Indian Journal of Animal Sciences **96** (2): 139–144, February 2026/Article
https://doi.org/10.56093/ijans.v96i2.172277

Effect of partial replacement of soyabean meal by black soldier fly (*Hermetia illucens*) larvae meal on growth performance and nutrient retention in broiler chickens

PRAVIN KUMAR[1], SANJAY KUMAR[2], KAUSHALENDRA KUMAR[3✉], PANKAJ KUMAR SINGH[4], DHARMENDRA KUMAR[5], SANKHANATH KOLEY[6], RAJNI KUMARI[7], SAVITA KUMARI[8], RAVI RANJAN KUMAR SINHA[9], DEEPAK KUMAR[10] and JAY PRAKASH GUPTA[11]

Bihar Animal Sciences University, Patna, Bihar 800 014 India

Received: 02 October 2025; Accepted: 09 June 2026

ABSTRACT

Poultry farming is expanding rapidly in India, with SBM being the primary protein source in diets. However, the rising demand for high-quality protein necessitates alternative, sustainable feed ingredients. Insects such as black soldier fly (*Hermetia illucens*) larvae provide a safe, cost-effective, and promising protein source, thereby reducing competition for plant-based protein like SBM. The present study was undertaken to evaluate the impact of partial replacement of soybean meal (SBM) with black soldier fly larvae meal (BSFLM) on growth and nutrient retention of broiler chickens. Two hundred day-old broiler chicks of the same hatch were randomly divided into four dietary groups, each with five replicates of 10 chicks, for a 35-day trial. The control group (T0) received a basal diet, while T1, T2, and T3 had SBM replaced with 2%, 5%, and 10% BSFLM, respectively. Growth performance, feed intake, nutrient utilization, and feed conversion ratio (FCR) were recorded. Results showed that final body weight, weight gain, feed intake, and performance index were significantly higher in T3, followed by T2 and T1. FCR also improved in T3 and T2. Nutrient retention, particularly ether extract, calcium, and phosphorus, was also enhanced in T3 group. The findings suggestd that 10% replacement of SBM with BSFLM enhance broiler performance.

Keywords: Black soldier fly larvae meal, Broiler chicken, Growth performance, Soyabean meal

In India, the demand for poultry meat and its by-products is steadily rising due to population growth and changing dietary preferences. Poultry farming has emerged as one of the fastest-growing sectors in Indian agriculture, contributing not only to nutritional security but also providing livelihood opportunities, especially for landless and marginal farmers. The productive potential of poultry has not been fully realized, primarily due to limitations in feed resources and the underutilization of advanced feeding technologies. Since feed constitutes 60–70% of the total cost of production (Coon, 2002), exploring alternative, affordable, and nutritionally rich protein sources is critical for economic poultry production. Soybean meal (SBM) is the most widely used plant-based protein, but rising demand and cost pressures necessitate sustainable alternatives.

One promising option is incorporation of insects, particularly black soldier fly larvae (BSFL), into poultry diets. Black soldier fly (*Hermetia illucens*) larvae is gaining global recognition as a sustainable, safe, and cost-effective protein source. It is nutritionally rich, providing protein (37-49%), fats (7-39%), essential amino acids, vitamins, and minerals (Dorper *et al.* 2021; Ewusie *et al.* 2019; Gold *et al.* 2020). BSFL has high lysine and threonine content nutrients which are often deficient in cereals, although it is poor in methionine and cysteine (Selaledi *et al.* 2020). Apart from nutrients, BSFL also contains bioactive compounds such as antimicrobial peptides, lauric acid, chitin, and chitosan. Chitin, found in the exoskeleton, has immunomodulatory effects, potentially enhancing disease resistance in poultry. Another advantage with BSFL is its unique ability to convert low-quality organic waste, such as kitchen scraps, agricultural residues, and animal manure into high-quality insect biomass, thereby contributing to waste management and circular economy practices. This protein conversion efficiency is far higher compared to conventional feed sources (Taylor *et al.* 1976). Moreover, BSFL farming requires significantly less land, water, and energy inputs compared to soybean or fishmeal production. It also generates lower greenhouse gas emissions and

