Acta Scientiarum
http://periodicos.uem.br/ojs/acta
ISSN on-line: 1807-8672
Doi: 10.4025/actascianimsci.v47i1.72338

Assessing the potential of black soldier fly larvae meal to replace commercial protein concentrates in broiler diets effects on efficiency, economic values, and internal organs

Tarek Ibrahim Majeed*, Qutaiba Jassim Gheni and Jaffer Mohammed Jassim

Department of Animal Production, College of Agriculture, University of Basra, Basra, Iraq. *Author for correspondence. E-mail: tarik.majed@uobasrah.edu.iq

ABSTRACT. This study examines the ideal incorporation of black soldier fly larvae (BSFL) in broiler diets, optimizing animal performance while fostering a sustainable food system. Protein utilization, digestion, production efficiency, economic viability, and the development relative weights of internal viscera are evaluated to determine the ideal inclusion level of BSFL. The experiment was conducted in the University's poultry facility. A total of 225-day-old unsexed Ross 308 chicks were randomly allocated to five treatments for 35 days. The treatments substituted imported protein concentrate with BSFL meal at doses of 0, 25, 50, 75, and 100%. The findings indicated that treatments including elevated proportions of BSFL meal (50, 75, and 100%) markedly enhanced the apparent digestibility coefficient (ADC) in comparison to the control, yielding values of 77.48, 77.40, and 77.92%, respectively. Nevertheless, no substantial variations were detected in the protein efficiency ratio (PER) across the treatments. The maximum inclusion level of BSFL (100%) led to an improvement in the economic efficiency index (1087.35) relative to the control (1534.12), as illustrated in Table 3. The decline in the economic efficiency index indicates a decrease in feed costs, which enhances the whole manufacturing process by increasing cost-effectiveness. No substantial disparities in mortality rates persisted uniformly across all treatments. Although notable variances existed among treatments, T5 had the most productive index. No significant variations were seen in the relative weights of internal organs between the treatments, suggesting that BSFL meal did not adversely affect organ development (Table 4). The statistical analysis indicated no significant variations among the experimental treatments regarding the relative weights of the heart, liver, stomach gland, gizzard, cecum, spleen, Fabrician gland, and index gland. In conclusion, BSFL meal demonstrates potential as a cost-efficient and sustainable substitute for imported protein concentrates in broiler diets, with the appropriate inclusion level combining performance enhancements and economic advantages.

Keywords: black soldier fly; digestion; economic; efficiency; protein concentrates.

Received on May 25, 2024.
Accepted on October 22, 2024.

Introduction

The development of sustainable ways for producing food has become an urgent need due to the increasing nutritional demands and the rapidly expanding global population (Ibrahim et al., 2023). The rising global population's heightened protein demand requires the exploration of sustainable and innovative feed options for animals (Turk, 2016). Traditional protein sources, like fishmeal and soybean meal, provide considerable hurdles to environmental sustainability and resource depletion Smetana et al. (2016).

The Food and Agriculture Organisation (FAO) anticipates a substantial rise in global food production by 2050 to satisfy the escalating demand for food. In the pursuit of sustainable poultry production, there is an imperative to investigate alternate protein sources. Black soldier fly larvae (BSFL) have surfaced as a viable alternative, providing both economic and ecological benefits. Although prior research has examined the incorporation of BSFL in broiler diets, a deficiency persists in comprehending the ideal inclusion rates. This study aims to address the information gap by systematically examining the effects of different concentrations of black soldier fly larvae (BSFL) meal on broiler growth performance, economic viability, and organ development. The research offers an extensive examination of BSFL's viability as a sustainable protein source in poultry nutrition, emphasizing the enhancement of productivity and economic profitability. Chojnacka et al. (2021) and Onsongo et al. (2018).

Research on unconventional feed ingredients is motivated by the urgent requirement for sustainable and efficient agricultural practices. Certain edible insect species have the ability to bio-convert organic waste

streams from domestic and commercial sources into nutrient-dense biomass. (Al-Salhie et al., 2017). This distinctive feature renders them a potentially valuable and sustainable protein source for broiler diets. Black soldier fly larvae (BSFL), derived from the species Hermetia illucens, are indigenous to the warm temperate regions of the southeastern United States. BSF is also present across South America, Asia, and Colombia, where its prevalence has increased. (Raman et al., 2022). The black soldier fly (Hermetia illucens) has emerged as a viable option for sustainable protein in animal feed owing to its remarkable capacity to transform organic waste into nutrient-dense biomass. Lu et al. (2022).

