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Effect of Dietary Inclusion of Full-Fat Black Solder Fly Larvae (*Hermetia illucens* L.) on Egg Production and Quality in Laying Hens

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Abstract

This study evaluated the effect of full-fat black soldier fly larvae meal (FF-BSFLM) on egg production and egg quality in Bovan Brown laying hens. Seventy-two 23-week-old hens were randomly assigned to four dietary treatments with FF-BSFLM inclusion levels of 0% (T_1), 3% (T_2), 6% (T_3), and 9% (T_4), replicated three times with six hens per pen. Over a 12-week period, feed intake, body weight change, egg production, egg quality and gastrointestinal tract characteristics were recorded. Feed intake and body weight changes were not significantly affected ($P>0.05$) by FF-BSFLM inclusion. However, egg production parameters such as hen-day (HDEP%) and hen-housed (HHEP%) egg production were significantly influenced ($P<0.05$), with T_3 (6% inclusion) showing the lowest HDEP (47%), while T_4 (9%) had a laying rate comparable to the control. Egg number and mass were significantly higher in T_1 and T_4. Treatment four also had the highest egg weight (58.86 g), indicating good nutrient availability and utilization. Most egg quality traits remained unaffected across treatments. The findings highlight FF-BSFLM as a viable alternative protein source to costly ingredients like soybean meals and meat and bone meals. Future research should refine inclusion levels to support sustainable poultry production in Ethiopia.

Keywords: Alternative protein feed source, Black soldier fly larvae, Egg production, Egg quality, Layer diet.

Introduction

Poultry production plays a vital role in enhancing food and nutrition security and generating income among rural low-income communities in Ethiopia. The national strategies and community-based initiatives underscore the growing importance of poultry production in improving livelihoods and addressing malnutrition. In 2023, Ethiopia launched the first National Poultry Development Strategy (NPDS) spanning from 2022 to 2031 by the Ministry of Agriculture in collaboration with the International Livestock Research Institute (ILRI). This strategy aims to double poultry meat production from 48,000 tons in 2020 to 106,000 tons by 2031, and egg production from 2.85 billion to 5.5 billion eggs in the same years (Tsigereda *et al.* 2022). The NPDS has emphasized enhancing productivity, improving veterinary services, and expanding market access to strengthening the role of the poultry sector in food security and poverty reduction. Moreover, government development initiatives such as “Ye Lemat Tirufat” focus on boosting the production of dairy, eggs, chicken meat, and honey to achieve food self-sufficiency and improve nutritional outcomes at both family and national levels (Tadelle *et al*. 2023). However, the poultry production in the country is increasingly challenged by the high cost and unreliable availability of conventional feed ingredients, particularly essential protein sources, such as soybean meals and fishmeal. This problem can be addressed through exploring alternative and non-conventional protein sources that are locally available, cost-effective, and environmentally sustainable. Since 2013, insect protein has gained recognition as a promising alternative to replace conventional feed ingredients in poultry diets, offering a potential solution to improve feed security (van Huis *et al*. 2013).

Insects have high conversion efficiency and can be reared on bio-waste streams. One kg of insect biomass can be produced from on average 2 kg of feed biomass (Collavo *et al*. 2005). The production of insects for poultry feed not only provides high quality nutrient but also contributes to environmental sustainability through conversation of biowaste into biomass and organic fertilizer. Veldkamp *et al.* (2012) and Chala *et al*. (2022) have demonstrated that large scale insect production using substrates from bio-waste and organic side streams, is technically feasible and increasingly recognized as alternative high quality protein source in pig and poultry diets.

