestone	1.4	1.5	1.45	1.45
Dicalcium phosphate	1.1	1.4	1.3	1
Mineral mixture	0.1	0.1	0.1	0.1
Lysine	0.2	0.2	0.3	0.3
Methionine	0.2	0.15	0.15	0.15
Vitamin Premix	0.1	0.1	0.1	0.1
Choline chloride	0.1	0.1	0.1	0.1
Total	100	100	100	100
Nutrient composition				
Nutrient	T ₁	T ₂	T ₃	T ₄
Metabolizable energy (kcal/kg)	3000.1	3000.98	3020.71	3034.61
Crude protein (%)	23.06	23.01	23.11	23.13
Calcium (%)	1.06	1.01	1.11	1.14
Phosphorus (%)	0.7	0.71	0.74	0.72
Lysine	1.33	1.32	1.36	1.33
Methionine	0.5	0.51	0.52	0.54

¹Provides per kg: Calcium-230 g and Phosphorus-180 g

²Provides per kg: Mn-80 mg, Zn-80 mg, I-3.29 mg, Fe-32 mg and Se-0.1 mg

³Provides per kg: A-12375IU, D3-18000IU, B2-7.5 mg, B1-4 mg, B6-8 mg, B12-40 μg , E-20 mg, Niacin-60 mg and Calcium pantothenate-12.5 mg.

^aanalyzed values, ^bcalculated value

Table 3: Percent ingredient and nutrient composition of starter diet

Ingredient	T ₁	T ₂	T ₃	T ₄
Yellow Maize	55.1	56.6	59.95	62.5
Soyabean meal	37	31	24	17
BSF larvae meal	0	5	10	15
Oil	4.4	3.8	2.2	1.5
Salt	0.5	0.5	0.5	0.5
Limestone	1.2	1.2	1.5	1.7
Dicalcium phosphate ¹	1.1	1.5	1.2	1
Mineral mixture ²	0.1	0.1	0.1	0.1
Lysine	0.2	0.15	0.2	0.25
Methionine	0.2	0.15	0.1	0.15
Vitamin Premix ³	0.1	0.1	0.1	0.1
Choline chloride	0.1	0.1	0.1	0.1
Total	100	100	100	100
Nutrient				
Nutrient	T ₁	T ₂	T ₃	T ₄
Metabolizable energy (kcal/kg) ^b	3102.1	3100.08	3104.34	3119.51
Crude protein (%) ^a	22.01	22.01	22.06	22.13
Calcium (%) ^b	1.00	1.01	1.10	1.12
Phosphorus (%) ^b	0.7	0.71	0.70	0.71
Lysine ^b	1.21	1.22	1.21	1.2
Methionine ^b	0.49	0.48	0.48	0.49

¹Provides per kg: Calcium-230 g and Phosphorus-180 g²Provides per kg: Mn-80 mg, Zn-80 mg, I-3.29 mg, Fe-32 mg and Se-0.1 mg³Provides per kg: A-12375IU, D3-18000IU, B2-7.5 mg, B1-4 mg, B6-8 mg, B12-40 µg, E-20 mg, Niacin-60 mg and Calcium pantothenate-12.5 mg.^aanalyzed values, ^bcalculated value**Table 4:** Percent ingredient and nutrient composition of finisher diet

Ingredient	T ₁	T ₂	T ₃	T ₄
Yellow maize	58	62.5	64.6	65.7
Soyabean meal	33	25.4	18.6	13.5
BSF larvae meal	0	5	10	15
Oil	5	4	2.5	1.2
Salt	0.5	0.5	0.5	0.5
Limestone	1.3	1.05	1.5	1.5
Dicalciumphosphate ¹	1.6	1.5	1.5	1.8
Mineral mixture ²	0.1	0.1	0.1	0.1
Lysine	0.1	0.1	0.35	0.3
Methionine	0.2	0.1	0.15	0.1
Vitamin Premix ³	0.1	0.1	0.1	0.1
Choline chloride	0.1	0.1	0.1	0.1
Total	100	100	100	100
Nutrient composition				
Nutrient	T ₁	T ₂	T ₃	T ₄
Metabolizable energy (kcal/kg) ^b	3201	3200.67	3203.45	3206.47
Crude protein (%) ^a	20.04	20.09	20.11	20.14
Calcium (%) ^b	1.00	1.02	1.05	1.07
Phosphorus (%) ^b	0.71	0.71	0.73	0.72
Lysine ^b	1.09	1.12	1.15	1.09
Methionine ^b	0.45	0.45	0.48	0.45