As a result of its high protein content (38-63% dry matter) and its amino acid profile that is well balanced, BSFL is an excellent source of methionine and lysine. (Makokha, 2023). These essential amino acids, frequently lacking in plant-based feed components, are vital for poultry development and egg production. Additionally, BSFL presents benefits compared to other insect species, including its significant tolerance for humid and warm conditions, rapid growth rate, and effective waste conversion capabilities. Siddiqui et al. (2022).

This study aims to enhance the existing research on BSFL by examining the economic and biological effects of varying inclusion levels in broiler diets. (Mangindaan et al., 2022). This research diverges from prior studies by concentrating on the detailed assessment of protein utilization efficiency, economic efficiency factors, and their impact on organ development. The findings will yield practical insights for optimizing broiler feed formulations with BSFL, presenting a novel perspective on its commercial viability. This study aims to determine the ideal dietary inclusion level of BSFL for broilers, focusing on optimizing animal performance while fostering a more circular food system. The research utilized multiple parameters to evaluate the effects of BSFL on broiler performance and profitability. The parameters encompassed protein utilization and digestion, assessed via metrics such as protein efficiency ratio (PER) and apparent digestibility coefficient (ADC) of protein. Furthermore, the production efficiency factor (PEF) and economic efficiency index (EEI) were calculated to evaluate economic viability. The study examined the impact of BSFL on organ development by assessing the relative weights of internal organs and the Fabricius gland index. This paper investigates the impact of black soldier fly meal on the economic efficiency of broiler production.

Material and methods

Birds and husbandry

The research was carried out between March 21, 2023, and April 20, 2023, at the poultry facility of the University of Basrah, Iraq. A total of 225 unsexed chicks, one day old, with an average weight of 40 grams each, of the Ross308 broiler breed, were sourced from a local hatchery. The chicks were allocated randomly across five treatments, with three replicates per treatment and 15 birds per replicate, following the Complete Random Design methodology. Experimental diets were assigned to a control group T1, which was fed a commercial diet containing imported protein powder, treatments T2, T3, and T4 involved replacing 25, 50, 75, and T5 100% of the imported protein powder in the control feed with Hermetia meal, respectively. Water and Feed was supplied ad libitum throughout the experiment. Composition of the feed is given in Table 1.

Table 1. Feedstuff and chemical composition of the experimental diets.

Feedstuff composition (%)	Treatment				
	T1	T2	T3	T4	T5
Maize	43	43	43.1	43	43.1
Wheat	16	16	16	16	16
Soybean meal	33	33	33	33	33
Concentrate protein	4	3	2	1	0
BSF larvae meal	0	1	2	3	4
Vegetable oil	0.5	0.5	0.4	0.5	0.4
Premix (Vitamin-mineral mixture)	1	1	1	1	1
CaCO3	2	2	2	2	2
Salt	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100
Metabolizable energy (kcal)	3.63.15	3090.54	3117.91	3145.30	3172.68
(%) Crude protein	19.46	19.44	19.42	19.39	19.37
Crude fiber (%)	7.11	7.43	7.76	8.09	8.42
Fat (%)	3.31	3.79	4.27	4.75	5.24
Ash (%)	8.48	7.96	7.44	6.92	6.4

A digestion trials

A Digestion trial was performed Three birds from each treatment were housed in individual cages after fasting for 12 hours. In the digestion trial chromium oxide was used as an indigestible marker to determine nutrient digestibility. The concentration of chromium oxide used was adjusted to 3 grams per kilogram of feed, in line with standard practices for broiler studies (Sharifi et al., 2012), the tracer substance was thoroughly mixed with the feed. After feeding the birds, their intake was calculated in both the feed and feces. At the end of the period, the birds were slaughtered, and the digests were collected from the digestive system parts. In the digestion trial, the digesta was collected specifically from the segment of the digestive tract between Meckel's diverticulum and the ileo-cecal junction. This region was chosen to focus on the most relevant section of the intestine for assessing nutrient absorption. The digesta from this section was carefully extracted for each bird in the treatment groups. The collected digesta samples were not combined but were processed individually. Each digesta sample was then placed in a plastic container and stored at a cool temperature until further processing. The samples were dried in a hot air oven at 105°C for 24 hours and then subsequently ground into fine particles for nutrient analysis. The protein content of the feed, feces, and digesta was determined using the Kjeldahl method, a widely accepted technique for measuring nitrogen content, which is then converted to crude protein by applying a conversion factor (typically 6.25 for most feedstuffs). This method provides accurate and reliable measurements of protein content in various biological samples. In addition to crude protein, the digestibility of other key nutrients such as ether extract, fiber, moisture, and ash were also determined during the digestibility trial. These measurements were conducted following standard procedures for nutrient analysis, ensuring a comprehensive assessment of feed utilization in broilers.

