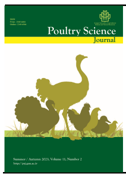

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Black Soldier Fly (*Hermetia illucens*): A Proteinous Substitution of Soybean and Fish Meal for Broiler and Layer Chicken: A Review

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Abstract
Protein source feed components are particularly important in broiler and layer feed formulation. Protein-rich insects may be the greatest substitute for protein-rich feed items such as fish and soybean meals. The black soldier fly (BSF) (*Hermetia illucens*) is an excellent example of an organism that can transform organic waste into protein, lipids, chitin, and other substances. Black Soldier Fly larvae (BSFL) have 42% crude protein, 29% fat, and 23% moisture content on a dry matter (DM) basis. Without specific infrastructure, commercial manufacturing of BSF is achievable. BSF could be used in poultry feed to help reduce pollution. A buildup of organic wastes may result in a possible pollution issue but BSF can transform a wide range of organic waste into a source of protein for poultry. Moreover, the most economical diets were those that had 25% and 100% of Black Soldier Fly Larvae Meal (BSFLM), respectively. The most significant benefit of BSF as a chicken feed ingredient is that it might be a sustainable protein source and a cost-effective replacement for high-cost protein feedstuffs. The importance of the BSF as a potential source of organic protein for broiler and layer chicken production is highlighted in this review of the literature.

Introduction

With an estimated global population increase of 8.5 billion by 2030 and 9.7 billion by 2050 (UN, 2019), developing and providing a secure and sustainable food system is critical. With an annual growth of 83 million people, food production is expected to increase by 70% to meet demand, resulting in greater competition for arable land and natural resources such as energy and water (FAO, 2020). However, lacking these crucial resources limits our agricultural sectors' potential to flourish, notably in the manufacture of sufficient and high-quality protein from traditional sources, posing a severe problem. The combined result of an increasing human population and better living standards in most developing countries will raise the need for animal-derived protein sources. So what will be the possible alternatives? According to research and experts (Kouřimská & Adámková, 2016), feed formulations containing insect meals could be a unique technique to increase nutritional security in animals and humans. For example, the large part of the necessary amino acid profile and nutrient profile of BSFL makes it a desirable element in monogastric animal feed. BSFL may boost animal health in addition to the nutritional potential in diets. Humans have also consumed insects on every inhabited continent throughout history. The use of edible insects is still in its early to middle stages. Although possible hazards have been raised, there are still insufficient global rules governing the use of insects as a food source (EFSA, 2015). According to various research, digestible insects contain a high quantity of protein, vital amino acids, vitamins, and minerals (Spranghers *et al*., 2018). Lauric acid (C12:0), which makes up 64% of the total amount of saturated fatty acids in BSFL, is one source of some potential health advantages (Ewald *et al*., 2020).

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Insects can be utilized as feed or food, potentially assisting in the solution to the worldwide food crisis (De Marco *et al*., 2015), but insect meal in poultry feed, on the other hand, is more consumer-friendly than direct human intake because certain cultures dislike eating insects. On every inhabited continent, people have engaged in entomophagy, or the consumption of insects, both historically (Ayieko *et al*., 2010) and currently (Meyer-Rochow & Chakravorty, 2013). Although some modern cultures promote the consumption of insects (Hanboonsong, 2010), others consider them taboo or unpalatable (Yen, 2009). Kadazan-Dusuns were primarily rural, and subsistence farmers consumed raw insects along with Tapai, a locally produced, fermented beverage. The fermented tapioca was used to make this beverage, where the larvae were gathered (Chung *et al*., 2002). Although many insects have been consumed, very few have received the attention of the researchers . But consuming insects worldwide are increasing in direct or indirect ways. Interested customers can buy dried whole BSFL, BSFL oil, and defatted, milled BSFL from businesses that make these products for animal feed. After defatting, the oil flavor became more intensely flavored with chocolate and malt. Insect preparations are high in proteins, good fats, certain trace elements and are delicious when prepared correctly (Bosch *et al*., 2014). According to Schluter *et al*. (2017), the amount of protein found in edible insects ranges from 35% to 60% when measured by dry weight or 10% to 25% when measured by fresh weight. This is significantly higher than the protein content found in plant-based protein sources such as cereal, soybeans, and lentils (Bukkens, 1997). In fact, at the high end of the range, insects provide more protein than meat and chicken eggs (Mlcek *et al*., 2014). Mlcek *et al*. (2014), also investigated that fat is the second most prominent nutrient found in insects. Schluter *et al*. (2017) suggest that the amount of fat present in insects is influenced by a variety of factors, including species, sex, reproductive stage, season, diet, and habitat. The carbohydrate content found in edible insects varies between different species. On average, the carbohydrate content ranges from 6.71% in stink bugs to 15.98% in cicadas (Mlcek *et al*., 2014). A rare study found that consuming insects can fulfill the daily mineral requirements for humans, especially with regards to iron (Latunde-Dada *et al*., 2016). Although research on the vitamin content of insects is limited, available data, as mentioned by Mlcek *et al*. (2014), suggests that they contain essential vitamins such as carotene, vitamin B_1, B_2, B_6, C, D, E, and K. Poultry is by far the most common type of livestock that has a significant contribution to protein demand. It has blessings with faster growth, and its products have the lowest water and carbon footprint compared to the rest of animal proteins, but with the constant growth of the human population, the demand for animal protein is predicted to rise soon. Increased demand for poultry meat constantly creates the need for poultry feedstuffs like soybean and fish meal. As a protein source, soybean meal is the main (Heuel *et al*., 2022), and fish meal is the most commonly utilized ingredient in chicken feed formulas. But rising energy and feed costs may impact the quality and amount of animal feedstuffs such as soybean meal. In recent years, the high price of this component has emerged as a significant concern for the long-term viability of the poultry industry, particularly in developing nations (Chadd, 2007).