Present address: [1]M.V.Sc. Scholar. [2]Professor and Head. [3]Associate Professor. Department of Animal Nutrition, BVC, BASU, Patna. [4]DRI-cum-Dean PGS, BASU, Patna. [5]Associate Professor, [6]Professor, Department of Animal Nutrition, BVC, BASU, Patna. [7]Senior Scientist, ICAR-RCER, [8]Associate Professor, Department of Veterinary Microbiology, BVC, BASU Patna. [9]Associate Professor, Department of LPM, BVC, BASU, Patna. [10]Associate Professor, Department of Veterinary Pathology, BVC, BASU, Patna. [11]Associate Professor, Department of AGB, BVC, BASU, Patna. ✉Corresponding author email: drkaushalbvc@gmail.com

reduces ammonia output (Pimental *et al.* 1975; Oonincx *et al.* 2010), making it environmentally sustainable.

The use of insects in poultry feed not only supports better growth performance and feed conversion, but also enhances the meat quality. Antimicrobial peptides of by insect origin have shown effectiveness against antibiotic-resistant microbes, which is especially important in the context of antimicrobial resistance challenges. Economically, BSFL meal offers a viable alternative to soybean meal, which contributes 25-30% of poultry feed, while maize provides 55-65%. Substituting SBM with BSFL meal could significantly reduce feed costs and dependence on plant-based protein. Thus, the present study was planned to investigate the effect of dietary inclusion of BSFLM for partial replacement of SBM as protein source on growth performance and nutrient utilization in broiler chickens.

MATERIALS AND METHODS

The study was conducted at Livestock Farm Complex, Bihar Animal Sciences University, Patna, Bihar, after receiving due approval from the Institutional Animal Ethics Committee (IAEC) of the Bihar Veterinary College, BASU, Patna.

Feeding, management and dietary treatment: The required quantities of feed ingredients, supplements, and feed additives used in formulating the experimental diets were procured from local markets in and around Patna, Bihar, India. Standard basal diets were formulated for three phases of broiler growth such as pre-starter (0-7 days), starter (8-21 days), and finisher (22-35 days) in accordance with the nutrient requirements recommended by BIS (2007). Experimental rations were initially formulated based on the analyzed crude protein content and standard metabolizable energy requirements, and subsequently reanalyzed for proximate composition to confirm nutrient adequacy and uniformity. All feed ingredients were thoroughly mixed to ensure homogeneity of nutrients.

For the feeding trial, 200 day-old broiler chicks of the same hatch were obtained and reared at the Livestock Farm Complex, Bihar Animal Sciences University, Patna. The chicks were individually weighed and randomly distributed into four treatment groups, each consisting of 50 birds. Each group was further divided into five replicates of 10 birds each, and all chicks were reared for a period of 35 days. Feed was weighed and provided daily at 8:00 a.m. to ensure ad libitum feeding while minimizing wastage. The birds were housed under a deep litter system, using dried sawdust spread to a depth of about 3 inches as bedding material. Continuous 24-h light was provided during the brooding phase, with adequate lighting and ventilation maintained throughout the experimental period. Standard managemental practices, including vaccination, were strictly followed. The experimental design included one control group (T0), which received only the basal diet. In treatment groups T1, T2, and T3, soybean meal in the basal diet was partially replaced with black soldier fly larvae meal (BSFLM) at 2%, 5%, and 10%, respectively, which enabled evaluation of the effects of incremental inclusion of BSFLM on broiler growth and performance. Proximate composition of feed ingredients was analyzed using AOAC (2005) methods, while calcium content was determined by the procedure of Talapatra *et al.* (1940).

