

Insights on the utilization of protein alternative maggot (*Hermetia illucens*) and earthworm (*Lumbricus* sp.) as feed in poultry: A review

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ABSTRACT

The poultry industry is continuously seeking sustainable, nutritionally balanced, and cost-effective feed ingredients to improve production efficiency while minimizing environmental impacts. Maggot (*Hermetia illucens*) and earthworm (*Lumbricus* sp.) have emerged as promising alternative animal protein sources due to their high-quality protein, balanced essential amino acids, beneficial fatty acids, and bioactive compounds that support growth performance, gut health, and immune function in poultry. Their cultivation also utilizes organic waste substrates, contributing to waste reduction and the development of a circular bioeconomy. This review synthesizes scientific findings on the nutritional characteristics, processing methods, and practical applications of maggots and earthworms in poultry feed formulations. Literature analysis indicates that these alternative proteins can enhance feed conversion ratio, carcass quality, and overall production performance when incorporated at optimal inclusion levels. Nonetheless, variations in nutrient composition, potential microbial contamination, and limited consumer acceptance remain key challenges. Further research is recommended to develop standardized rearing and processing protocols, ensure feed safety, and evaluate long-term effects on poultry productivity and product quality.

Introduction

Poultry production is a vital component of the global livestock sector and plays a central role in meeting the increasing demand for animal protein. In 2023, poultry meat accounted for nearly 40% of total global meat production, and its consumption continues to rise due to its affordability and wide consumer acceptance (FAO, 2023). Poultry is therefore recognized as one of the major providers of animal protein worldwide. However, the sustainability of poultry production is closely linked to feed availability, which represents up to 60–70% of total production costs (Makkar *et al.*, 2014). Current poultry feed formulations remain highly dependent on conventional protein sources such as soybean meal and fishmeal. These ingredients are increasingly problematic due to their high and fluctuating prices, competition with human food resources, and negative environmental impacts. Soybean cultivation is strongly associated with deforestation and biodiversity loss in major producing countries, while fishmeal production contributes to overfishing and marine ecosystem depletion (FAO, 2022). Consequently, finding sustainable and cost-effective alternative protein sources has become a global priority for poultry nutrition.

Insects and other invertebrates have emerged as promising candidates due to their ability to bioconvert low-value organic waste into high-quality biomass. Among them, black soldier fly larvae (BSFL, *Hermetia illucens*) and earthworms (*Lumbricus* spp.) stand out for their nutritional profiles and ecological benefits. BSFL contain 30–50% crude protein and beneficial lipids rich in essential fatty acids, while simultaneously reducing large amounts of agricultural and food waste (Aniebo *et al.*, 2008; Mahmud *et al.*, 2020b; Widiyastuti *et al.*, 2024). Earthworms, in addition to their ecological role as decomposers, provide 55–70% crude protein (dry matter basis), a balanced amino acid profile, bioactive compounds, and digestive enzymes that may improve gut health and immunity in poultry (Balamuralikrishnan *et al.*, 2019; Devi *et al.*, 2021). The integration of mag-

gots and earthworms into poultry feed formulations therefore represents a dual strategy: providing highly nutritious and digestible protein while promoting sustainable waste management within a circular economy framework. However, despite their potential, the practical use of these resources is still constrained by issues of digestibility, processing technologies (e.g., drying, fermentation, enzymatic hydrolysis), and possible antinutritional or safety concerns.

Accordingly, this review seeks to provide a comprehensive overview of the potential of *Hermetia illucens* and *Lumbricus* spp. as alternative protein sources in poultry feed, highlighting their nutritional value, functional benefits, challenges, and opportunities in building more sustainable and environmentally responsible poultry production systems.

Research articles and inclusion criteria

This review was conducted using a systematic approach to collect, select, and analyze relevant scientific literature regarding the utilization of maggot (*Hermetia illucens*) and earthworm (*Lumbricus* sp.) as alternative protein sources in poultry feed. Data sources included peer-reviewed journal articles, conference proceedings, and academic theses published between 2000 and 2025. Literature searches were performed using online scientific databases such as Scopus, Web of Science, ScienceDirect, and Google Scholar. The search terms included "*Hermetia illucens* poultry feed," "black soldier fly larvae nutrition," "*Lumbricus* sp. poultry feed," "alternative protein sources in poultry," and "insect-based poultry nutrition."