Insects are a natural part of poultry feed; current research suggests that integrating insect meals in feed formulation could improve the sustainability of the poultry supply chain (Abd El-Hack *et al*., 2020). Several Diptera and Coleoptera species can be raised on low-grade biological waste and converted into good-quality proteins BSFLseem to offer a lot of potential for substituting soybeans in chicken diets (Heuel *et al*., 2022). It is local to the Americas (The American continent, including North, South, and Central America). Also, it can be in tropical and temperate climates and survive a broad environmental range of circumstances. The final larvae of the BSF have distinct properties that make it a promising insect for industrial and commercial use. Their last larval stage, the prepupa, is rich in protein and fat (i.e., consisting up to 35% ether extract and 47% crude protein on a DM basis) (De Marco *et al*., 2015; St-Hilaire *et al*., 2007b). Moreover, insect meal is near to being a suitable feedstuff (Dabbou *et al*., 2018; De Marco *et al*., 2015, Schiavone *et al*., 2019) which boosted the growth of commercial fish, poultry, and pigs (St-Hilaire *et al*., 2007a). According to Ipema and Bolhuis (2022), utilizing live BSFL in broiler meals, where increased activity improves the welfare of the birds.

Insects have increased feed conversion ratio (FCR) and growth figures (Van Huis, 2013), enabling them to provide the best-quality and possibly economical feed for livestock. Their main advantage over other animal proteins is that they have a smaller environmental effect, which describes why they are often hailed as saviors in a world where food is scarce. Insects also have higher protein conversion efficiency from feed than swine, cattle (Oonincx *et al*., 2015) even poultry, and emit fewer ammonia and greenhouse gases than conventional farm animals (Costa-Neto, 2014; Van Huis, 2013). Several longitudinal types of research have revealed fascinating findings on the suitability of various insect meals as feedstuffs for livestock (poultry, pigs, and fishes) (St-Hilaire *et al*., 2007a). However, data received from insect digestibility experiments in poultry have been updated but limiting the development of proper insect-based diets for poultry.

Research on BSFL nutrition for poultry has been rising significantly (Abd EL-Hack *et al*. 2020). This review aims to bring the nutritional value of BSF as an alternate feedstuff in broiler and layer chicken diets and its contribution to the bioconversion of the organic-bio-waste into valuable protein biomass.

Nutritional potentionl of BSFL

Body composition

Body composition of BSFLs is variable (e.g., CP: 37-63% and fat: 7-39% on DM) and highly depends on subrtrates in their environment (Newton *et al*., 2005; Nguyen *et al*., 2015). In addition, there can be a lot of variances in body composition during the larval growth process. For example, crude protein content declines with age, with the highest percentage observed for larvae aged 5 days (61%) and lower percentages reported for larvae aged 15 (44%) and 20 (42%) days (Nguyen *et al*., 2015; Oonincx *et al*., 2015). These larvae can transform a variety of organic waste products, such as animal dung, food scraps, and agricultural waste, into a high-quality protein supply. BSFL efed cow manure contains less protein than that those fed swine manure (Newton *et al*., 2005; St-Hilaire *et al*., 2007a). BSFL fed with animal manures had a crude fat content of around 30%, with the highest larvae development and crude fat being observed when fed on chicken manure, as reported by Li *et al*. (2011b) (Table 1). Moreover, Nguyen *et al*. (2015) found that larvae fed on liver and fish had higher levels of fat and protein compared to those fed on chicken feed. These findings suggest that BSFL have the potential to accumulate high levels of crude fat, depending on their feed source, and could be a valuable source of fat for various applications

Table 1: Crude protein and crude fat content of BSFL raised on various substrates

Substrate		Crude protein %	Crude fat %	References
Fish meal		57.9	34.6	Nguyen *et al.*, 2015
Swine manure		43.2; 43.6	25.4	St-Hilaire *et al.*, 2007b
Cattle	Manure	42.1	34.8; 29.9	Li *et al.*, 2011b
	Blood	47.6	25.3	Nguyen *et al.*, 2015
Cow manure: Fish offal (1:1)		-	30.44	St-Hilaire *et al*. 2007a
Chicken	Manure	40.1	27.9	Li *et al.*, 2011a; Li *et al.*, 2011b
	Feed	47.9	14.6	Bosch *et al*., 2014; Nguyen *et al*., 2015; Oonincx *et al.*, 2015
		41.2	33.6	Spranghers *et al*. 2018
Liver		62.7	25.1	Nguyen *et al.*, 2015
Restaurant waste		-	39.2	Zheng *et al.*, 2012
		43.1	38.6	Spranghers *et al*. 2018
By-products		41.7	-	Oonincx *et al.*, 2015
Fruits and vegetables		38.5	6.63	Nguyen *et al.*, 2015
Biogas digestate		42.2	21.8	Spranghers *et al*. 2018