Performance parameters and nutrient retention: The growth performance of broiler chickens was assessed through the evaluation of feed intake (FI), body weight (BW), body weight gain (BWG), feed conversion ratio (FCR), and performance index (PI). A daily record of feed offered to each group was maintained, and residual feed was collected and weighed weekly. Weekly feed intake was calculated by subtracting the weight of leftover feed from the total feed provided. The body weight of each bird was recorded individually at the start of the experiment and subsequently at weekly intervals until the completion of the trial. From these data, weekly and cumulative BWG were determined. FCR was calculated as the ratio of feed consumed to body weight gain, while PI was derived by dividing BWG by the corresponding FCR.

To determine nutrient utilization, a 5-day metabolic trial was conducted during the final week of the experimental period. Twenty birds (five per group) representing the average body weight of each treatment group were randomly selected and housed in individual metabolic cages. After a 2-day adaptation phase, excreta were quantitatively collected for 5 consecutive days to estimate the apparent total tract retention of nutrients, including dry matter (DM), crude protein (CP), ether extract (EE), calcium (Ca), and phosphorus (P). During the collection phase, a weighed quantity of feed was offered to each bird daily at 9:00 a.m., and the leftover feed was collected and weighed the following morning to accurately determine feed intake. For excreta collection, faecal trays lined with polythene sheets were placed under each cage. Excreta were collected daily, pooled, and subsequently dried in a hot air oven at 70°C for 48 h to estimate dry matter content. The dried samples were then preserved for further analysis. Representative samples of both the experimental diets and faeces were subjected to proximate analysis to determine nutrient composition. Phosphorus content was estimated following the AOAC (2005) method, while calcium content was analyzed as per the procedure described by Talapatra *et al.* (1940).

Statistical analysis: Statistical analyses were performed using SPSS software (version 20.0). A generalized linear model (GLM) ANOVA was employed to compare differences among multiple groups, and Duncan's multiple range test was used to identify significant differences between the control and treatment groups. The analytical procedures followed the methodology outlined by Snedecor and Cochran (1994).

RESULTS AND DISCUSSION

In the present study, different parameters like feed intake, body weight, weekly body weight gain, feed

Table 1. Compositional analysis of pre-starter, starter and finisher diet.

Attributes	Pre-starter	Starter	Finisher
CP (%)	22.97	21.72	20.08
ME (kcal/kg)	2968.95	3090.55	3175.50
Ca (%)	0.80	0.79	0.78
Av. P (%)	0.66	0.64	0.62

conversion ratio, performance index and nutrient retention were observed. The chemical composition of the feed ingredients used in the experiment, expressed on a dry matter (DM) basis, is presented as follows. Yellow maize contained 91.18% DM, 97.11% organic matter (OM), 9.79% crude protein (CP), 4.19% ether extract (EE), 2.26% crude fiber (CF), 2.89% total ash (TA), 1.16% acid-insoluble ash (AIA), 80.87% nitrogen-free extract (NFE), 0.11% calcium (Ca), and 0.43% phosphorus (P). Soybean meal had 91.66% DM, 94.02% OM, 46.04% CP, 0.46% EE, 5.61% CF, 5.98% TA, 1.19% AIA, 41.91% NFE, 0.36% Ca, and 0.64% P. Black soldier fly larvae meal (BSFLM) contained 96.54% DM, 91.37% OM, 30.96% CP, 22.49% EE, 4.54% CF, 8.63% TA, 1.39% AIA, 29.92% NFE, 2.29% Ca, and 1.12% P. The compositional analysis of pre-starter, starter and finisher is depicted in Table 1.

Feed intake: The total feed intake of broilers under different dietary treatments was recorded, and the corresponding analysis of variance results are presented in Table 2. The average feed intake (FI) of broilers during the experimental period ranged from 2416.38 g in the T1 group to 2708.10 g in the T3 group. Weekly feed consumption in the first week varied between 200.01 g (T1) and 213.25 g (T0), with no significant differences among treatments. However, from the second week onwards, FI showed significant variation among groups. In the second week, FI ranged from 343.80 g (T1) to 385.45 g (T2); in the third week, from 395.37 g (T1) to 472.37 g (T2); in the fourth week, from 709.38 g (T0) to 810.99 g (T3); and in the fifth week, from 681.38 g (T0) to 838.64 g (T3). These results indicated a progressive increase in feed intake across the weeks, with significant (P<0.05) differences observed among treatment groups. Overall, the T3 group consumed 2.87% more feed compared to the control group (T0), suggesting improved palatability and acceptance of diets containing higher levels of black soldier fly larvae meal (BSFLM).

