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Black soldier fly as an alternative protein source in poultry diet: A review

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Abstract

Insects are gaining attention as alternative protein sources for poultry nutrition, with Black soldier fly (BSF), *Hermetia illucens*, being one of the most promising option. BSF larvae contain high levels of protein and fat, making them a valuable ingredient for poultry feed formulations. The amino acid composition of BSF protein is comparable to that of commonly used protein sources such as fish meal and soybean meal. An important advantage of BSF is its ability to convert organic waste materials into nutrient rich biomass, including proteins, lipids and chitin, thereby helping to reduce environmental pollution and waste accumulation. Due to its adaptability to different organic substrates, BSF production offers a sustainable and eco-friendly approach to feed resource generation. This review highlights the nutritional value of BSF meal and its potential application as a partial or complete replacement for conventional protein ingredients in poultry diets.

Keywords: Black soldier fly, nutritional value, alternative protein source, poultry

Introduction

The rapid growth of the global human population, coupled with improving living standards in developing countries, is expected to substantially increase the demand for animal-derived protein sources (FAO, 2009) ^[1]. Among livestock sectors, the global poultry industry particularly broiler and layer production systems has demonstrated remarkable growth and intensification. Despite significant advancements in genetics, housing and health management, feed formulation and feeding strategies remain major challenges in poultry production. Feed costs account for approximately 65–70% of total broiler production costs and 75–80% of layer production costs (Chatterjee *et al.*, 2015) ^[2], emphasizing the urgent need to identify sustainable and cost effective alternative feed ingredients to reduce reliance on conventional feedstuffs. In recent years, insects have emerged as promising alternative protein sources for poultry nutrition, with particular attention given to Black soldier fly larvae (BSFL). Insects are inherently protein rich and exhibit high growth rates and superior feed conversion efficiency (Van Huis, 2013) ^[3], making them a high quality and potentially profitable feed resource for livestock production (Veldkamp *et al.*, 2012) ^[4]. As poikilothermic organisms, insects efficiently convert organic waste materials into high value biomass, further enhancing their sustainability and economic feasibility as feed ingredients (Premalatha *et al.*, 2011) ^[5]. Insect meals provide substantial quantities of crude protein, essential amino acids, fatty acids, vitamins and minerals. They are particularly rich in vitamins such as folic acid, riboflavin, thiamine and cyanocobalamin, along with trace amounts of retinol (Rumpold and Schlüter, 2013) ^[6]. In addition, insects supply essential minerals including iron, calcium and zinc (Van Huis *et al.*, 2013; Abd El-Hack *et al.*, 2020) ^[3, 7]. The crude protein content of most insect species typically ranges between 42 & 63%, with amino acid profiles capable of meeting the nutritional requirements of poultry and other monogastric animals (Makkar *et al.*, 2014) ^[8]. Beyond their role as protein sources, insect derived lipids can partially or fully replace conventional vegetable oils and fats in poultry diets (Ahmed *et al.*, 2020) ^[9]. Insects are also notably rich in lysine, threonine and methionine-essential amino acids that are often limiting in

cereal and legume based poultry diets (Verkerk *et al.*, 2007)^[10]. Species such as *Tenebrio molitor* (yellow mealworm) and *Hermetia illucens* (black soldier fly) have been identified as excellent sources of metabolizable energy and highly digestible amino acids (De Marco *et al.*, 2015)^[11]. Additionally, yellow mealworms, houseflies and blowflies have been recognized as viable alternative protein sources for poultry feeding (Čičková *et al.*, 2015)^[12]. Numerous studies have demonstrated that insect based ingredients can partially replace conventional protein and fat sources in poultry diets without negatively affecting growth performance, feed efficiency or product quality. Consequently, the inclusion of insect meals in poultry nutrition represents a sustainable, nutritionally adequate and economically viable strategy to address the rising demand for animal protein while reducing feed costs and environmental impact.