Amino Acid and Crude Protein Content

The crude protein percentage of BSFL varies with the larval form; for example, the crude protein content is lower at 38% during the larval phase, but it steadily increases with the progression of larvae development, reaching 39.2% in mature larvae at 14 days (Abd El-Hack *et al*. (2020). Costa-Neto, (2014), also reported that BSFL reached a maximum crude protein concentration of 46.2% in the early pupa stage and surprisingly, the highest level of CP content (57.6%) was found in the post-mortem (PM) adult stage (Table 2). Additionally, BSFLM has a CP concentration that is equal to or slightly greater than some agricultural plant proteins, including sunflower meal, linseed meal, wheat distillers, cottonseed meal, grains, lupins, and soybean as stated by Cheng *et al*., (2023) and Liu *et al*. (2017) (Table 1). The protein efficiency ratio (PER) chick growth assay model was used in an experiment to examine the protein quality of BSFLM, soybean meal (SBM), and fishmeal (FM). Six test diets were given to a total of 240 male day-old Ross Ross broiler chicks for a 10-day test. The diets made from corn starch and dextrose included five test diets with casein-based 10% crude protein (CP), SBM, FM, or BSFLM without or with (BSFLM+) other essential amino acids (EAA) to match the amounts of the SBM diet on a digestible basis. For the casein, SBM, FM, BSFLM, and BSFLM+ diets, the analyzed CP (as fed) was 10.1, 12.8, 9.5, 11.7, and 14.9%, respectively (Cheng *et al*., 2023). Recently, specific conversion factors for nitrogen-to-protein (N:P) have been established for processed insect meals because the amount of non-protein nitrogen in insects was previously overestimated. Using the traditional 6.25 N:P conversion factor, the digestibility of dietary crude protein was slightly lower (P < 0.005) compared to the use of weighted average conversion factors of

5.66 and 5.65. When using the conventional 6.25 N:P conversion factors for the basal diet and excreta and the weighted average 6.09 N:P conversion factors for the insect meal diets, the digestibility of the diet's crude protein was significantly reduced ($P < 0.005$). Therefore, the mean 5.60 N:P conversion ratio appears to be more accurate than the traditional 6.25 in determining the crude protein content of poultry diets using processed insect meals. (Nery *et al*., 2018). It also has the most important essential amino acid (Table 2). BSF larvae protein is notably high in lysine (protein content 6-8%), according to the amino acid profile, and compared to animal feed published values. The amino acid content of larvae living on cattle manure (St-Hilaire *et al*., 2007b) was somewhat higher than that of larvae given chicken manure or swine manure (Newton *et al*., 2005).

Table 2: Crude protein content and profile of amino acids in BSFL

Crude protein %	Amino acids (Dry Matter) %						References
	Arginine	Isoleucine	Lysine	valine	Methionine	Threonine	
57.52	2.79	2.44	3.3	3.47	0.92	2.32	Mwaniki *et al*. 2018a
62.7	-	3.18	4.14	5.13	1.33	2.37	Marono *et al*. 2017
65.5	2.7	2.4	2.5	3.5	0.86	2.2	De Marco *et al*. 2015
54.8	1.73	2.34	2.1	3.8	0.66	2.04	Cullere *et al*. 2016
55.3	2.2	1.9	2.1	2.7	0.65	1.7	De Marco *et al*. 2015
36.9	1.94	1.72	2.23	2.2	0.9	1.52	De Marco *et al*. 2015
40.7	3.27	2.17	2.9	2.6	1.3	2	Barroso *et al*., 2014
36.2	2.98	2.1	2.75	2.28	0.54	1.95	Barroso *et al*. 2014
43.6	2.95	2.03	2.62	2.79	0.74	1.78	St-Hilaire *et al*. 2007b
39.9-43.1	1.99-2.03	1.72-1.91	2.34-2.57	2.41-2.82	0.71-0.87	1.54-1.68	Spranghers *et al*. 2018

Table 3: Percentage of the fatty acid composition of BSF larvae reared in different substrates

Substrates	α-linolenic	Capric	Linolenic	Oleic	Palmitoleic	Myristic	Palmitic	Lauric	Stearic	References
Cattle manure (CM)	0.2	3.1	4.5	26.1	5.1	3.9	16.9	26.7	5.3	Li *et al*., (2011b)
Chicken feed	0.6;0.8	0.9	9.4	10.2-14	3.4	6.5; 9.2	15; 12.7	47; 46.6	2.2; 2.1	Li *et al*., (2011a), Li *et al*., (2011b)
CM+ fish offal	0.5;0.7	-	3.9; 5.9	16.5;18.8	7.6	6.3; 6.5	14.3;17.3	34.1;37.1	2; 2.4	Sealey *et al*., (2011), Kroeckel *et al*., (2012)
By-products (high fat)	0.8;1.5	0.7;0.8	8.3; 17.1	15.9;18.1	2.9; 3.4	7.4; 7.8	14.4;17	28.9;38.4	2.4; 2.8	Oonincx *et al*., (2015)
By-products (low fat)	0.6;1	0.3;1.2	3.6; 6	10.3;10.8	4.7; 6.6	9.9; 9.5	11.6;11.8	48.4;50.7	1.8; 2	Oonincx *et al*., (2015)
Swine manure	0.1	-	3.7	11.8	3.5	6.8	10.5	49.3	2.8	St-Hilaire *et al*., (2007a)
Restaurant waste	-	1.8	7.5	27.1	9.4	–	18.2	23.4	5.1	Zheng *et al*., (2012).