The findings aligned with Permana *et al.* (2024), who reported significant effects (P<0.05) of BSFLM inclusion in broiler finisher diets on FI, where substitution levels of 7.5% and 15% enhanced intake compared to control diets. Similarly, Sumbule *et al.* (2021) observed significant variations in average daily feed intake of layer chicks and growers when BSFLM was incorporated in their diets. These observations confirmed that dietary inclusion of BSFLM influences feed intake in poultry, with higher levels (10%) supporting better intake without adverse effects, consistent with earlier reports on broiler and layer birds.

Average body weight: The average body weight of broiler chickens from different treatment groups, recorded at weekly intervals, is presented in Table 2. During the first week, BW ranged from 164.10 g in T2 to 168.80 g in T0. By the second week, it varied from 377.30 g in T1 to 402.20 g in T3, showing a significant effect (P<0.05). In the third week, BW ranged from 620.90 g in T1 to 686.26 g in T2, while in the fourth week it varied from 1098.56 g in T0 to 1193.69 g in T3. By the fifth week, the BW ranged between 1546.06 g in T0 and 1733.09 g in T3. Statistical analysis revealed that the differences in BW were highly significant (P<0.01) from third to fifth week. At the end of the experiment (fifth week), the T3 group showed highest BW, recording a 12.10% increase as compared with the control group (T0), followed by T2 (6.79%) and T1 (0.06%). These results clearly demonstrated that the inclusion of BSFLM in broiler diets, particularly at higher levels, significantly enhanced their growth performance.

The present findings were in agreement with Permana *et al.* (2024), who reported that substitution of poultry concentrate protein with different levels of BSFLM significantly (P<0.05) affected BW in broilers. Similarly, Chu *et al.* (2020) observed a quadratic increase in final body weight when defatted BSFLM was included in broiler diets at levels of 0, 3, 6, and 9%, with higher inclusion resulting in improved growth performance. Thus, the current study reaffirmed the potential of BSFLM as a sustainable protein

Table 2. Effect of partial replacement of soyabean meal by black soldier larvae meal on weekly average feed intake (g)/bird in broiler chickens.

Weeks	T0	T1	T2	T3	SEM	P-value
1^{st}	213.25	200.01	200.49	209.02	4.14	0.150
2^{nd}	362.83 ^{ab}	343.80 ^{a}	385.45 ^{b}	385.14 ^{b}	10.17	0.050
3^{rd}	446.14 ^{b}	395.37 ^{a}	472.37 ^{b}	458.31 ^{b}	12.79	0.008
4^{th}	709.38 ^{a}	809.94 ^{b}	748.71 $^{a'}$	810.99 ^{b}	18.02	0.005
5^{th}	681.38 ^{a}	692.16 ^{a}	768.11 ^{ab}	838.64 ^{b}	36.71	0.041
1 - 5^{th} weeks	2416.38	2447.28	2581.13	2708.1	40.16	0.047

^{ab} Values with different superscripts in a row differ significantly (P<0.05; 0.01).

Table 3. Effect of partial replacement of soyabean meal by black soldier larvae meal on weekly average body weight (g) and feed conversion ratio in broiler chickens.