Inclusion criteria for article selection were: (1) studies providing quantitative or qualitative data on the nutritional composition, processing methods, and feeding trials of maggot or earthworm in poultry; (2) research published in English or Indonesian; and (3) full-text availability. Exclusion criteria were: (1) studies unrelated to poultry; (2) publications without primary data (e.g., opinion pieces without references); and (3) duplicated content across sources.

Data from the selected literature were extracted and summarized, focusing on nutrient profiles, processing techniques, feeding trial results, effects on growth performance, feed conversion ratio, carcass quality, gut health, and sustainability aspects. The analysis emphasized identifying patterns, gaps, and practical implications for the integration of maggot and earthworm as alternative protein sources in poultry feed.

Maggot (*Hermetia illucens*)

The utilization of *Hermetia illucens*, commonly known as the Black Soldier Fly (BSF), has garnered significant attention as a sustainable and efficient source of protein in poultry nutrition. This insect represents a promising alternative to conventional protein sources such as soybean meal and fishmeal, owing to its high protein content and its capacity to convert organic waste into high-value nutrients. The integration of BSF larvae into poultry feed has been shown to support growth performance, enhance gut health, and strengthen the immune response in poultry.

Most studies report that the dry matter (DM) content of BSF ranges between 88–90% (Makkar *et al.*, 2014). Fourth, the amino acid and fatty acid profiles of BSF have been widely studied. The contents of lysine, leucine, and valine are relatively high, while the dominant fatty acids are lauric, palmitic, and oleic acids, which are beneficial for poultry gut health (Oonincx *et al.*, 2015; Schiavone *et al.*, 2017).

From a productivity perspective, (Yaman *et al.*, 2023) reported that the inclusion of BSF maggot meal at levels of 9–12% in poultry diets did not exert any negative effects on growth performance or protein retention in hybrid chickens. (Mahmud *et al.*, 2020a) also noted that the duration of larval rearing influences dry matter content, crude fat, and crude protein levels, which are critical in determining the quality of larvae as a feed ingredient. Nutritionally, BSF maggots possess a high crude protein content, unsaturated fatty acids, and a complete profile of essential amino acids, making them a strong candidate as an alternative animal protein source in poultry feed (Widiyastuti *et al.*, 2024). Their use has been shown to improve growth performance, product quality, antioxidant function, as well as digestive and immune health (Alifian *et al.*, 2025).

From an environmental perspective, the cultivation of BSF larvae contributes to the recycling of organic waste into biomass that can be utilized as both animal feed and organic fertilizer. This process not only reduces the burden of waste management but also produces biofertilizer residues that are beneficial for agricultural applications. (Leyo *et al.*, 2021). Moreover, since BSF larvae do not compete directly with human food sources and can thrive on a wide range of waste substrates, their utilization is considered highly environmentally friendly and aligns well with the principles of a circular economy (Leyo *et al.*, 2021). From an economic standpoint, the production of BSF maggots can be carried out at low cost due to the use of substrate materials derived from household, agricultural, or food industry waste, which are widely available and inexpensive (Leyo *et al.*, 2021; Noviadi *et al.*, 2023). These studies noted that the inclusion of maggot meal in broiler diets not only reduces feed costs but also enhances the economic efficiency of production.

Nevertheless, several challenges must still be addressed to promote the widespread adoption of *Hermetia illucens* in the livestock industry. Feed safety remains a key concern, particularly regarding the potential for microbial contamination and the transmission of antibiotic resistance through larvae. Treatments such as high-temperature processing and fasting (gut emptying of larvae) have been shown to reduce microbial loads in both the substrate and the larvae (Shelomi, 2020). Blanching (rapid heat treatment) has also been shown to be effective in reducing microbial contamination (Bessa *et al.*, 2021).

Various studies have demonstrated that BSF maggots have the potential to replace conventional protein sources in poultry diets, in terms of production performance, product quality, as well as environmental and economic impact. In broiler chickens, the inclusion of BSF maggots in the diet has been shown to support growth performance (Adam *et al.*,

2024; Mazlan *et al.*, 2024; Lee *et al.*, 2025; Saidani *et al.*, 2025). Up to 20% BSF meal can be included in poultry feed without adversely affecting feed intake, growth performance, or nutrient digestibility. However, inclusion levels exceeding 20% may potentially reduce nutrient digestibility (Adam *et al.*, 2024). In addition, the consumption of BSF maggots has been shown to enhance gut health by reducing the population of pathogenic bacteria such as *E. coli* and increasing the abundance of beneficial bacteria such as *Lactobacillus* spp. (Mazlan *et al.*, 2024; Saidani *et al.*, 2025). The inclusion of BSF maggots in poultry diets can also improve carcass and meat quality without causing significant differences in the sensory or physical attributes of the meat (Saidani *et al.*, 2025) (Gariglio *et al.*, 2019). Furthermore, BSF maggots have been shown to help broiler chickens cope with heat stress by maintaining corticosterone levels and improving gastrointestinal health (Mazlan *et al.*, 2024).