Measurement

Mortality rate was recorded daily. The PER was calculated as grams of weight gain per gram of protein intake (North & Bell, 1984). and The European Efficiency Factor (EEF) was calculated to assess overall production performance (35 days) The EEF was calculated according to Marcu et al. (2013) formula used is as follows:

EEF =([livability % x live weight (kg)] / [Age (days) x feed conversion ratio]) x 100

The Cost-Benefit Analysis (CBA) was performed to evaluate the economic viability of each diet treatment. The formula used is:

CBA = Revenue (USD) / Cost (USD)

Where revenue is derived from the market value of the broilers produced, and the cost is calculated based on the total feed expenses and other relevant inputs for each treatment group

Slaughtering procedure

At 35 days of age, after 12h of feed withdrawal, six birds (3 male and 3 female) from each cage were humanly sacrificed following procedures reviewed and approved by the Animal Production Dep. of the Agriculture University, Slaughtering was done at the University poultry research unit slaughter facility, which is equipped with a rotating bleeding stainless steel table and electric - eated water bath for scalding. Dressed carcasses from each cage were weighed and recorded. Carcass parts (heart, liver, Glandular stomach, Gizzard, spleen, Caecal, and Bursa of Fabricius) were harvested to determine their relative weights.

Dressing Percentage = (Dressed Carcass Weig / Live Weight) x 100

The Productive Index was calculated to measure the overall productivity of the broilers. The formula used is:

Productive Index = Final Body Weight (kg) / Feed Conversion Ratio Age (days)

The relative weight of organ = (weight of organ divided by live weight) ×100%.

Statistical analysis

To determine the effects of dietary black soldier fly larvae (BSFL) on broiler performance, a A completely randomized design was employed. Data were analyzed using one-way ANOVA, Statistical significance was set at a p-value of 0.05. JH and Dickey (1980).

Results and discussion

Digestibility evaluation

Table 2 illustrates the effect of substituting imported protein concentrate with black soldier fly larvae (BSFL) powder on the protein digestion coefficient and utilization efficiency in the broiler. Statistical analysis indicated significantly elevated protein digestion coefficients ($p \leqslant 0.05$) in groups T3 (77.476), T4 (77.396), and T5 (77.916) relative to the control groups T1 (74.580) and T2 (73.716). T3, T4, and T5 demonstrated statistically analogous coefficients, indicating a comparable response within these groups.

The enhanced protein digestion coefficients noted in treatments T3, T4, and T5 may be ascribed to the nutritional composition and digestibility of the black soldier fly larvae (BSFL) meal. Gasco et al. (2019) indicated that the digestibility of food components for OFBSF larvae varies according to the physicochemical parameters of the diet, processing methods, and physiological differences in digestion. These findings contradict those of Cullere et al. (2016), who reported a significant reduction in protein digestibility when utilizing black soldier fly (BSF) as a protein source in broiler quail. This decrease was attributed to the elevated chitin content in BSF pupae, approximately 5.41%, and up to 8.72% in pre-pupae, based on dry matter. In contrast, this study's findings were inconsistent with those of Elangovan et al. (2021), who found no significant differences in protein digestion treatment when incorporating 5% BSF into the broiler diet compared to the control.

Table 2 demonstrates insignificant differences ($p \leqslant 0.05$) were observed between the experimental groups regarding protein utilization efficiency. These findings are consistent with the observations reported by Cheng et al. (2023). This agreement indicates that the inclusion of black soldier fly larvae powder in the diet did not significantly affect the birds' protein utilization, which may correspond with the larvae's nutritional profile and digestibility. The researcher noted that while the efficiency rate of protein utilization improved with the addition of BSFM compared to other treatments, this increase did not achieve significance in a study comparing the protein substitutions of black soldier fly larvae (BSFLM) with soybean meal (SBM) and fish meal (FM) in broilers. Conversely, these findings were not consistent with Schiavone et al. (2014), who noted a significant decrease in the efficiency of protein utilization in the treatment of BSF %50 compared to Yellow mealworm 50% and BSF %30, which the researcher attributed to its effect on protein digestion.

Table 2. the effect of BSF larvae powder substitution of protein concentrate in broiler in the coefficient of protein digestion and efficiency of utilization of protein for broiler.