Weeks	T0	T1	T2	T3	SEM	P-value
			Average body weight (g)			
1_{st}	168.800	165.43	164.10	168.46	2.11	0.477
2^{nd}	388.46^{ab}	377.30^{a}	397.50^{b}	402.20^{b}	4.88	0.015
3^{rd}	657.53^{b}	620.90^{a}	686.26^{b}	681.73^{b}	8.91	0.035
4^{th}	1098.56^{a}	1110.20^{a}	1152.30^{b}	1193.69^{c}	10.10	0.042
5^{th}	1546.06^{a}	1547.00^{a}	1651.09^{b}	1733.09^{c}	20.26	0.047
			Feed conversion ratio			
1_{st}	1.70	1.68	1.69	1.67	0.006	0.942
2^{nd}	1.67^{a}	1.65^{a}	1.65^{bc}	1.64^{c}	0.005	0.002
3^{rd}	1.65^{a}	1.64^{ab}	1.64^{ab}	1.62^{b}	0.007	0.063
4^{th}	1.63^{a}	1.62^{ab}	1.60^{ab}	1.59^{b}	0.008	0.018
5^{th}	1.60^{a}	1.59^{ab}	1.58^{ab}	1.57^{b}	0.007	0.057
1 - 5^{th} weeks	1.61^{ab}	1.63^{a}	1.61^{ab}	1.60^{b}	0.008	0.051

^{abc}Values with different superscripts in a row differ significantly ($P<0.05$; $P<0.01$).

source capable of supporting superior body weight gain in broilers when incorporated at optimal levels.

Feed conversion ratio: The average weekly feed conversion ratio (FCR) during the experimental period ranged from 1.60 in T3 group to 1.63 in T1 group (Table 3). In the first week, FCR values varied between 1.67 (T3) and 1.70 (T0), while in the second week, it ranged from 1.64 (T3) to 1.67 (T0). During the third week, FCR varied from 1.62 (T3) to 1.65 (T0), whereas in the fourth week, it ranged between 1.59 (T3) and 1.63 (T0). In the fifth week, the values were lowest in T3 (1.57) and highest in T1 (1.63). Statistical analysis indicated that the differences in FCR were non-significant ($P>0.05$) in the first and third weeks, where values remained comparable among treatments. However, significant differences were observed during the second and fourth weeks ($P<0.01$) and in the fifth week as well as overall average FCR across the 1st–5th week period ($P<0.05$). Fluctuations in weekly FCR were noted across treatments; however, the overall trend suggested improved efficiency in groups supplemented with BSFLM. The overall average FCR showed improvement in T3 (0.37%) followed by T2 (0.21%), while T1 recorded a deterioration of 1.21% compared with the control group (T0). These improvements are attributed to better nutrient availability and utilization, which enhanced growth performance in the higher BSFLM-supplemented groups. The findings were in agreement with Brah *et al.* (2024) and Chu *et al.* (2020), who also reported that dietary inclusion of BSFLM improved feed conversion efficiency in broilers by enhancing nutrient digestibility and growth response.

Nutrient retention: The results on total tract nutrient retention are summarized in Table 4. The retention of dry matter (DM) ranged from 71.50% in T1 to 72.19% in T3, with no significant differences among the groups ($P=0.771$). Although the variation was not statistically significant, there was a numerical increase in the T3 group, suggesting a slight improvement in overall nutrient utilization with higher inclusion of BSFLM. The consistency in DM retention indicated that partial replacement of soybean meal by BSFLM did not adversely affect the overall digestibility of the diet. These results aligned with Bovera *et al.* (2016), who reported that DM digestibility remained relatively stable in broilers fed diets containing 5–10% BSFLM.

Nitrogen retention, an indicator of protein utilization,

Table 4. Effect of partial replacement of soyabean meal by black soldier larvae meal on nutrient retention percentage in broiler chickens.

Attributes	T0	T1	T2	T3	SEM	P-value
Dry matter retention %	71.61	71.50	71.59	72.19	0.509	0.771
Nitrogen retention %	61.17	61.98	62.23	62.76	0.368	0.068
Ether extract retention %	71.17^{a}	72.48^{abc}	72.93^{bc}	73.76^{c}	0.368	0.002
Calcium retention %	51.65^{a}	51.66^{a}	52.87^{ab}	53.75^{b}	0.455	0.021
Phosphorus retention %	45.20^{a}	45.60^{a}	45.38^{a}	47.26^{b}	0.239	0.001

^{abc}Values with different superscripts in a row differ significantly ($P<0.05$; 0.01).

ranged from 61.17% in T0 to 62.76% in T3. The increase was not statistically significant (P=0.068), though it showed a positive trend with higher BSFLM inclusion. The improvement may be due to the high-quality protein content of BSFLM, which is rich in essential amino acids such as lysine and threonine (Rumpold and Schluter, 2013). Similar findings were reported by Chu *et al.* (2020), who observed enhanced protein retention when conventional protein sources were partially replaced with BSFLM in broiler diets.