Among insects, black soldier fly (BSF) has emerged as a sustainable solution for converting organic waste into biomass rich in protein, fat and minerals for poultry and aquaculture production. Black Solder fly larvae (BSFL) contain high-quality protein, essential amino acids, and bioactive compounds that can enhance poultry performance and health (Anna *et al*. 2024; Sajid *et al*. 2023). Previous studies suggested that partial or full replacement of conventional protein sources with BSFL meal can improve egg production, egg quality, and feed efficiency in layers without compromising animal welfare (Zipporah *et al*. 2020; Mwaniki *et al*. 2018). In developing and least-developed countries like Ethiopia, where feed security is a pressing concern, the integration of BSFL into poultry rations has the potential to improve feed availability while promoting circular bioeconomy practices and reducing environmental footprints (Shahida *et al*. 2024). BSFL production and utilization as a feed ingredient is at its early stages in Ethiopia. Therefore, this study aims to evaluate the effect of different levels of dietary inclusion of BSFL meal in layer rations on egg production, egg quality traits and gut characteristics. The findings of this study provide valuable insights into the role of insect-based feed ingredients for sustainable poultry production in Ethiopia.

Materials and Methods

The experiment was conducted at Debre Zeit Agricultural Research Center (DZARC), recently renamed as Bishoftu Agricultural Research Center (BARC), located 47 km southeast of Addis Ababa, Ethiopia. It is coordinated at 8.7655^0N and 38.9978^0E with an altitude of 1900 meters above sea level. The average annual rainfall is 1100 mm, and the average maximum and minimum temperatures of the area are 28.3 and 8.9°C, respectively (http://www.eiar.gov.et/main-center-debrezeit/). The poultry research houses at the farm use a deep litter system. One of the longer sides has a half wall and is open above, covered with mesh wire and equipped with curtains for weather control.

Table 1. Chemical composition of feed ingredients used to formulate an experimental feed

Nutrient	White maize	Wheat middling	Noug seed cake	Soybean meal	Meat and bone meal	FF-BSFL[1]
Dry Matter (DM) %	92.10	92.90	94.90	94.00	92.50	90.00
Crude Protein (%DM)	8.70	15.60	34.60	43.50	50.00	44.00
Crude Fiber (%DM)	2.10	9.20	17.20	6.10	2.80	7.00
Ether Extract (%DM)	3.60	3.60	7.10	6.80	8.50	46.12
Ash (%DM)	3.30	4.00	10.40	6.00	30.00	7.00
[2]ME (kcal/kg of DM)	3340	1980	2400	2180	2530	4700
Calcium (%DM)	0.04	0.11	0.26	0.30	9.20	6.50
Phosphorus (%DM)	0.30	1.05	0.70	0.65	6.0	0.80

[1]FF-BSFL=full-fat black soldier fly larvae; [2]ME= metabolizable energy

Sources and production of black soldier fly larvae

BSF rearing pilot site was established at BARC through funding from the EU-NESTLER project. The startup colony at larval stage was donated by the International Center of Insect Physiology and Ecology (ICIPE), Ethiopia, from Adama station. A substrate composed of wheat bran and molasses was prepared to attract adult BSF to induce egg-laying and hatching. The larvae had been reared on a substrate composed of vegetable and kitchen wastes. BSF larvae were harvested every 15-18 days using multi-mesh sieves. To kill larvae and remove residual organic matter, they were immersed in hot water at approximately 60°C for 5 minutes. After blanching, the larvae were sieved again and spread evenly on aluminum trays for sun drying. Regular turning was done to ensure uniform drying, which typically took two to three days, depending on sunlight intensity. Once fully dried, the larvae were ground into a full-fat meal using standard mills for further analysis and use.

Formulation of experimental diets

The chemical compositions of the feed ingredients (Table 1) were analyzed (AOAC, 2023) from representative samples of white maize, wheat middling, noug seed cake, soybean meal (SBM), and full-fat black soldier fly larvae meal (FF-

BSFLM) before formulating the experimental diets. Ingredients such as maize, noug seed cake, and salt were milled and hammered in a size of 5 mm. Based on the chemical analysis results, four treatment rations containing FF-BSFLM were formulated to be nearly isocaloric and isonitrogenous at 2750 kcal/kg DM ME and 16.5% CP, at a maximum of 8% CF and EE, at a minimum of 3.9% Ca and 0.8% of P using FeedWin feed software. Four experimental feeds were prepared with different inclusions of FF-BSFL meal, hereafter designated as T_1= 0% FF-BSFLM, T_2 = 3% FF-BSFLM, T_3= 6% FF-BSFLM and T_4= 9% FF-BSFLM (Table 2).