Meanwhile, in laying hens, the inclusion of BSF maggots can be implemented without adverse effects on egg production or quality. Several studies have even reported improvements in yolk color and albumen height (Bejaei & Cheng, 2020; Zhang *et al.*, 2020; Navasero *et al.*, 2022). Protein and fat digestibility also increase significantly with BSFL supplementation (Navasero *et al.*, 2022). Additionally, BSFL positively influences metabolism and gut health by promoting the growth of beneficial bacterial populations and increasing short-chain fatty acid production, which ultimately contributes to improved nutrient absorption (Zhao *et al.*, 2023).

In ducks, BSF maggots can be included in the diet at levels up to 9% without negatively affecting growth performance or nutrient digestibility (Narushin *et al.*, 2021; Kurniawan *et al.*, 2025). However, supplementation above this level may lead to reduced growth performance (Aldis *et al.*, 2024). The inclusion of BSF maggots has also been reported to improve carcass quality and enhance the fatty acid profile of duck meat (Gariglio *et al.*, 2019), indicating potential added value in the quality of the final product.

Quail have also shown positive responses to the inclusion of BSF maggots. Several studies have revealed that BSF maggots can be incorporated into the diet at levels up to 27% without reducing feed conversion ratio, and may even enhance average daily weight gain and feed intake (Silva *et al.*, 2024; Mustafa *et al.*, 2025). In terms of egg production, BSFL supplementation does not have negative effects and has been shown to increase eggshell thickness (Suparman *et al.*, 2020; Zotte *et al.*, 2019) this is an important aspect in enhancing the eggs' resistance to physical damage.

From sustainability and economic perspectives, BSFL holds significant value due to its ability to convert organic waste into protein-rich biomass, thereby supporting the principles of a circular economy (Striffler *et al.*, 2017; Msangi *et al.*, 2022; Salahuddin *et al.*, 2024). The use of BSFL has also been demonstrated to significantly reduce feed costs, particularly when used to replace expensive feed ingredients such as fishmeal (Ahmad *et al.*, 2022; Lokaewmanee *et al.*, 2023). Overall, the use of Black Soldier Fly larvae in the diets of various poultry species demonstrates great potential not only in terms of animal performance and health but also from environmental sustainability and economic efficiency perspectives. Nevertheless, appropriate dosage regulation and further investigation into the long-term effects are necessary to ensure its safety and effectiveness within modern poultry production systems.

The appropriate age of maggots for use as poultry feed has not yet been clearly determined. However, the concentration of essential amino acids is known to vary throughout the larval life cycle, with the highest values observed during the early larval stage (days 4 to 6) and stabilizing at the prepupal stage (Sprangers *et al.*, 2017; Barragan-Fonseca *et al.*, 2020). The most effective processing method is drying (oven or sun) combined with defatting, which has been shown to increase protein content and improve product stability (Wang and Shelomi, 2017; Cullere *et al.*, 2019).

The optimal nutrient composition of substrates for BSF growth has not yet been practically established. Recent studies have developed dy-

namic growth models that take into account feed quality, temperature, and humidity; however, the formulation of an ideal substrate still requires further investigation (Gold *et al.*, 2020). Regarding the replacement of fishmeal or soybean meal, several studies have reported that BSF maggot meal has a superior amino acid profile compared to plant-based protein sources and can replace up to 25–50% of fishmeal in poultry diets without reducing performance (Cullere *et al.*, 2019; Khan *et al.*, 2018). Nevertheless, long-term field studies are still required to determine the optimal substitution level from both economic and physiological perspectives.

Table 1. Content of Maggot (*Hermetia illucens*).