Ether extract (EE) retention significantly increased (P=0.002) with BSFLM supplementation, ranging from 71.17% in T0 to 73.76% in T3. This improvement indicated better utilization of dietary fats, which can be attributed to the high lipid content and digestibility of BSFLM, particularly its rich medium-chain fatty acids such as lauric acid. Enhanced fat absorption contributes to energy availability and overall growth performance. These results were consistent with Bovera *et al.* (2016) and El-Kaiaty *et al.* (2022), who reported improved EE retention and energy efficiency in broilers fed diets containing insect meal.

Calcium retention improved significantly (P=0.021), from 51.65% in T0 to 53.75% in T3. This suggested that mineral bioavailability was enhanced in BSFLM-supplemented diets. The presence of chitin and other bioactive compounds in BSFLM might have enhanced intestinal absorption of minerals (Henry *et al.* 2015). Improved calcium retention supports bone development and overall skeletal integrity, which is crucial for rapidly growing broilers.

Phosphorus retention was also significantly higher (P=0.001) in the T3 group (47.26%) compared with T0 (45.20%). Phosphorus utilization is critical for energy metabolism and skeletal growth. The improvement may be due to increased phosphorus availability in BSFLM and its possible synergistic effect with chitin, which might have enhanced intestinal nutrient absorption. These findings corroborated previous studies by Bovera *et al.* (2016) and Henry *et al.* (2015), highlighting that BSFLM can improve mineral retention and utilization in broiler diets.

The study indicated that partial replacement of soybean meal with BSFLM enhanced the retention of ether extract, calcium, and phosphorus in broilers, while dry matter and nitrogen utilization remain stable. Improved EE and mineral retention is likely to have contributed to the better growth performance and feed efficiency observed in BSFLM-supplemented groups. These results suggested that BSFLM is a nutritionally efficient and sustainable alternative protein source for broiler diets, capable of supporting enhanced nutrient utilization and overall performance.

The study demonstrated that partial replacement of soybean meal with black soldier fly larvae meal (BSFLM) significantly improved growth performance, feed efficiency, and nutrient retention in broiler chickens. The T3 group (10% BSFLM) exhibited the highest feed intake, body weight, and improved feed conversion ratio. Nutrient retention analysis revealed significant enhancements in ether extract, calcium, and phosphorus, while dry matter and nitrogen retention remained stable. These findings indicated that BSFLM is a safe, sustainable, and nutritionally efficient alternative protein source for broiler diets, supporting better growth and feed utilization for broiler poultry production.

ACKNOWLEDGMENT

The authors express their sincere gratitude to the Hon'ble Vice-Chancellor of Bihar Animal Sciences University, Patna, Bihar, India, for generously providing the funding necessary for this study.

REFERENCES

AOAC. 1995. *Methods of Analysis*. 16th edn, Vol. 1. Association of official analytical chemists, Washington, DC.

AOAC. 2005. *Official method of Analysis*. 18th Edition, Association of Officiating Analytical Chemists, Washington DC, Method 935.14 and 992.24.

BIS. 2007. Indian standard, poultry feeds specifications, IS-1374:2007. Bureau of Indian Standards. 9, Bahadur Shah Zafar Marg, Manak Bhawan, New Delhi, India.

Bovera F, Loponte R, Marono S, Piccolo G, Parisi G, Iaconisi V, Gasco L and Nizza A. 2016. Use of *Tenebrio molitor* larvae meal as a protein source in broiler diet: effect on growth performance, nutrient digestibility, and carcass and meat traits. *Journal of Animal Science* **94**: 639–647.