Crude Fat and Fatty Acids Content

The percentage of mono and polyunsaturated fatty acids in BSF larvae and prepupae was reported to be 58–72% and 19–40%, respectively (Kroeckel *et al*., 2012; Li *et al*., 2011b), with high concentrations of palmitic acid, oleic acid, and lauric acid. The profile of fatty acid (FA) larvae meal and prepupae appear to be influenced by the FA content of their food (Table 3). When n-3 FAs like - eicosatetraenoic acid or linolenic acid are present in their diet, BSF prepupae may assimilate them (Sealey *et al*., 2011; St-Hilaire *et al*., 2007a). According to Oonincx *et al*. (2015), increasing dietary fat percentage resulted in a large portion of FA being converted to lauric acid, implying that there are limited options for adapting the FA profile of BSF larvae. A recent study showed that BSFL contains crude fat 12 to 30% (Matin *et al*., 2021).

Essential fatty acids are gaining popularity in chicken feed to increase bird health and productivity. However, BSF fats are adequate as a critical source of essential fatty acids in poultry diets. But regular inclusion of larval meal and pre-pupae as an element in chicken diets requires considerable awareness of the fatty acid and fat content (Kawasaki *et al*., 2019).

Mineral Content

Compared to other insects utilized in controlled feeding programs, BSF larvae have higher mineral concentrations. Iron (Fe) (0.02), manganese (Mn) (0.02), phosphorus (P) (0.91), zinc (Zn) (0.01), calcium (Ca) (2.41), and copper (Cu) (0.001) are all abundant, with a maximum Ca:P ratio of 8.4 recorded (Makkar *et al*., 2014). But in contrast to other insects, sodium (Na) is found in lower concentrations. BSF larvae fed on swine manure compare to poultry droppings has different mineral contents, presumably reflecting changes mineral content and availability (Newton *et al*. 2005) (Table 4). Matin *et al*. (2021)

calculated total P (0.7-1.1%), and Ca (0.04-3.6%) in BSFL. Their findings revealed vitamin E concentrations in immature prepupa (3.26 mg/100g) were lower than those in the mature larval (6.68 mg/100 g). Their research also discovered that micronutrients were mainly found in the final stages of larvae growth. Early prepupa larvae (620 mg/100 g) had phosphorus levels nearly twice as high as adult larvae (350 mg/100 g) on day 14. On a DM (Dry Matter) basis, phosphorous concentration was higher in BSF larvae grown on horse manure, with 920 mg/100g DM. Meanwhile, the concentrations other minerals were 4.43% calcium (Ca), 1.56 % potassium (K), 0.41% magnesium (Mg), and 0.3% sodium (Na) (Moula *et al*., 2018).

Table 4: Reveals crude fat % and mineral % quantity in black soldier flies (BSF)

References	Crude fat (%)	Ash %
Marono *et al*. 2017	4.7	8
De Marco *et al*. 2015	4.6	9.3
Cullere *et al*. 2016	15.6	7.7
De Marco *et al*. 2015	18	9.9
De Marco *et al*. 2015	34.3	17.3
Barroso *et al*. 2014	15.6	19.7
Barroso *et al*. 2014	18	9.3
St-Hilaire *et al*. 2007a	33.1	15.5
Spranghers *et al*. 2018	21.8-38.6	2.7-19.7

Chitin

Due to their biological and commercial value, chitin (arthropod exoskeleton's major component), chitosan (produced as a result of chitin deacetylation) and chitooligosaccharides (chitosan or chitin degraded products) have received a lot of attentions (Lee *et al*., 2008; Liaqat and Eltem, 2018). Chitin, nature's second most prevalent polysaccharide, is present in crustaceans, fungi, and insects but absent in mammals (Lee *et al*., 2008). The BSF in feed is an efficient technique to transform trash into valuable nutrients like proteins, lipids, and chitin (Caligiani *et al*., 2018). Furthermore, some studies have revealed antibacterial activity (Mateos-Aparicio *et al*., 2016), antifungal activity (Mei *et al*., 2015), and antiviral activity (Niu *et al*., 2018) of chitin against various bacteria, fungi, and viruses. In addition, different research has reviewed and explored the necessity of chitin as feed ingredients in chicken and pig nutrition (Hu *et al*., 2018; Mateos-Aparicio *et al*., 2016). Insect products have unique properties that make them one of the most effective alternatives to reduce using antibiotics excessively in chicken feed (Van Huis, 2013).