¹Provides per kg: Calcium-230 g and Phosphorus-180 g²Provides per kg: Mn-80 mg, Zn-80 mg, I-3.29 mg, Fe-32 mg and Se-0.1 mg³Provides per kg: A-12375IU, D3-18000IU, B2-7.5 mg, B1-4 mg, B6-8 mg, B12-40 µg, E-20 mg, Niacin-60 mg and Calcium pantothenate-12.5 mg.^aanalyzed values, ^bcalculated value**Table 5:** Effect of feeding Black soldier fly larvae meal on Colour parameters in commercial broilers

Parameters	T ₁	T ₂	T ₃	T ₄
Redness (a*)	2.70±0.11 ^b	2.97±0.14 ^{ab}	2.98±0.07 ^{ab}	3.20±0.11 ^a
Yellowness (b*)	11.03±0.14 ^a	10.38±0.24 ^{ab}	10.18±0.40 ^{ab}	9.68±0.23 ^b
Hue (h)	0.51±0.003	0.52±0.004	0.50±0.005	0.51±0.005
Chroma (C)	3.32±0.02 ^b	3.22±0.03 ^{ab}	3.18±0.06 ^{ab}	3.11±0.03 ^a
Myoglobin (mg/g)	0.88±0.01 ^b	0.94±0.03 ^{ab}	0.93±0.05 ^{ab}	1.06±0.05 ^a
Met-Myoglobin (%)	66.17±1.12	68.28±2.65	68.60±1.11	65.87±2.55

Means bearing different superscripts (a, b, c) between the columns differ significantly ($p < 0.05$)T₁ represents control (Basal diet), T₂ represents (5% BSF larvae meal inclusion), T₃ represents (10% BSF larvae meal inclusion) and T₄ represents (15% BSF larvae meal inclusion).**Table 6:** Effect of feeding Black soldier fly larvae meal on structural attributes in commercial broilers

Parameters	T ₁	T ₂	T ₃	T ₄
Shear force (kg/cm ²)	5.50±0.11	5.48±0.08	5.43±0.11	5.32±0.07
Muscle Fiber Diameter (µm)	54.69±0.77	56.05±1.5	55.52±0.34	54.73±1.4
Sarcomere Length (µm)	1.36±0.03	1.30±0.02	1.31±0.02	1.32±0.02
Collagen Content (mg/g)	363.67±5.18	367.21±2.47	367.57±4.23	362.61±4.01
Collagen Solubility (%)	17.97±0.39	18.30±0.30	18.38±0.25	18.52±0.43
MFI	59.18±0.79	61.58±1.75	60.67±3.96	61.01±1.13

T₁ represents control (Basal diet), T₂ represents (5% BSF larvae meal inclusion), T₃ represents (10% BSF larvae meal inclusion) and T₄ represents (15% BSF larvae meal inclusion).**Table 7:** Sensory evaluation scores of breast meat in commercial broilers fed with Black soldier fly larvae meal

Parameters	T ₁	T ₂	T ₃	T ₄
Appearance	7.23±0.22	7.18±0.30	7.50±0.34	7.33±0.33
Juiciness	7.21±0.21	7.00±0.26	7.33±0.33	7.17±0.31
Tenderness	6.66±0.33	6.67±0.21	6.82±0.31	6.60±0.22
Flavour	7.16±0.32	7.50±0.22	7.02±0.37	7.05±0.31
Overall acceptability	7.33±0.21	7.16±0.40	7.33±0.33	7.21±0.22

T₁ represents control (Basal diet), T₂ represents (5% BSF larvae meal inclusion), T₃ represents (10% BSF larvae meal inclusion) and T₄ represents (15% BSF larvae meal inclusion).

Conclusion

The increase in redness values in commercial broiler breast meat could be attributed to the fact that BSF larvae contain higher concentrations of minerals, including Fe, leads to concentration of heme pigments in meat. BSF larvae meal feeding did not cause any adverse effect on the eating quality attributes such as juiciness, tenderness and flavor as compared to that of control group

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