Brah N, Amadou L, Tougiani A, Moussa M, Moussa B, Moussa H O and Abdoulaye T. 2024. Effects of the incorporation rate of black soldier fly (*Hermetia illucens*) larvae meals on zoo-economic performance and carcass quality of broiler chickens. *Brazilian Journal of Poultry Science* **26**(3): eRBCA-2024.

Chu X, Li M, Wang G, Wang K, Shang R, Wang Z and Li L. 2020. Evaluation of the low inclusion of full-fatted *Hermetia illucens* larvae meal for layer chickens: Growth performance, nutrient digestibility, and gut health. *Frontiers in Veterinary Science* **7**: 585–843.

Coon C N. 2002. Feeding egg type replacement pullet. Springer Science Business Media. Pp: 267–285.

Dorper A, Veldkamp T and Dicke M. 2021. Use of black soldier fly and house fly in feed to promote sustainable poultry production. *Journal of Insects as Food and Feed* **7**: 761–780.

El-Kaiaty A M, Dawa D T and El-Sayed T R. 2022. The impact of black soldier fly (*Hermetia illucens*) as feed supplementation on productive and physiological performance of broiler chickens. *World Veterinary Journal* **2**: 133–140.

Ewusie E A, Kwapong P K, Ofosu-Budu G, Sandrock C, Akumah A M, Nartey E K, Tetegaga C and Agyakwah S K. 2019. The black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae): Trapping and culturing of wild colonies in Ghana. *Scientific African* **5**: e00134.

Gold M, Cassar C M, Zurbrugg C, Kreuzer M, Boulos S, Diener S and Mathys A. 2020. Biowaste treatment with black soldier fly larvae: Increasing performance through the formulation of biowastes based on protein and carbohydrates. *Waste Management* **102**: 319–329.

Henry M, Gasco L, Piccolo G and Fountoulaki E. 2015. Review on the use of insects in animal feed. *Animal Feed Science and Technology* **204**: 1–18.

Oonincx D G, van Itterbeeck J, Heetkamp M J, van den Brand H, van Loon J J and van Huis A. 2010. An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PloS one* **5**(12): e14445.

Permana I G, Suci D M, Yuwono A S, Firdaus Y, Mawarni S R and Rosmalia A. 2024. Supplementing broiler diets with black soldier fly (*Hermetia illucens*) as a protein source, performance, carcass traits, viscera organ, and economic perspectives. *Journal of Advanced Veterinary Research* **14**(6): 959–963.

Pimental D, Dripschilo W, Krummel J and Kupzman J. 1975. Energy and land constraints in food protein production. *Science* **190**: 754–761.

Rumpold B A and Schluter O K. 2013. Nutritional composition and safety aspects of edible insects. *Molecular Nutrition and Food research* **57**(5): 802–823.

Selaledi L, Mbajiorgu C A and Mabelebele M. 2020. The use of yellow mealworm (*T. molitor*) as alternative source of protein in poultry diets: a review. *Tropical Animal Health and Production* **52**: 7–16.

Snedecor G W and Cochran W G. 1994. *Statistical Methods*. 9th edn. The Iowa State University Press, Ames, Iowa.

SPSS. 2011. *Statistical Packages for Social Sciences Version 20.0.* SPSS, Chicago, IL, USA.

Sumbule E K, Ambula M K, Osuga I M, Changeh J G, Mwangi D M, Subramanian S and Tanga C M. 2021. Cost-effectiveness of black soldier fly larvae meal as substitute of fishmeal in diets for layer chicks and growers. *Sustainability* **13**(11): 6074.

Talapatra S K, Roy S C and Sen K C. 1940. The analysis of mineral constituents in biological materials. I. Estimation of phosphorus, calcium, magnesium, sodium and potassium in food stuffs. *Indian Journal of Veterinary Science and Animal Husbandry* **10**: 243–258.

Taylor R L, Carter B J and Tweed J G. 1976. *Entertaining with insects: The original guide to insect cookery*. Woodbridge Press Pub. Co.