BSFL Effects on Broiler Performance

Feed Intake, Live Weight, Daily Body Gain, and Feed Conversion Ratio (FCR)

BSF larval meal is also an excellent element for broiler diet formulation because of its high apparent amino acid, metabolizable energy, and coefficients of apparent ileal digestibility (De Marco *et al*., 2015). This result was consistent with the latest experiment in which native chickens (Ardennaise chickens) were reared with a typical commercial feed with 8% substituted by BSF de-frozen larval meal equating to 2% DM (dry matter) from 30-80 days of age without having statistically different from the control diet (Moula *et al*., 2018). This could be possible due to fatty acids (short-chain) in larvae, which may act as critical signaling molecules between host physiology and the gut microbiota (Jocken *et al*., 2018). Additionally, when compared to a control diet based on 25% fish meal (animal protein), adding 25% house fly larval meal to a broiler diet revealed higher feed consumption, but giving either 10% larvae meal *Musca domestica* or 10% fish meal resulted in no significant differences in feed intake and (Pretorius, 2011). Similar findings were observed in a study involving broiler chickens, both dried house fly larvae meal and soybean-based control meal were used as feeds during a three-phase feeding system (0-3 weeks, 4-5 weeks, and 0-5 weeks), with no significant differences observed in feed intake between the two diets (Hwangbo *et al*., 2009).

The live body weight increased dramatically when the larval meal was added to the broiler diet for 5–20% of the time during the 5-week developing phase. The group fed with a 15% larval meal diet had the highest body weight, 1.785kg vs. 1.638kg, compared to the control group (Hwangbo *et al*., 2009). Due to the addition of BSFL to broiler diets, a quadratic and linear response in average daily weight gain and body weight were observed at the starter and growing periods, while average daily gain reduced linearly during the final stage, which could be due to some adverse role of BSF larval meal on intestinal morphological features when administered at a maximum of level 10% (Dabbou *et al*., 2018). Ardennaise local chickens aged 30 days fed a diet having 8% fresh BSF larval meal for 50 days had a weekly body weight that was somewhat higher than control birds (Moula *et al*., 2018). While broiler showed no significant variations in growth performance when fish meal (10%) or BSFL (10%) was added to broiler diets (Pretorius, 2011). Similar results were reported in other studies where there were no significant differences observed in terms of daily gain or final weight during the grower phase in broiler quails fed with either a control diet or a diet containing BSFLM (Cullere *et al*. 2016)

When house fly larvae meal was included in broiler diet at levels of 5-20% during the first three weeks resulted in better feed conversion ratio (FCR) compared to the control group. The 5% supplemented group had the best FCR (1.33 vs. 1.40 for the control) among all the groups tested. Moreover, the dietary treatments significantly improved the FCR during two-phase feeding systems (28-35 days and 0-35 days) compared to a soybean-based control diet. These positive outcomes may be attributed to the higher nutrient content of larvae meal compared to soybean meal, particularly in essential amino acids (29.5% vs. 18.3%, respectively), and the better digestibility values of crude protein and amino acids in maggot in comparison to soybean meal (Hwangbo *et al*., 2009), while there were linear and quadratic responses observed in broilers fed with increasing levels of BSFLM, with the highest correspondence observed in broilers fed up to 15% BSF larvae meal during all growing stages. (Dabbou *et al*., 2018). Heuel *et al*. (2022) also reported that broilers from the insect-based feeding groups thrived well compared to the control group. Additionally, they kept more nitrogen in the body than the group that only consumed non-insect sources.

Diseases and Mortality

Broilers fed BSFLM-based diets showed no clinical symptoms of common illnesses. Incorporating BSF larval meal into the broiler quail grower diet had no adverse effects on mortality (Agunbiade *et al*., 2007; Cullere *et al*., 2016). Moreover, house fly larvae-based broiler diets did not cause gizzard erosion or toxicity (Pretorius, 2011). These findings suggest that including insect meal in poultry feed ingredients has no negative impact on mortality rates (Abd El-Hack *et al*., 2020).