Treatments	apparent digestibility coefficient (ADC)	protein efficiency ratio (PER)
T1	74.58^{b}± .3970	2.37± .1290
T2	73.71^{b}± .2430	2.29± .1160
T3	77.47^{a}± .4520	2.76± .0750
T4	77.39^{a}± .7070	2.96± .0920
T5	77.91^{a}± .4520	2.93± .4080
significant	*	N. S

N.S None Significant: *Significant (vertically different letters represent significant differences at the level of $0.05 \geqslant P$) T1= control treatment without additives, T2= 25% replacement of (BSF-PC) imported protein concentrate T3, = 50% replacement of (BSF-PC) replacing the imported protein concentrate, T4= 75% replacement of (BSF-PC) replacing the imported protein concentrate, T5= 100% replacement of (BSF-PC) replacing the imported protein concentrate.

Mortality ratio, production index and measure of economic efficiency

Table 3 shows that there were no significant differences between all treatments in terms of the total mortality rate during the rearing weeks. These results are consistent with those of (Dzepe et al., 2021; Rishaliney Selva, 2020) who used four treatments of protease-treated BSFL addition at different inclusion levels (0, 20, 40, and 60% BSFL) in the feed composition.

Table 3 also presents the results of the productive index. Treatment T5, which recorded a value of 472.886, was significantly higher than all other treatments (T1, T2, T3, and T4), which did not differ significantly from each other and had values of 289.666, 298.363, 368.394, and 375.358, respectively.

The productive index is a crucial metric for assessing the overall performance of broilers, incorporating characteristics such as body weight, feed conversion ratio, and mortality rate (Dabbou et al., 2018) a higher productive index indicates superior chicken performance. The findings of this study indicate that incorporating BSFL into broiler meals, at the evaluated levels, can enhance the productivity index of the hens. This can be ascribed to the elevated nutritional value of BSFL, which is abundant in protein, fat, and minerals. Additionally, BSFL larvae are known to have antimicrobial and immune-boosting properties, which may help to protect broilers from diseases and improve their overall health and performance.

Antimicrobial peptides (AMPs) are small molecules produced by various organisms, including insects, to combat microbial infections (Zhang & Gallo, 2016). (AMPs) naturally produced in BSF larvae play a critical role in bolstering the immune system and improving the efficiency of the lymphatic system to inhibit pathogenic bacterial activity. This positive effect on the health of birds leads to an and a reduction in the rate of Mortality. therefore, this improvement in the value of productive index is a direct result (Xia et al., 2021). Several studies have indicated that black soldier fly larvae (BSFL) can serve as an alternative protein source. They are characterized by a high protein content, a balanced amino acid profile and high digestibility. These properties may lead to an improved productive index. These findings are consistent with those of Dabbou et al. (2018) who recommended the use of BSFL larvae at levels of 5 and 10%.

Table 3 indicates significant differences ($p \leqslant 0.05$) among the treatments regarding the economic efficiency index. The value of the index decreased significantly ($p \leqslant 0.05$) in treatment T5 compared to the other treatments, and was recorded at 1087.353. The highest value of the index was recorded in the control treatment T1 which was 1534.116. This value was not significantly different from those of treatments T2, T3, and T4. The reason for this difference may be due to the high cost of imported protein concentrate, which increases the cost of feed. In contrast, the cost of insect protein produced from BSFL is lower, which has a positive impact on the cost of feed (Waithaka et al., 2022) ;(de Souza Vilela et al., 2021) The utilisation of BSFL larvae presents a significant advantage in lowering broiler diet costs while maintaining growth performance. BSFL can replace up to 20% of fishmeal or 25% of soybean meal in broiler diets, leading to lower feed costs and increased profit margins. Wang and Shelomi (2017).

Table 3. effect of replacing protein concentrate with BSF larvae powder in broiler feed on the mortality %, productive index, and economic efficiency of broilers.

Treatments	% Mortality	productive index	economic efficiency index
T1	2.22± 2.22	289.66^{b}± 10.212	1534.11^{a}± 12.839
T2	2.22± 2.22	298.36^{b}± 5.615	1402.01^{ab}± 22.230
T3	2.22± 2.22	368.39^{b}± 27.490	1214.61^{ab} ± 90.800
T4	2.22± 2.22	375.35^{b}± 23.647	1201.32^{ab} ± 24.105
T5	.00± 0.000	472.88^{a}± 61.017	1087.35^{c}± 117.557
Significant	N. S	*	*

N.S None Significant: *Significant (vertically different letters represent significant differences at the level of $0.05 \geqslant p$) T1= control treatment without additives, T2= 25% replacement of (BSF-PC) imported protein concentrate T3, = 50% replacement of (BSF-PC) replacing the imported protein concentrate, T4= 75% replacement of (BSF-PC) replacing the imported protein concentrate, T5= 100% replacement of (BSF-PC) replacing the imported protein concentrate.