Table 2. Proportion of ingredients used in formulating a layer ration and analyzed chemical composition of the treatments diet

Item	Treatement[2]			
Ingredient (%)	T_1	T_2	T_3	T_4
White maize	60.00	60.00	59.00	55.50
Wheat middling	6.00	5.00	5.00	8.30
Noug seed cake	5.00	6.00	6.00	5.00
Soybean meal	15.00	12.50	12.00	11.00
Meat and bone meal	3.50	3.00	2.00	1.00
FF-BSFL[1] meal	0.00	3.00	6.00	9.00
Salt	0.40	0.40	0.40	0.40
Dicalcium phosphate	1.40	1.70	1.80	2.00
Limestone	8.30	8.00	7.70	7.40
L-lysine	0.20	0.20	0.20	0.20
DL-methionine	0.20	0.20	0.20	0.20
Total	100.00	100.00	100.00	100.00
Calculated Analysis				
Dry Matter (DM) %	93.09	93.00	92.90	92.80
Crude Protein (%DM)	16.47	16.64	16.83	17.40
Crude Fiber (%DM)	3.69	3.81	3.94	4.12
Ether Extract (%DM)	3.33	4.65	5.91	7.11
Ash (%DM)	5.91	6.14	6.05	6.01
Calcium (%DM)	3.90	4.00	4.01	4.05
Phosphorus (%DM)	0.82	0.85	0.83	0.85
Metabolizable Energy (kcal/kg DM)	2675	2753	2816	2842

[1]FF-BSFLM= full-fat black soldier fly larvae meal; [2]T_1= treatment diet without FF-BSFLM (control diet), T_2= treatment diet containing 3% FF-BSFLM, T_3= treatment diet containing 6% FF-BSFLM and T_4= treatment diet containing 9% FF-BSFLM.

Source of experimental animals and experimental setup

The experimental birds were initially sourced from Alema Farms PLC, Bishoftu, and reared at BARC according to standard handling protocols of the farm. A total of 72 Bovans Brown layer hens, 23 weeks of age with an initial body weight of 1.50±0.75 kg (mean ± SD), were randomly assigned to four dietary treatments, each with three replications. The 12 pens used for the study were uniformly partitioned with concrete floors covered with disinfected teff straw litter. Prior to the start of the experiment, all pens, feeding and watering troughs, and laying nests were thoroughly cleaned, disinfected, and sprayed to control external parasites. Each treatment pen consisted of six randomly distributed birds. All hens were vaccinated against Newcastle, Gumboro (infectious bursal disease), fowl typhoid, and fowl pox, with additional health and sanitation measures maintained throughout the study period. Birds were provided with experimental diets at a rate of 125 g/bird/day, and clean water was available *ad libitum*. Feed was offered in round feeders, and water was supplied with plastic jars. Fluorescent lamps were installed to ensure uniform lighting conditions, and birds underwent a one-week adaptation period to experimental diets prior to the initiation of data collection. The IoT devices (Syn Air integrated with Syn Field Nodes) were installed outdoors to monitor the light intensity and air conditioning like temperature, humidity, ammonia and CO_2 inside the experimental house. These devices were donated by the NESTLER project partners and received from SYNELIXIS in Greece.