Apparent and Ileal Amino Acid Digestibility

In a digestibility test of broiler pupa, housefly larval meal was used. The crude protein digestibility for larval and pupae meals was 69 % and 79 %, respectively (Pretorius, 2011). In another study, De Marco *et al*. (2015) found that when fed to broilers, the apparent digestibility of BSF larval meal for gross energy, crude protein, and ether extract was calculated to be 69%, 51%, and 99%, respectively, while digestibility of dry matter and organic matter was 53% and 66%. Cullere *et al*. (2016) investigated a partial substitution of soybean oil and soybean meal in the broiler quail grower diet (10 to 28 days of age) with two amounts of de-fatted BSFLM (10% and 15%). When 10% black soldier larvae meal was added to the diet, it replaced 16.1% of soybean meal and 28.4% of soybean oil, in contrast, 15% BSFLM replaced 100% of soyabean oil and 24.8% of soybean meal. They also experimented that there were no statistically significant differences in the digestibility of crude protein (45.1, 42.9, and 34.0%), starch (93.9, 95.7, and 95.7%), dry matter (54.0, 58.9, and 55.2%), organic matter (58.4, 62.9, and 59.1%), or energy (62.0, 65.3, and 63.1%) for control, 10% BSF, and 15% BSF diets, respectively. Hwangbo *et al*. (2009) fed 28-day-old male broilers a diet containing 30% soybean meal or housefly larval meal for one week to determine the apparent digestibility of amino acids and crude protein. When compared with the soybean group, housefly larval meal had the greatest digestibility values for crude protein (98.5 vs. 98%), essential amino acids (94.8 vs. 92.4%), and non-essential amino acids (94.7 vs. 92.2%). These findings offer insight into the potential of BSF as a viable alternative to conventional feedstuff in poultry diets (Abd El-Hack *et al*., 2020). In addition, some studies found that BSFL has a chitin content of about 5.41% DM, prepupae have a chitin content of 8.72% DM, and this element makes cross-linked with proteins and reduces protein digestibility by 8 to 11 % (Kroeckel *et al*., 2012; Sealey *et al*., 2011). As a result, whenever fish meal and soybean meal protein are substituted with either total or partial BSF prepupae, the maximum amino acid status, the dietary amino acids balance and reliable digestibility coefficients for broiler should all be taken into consideration (Sealey *et al*., 2011). To determine the apparent digestibility of defatted BSF larval meal, 32-day-old broilers were given a corn–soybean-based diet mixed with 250 g/kg of substantially or partially defatted BSF larval meal. After a six-day adaption period, the feed experiment lasted four days in a row. In the partially defatted BSF larval meal, compared to corn–soybean-based diet the mean apparent digestibility for ether extract, crude protein, dry matter, gross energy, and organic matter was 98 vs. 93%, 62 vs 62%, 63 vs. 59, 61 vs. 50%, and 69 vs 64%, respectively, (Schiavone *et al*., 2017).

In poultry feed formulation, determining the digestibility of amino acids is critical. It indicates the availability of amino acids in feed ingredients, but there has been little research on the digestibility of ileal amino acids in the BSF larvae diet. (Abd El-Hack *et al*., 2020). In a trial broiler chicken fed with whole BSFL feed, 17 amino acids in apparent ileal digestibility were calculated. In this study, after a 6-day adaption phase, 32-day-old broiler chickens were allowed to be fed a maize and soybean-based diet with 250 g/kg larval meal for four days. The apparent ileal digestibility of BSFL amino acids ranged from 42% to 89%, with a mean of 68%. The digestibility of essential amino acids such as isoleucine, methionine, and lysine was lower, at 45%, 42%, and 46%, respectively, while dispensable amino acids such as histidine, arginine, and leucine had higher values of 79%, 83%, and 76%, respectively. The highest digestibility values were recorded for dispensable amino acids, such as proline, alanine, and cysteine, at 89%, 86%, and 82%, respectively. The apparent ileal digestibility of the 17 amino acids was examined using 32-day-old broiler chicks in a different digestibility test. The broiler chickens were fed a corn-soybean diet containing 250 g/kg of either partially or completely defatted BSF larval meals. 17 amino acids' apparent ileal digestibility was unaltered by defatting levels, with values of 65% in the partially defatted meal and 82% in the fully defatted meal, respectively, excluding proline (Schiavone *et al*., 2017). Furthermore, compared to animal protein sources such as meat, feather, and bone meal, the perceived ileal amino acid digestibility in defatted BSF larvae diets was similar to that observed in a soybean meal and fish meal (Kroeckel *et al*., 2012). These findings revealed that the BSF larval feed has a high amount of amino acids and a high ileal digestibility value (Abd El-Hack *et al*., 2020).

Blood and Antioxidant Status

In broiler, the P (phosphorous) level increased with the increasing amount of BSFL, and it reached a maximum at 10% level of BSF larval meal compared to other groups. However, no effects on serum Ca, or other blood bocemicals such as erythrocyte, leukocyte etc were identified (Dabbou *et al*., 2018). Incorporating BSFLM or commercial chitin in broiler diets reduced cholesterol and triglycerides (Borrelli *et al*., 2017). Chitin's hypocholesterolemia effect could be related to chitosan, which has a high bile acid-binding capacity and anion-exchange activity, potentially disrupting enterohepatic circulation and increasing fecal triglycerides (Bedford & Gong, 2018).

The total antioxidant profile in the glutathione peroxidase (GPx) activity, hemoglobin content, and plasma in the blood was measured in male broilers fed nutritional BSF larval meal. Entire antioxidant status and GPx activity increased linearly as dietary BSFLM increased by up to 15% (Dabbou *et al*., 2018). The nitrotyrosine and plasma oxidative metabolites malondialdehyde were modified by dietary inclusion amounts of BSF larval meal, and their results indicated a linear decline as a healthy sign of antioxidant status (Gariglio *et al*., 2019).

Gut Health and Cecal Fatty Acid

There is strong evidence that the gut microbiota and its metabolites play a key role in the host metabolism, health, and growth. When conventional dietary proteins are replaced with entire prepupae in monogastric diets, recent research suggests that BSF's antibacterial capability may play a substantial impact (Spranghers *et al*., 2018). In addition, many published studies (Schiavone *et al*., 2018) have suggested that medium-chain fatty acids may improve gut health by improving intestinal shape. But in the case of BSF larvae fat, Schiavone *et al*. (2018) found that replacing soybean oil with BSFLM fat by 50% or 100% did not influence the intestinal morphology of broiler chickens. Furthermore, the study found that higher concentrations of BSFLM in the broiler diet up to 15% had a negative impact on gut shape, while a lower level of BSFLM (less than 10%) was more beneficial (Dabbou *et al*., 2018). Unfortunately, there are few specific additional studies on these issues regarding histological characteristics. However, a study on male broilers demonstrated no significant effects of dietary BSFLM on hematochemical or histological features (Dabbou *et al*., 2018).