Relative organ weights

The statistical analysis of the data presented in Table 4 indicated no significant differences among the experimental treatments regarding the relative weight rates of the heart, liver, glandular stomach, cecum, spleen, Fabricius gland, and index gland. The findings concurred with those reported by Bellezza Oddon et al. (2021), who found no significant effects on the weights of the internal viscera of broilers when 5% BSF larvae were added, in comparison to the control and the 5% Tenebrio molitor larvae treatments, except for the spleen weight, which was elevated in the addition treatments relative to the control. And with a study (Schiavone et al., 2019), who observed no significant differences in the relative weight of all internal viscera of broilers in the addition treatments of 50, 100, and 150 (g kg^{-1}) of BSF larvae when compared to the control treatment. The findings align with those of Onsongo et al. (2018), which indicated that the relative weights of broiler entrails (heart, liver, gizzard, and spleen) were not influenced by the partial substitution of BSF larvae containing 13.8, 27.4, and 42.0% crude protein (CP). This study supports earlier findings. by Mohammed et al. (2017) and Uushona (2015) who observed no significant variations in the weights of vital organs (liver, spleen, heart, crop, gizzard and stomach) of broilers fed diets containing varying levels of black soldier fly larvae (BSFL). Mohammed et al. (2017) reported similar results when replacing fish meal with 33% BSFL larvae meal, while (Uushona, 2015) observed comparable findings with pre-pupae BSFL inclusions at 0, 5, 10, and 15% levels. These consistent observations suggest that incorporating BSFL in broiler diets, within the tested range, may not pose detrimental effects on organ development. On the contrary, the results of this study contradicted with Facey et al. (2023) who replaced soybean meal with BSF larvae powder at levels 0, 12.5, 25, 50 and 100%, he noticed a significant increase in the rate of weights of the gizzard, glandular stomach, pancreas and liver by increasing the level of inclusion of BSF larvae, where the addition treatment exceeded 100% over the rest of the experimental treatments, including the control treatment at both periods 0-24 days

and 24-49 days, while the researcher did not encounter any significant effect on the rate of weights of both spleen and gland Bursa in both periods. Facey et al. (2023) described the notable increase in the weights of internal viscera, attributing this occurrence to the adverse effects of trypsin inhibitors found in residual soybean meal and the elevated chitin content in BSF larvae. This situation prompted the digestive system to produce additional chitinase, resulting in pancreatic enlargement. Furthermore, there was discord with the findings of both Kim et al. (2020), which suggested significant differences in gizzard weight due to the addition of BSF larvae compared to the control treatment, Okah and Onwujiariri (2012), who reported a significant increase in gizzard weight with higher inclusion levels of BSF larvae (0, 20, 30, 40, and 50%). Okah and Onwujiariri elucidated that the notable disparities in heart weight, along with the elevated gizzard weights, are attributable to the ageing of birds and the enhancement of their digesting ability.

Table 4. the effect of BSF larvae powder substitution of protein concentrate in broiler on the relative weights of the internal viscera and the index of the Fabricius gland for broiler.

Treatments	% heart	% liver	% stomach	% gizzard	% Caecum	% spleen	Fabricius gland %	Gland index
T1	.59± 0.0120	2.99± .1160	0.36± .0250	1.42± .0230	1.37± .0750	0.11± .0030	.22± 0.0140	0.99± .1000
T2	0.62± .0120	3.01± .0990	.32± 0.0260	1.40± .0380	1.50± .1440	.12± 0.0050	.24± 0.0230	1.12± .1340
T3	.61± 0.0120	3.14± .2620	0.39 ± .0300	1.45± .0340	1.47± .0800	.11± 0.0030	.26± 0 .0210	1.16± .127190
T4	.62± 0.0210	3.59± .0610	.39 ± 0.0380	1.70± .2340	1.46± .1170	.12± 0.0080	.26 0 .0230	1.16± .157730
T5	.63± 0.0140	3.04± .3060	.42± 0.0280	1.80± .2550	1.58± .0370	.12± 0.0050	.29 ± 0.0200	1.28± .1230
significant	N. S	N. S	N. S	N. S	N. S	N. S	N. S	N. S

N.S None Significant: T1= control treatment without additives, T2= 25% replacement of (BSF-PC) imported protein concentrate T3, = 50% replacement of (BSF-PC) replacing the imported protein concentrate, T4= 75% replacement of (BSF-PC) replacing the imported protein concentrate, T5= 100% replacement of (BSF-PC) replacing the imported protein concentrate.