Black soldier fly (*Hermetia illucens*)

The black soldier fly (*Hermetia illucens* L.) is a non-pest dipteran insect belonging to the family *Stratiomyidae*. The BSF originated in United States and was disseminated across temperate and tropical regions from Argentina to central America (Sheppard *et al.*, 1994; Sheppard *et al.*, 2002)^[13, 14]. It is transported to other parts of the world, including Europe, Asia, Australia and Africa, by human activities. BSF's broad use in many places is due to its ability to withstand a wide range of environmental conditions (Martínez-Sánchez *et al.*, 2011; Gujarathi and Pejaver, 2013)^[15, 16]. The black soldier fly is a polyphagous insect whose gut secretions exhibit significant protease, amylase and lipase activities, enabling efficient digestion of diverse organic substrates (Kim *et al.*, 2011)^[17]. These enzymatic capabilities make BSF larvae highly suitable for the bioconversion of faecal matter (Oonincx *et al.*, 2015)^[18], animal by-products and carcass residues (Myers *et al.*, 2014)^[19], as well as various forms of organic waste (Gujarathi and Pejaver, 2013)^[16]. Owing to this remarkable substrate versatility, BSF larvae effectively transform low-value animal waste into high quality biomass rich in protein and lipids, which can be utilized as an alternative protein source in poultry diets (Veldkamp *et al.*, 2012)^[4].

In the last decade, black soldier fly larvae have generated significant interest due to their potential applications in the bioconversion of organic waste and by-products of the agri-food production chain (Gold *et al.*, 2018)^[20]. Importantly, adult black soldier flies do not feed, are not considered disease vectors and do not pose a nuisance to humans or animals, making them suitable for large-scale industrial production (Sheppard *et al.*, 2002)^[14]. These attributes, combined with the larvae's high protein (40–60%) and fat (15–35%) content, position BSF as a promising component of circular bioeconomy systems (Makkar *et al.*, 2014)^[8].

Life cycle of BSF larvae

The life cycle of *Hermetia illucens* is holometabolous and comprises five distinct developmental stages: egg, larva, prepupa, pupa and adult. Under optimal conditions, the complete life cycle is typically completed within 35–45 days; however, its duration varies depending on environmental factors such as temperature, humidity, diet availability and rearing conditions (Tomberlin *et al.*, 2002; Diener *et al.*, 2009)^[21, 22].

Egg Stage

Female black soldier flies lay approximately 400–900 eggs in

clusters within crevices adjacent to decomposing organic substrates. The eggs are creamy white and oval-shaped, hatching within 3–4 days under favourable conditions, particularly temperatures ranging from 27 to 33°C and adequate humidity (Tomberlin *et al.*, (2002); Alvarez, (2012))^[21, 22].

Larval Stage

The larval stage is the longest and most nutritionally significant phase, lasting about 14–18 days. During this period, larvae actively consume organic substrates, efficiently converting waste materials into protein and lipid rich biomass. Larvae undergo 5–6 instars and exhibit rapid growth, with body weight increasing several thousand fold (Diener *et al.*, 2011)^[23]. Owing to its high nutrient density and digestibility, this stage is of primary importance for animal feed applications (Veldkamp *et al.*, 2012)^[4].

Prepupal and Pupal Stages

Upon completion of the larval phase, larvae enter the prepupal stage, marked by cuticle darkening and cessation of feeding. Prepupae migrate away from the feeding substrate to drier areas, a behaviour that facilitates self-harvesting in mass rearing systems. The subsequent pupal stage lasts approximately 7–14 days, during which metamorphosis into the adult fly occurs (Sheppard *et al.*, 2002)^[14].

Adult Stage

Adult black soldier flies emerge from pupae with a short lifespan of approximately 5–8 days. Adults do not feed and depend entirely on energy reserves accumulated during the larval stage. They are neither pests nor disease vectors and their primary biological function is reproduction. Successful mating typically requires adequate light intensity, along with warm and humid environmental conditions (Tomberlin *et al.*, 2002)^[21].

Nutritional composition of BSF

The black soldier fly (*Hermetia illucens*) efficiently converts a wide range of organic wastes, including food residues and manure into insect biomass. These larvae are often referred to as BSF larvae meal, BSF prepupae meal, or BSF maggot meal can be utilized in poultry feed in various forms including live or processed (Siddiqui *et al.*, 2024)^[24]. In animal feed, BSFL were two types: defatted and full fat, with the primary difference being in fat and saturated fatty acid content. The larvae contain approximately 29 and 42 per cent, fat and crude protein, respectively.