Carcass and Meat Quality Characteristics

In a study conducted on broiler chickens, it was observed that feeding them with varying levels (5%, 10%, 15%, and 20%) of housefly larvae meal resulted in a significant increase in the percentage of dressing and breast muscle weight compared to those fed on a control diet (Hwangbo *et al*., 2009). Dietary changes in the physicochemical quality of meat have little practical significance. The breast meat lipids' fatty acid profile demonstrated the significant lauric acid content of the BSFL lipids, resulting in up to 80 times higher proportions than when given the diets based on soybeans (Heuel *et al*., 2022). The fat incorporation amount of BSF larvae significantly impacted broiler chickens' breast fatty acid profile. The amount of saturated fatty acid rose as the fat incorporation rate of BSF larvae increased at the expense of the polyunsaturated fatty acid (PUFA) fraction. In addition, the n-6/n-3 ratio also increased (Cullere *et al*., 2019). Incorporating 15% BSF larval meal into the broiler diet resulted in increased Ca and reduced K concentrations in breast meat than in the control group, indicating that the nutrient composition of the diet is essential (Cullere *et al*., 2016). Furthermore, in broiler chicks given a housefly larval diet for 35 days, there was no significant influence on crude protein content or total essential amino acid composition of breast muscle. However, broilers fed a larval meal had greater values than those fed a control diet (soybean-based). The larval meal group had considerably higher lysine, tryptophan, and total amino acid levels than the control group (Hwangbo *et al*., 2009). Because of the dietary supplementation with 15% defatted BSF, the biological value (B-value) of meat protein was raised, with increased amounts of aspartate, alanine, glutamate, tyrosine, serine, and threonine (Cullere *et al*., 2016). Breast meat from broilers fed with 15% BSF larval meal had a higher redness (a*) index than the control, while birds provided 5% and 10% had intermediate values. Pigments produced by larvae diet could explain these observations. In contrast, increasing the BSFLM quantity resulted in a linear drop in the yellowness value (b*), this was due to the low content of corn gluten in BSF diets (Schiavone *et al*., 2019)

Regarding carcass quality, broiler diets, including up to 10% defatted BSF larval meal, had no adverse effects on the carcass or meat quality (Schiavone *et al*., 2019). When a local chicken breed (Ardennaise chicken) was fed a diet containing 8% fresh BSF larval meal from 30 to 80 days old (slaughter age), the carcass yield, pectoral muscle, drumstick, and thigh weights, as well as the weights of internal organs, were unaffected (Moula *et al*., 2018). Broiler chickens fed various levels of house fly larval meal (5%, 10%, 15%, or 20%) had significantly larger percentages of breast muscle weight and dressing percentage than those fed a control diet (Hwangbo *et al*., 2009). A study was conducted to compare the carcass traits of broilers fed diets containing 10% Musca domestica larvae, 10% fish meal, or a control-based diet. The results showed that the carcass weight and breast muscle percentage were significantly higher in chicks fed diets that included either 10% house fly larvae meal or 10% fish meal compared to the control diet. Specifically, the increase in carcass weight was 11.22% and the increase in breast muscle was 8.75% for the group fed 10% house fly larvae meal, while the corresponding values for the group fed 10% fish meal were 8.58% and 7.20%, respectively (Pretorius, 2011).

BSF Effects on Layer Chicken

Feed Intake, Live Weight, Daily Body Gain, and Feed Conversion Ratio

Final weight and average daily gain increased quadratically when dietary full-fatted BSFM inclusion levels increased, whereas the feed/gain ratio decreased quadratically as these levels climbed (Chu *et al*., 2020). But compared to the breeder's (Lohmann) norm for the same age, soybean cake replaced by either wholly or partially defatted BSF larval meal in the laying hen diet demonstrated no significant effects on feed consumption (Maurer *et al*., 2016). These findings were persistent with other findings comparing the substitution results of soybean oil and meal in a corn–soybean-based control diet with 10% (w/w) dry pre-pupae and 10% (w/w) dried BSF larvae grown on household organic waste. The experimental diets were fed to 24-week-old laying hens and lasted for the next five weeks. There were no significant differences on feed intake between treatments. (Kawasaki *et al*., 2019). The entire substitution of soybean meal with BSF larval meal in Lohmann Brown Classic chicken hens fed over 21 weeks resulted in a 13% reduction in feed intake (Borrelli *et al*., 2017; Marono *et al*., 2017). The flavor and color of BSF meals may be to blame for the decrease in feed consumption (Borrelli *et al*., 2017). However, there were no discernible differences in feed intake in comparison. In an on-range choice feeding system, ISA brown laying chickens were fed 15g of BSF larval meal per day for six (6) weeks (Ruhnke *et al*., 2018).