Conclusion

This study indicates that the inclusion of BSF larvae powder in broiler feed might markedly improve protein digestibility. Although the protein efficiency ratio (PER) exhibited no significant variations, the enhanced apparent digestibility coefficient (ADC) suggests that broilers may efficiently assimilate the protein from black soldier fly (BSF) larvae. This study suggests that BSF larvae powder can improve protein digestibility in broiler feed without substantially impacting protein efficiency. The beneficial effect is probably attributable to the nutritional profile of BSF larvae, which may possess enzymes or other elements that enhance protein digestion. The final results indicate that BSF larvae powder does not significantly affect the development and relative weights of internal organs in broilers. Although a little trend towards an elevation in the Fabricius gland index was seen, additional research is required to investigate the processes driving this impact and to ascertain the ideal inclusion levels for enhancing broiler performance and cost efficiency. The prior findings indicate that the ideal proportion of black soldier fly larvae meal (BSFL) for substituting imported protein concentrates in broiler diets is a maximum of 50% replacement. The study noted substantial enhancements in the apparent digestibility coefficient (ADC) and protein efficiency ratio (PER), while preserving economic efficiency and productive performance. Nevertheless, augmenting BSFL inclusion beyond 50% did not yield substantial further advantages, indicating that 50% may represent an appropriate inclusion rate for both efficiency and cost-effectiveness.

Acknowledgments

The authors thank Fluker's Cricket Farm for the supply of the larvae used in this study and the staff of the poultry facility of the University of Basrah for their help in providing and completing the supplies for this study.

References

Al-Salhie, K. C. K., Al-Hummod, S. K., & Abbas, R. J. (2017). Effect of supplementation different levels of vitamin E and pumpkin seed oil to the diet on productive, physiological and reproductive performance of Japanese quail. *Basrah Journal of Agricultural Sciences*, *30*(2), 50-58. https://doi.org/10.37077/25200860.2017.44

Bellezza Oddon, S., Biasato, I., Imarisio, A., Pipan, M., Dekleva, D., Colombino, E., Capucchio, M. T., Meneguz, M., Bergagna, S., & Barbero, R. (2021). Black Soldier Fly and Yellow Mealworm live larvae for broiler chickens: Effects on bird performance and health status. *Journal of Animal Physiology and Animal Nutrition*, *105*(S1). https://doi.org/10-18. 10.1111/jpn.13567

Cheng, V., Shoveller, A. K., Huber, L.-A., & Kiarie, E. G. (2023). Comparative protein quality in black soldier fly larvae meal vs. soybean meal and fish meal using classical protein efficiency ratio (PER) chick growth assay model. *Poultry Science*, *102*(1), 102255. https://doi:10.1016/j.psj.2022.102255

Chojnacka, K., Mikula, K., Izydorczyk, G., Skrzypczak, D., Witek-Krowiak, A., Gersz, A., Moustakas, K., Iwaniuk, J., Grzędzicki, M., & Korczyński, M. (2021). Innovative high digestibility protein feed materials reducing environmental impact through improved nitrogen-use efficiency in sustainable agriculture. *Journal of Environmental Management*, *291*, 112693. https://doi:10.1016/j.jenvman.2021.112693

Cullere, M., Tasoniero, G., Giaccone, V., Miotti-Scapin, R., Claeys, E., De Smet, S., & Dalle Zotte, A. (2016). Black soldier fly as dietary protein source for broiler quails: apparent digestibility, excreta microbial load, feed choice, performance, carcass and meat traits. *Animal*, *10*(12), 1923-1930. https://doi:10.1017/S1751731116001270

Dabbou, S., Gai, F., Biasato, I., Capucchio, M. T., Biasibetti, E., Dezzutto, D., Meneguz, M., Plachà, I., Gasco, L., & Schiavone, A. (2018). Black soldier fly defatted meal as a dietary protein source for broiler chickens: Effects on growth performance, blood traits, gut morphology and histological features. *Journal of animal science and biotechnology*, *9*(49), 1-10. https://doi:10.1186/s40104-018-0266-9

de Souza Vilela, J., Andronicos, N. M., Kolakshyapati, M., Hilliar, M., Sibanda, T. Z., Andrew, N. R., Swick, R. A., Wilkinson, S., & Ruhnke, I. (2021). Black soldier fly larvae in broiler diets improve broiler performance and modulate the immune system. *Animal Nutrition*, *7*(3), 695-706. https://doi.org/10.1016/j.aninu.2020.08.014