Measurements

The experiment was conducted for 12 weeks. Feed offered and feed refusals were recorded daily to calculate feed intake as the difference between the amount offered and refused. Initial and final weight of the hens was measured at the beginning and end of the experiment to determine the weight change during the experimental period. Eggs were collected three times daily from each pen at 08:00, 13:00, and 17:00 hours. The total number of eggs collected during time intervals along with the number of live birds was recorded and summarized over the experimental period. Eggs collected daily were weighed immediately after collection, and the average egg weight per pen was calculated by dividing the total egg mass by the number of eggs produced. Egg mass per hen was calculated as total egg mass divided by the number of hens in the pen and dozen from number of eggs divide by 12. Hen-day egg production (HDEP), expressed as a percentage, was determined using the method described by Hunton (1995):

$$\%HDEP = \frac{\text{Number of eggs collected per day}}{\text{Number of hens present that day}} \times 100$$

Feed conversion ratio was calculated as the ratio of feed consumed (g) to egg mass produced (g). Mortality was recorded as it occurred, and the general health status of the birds was monitored throughout the experimental period. To assess egg quality, four freshly laid eggs per replicate were randomly sampled at 15-day intervals. External egg quality parameters included egg weight and shape index were measured and calculated. By breaking each egg on flat glass and separating its components, internal quality parameters including shell weight, shell thickness, yolk color, yolk weight, yolk length, yolk height, yolk index, albumen weight, albumen heights, and Haugh unit were evaluated. The shell, albumen, and yolk were carefully separated and weighed using a precision balance (±0.01 g). Shell thickness was measured at the blunt, middle, and sharp ends of the egg using a digital micrometer, and the average value was recorded. Albumen and yolk heights were measured using a micrometer. The Haugh unit was calculated following Haugh (1937) using the formula:

$$HU = 100 \log_{10} (h + 7.57 - 1.7w^{0.37}),$$

Where h is albumen height (mm) and w is egg weight (g).

Yolk color was assessed by comparing the mixed yolk sample placed on glass plate against the Roche Color Fan scale, which ranges from 1 (pale yellow) to 15 (deep orange yellow). Egg and yolk dimensions (length and width) were measured using digital caliper. The egg shape index and yolk index were calculated as described by Panda (1996) using the following formulas:

$$\text{Egg shape index} = \frac{\text{Width of egg}}{\text{Length of egg}} \times 100$$

$$\text{Yolk Index} = \frac{\text{Yolk height}}{\text{Length of egg}} \times 100$$

Statistical analysis

Data were analyzed using the General Linear Model (GLM) procedure of SAS software (SAS, 2002), with the model including treatment effects. Differences between treatment means were separated using the Tukey HSD test. Below is the model used:

$$Yij = \mu + \alpha i + \varepsilon i$$

Where

Yijk = Response variable, μ = Overall mean, αi = Effect of treatments, εi = Random error

Results and Discussion

Full fat BSFLM exhibited higher levels of CP (44%), EE (46.12%), ME (4700 kcal/kg DM), Ca (6.50%) and P (0.80 %) compared to the conventional ingredients such as soybean meal (SBM) and noug seed cake (NSC) (Table 1). Notably, the EE and ME values of FF-BSFLM were significantly higher ($P<0.05$)

than other ingredients used to formulate experimental diets. The CP content was comparable with soybean meal, which typically contain around 44% as indicated in the previous studies ranging between 44-48% (Makkar *et al*. 2014; Barragan-Fonseca *et al*. 2017, Aschalew *et al*. 2024). Although the protein content in FF-BSFLM varies based on the substrate ingredients for larval growth, Chia *et al*. (2020) and Mwaniki *et al*. (2022) indicated BSFL protein levels between 40-45% have shown good digestibility and support growth performance in poultry.