On a dry matter basis, black soldier fly (BSF) larvae have been reported to contain 43.6% crude protein (CP), 15.5% ash, 33.1% lipid (St-Hilaire *et al.*, 2007)^[25]. Furthermore Maurer *et al.* (2016)^[26] investigated different composition meal between dried, full-fat and dried, partially defatted BSFL where they found dried full-fat BSFL meal contain 41.5% CP, 26.5% CF, 4.3% ash; while in dried partially defatted contain higher protein content (59.0% CP) and lower fat content (11.0% CF), with 5.0% ash. In another study, CP increases just after hatching, it gradually decreases over time as it would be around 38–39% on day 14 of the larval stage. It then increases and reaches 45–46% and 56–57% at the prepupa and pupa harvested stages, respectively (Liu *et al.*, 2017)^[27]. Defatting of BSF increases the protein content more than the full-fat BSF larva meal (Veldkamp and Bosch, 2015)^[28]. The crude protein of fully defatted BSF is reported to be 66% that is higher than incompletely defatted BSF reported as

55% (Schiavone *et al.*, 2017; Crosbie *et al.*, 2021) [29, 30] and these values were nearly parallel to meat and fish meal. (Mahmud *et al.*, 2020) [31] studied the BSF maggot based on the rearing period, they found that they significantly affect the levels of dry matter, crude fat and crude protein but not crude fiber levels. A rearing period of 25 days resulted in the highest dry matter content (30.47%) and crude fat level (34.09%), significantly exceeding those observed at earlier rearing stages. Crude fiber content peaked at 20 days (10.50%) than Day 0. In contrast, crude protein was highest at day 0 (49.91%) and declined with increasing rearing duration. Therefore, they found that increasing rearing duration of BSF larvae, DM, crude fat and CF contents increases, whereas crude protein content shows a slight, non-significant decline (Ogello *et al.*, 2025) [32] who found the CP content was $53.5 \pm 2.1\%$ whereas in mixed organic waste yield larvae were 45.9 ± 3.30 and fat $32.3 \pm 1.40\%$, respectively.

Table 1: Chemical composition of black soldier fly larvae

Parameters	Amount	Unit
Crude protein	18-65.5	% DM
Fat	4.6-57	% DM
Ash	2.7-33	% DM
Gross energy	8.7-24.1	MJ/kg DM

Source: Adapted from Makkar *et al.* (2014) [8], Barragan-Fonseca *et al.* (2017) [33], Liu *et al.* (2017) [27], Shumo *et al.* (2019) [34], Alfiko *et al.* (2022) [35], Zulkifli *et al.* (2022) [36], Li *et al.* (2022) [37], Loho and Lo, (2023) [38], Gadzama *et al.* (2023) [39], Macwan *et al.* (2023) [40] and Lo *et al.* (2024) [41].

Apparent metabolizable energy

Apparent metabolizable energy (AME) and nitrogen corrected AME (AMEn) values of black soldier fly larvae (BSFL) meals vary widely depending on fat content and processing method but are generally higher than those of conventional protein sources such as soybean meal (SBM). Diets containing full-fat BSFL consistently exhibit significantly greater energy values than SBM, reflecting their high lipid concentration. Reported AME values for full-fat BSFL range from 22.53 to 24.54 MJ/kg DM, while corresponding AMEn values range from 22.35 to 24.34 MJ/kg DM, markedly exceeding those reported for SBM (AME: 14.67 MJ/kg DM; AMEn: 14.54 MJ/kg DM).

Variability among studies is evident and can be attributed to differences in larval substrate, age, processing and experimental conditions. For instance, Schiavone *et al.* (2017) [29] reported comparatively lower AME and AMEn values of 11.55 and 9.87 MJ/kg DM, respectively for BSFL meal, highlighting the influence of defatting degree and methodological differences on energy utilization. In partially defatted BSFL meal containing approximately 18% ether extract, AME and AMEn values increased to 16.25 and 14.87 MJ/kg DM, respectively indicating that even moderate fat levels substantially enhance dietary energy contribution.