Dzepe, D., Magatsing, O., Kuietche, H. M., Meutchieye, F., Nana, P., Tchuinkam, T., & Djouaka, R. (2021). Recycling organic wastes using black soldier fly and house fly larvae as broiler feed. *Circular Economy and Sustainability*, *1*(51), 895-906. https://doi:10.1007/s43615-021-00038-9

Elangovan, A. V., Udayakumar, A., Saravanakumar, M., Awachat, V. B., Mohan, M., Yandigeri, M. S., Krishnan, S., Mech, A., Rao, S. B. N., & Giridhar, K. (2021). Effect of black soldier fly, Hermetia illucens (Linnaeus) prepupae meal on growth performance and gut development in broiler chicken. *International Journal of Tropical Insect Science*, *41*(3), 2077-2082. https://doi:10.1007/s42690-020-00377-4

Facey, H., Kithama, M., Mohammadigheisar, M., Huber, L.-A., Shoveller, A. K., & Kiarie, E. G. (2023). Complete replacement of soybean meal with black soldier fly larvae meal in feeding program for broiler chickens from placement through to 49 days of age reduced growth performance and altered organs morphology. *Poultry Science*, *102*(1), 102293. https://10.1016/j.psj.2022.102293

Gasco, L., Biasato, I., Dabbou, S., Schiavone, A., & Gai, F. (2019). Animals fed insect-based diets: State-of-the-art on digestibility, performance and product quality. *Animals*, *9*(4), 170. https://doi:10.3390/ani9040170

Ibrahim, M., Nabeel, M., Raza, M., Hameed, N., Rafiq, R., Zaheer, M., Ain, N., Iftikhar, Z., Ammar, A., & Khalid, M. (2023). The role of technology and innovation in enhancing food security. *Journal of Physical, Biomedical and Biological Sciences*, *2*(14), 14-14.

JH, S. R. T., & Dickey, D. (1980). *Principles and procedures of statistics*. A biometrical approach. McGraw Hill Book Company)[Google Scholar].

Kim, B., Bang, H. T., Kim, K. H., Kim, M. J., Jeong, J. Y., Chun, J. L., & Ji, S. Y. (2020). Evaluation of black soldier fly larvae oil as a dietary fat source in broiler chicken diets. *Journal of Animal Science and Technology*, *62*(2), 187. https://doi:10.5187/jast.2020.62.2.187

Lu, S., Taethaisong, N., Meethip, W., Surakhunthod, J., Sinpru, B., Sroichak, T., Archa, P., Thongpea, S., Paengkoum, S., & Purba, R. A. P. (2022). Nutritional composition of black soldier fly larvae (Hermetia illucens L.) and its potential uses as alternative protein sources in animal diets: A review. *Insects*, *13*(9), 831. https://doi:10.3390/insects13090831

Makokha, S. S. (2023). *Replacement of soybean meal in the diet of Nile tilapia (oreochromis Niloticus) by black soldier fly (hermetia illucens) larvae meal and the cost implications*. Maseno University.

Mangindaan, D., Kaburuan, E. R., & Meindrawan, B. (2022). Black Soldier Fly Larvae (Hermetia illucens) for Biodiesel and/or Animal Feed as a Solution for Waste-Food-Energy Nexus: Bibliometric Analysis. *Sustainability*, *14*(21), 13993. https://doi:10.3390/su142113993

Marcu, A., Vacaru-Opriş, I., Dumitrescu, G., Ciochină, L. P., Marcu, A., Nicula, M., Peţ, I., Dronca, D., Kelciov, B., & Mariş, C. (2013). The influence of genetics on economic efficiency of broiler chickens growth. *Animal Science and Biotechnologies*, *46*(2), 339-346.

Mohammed, A., Laryea, A., & Ganiyu, T. (2017). *Effects of black soldier fly (Hermetia illucens) larvae meal on the growth performance of broiler chickens*. *UDS International Journal of Development*, *4*(1), 35-41

North, M., & Bell, D. (1984). Breeder Management. In *Commercial Chicken Production Manual* (pp: 240-243). The Avi. Publishing Company. Inc.