Table 3 showed the effect of feeding FF-BSFLM on feed consumption, body weight changes and egg laying performance in laying hens. Daily feed intake (g/bird) ranged from 92.82 g (T_3) to 109.39 g (T_4) although there is no significant difference (P>0.05) among the treatments. Similarly, the total feed consumption ranged from 7.80 kg (T_3) to 9.19 kg (T_4) and was not significantly different (P>0.05) among the treatments. The body weight changes showed no significant difference (P>0.05) among the treatments though higher weight gain was observed in T_4 (166.11 g). This study showed that the increasing level of FF-BSFL from 0 to 9% had no adverse effect on feed intake or body weight change. Hens in T_3 diet showed significantly low (P<0.05) HDEP and HHEP values compared with other treatment diets which could be associated with laying rate. Total egg number and egg mass were significantly higher (P<0.05) in T_1 and T_4 suggesting replacement of conventional protein sources with FF-BSFLM may enhance yolk lipid content and improve egg weight (Mwaniki *et al*. 2020). The egg weight and egg mass in T_4 were significantly higher (P<0.05) than T_2 and T_3 indicating the potential of FF-BSFL to enhance egg mass and egg quality as previously reported by Mwaniki *et al.* (2020) and Biasato *et al.* (2019).

Several studies support the use of FF-BSFLM as a sustainable protein and fat source in poultry diets. Culler *et al.* (2018) and Mwaniki *et al*. (2020) indicated the potential of BSFLM to replace conventional protein source (SBM or fishmeal) without adverse effects on egg quality and laying performance. Attivi *et al*. (2022) found that up to 12% inclusion of BSFLM in layer diets increased egg production, egg weight and feed conversion ratio due to the fat content, supporting the current study result in T_1 and T_4.

Table 3. Feed consumption, body weight changes, and egg laying performance of laying hens fed with different levels of FF-BSFL meal

Parameter[2]	Treatments[1]				SEM	P-value
	T_1	T_2	T_3	T_4		
Feed intake (g/bird/day)	104.40	99.86	92.82	109.39	2.44	0.070
Total feed consumption (kg/bird)	8.77	8.39	7.80	9.19	0.21	0.070
Initial body weight (g)	1539.44	1472.78	1508.33	1535.00	22.10	0.760
Final body weight (g)	1606.67	1552.22	1606.67	1701.11	98.24	0.350
Body weight changes (g)	67.22	79.44	98.34	166.11	23.31	0.500
HDEP%	70.00^{a}	60.33^{a}	47.00^{b}	62.33^{a}	2.77	0.003
HHEP%	70.00^{a}	58.33^{ab}	47.00^{b}	62.33^{a}	2.82	0.004
Egg weight (g)	57.96^{ab}	55.46^{b}	56.50^{ab}	58.86^{a}	0.49	0.030
Eggs/hen (number)	59.00^{a}	50.33^{ab}	39.33^{b}	52.67^{a}	2.38	0.003
Egg mass (kg)	4.06^{a}	3.35^{ab}	2.66^{b}	3.67^{a}	172.02	0.003
Dozen Eggs (12)	4.92^{a}	4.19^{ab}	3.28^{b}	4.39^{a}	0.20	0.003
FCR in egg mass	2.16^{a}	2.52^{ab}	2.95^{b}	2.53^{ab}	0.11	0.032
FCR in Dozen eggs	1.79	2.01	2.39	2.11	0.09	0.100

[a, ab, b] Means within a row with different superscripts differ significantly ($P<0.05$).
[1]=T_1: 0% full fat black soldier fly larvae meal (FF-BSFLM) (control diet), T_2: layer diet containing 3% FF-BSFLM, T_3: layer diet containing 6% FF-BSFLM, T_4: layer diet containing 9% FF-BSFLM.
[2]= FCR: feed conversion ratio, HHEP: hen-housed egg production, HDEP: hen-day egg production.