Component	Content	Literatures
Crude protein	39.19% – 57 %	
Crude fat	6.66 % – 27.65 %	
Crude fiber	3.37 % – 14.11 %	Ahmad <i>et al.</i> (2022)
Ash	7.31 % – 8.33 %	
Metabolizing Energy	3955 Kcal/kg	
Amino Acids	High in essential amino acids (Includes lysine, methionine, glutamic acid, aspartic acid, and others)	Fatmawati <i>et al.</i> (2024) and Widiyastuti <i>et al.</i> (2024)
Fatty Acid	High in lauric and oleic acids (Lauric acid content varies with substrate)	Widiyastuti <i>et al.</i> (2024)

Table 2. Inclusion levels of BSF Maggot meal in poultry feed.

Poultry	Inclusion	Benefit	Notes
Broiler	20%	Growth, gut health, carcass quality	Higher inclusion levels may reduce digestibility
Layer	3%	Egg quality, nutrient digestibility	Enhances yolk color and albumen height
Duck	9%	Growth, carcass quality	Higher inclusion rates may decrease performance
Quail	27%	Growth, egg production	Increases eggshell thickness

Earthworms (*Lumbricus* sp.)

The life cycle of earthworms begins with eggs or cocoons, which typically hatch within 2–3 weeks, depending on environmental conditions such as temperature and moisture (Edwards & Bohlen, 1996). Newly hatched worms, known as juveniles, are small, thin, and transparent, and they have not yet developed a clitellum. At this stage, the protein content is relatively high, ranging from 60–65% on a dry matter basis, although the total biomass remains low due to their small body size (Sogbesan and Ugwumba, 2008; Gunya *et al.*, 2020).

After reaching 6–8 weeks of age, earthworms enter the young adult phase, characterized by the appearance of the clitellum. During this period, the body size becomes optimal, and the protein content decreases slightly to approximately 55–60%. This developmental stage is considered the most suitable for harvesting as animal feed, since the worms provide both high-quality protein and sufficient biomass (Rakhmani *et al.*, 2019; Janković *et al.*, 2015).

If earthworms are allowed to grow into full maturity (2–3 months or older), their protein content declines further to about 45–50%, as more energy and nutrients are diverted toward reproduction and cocoon production (Gunya *et al.*, 2020; Edwards & Bohlen, 1996). Although the overall biomass continues to increase at this stage, the quality of protein is lower compared to younger worms.

Therefore, the optimal harvesting age for animal feed is between 40–60 days, when earthworms have achieved adequate body mass while maintaining relatively high protein levels and a soft body texture, which enhances digestibility for both poultry and fish (Sogbesan & Ugwumba,

2008; Rakhmani *et al.*, 2019).

Earthworm meal (EWM), particularly derived from *Lumbricus rubellus*, has emerged as a promising alternative protein source for poultry. With a high protein content of approximately 41.42% on a dry matter basis, EWM offers a nutrient-rich option for poultry feed (Janković *et al.*, 2015). In addition to its protein content, EWM presents a favorable amino acid profile that aligns well with the nutritional requirements of poultry. From a safety perspective, both fresh and processed earthworms have been found to be free of heavy metals and pathogenic bacteria, making them safe for poultry consumption (Janković *et al.*, 2015).

The impact of EWM on poultry performance has shown positive results. In broiler chickens, dietary supplementation with EWM significantly increased body weight gain and improved feed conversion ratio (Sofyan *et al.*, 2010; Nalunga *et al.*, 2021). Broilers receiving EWM also demonstrated more efficient feed utilization compared to those receiving antibiotics or a control diet (Sofyan *et al.*, 2010). Regarding product quality, increased supplementation of EWM improved the freshness and flavor of broiler breast meat without adversely affecting other sensory attributes such as aroma, tenderness, or residue levels (Nalunga *et al.*, 2021).

Table 3. Nutrition content of *Lumbricus* sp.

Nutrition	Content (%)	Literatures
Protein	41-65%	Sogbesan & Ugwumba (2008); Gunya <i>et al.</i> (2020); Janković <i>et al.</i> (2015)
Fat	5-12%	Sogbesan & Ugwumba (2008); Sofyan <i>et al.</i> (2010)
Crude fiber	2-7%	Sogbesan and Ugwumba (2008)
Ash	8-15%	Janković <i>et al.</i> (2015); Nalunga <i>et al.</i> (2021)
Carbohydrate	10-15%	Sogbesan & Ugwumba (2008)
Metabolism Energy	2500-2900 Kkal/kg	Sofyan <i>et al.</i> (2010); Nalunga <i>et al.</i> (2021)

In laying hens, replacing commercial feed with vermicompost did not significantly alter production parameters but did enhance egg quality, particularly in terms of yolk color intensity and shell thickness (Suárez-Car-doso *et al.*, 2016). This suggests that earthworms can enhance not only growth and performance but also the quality of poultry products. From a health standpoint, EWM has demonstrated potential immunomodulatory effects. Broiler chickens treated with EWM showed reduced necrosis in vital organs such as the liver and intestines when infected with *Salmonella pullorum*, indicating improved disease resistance and internal organ integrity (Sofyan *et al.*, 2010).