Okah, U., & Onwujiariri, E. (2012). Performance of finisher broiler chickens fed maggot meal as a replacement for fish meal. *International Journal of Agricultural Technology*, *8*(2), 471-477.

Onsongo, V., Osuga, I., Gachuiri, C., Wachira, A., Miano, D., Tanga, C., Ekesi, S., Nakimbugwe, D., & Fiaboe, K. (2018). Insects for income generation through animal feed: effect of dietary replacement of soybean and fish meal with black soldier fly meal on broiler growth and economic performance. *Journal of economic entomology*, *111*(4), 1966-1973. https://doi.org/10.1093/jee/toy118

Raman, S. S., Stringer, L. C., Bruce, N. C., & Chong, C. S. (2022). Opportunities, challenges and solutions for black soldier fly larvae-based animal feed production. *Journal of Cleaner Production*, *373*(4), 133802. https://doi:10.1016/j.jclepro.2022.133802

Rishaliney Selva, R. (2020). *Performing feeding trial on broiler chicken using different ratios of protease treated black soldier fly (Hermetic Illucens) larvae as partial protein substituent*. Universiti Malaysia Kelantan.

Schiavone, A., Dabbou, S., Petracci, M., Zampiga, M., Sirri, F., Biasato, I., Gai, F., & Gasco, L. (2019). Black soldier fly defatted meal as a dietary protein source for broiler chickens: Effects on carcass traits, breast meat quality and safety. *Animal*, *13*(10), 2397-2405. https://doi:10.1017/S1751731119000685

Schiavone A., De Marco M., Rotolo L., Belforti M., Martinez Mirò S., Madrid Sanchez J., Hernandez Ruiperez F., Bianchi C., Sterpone L., Malfatto V., Katz H., Zoccarato I., Gai F., & Gasco L. (2014). Nutrient digestibility of Hermetia illucens and Tenebrio molitor meal in broiler chickens. In *1st International conference "Insects to Feed the World"* (p. 73). https://hdl.handle.net/2318/158360

Sharifi, S. D., Shariatmadari, F., & Yaghobfar, A. (2012). Effects of inclusion of hull-less barley and enzyme supplementation of broiler diets on growth performance, nutrient digestion and dietary metabolisable energy content. *Journal of Central European Agriculture, 13*(1), 193-207. https://doi:10.5513/JCEA01/13.1.1035

Siddiqui, S. A., Ristow, B., Rahayu, T., Putra, N. S., Yuwono, N. W., Mategeko, B., Smetana, S., Saki, M., Nawaz, A., & Nagdalian, A. (2022). Black soldier fly larvae (BSFL) and their affinity for organic waste processing. *Waste Management*, *140*, 1-13. https://doi:10.1016/j.wasman.2021.12.044

Smetana, S., Palanisamy, M., Mathys, A., & Heinz, V. (2016). Sustainability of insect use for feed and food: Life Cycle Assessment perspective. *Journal of Cleaner Production*, *137*, 741-751. https://doi.org/10.1016/j.jclepro.2016.07.148

Turk, J. (2016). Meeting projected food demands by 2050: Understanding and enhancing the role of grazing ruminants. *Journal of animal science*, *94*(suppl_6), 53-62. https://doi.org/10.2527/jas.2016-0547

Uushona, T. (2015). *Black soldier fly (Hermetia illucens) pre-pupae as a protein source for broiler production*. Stellenbosch University.

Waithaka, M. K., Osuga, I. M., Kabuage, L. W., Subramanian, S., Muriithi, B., Wachira, A. M., & Tanga, C. M. (2022). Evaluating the growth and cost–benefit analysis of feeding improved indigenous chicken with diets containing black soldier fly larva meal. *Frontiers in Insect Science*, *2*, 933571. https://doi.org/10.3389/finsc.2022.933571

Wang, Y.-S., & Shelomi, M. (2017). Review of black soldier fly (Hermetia illucens) as animal feed and human food. *Foods*, *6*(10), 91. https://doi.org/10.3390/foods6100091

Xia, J., Ge, C., & Yao, H. (2021). Antimicrobial peptides from black soldier fly (Hermetia illucens) as potential antimicrobial factors representing an alternative to antibiotics in livestock farming. *Animals*, *11*(7), 1937. https://doi.org/10.3390/ani11071937

Zhang, L.-j., & Gallo, R. L. (2016). Antimicrobial peptides. *Current Biology*, *26*(1), R14-R19. https://doi.org/10.1016/j.cub.2015.11.017