In this study, egg width value recorded in T_4 was relatively higher than other treatments (Table 4). A wider egg could be associated with better shell formation due to the calcium and fat content in BSFL enriched meal (Spranghers *et al.* 2017). As previous studies indicated, the shape index, shell thickness and weight did not vary among treatments, indicating different levels of BSFL inclusion has no effect on these parameters, Borrelli *et al*. (2017). Albumen height and Haugh unit values differed significantly ($P<0.05$) among the treatments. The highest albumen height (10.42 mm) was recorded in T_2, which was statistically like T_3 and T_4. Albumen height is directly related to freshness and quality and higher value in T_2 reflect better protein digestibility and amino acid balance from FF-BSFLM (Makkar *et al*. 2014; Schiavone *et al*. 2017). Haugh unit scores greater than 90 indicate excellent egg quality which are shown in T_2, T_3 and T_4. The higher Haugh unit score in T_2 (102.10) indicate inclusion of FF-BSFLM at moderate level may support superior egg freshness and internal quality (Veldkamp and Bosch, 2015). This study did not show a difference in yolk characteristics with increasing BSFL inclusion which might be because of lack of pigments like xanthophylls in FF-BSFLM unlike yellow maize and other leaf meals (Altmann *et al.* 2020).

Table 4. Egg quality characteristics of laying hens fed different levels of FF-BSFL meal

Parameter	Treatments[1]				SEM	P-value
	T_1	T_2	T_3	T_4		
Sampled egg weight (g)	57.96^{ab}	55.46^{b}	56.50^{ab}	58.86^{a}	0.49	0.03
Egg length (mm)	55.90	56.07	56.03	57.75	0.32	0.12
Egg width (mm)	42.79^{ab}	42.69^{ab}	42.52^{b}	43.36^{a}	0.12	0.04
Shape index	76.61	76.19	75.97	75.09	0.42	0.69
Shell thickness (mm)	0.37	0.36	0.36	0.36	0.00	0.10
Shell weight (g)	7.64	7.49	7.29	7.62	0.16	0.89
Albumen height (mm)	8.00^{b}	10.42^{a}	8.92^{ab}	9.67^{ab}	0.32	0.01
Albumen weight (g)	34.73	32.89	33.37	36.20	0.50	0.05
Haugh unit	89.53^{b}	102.10^{a}	95.03^{ab}	97.93^{ab}	1.61	0.01
Yolk weight (g)	13.51	13.59	13.70	12.95	0.18	0.55
Yolk height (mm)	15.75	15.42	15.25	15.17	0.12	0.41
Yolk index	36.00	35.00	33.00	34.00	0.01	0.23
Yolk color (RCF)[2]	1.00	1.00	1.00	1.00	-	-

a, ab, b Means within a row with different superscripts differ significantly (P<0.05).
[1]=T1: 0% (control diet), T2: layer diet containing 3% full fat black soldier fly larvae meal (FF-BSFLM), T3: layer diet containing 6% FF-BSFLM, T4: layer diet containing 9% FF-BSFLM.
[2]=RCF: Roche Color Fan

The slaughter and total GIT weights showed no significant differences (P>0.05) among treatments, indicating that FF-BSFLM inclusion had no adverse effect on overall body development of GIT (Table 5). Hens that fed T_4 diet (9% FF-BSFLM inclusion) had numerically the highest slaughter weight (1745.00 g), which may suggest a trend toward improved body weight with higher FF-BSFLM inclusion. The weights of crop, proventriculus, gizzard, and intestines (small, large, and caeca) with and without contents showed no significant differences across treatments (P>0.05). Gizzard weight (with contents) tended to increase with FF-BSFLM inclusion (T_4= 72.90 g), might be due to the increased fiber or chitin content from insect meal stimulating mechanical digestion (Bovera, 2016). No pathological enlargement or reduction was observed supporting the safety of FF-BSFLM in layer diets. Liver and spleen weights did not differ significantly P>0.05) among treatments though T_4 had the highest liver weight (46.10 g) which could be associated with improved metabolic activity due to fat metabolism from FF-BSFLM within a healthy range (Mwaniki *et al.* 2020). Abdominal fat was higher in T_4 which might be due to the increased inclusion of FF-BSFLM leading to fat deposition in poultry (Schiavone *et al.* 2017).