More recent findings further support the high energy potential of BSFL based ingredients. Mahmoud *et al.* (2023) [42] reported AME and AMEn values of 17.38 and 16.60 MJ/kg DM and 19.1 and 18.0 MJ/kg DM, respectively, for full-fat BSFL meals, while full-fat BSF prepupae meal yielded values of 18.44 MJ/kg DM (AME) and 16.94 MJ/kg DM (AMEn). Collectively, these results demonstrate that BSFL meals, particularly in full-fat form, represent a highly energy-dense feed ingredient and can effectively contribute to meeting the metabolizable energy requirements of poultry diets, potentially reducing reliance on conventional energy sources.

Amino acid

The amino acid profile of black soldier fly (BSF) meal is characterized by high levels of essential amino acids, particularly leucine and valine, while alanine and glutamic acid predominate among dispensable amino acids in defatted BSF larvae meal (Cullere *et al.*, 2016) [44]. (Schiavone *et al.*, 2017) [29] reported leucine as the most abundant indispensable amino acid, with concentrations of 28.6 and 36.7 g/kg DM in partially (BSFp) and highly defatted (BSFh) meals, respectively, whereas glutamic acid was the principal dispensable amino acid (48.7 and 63.7 g/kg DM in BSFp and BSFh, respectively); cysteine was present at low levels (0.1–0.2 g/kg DM). Overall, leucine (mean 44.6 g/kg; 27.8–78.3), lysine (38.8 g/kg; 23.0–68.2) and valine (40.1 g/kg; 28.2–67.9) are the predominant essential amino acids, occurring at concentrations higher than those in soybean meal, with valine exceeding fish meal, whereas methionine and tryptophan are the least abundant and are comparable to soybean meal but markedly lower than fish meal (Council, 2012) [44].

Furthermore (Maurer *et al.*, 2016) [26] reported compositional differences between dried, full-fat and dried, partially defatted BSF larvae meals. Dried full-fat BSF larvae meal contained 41.5% CP, 26.5% CF, 4.3% ash, 0.80% Ca, 0.50% P, 0.08% Na and 0.33% chloride, while dried partially defatted BSF larvae meal exhibited a higher protein content (59.0% CP) and lower fat content (11.0% CF), with 5.0% ash, 0.98% Ca, 0.63% P, 0.08% Na and 0.28% chloride.

Fatty acid

The fatty acids obtained from insects are more suitable and nutritious, compared to soybean and palm kernel cake without any unfavorable outcomes on productivity, digestibility and intestinal health (Gasco *et al.*, 2019) [45]. The lipid fraction of black soldier fly (BSF) larvae is characterized by a predominance of saturated fatty acids, notably lauric acid (C12:0), which constitutes approximately 35–50% of total fatty acids and exhibits antimicrobial properties (Oonincx *et al.*, 2015) [18]. Myristic acid (C14:0) is also present at higher levels in BSF compared with soybean meal (Leni *et al.*, 2017) [46]. Overall, BSF lipid profiles are rich in saturated fatty acids (C12:0, C14:0, C16:0), contain moderate proportions of monounsaturated fatty acid and approximately 15% polyunsaturated fatty acids, consistent across multiple studies (Hoc *et al.*, 2020; Zarantonello *et al.*, 2020) [47, 48]. Fatty acid composition varies with larval age and substrate, with higher linoleic acid (31.4%) and α -linolenic acid (1.6%) reported during early larval development compared with later stages (Paul *et al.*, 2017) [49], while oleic acid typically accounts for 10–15% of total fatty acids depending on the growth substrate (Michaelson *et al.*, 2009) [50]. Studies found that the impact of BSFL on fatty acid profile on broiler meat, where both (La Mantia *et al.*, 2024) [51] and (Yalçın *et al.*, 2024) [52] reported increased saturated fatty acids (SFA) and decreased polyunsaturated fatty acids (PUFA) in thigh and breast meat from broilers fed BSFL diets. This shift in fatty acid composition is likely due to the high SFA content in BSFL, particularly lauric acid.