Economically, EWM is a cost-effective solution, particularly for small-scale poultry farmers. The use of earthworm compost in poultry feed has been reported to reduce production costs by up to 20% (Suárez-Cardoso *et al.*, 2016), providing a sustainable and affordable alternative to more expensive conventional feed ingredients such as fishmeal.

Ecologically, earthworms play a vital role in sustainable agriculture. Their involvement in nutrient cycling, soil structure enhancement, and microbial biodiversity supports overall ecosystem health (Schrader *et al.*, 2020; Manggay & Meiyasa, 2023; R. Liu *et al.*, 2025). Their activity in decomposing organic matter indirectly benefits poultry farming by improving the quality of plant-based feed ingredients such as forage and agricultural residues (Vidal *et al.*, 2023; R. Liu *et al.*, 2025). Earthworm meal (*Lumbricus* sp.) represents a valuable alternative protein source for poultry, offering nutritional benefits, enhanced growth performance, and economic advantages. Additionally, earthworms contribute to sustainable agricultural practices, improving soil health and productivity, which in turn supports livestock systems. Further research is necessary to optimize inclusion levels and fully understand the broader implications of incorporating earthworm meal into poultry diets.

Studies suggest that earthworm meal can be included up to 10% in broiler diets without adverse effects on growth performance. Specif-

ically, a 5% inclusion level improved weight gain and feed conversion ratios (Gunya *et al.*, 2019; Nazeri *et al.*, 2021). Another study indicated that substituting fish meal with earthworm meal (up to 100%) did not significantly affect productive performance (Janković *et al.*, 2015). The optimal inclusion level appears to be around 5% for improved growth and feed efficiency (Gunya *et al.*, 2019; Nazeri *et al.*, 2021).

For Laying hen here is limited specific data on laying hens. However, general findings from other poultry suggest that earthworm meal can be included up to 10% without negative effects. For laying quails, which can be a proxy, 1.5% earthworm meal improved body weight and feed intake, while 0.5-1.0% improved egg productivity (Nazeri *et al.*, 2021). Based on quail data, an inclusion level of 0.5-1.5% may be optimal for laying hens (Nazeri *et al.*, 2021)

For Muscovy ducks, earthworm hydrolysate (a processed form of earthworm meal) was tested at 1.5% and 2.5. Both levels improved growth performance, antioxidant capacity, and gut health. The optimal inclusion level for ducks appears to be around 1.5-2.5% (Z. Liu *et al.*, 2023). Earthworm meal can be included up to 15% in quail diets. However, higher levels (15%) may reduce feed consumption and body weight gain. An inclusion level of 10% provided good growth performance and feed conversion. The optimal inclusion level for quails is around 10% (Prayogi, 2011)

Conclusion

Based on the reviewed literature, biological waste-derived proteins such as black soldier fly (BSF, *Hermetia illucens*) maggot and earthworms (*Lumbricus* spp.) represent promising alternatives for poultry feed. BSF maggot meal, containing approximately 31% crude protein, can replace 25–50% of soybean meal and, in some cases, fully substitute fishmeal when diets are adequately balanced for lysine and methionine. Its lipid fraction, particularly lauric acid, provides functional benefits for gut health and antimicrobial activity, though excessive inclusion may increase carcass fat. Earthworm meal, with 41% crude protein and a favorable amino acid profile, can replace up to 50% of conventional protein sources, with optimal benefits observed at 5–10% dietary inclusion. While BSF maggots offer greater scalability and potential for large-scale poultry production, earthworms remain more suitable as supplementary protein sources due to production limitations. Future research should focus on optimizing combined formulations and developing sustainable cultivation and processing systems to ensure a consistent, safe supply of these alternative feed ingredients.

Conflict of interest

The authors declare that they have no conflict of interest.

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