The inclusion of FF-BSFLM in layer diets did not significantly alter the GIT morphology or visceral organ weights, supporting its nutritional safety and digestive compatibility with layer physiology. Chitin content and structural polysaccharide in BSFL exoskeletons may promote gut health by acting as a prebiotic and mechanically stimulating gizzard function; however, excessive levels (beyond 15%) might limit digestibility if not balanced with enzymes or grit

(Schiavone *et al.* 2017; Mwaniki *et al.* 2020). Insect meals like FF-BSFL are known to influence lipid metabolism due to their high lauric acid content, which can affect abdominal fat deposition and liver size (Benzertiha *et al*. 2019; Cullere *et al*. 2019). In this study, T_4 showed higher abdominal fat which aligns with Sogari *et al*. (2019) who suggested moderate inclusion of FF-BSFLM as safe. Insignificant difference among treatments particularly in immune organs like spleen suggests that FF-BSFLM does not compromise immunological status. Previous studies reported enhanced immune responses with BSFL inclusion due to bioactive compounds (Spranghers *et al*. 2018).

Table 5. Gastrointestinal tract characteristics of 34-week-old hens fed a diet containing FF-BSFL meal

Parameters	Treatments[1]				SEM	P-value
	T_1	T_2	T_3	T_4		
Slaughter weight (g)	1696.70	1583.30	1553.30	1745.00	56.76	0.65
Total GIT[2] weight (g)	209.30	240.03	201.83	227.23	8.88	0.47
Crop weight with contents (g)	15.60	17.47	16.20	16.00	1.33	0.98
Proventriculus weight with contents (g)	13.27	11.53	11.07	13.63	0.60	0.39
Gizzard weight with contents (g)	52.60	56.00	67.93	72.90	4.00	0.24
Small intestine weight with contents (g)	93.23	83.03	72.00	88.53	4.19	0.35
Large intestine weight with contents (g)	6.83	10.73	6.53	8.63	0.88	0.34
Caeca weight with contents (g)	14.80	15.50	13.63	14.03	0.56	0.71
Crop weight without contents (g)	9.17	10.73	12.37	11.40	0.52	0.16
Proventriculus weight without contents (g)	11.00	8.87	10.73	11.00	0.54	0.50
Gizzard weight without contents (g)	34.60	37.13	41.47	44.13	2.04	0.39
Small intestine weight without contents (g)	60.20	51.70	51.87	61.10	1.99	0.16
Large intestine weight without contents (g)	4.50	5.77	3.47	5.00	0.45	0.37
Caeca weight without contents (g)	7.97	7.87	6.87	6.53	0.51	0.74
Liver weight (g)	34.67	40.57	36.47	46.10	2.31	0.34
Spleen weight (g)	1.83	2.40	1.57	2.73	0.24	0.33
Abdominal fat weight (g)	18.10	17.20	19.07	32.00	4.27	0.64

[1]=T_1: 0% (control diet), T_2: layer diet containing 3% full fat black soldier fly larvae meal (FF-BSFLM), T_3: layer diet containing 6% FF-BSFLM, T_4: layer diet containing 9% FF-BSFLM.
[2]=gastrointestinal tracts

Conclusion

This study demonstrated that FF-BSFLM has superior nutritional value compared to conventional protein sources in layer diets. Feed intake, body weight changes, egg production, and quality remained unaffected or improved at higher inclusion levels (up to 9%), indicating its dietary suitability and safety. Notably, egg weight, albumen quality, and Haugh unit scores improved at the 9% inclusion, with no adverse effects on yolk color or gut morphology. Given the high cost and limited availability of conventional poultry feeds in Ethiopia, FF-BSFL offers a viable and cost-effective alternative. Future research should focus on standardizing inclusion rates, optimizing BSF production and utilization by different poultry production systems, and conducting cost-benefit analyses to support broader adoption in broilers and dual-purpose chickens.

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