Micronutrients composition

Minerals and vitamins have major and substantially contribution to the nutritional value of poultry feeds. Although earlier studies on insects have primarily emphasized protein and lipid fractions, insects also contain appreciable levels of essential minerals, including iron, calcium, phosphorus and zinc, which tend to accumulate during the

later larval stages (Liu *et al.*, 2017) ^[27]. Similarly, (Liland *et al.*, 2017) ^[53] who found significant amount mineral like Ca, Fe, Zn, P and also Vitamin E, they reported the Vitamin E had increased twice (6.7 mg/100 g) at Day 14 than pre pupa stage (3.2 mg/100 g). However, the potential accumulation of undesirable elements, such as toxic metals, necessitates careful monitoring during production and further evaluation of mineral bioavailability, particularly for iron, zinc and cadmium (Michaelsen *et al.*, 2009) ^[50].

Black soldier fly larvae, in both full-fat and defatted forms, are rich sources of minerals, with calcium being the most abundant. Reported concentrations (g/kg DM) vary widely, reflecting differences in substrate and rearing conditions: Ca (1.2–35.7), P (1.0–10.3), K (1.7–15.4), Na (0.7–15.6), Mg (1.0–3.5), Fe (0.1–191.0), Zn (0.7–103.0), Cu (0.1–15.0) and Mn (0.2–166.0) (Sprangers *et al.*, 2017; Shumo *et al.*, 2019; Smets *et al.*, 2020; Yildirim-Aksoy *et al.*, 2020; Shah *et al.*, 2022) ^[54, 34, 55, 56, 57]. Consistently high mineral levels have also been reported by Finke, (2013) ^[58] recorded mineral (g/kg) content in BSF larvae meal were Ca - 2.40, Mg - 4.50, P - 9.20, Cu - 10.40, Fe - 171.70, Mn - 159.30 and Zn - 144.90.

Effects of Black Soldier Fly larvae on growth performance in poultry

Numerous studies have evaluated the effects of black soldier fly larvae (BSFL) meal on growth performance in poultry, with outcomes largely influenced by inclusion level, processing method and bird species. In broilers, early work by Oluokun (2000) ^[59] demonstrated that BSFL meal can effectively replace fish meal in soybean meal (SBM) based diets without adversely affecting body weight gain, feed intake, or feed conversion ratio (FCR). Similarly, Makkar *et al.* (2014) ^[8] reported comparable body weight gain but reduced feed intake when SBM was replaced with dried BSFL, indicating improved feed efficiency.

Positive growth responses have also been reported at moderate inclusion levels. Dabbou *et al.* (2018) ^[60] observed increased body weight and average daily gain (ADG) during the starter and grower phases; however, a linear decline in ADG during the finisher phase was noted, possibly due to adverse effects on intestinal morphology at higher inclusion rates. In contrast, high substitution levels appear detrimental. Murawska *et al.* (2021) ^[61] found that complete replacement of SBM with full-fat BSFL reduced live weight, ADG, daily feed intake, FCR, carcass yield and muscle weight, while increasing abdominal fat deposition, likely due to excess saturated fatty acids. Consistently, La Mantia *et al.* (2024) ^[51] reported reduced carcass weight in broilers fed 100% BSFL meal compared with control and 50% inclusion diets. Conversely, Permana *et al.* (2024) ^[62] observed no adverse effects on carcass weight with 7.5% or 15% BSFL inclusion during the finisher phase, although El-Gendy (2023) ^[63] reported reduced dressing percentage at 12–15% inclusion of defatted BSFL meal, suggesting variability based on processing and inclusion level.

In broiler quail, Cullere *et al.* (2016) ^[43] demonstrated that defatted BSFL meal could be included up to 15% (replacing SBM and soybean oil) without affecting growth performance, feed intake, FCR, mortality, nutrient digestibility, or carcass and meat quality.

In ducks, moderate inclusion levels generally showed neutral effects. Gariglio *et al.* (2023) ^[64] and Colombino *et al.* (2024) ^[65] reported that 5% live BSFL inclusion did not influence live weight, ADG, ADFI, or FCR. Similarly, Nha and Thuy,

(2024) ^[66] observed comparable growth when up to 60% of fishmeal protein was replaced with BSFL protein in Muscovy ducks, whereas an 80% replacement level impaired weight gain, indicating an upper inclusion threshold.

In turkeys, BSFL inclusion has demonstrated both nutritional and behavioural benefits. Veldkamp and Van Niekerk, (2019) ^[67] reported increased feed intake and final body weight with 12% live BSFL inclusion, while 10% inclusion reduced aggressive pecking behaviour, likely due to enhanced foraging stimulation. However, replacement of soybean oil with BSFL fat showed no growth advantage. Kierończyk *et al.* (2018) ^[68] and Sypniewski *et al.* (2020) ^[69] reported no significant effects on body weight, feed intake, or FCR when soybean oil was partially or fully replaced with BSFL fat.

Overall, these findings suggest that BSFL can be successfully incorporated into poultry diets at moderate inclusion levels, whereas excessive replacement particularly with full-fat forms may compromise growth performance and carcass traits.

Effects of Black Soldier Fly Larvae on laying hen performance and egg quality

Several studies have evaluated the suitability of black soldier fly (BSF) larvae and pre-pupae meals as alternative protein sources in laying hen diets, with generally positive outcomes on production performance and egg quality. Hopley (2016) ^[70] reported satisfactory production parameters and improved FCR in hens fed BSF larvae and pre-pupae meals. Similarly, Al-Qazzaz *et al.*, 2016) ^[71] observed that egg quality traits in BSF-fed layers were comparable to or superior to those of control hens, supporting the nutritional adequacy of BSF larvae in layer diets.

Moderate inclusion levels appear to be well tolerated, whereas complete replacement of conventional protein sources may negatively affect performance. Mwaniki *et al.* (2018) ^[72] found that inclusion of 7.5% defatted BSF larvae meal (19–27 weeks of age) increased feed intake and FCR, while Borrelli *et al.* (2017) ^[73] reported reduced body weight following total replacement of soybean meal with BSF larvae meal over a 21 week period. Van Schoor, (2017) ^[74] demonstrated that inclusion of BSF pre-pupae meal at 10% did not adversely affect egg production, egg quality, or shelf life, concluding that this inclusion level is safe for layer diets. In addition to production effects Star *et al.* (2020) ^[75] reported improved feather condition in hens fed BSF larvae, indicating potential welfare benefits.

Recent studies have focused on eggshell and internal egg quality. Anas *et al.* (2024) ^[76] reported improved eggshell weight and thickness when layers were fed 2% black soldier fly larvae oil calcium salt (BSFLO-SCa), suggesting enhanced calcium utilization. Regarding albumen quality, whereas BSFLO-SCa supplementation increased albumen weight, height and proportion.

The effects of BSFL on yolk colour remain inconsistent across studies. Darker yolk pigmentation was reported with BSFL meal or oil inclusion (Dörper *et al.*, 2024) ^[77]. In contrast, (Anas *et al.*, 2024) ^[76] observed increased yolk lightness and yellowness but reduced redness with BSFLO-SCa supplementation. These discrepancies are likely attributable to differences in BSFL form, inclusion level, dietary pigments and their bioavailability.

Overall, evidence suggests that BSF larvae and pre-pupae meals can be safely incorporated into laying hen diets at moderate inclusion levels, with neutral or positive effects on production performance, egg quality and hen welfare, while excessive replacement of conventional protein sources may

compromise performance.

Conclusion

Insects represent a sustainable and promising protein source for poultry feeding and may contribute significantly to global food security. Their use can help address major challenges such as rising feed costs, limited availability of conventional protein sources and environmental pollution. When insects are reared on organic waste materials and incorporated into poultry diets, they not only improve economic sustainability but also support waste reduction and environmental protection. This integrated approach adds value to organic waste generated from households, restaurants and agricultural activities. For successful large scale utilization, careful selection of insect species is essential, with emphasis on high growth rate, efficient feed conversion, disease resistance and good nutritional quality. Among various insect species, black soldier fly (BSF) has emerged as a highly suitable candidate due to its rich protein content and adaptability. Recent studies indicate that BSF meal can partially or completely replace soybean meal or fish meal in broiler and layer diets without adverse effects on performance. However, further research is needed to determine the optimal inclusion levels of BSF meal in poultry diets. Additional studies should also examine its effects on growth performance, nutrient composition, palatability, meat and egg quality and consumer acceptance. Attention must be given to fatty acid profile, chitin content and food safety standards to ensure suitability for both poultry and human consumption. Overall, BSF meal holds strong potential as an alternative feed ingredient in sustainable poultry production systems.

Conflict of Interest

Not available

Financial Support

Not available

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