A recent study compared the impact of replacing soybean meal and oil with 10% (w/w) dried black soldier fly (BSF) larvae and 10% (w/w) dried pre-pupae raised on experimental household organic waste in a corn-soybean-based control diet. The study was conducted on 24-week-old laying hens for a period of 5 weeks. The results showed that there were no significant differences in feed intake between the treatments (Kawasaki *et al*., 2019). Incorporating 7.5% larval meal into the diet of laying hens from 19 to 27 weeks resulted in a significantly greater body mass index than other groups (Mwaniki *et al*., 2018a). After a 21-week feeding period, Borrelli *et al*., (2017) found that completely replacing soybean meal with BSF larval meal in laying chickens lowered their body mass (2.09 vs. 1.89 kg). Hens fed a cassava product-based layer diet with maggot meal had the best (FCR) feed conversion ratio (2.78 kg feed/kg egg) when compared to those fed with 25% of fish meal (3.04 kg feed/kg egg) as a source of protein. Furthermore, when soybean meal was completely replaced with BSF larval meal in laying chicken feed, scientists discovered a reduced FCR compared to the control diet based on soybean meal (Marono *et al*., 2017). FCR, on the other hand, increased dramatically when de-fatted BSFLM was mixed with the laying chicken diets (Mwaniki *et al*., 2018a). The age and strains of birds could explain the discrepancies in responses across different investigations.

Gut Health and Digestibility of Laying Hen

The Lactobacillus and Bifidobacterium populations were considerably lower in BSF-fed hens' guts than in the control group (Kawasaki *et al*., 2019). This could be because BSF or chitin-saturated fatty acids like lauric acid has antibacterial properties. Chitin and chitosan (a derivative of chitin) exhibit high antibacterial action through the following mechanisms: (1) their polycationic nature, which disrupts bacterial metabolism by electrostatic stacking at the surface of bacterial and (2) their ability to inhibit RNA transcription from DNA is due to the adsorption of chitosan to DNA molecules, which prevents transcription (Benhabiles *et al*., 2012).

Furthermore, The impact of *H. illucens* larvae meal administration on the cecal microbiota and short-chain fatty acid (SCFA) synthesis in laying hens was examined in a study by Borrelli *et al*. (2017). 16S rDNA sequencing revealed significant variations in the type and relative abundance (unweighted and weighted beta diversity) of microbial species between the cecal microbiota of soybean (SD) and insect diet (ID) groups. In particular, *Flavonifractor plautii, Alkaliphilus transvaalensis, Christensenella minuta, Vallitalea guaymasensis, Bacteroides plebeius, and Elusimicrobium minutum* contributed significantly to alterations in the gut microbiota composition of the ID group (FDR p-values 0.05). These can break down the insect meal's chitin, and *F. plautii, C. minuta, and A. transvaalensis* are associated with the ID group's high levels of gut SCFA production. Thus, these microorganisms may link the creation of high levels of SCFAs with the degradation of chitin, and researchers also indicated *H. illucens* as a potential prebiotic by adequately nourishing the gut microbiota.

In terms of entire BSF larvae and pre-pupa meals, laying hens fed a 10% BSFLM diet or a 10% BSF pre-pupa meal diet as contrasted to those fed a corn-soybean control diet were not impacted in terms of villus height and crypt depth in small intestinal segments (duodenum, jejunum, and ileum) (Kawasaki *et al*., 2019). However, compared with the control group, the intestinal villi height of hens fed dietary BSF was higher in the duodenum and lowered in the jejunum and ileum. In contrast, crypt depth was more significant in the ileum of laying hens fed a BSF meal, with no differences in the duodenum or jejunum (Chu *et al*., 2020). Cutrignelli *et al*., (2018) also reported that dietary full-fatted BSFM inclusion levels raised ileum mucosal IgA concentration linearly, ether extract, and crude protein digestibility quadratically, but had no impact on intestinal morphology. Ileal digestibility compared to control birds, layers fed with complete replacement of soybean-based meal with defatted BSF larval meal more than 21 weeks of age had a marked reduction in DM, crude protein, and organic matter, of 3.76%, 13.57%, and 4.17%, respectively. In contrast, ether extract digestibility was insignificant (by 5.60 %). A drop in digestibility resulted due to the lower feed consumption in the BSF treatment group (Abd El-Hack *et al*., 2020).

Cecal Volatile Fatty Acid

Evaluation of cecal volatile fatty acid laying hens fed defatted BSF larval meal as a complete replacement for dietary soybean meal revealed higher levels of butyrate and acetate (increases of 62.6% and 36.1%, respectively, higher than the control),. However, no variations in relative levels as a proportion of entire volatile fatty acid were found across groups (Cutrignelli *et al*., 2018). This indigestible chitin could behave as fermentable materials, modulating the quantity of SCFAs in hens' cecum. Complete SCFAs, particularly n-butyric acid, and propionic acid, were higher in birds fed with BSF larval meal than in chickens fed with a soybean meal diet in a prior study (Borrelli *et al*., 2017).

Laying Performance and Egg Quality

BSF has already been tested in poultry as a potential replacement for fish and soybean meal in either partially or entirely nutritional formulations. Two recent studies on layers indicated that employing defatted BSF larvae as a nutrition source could improve the quality of eggs produced by hens during the laying phase, including eggshell thickness, egg yolk, and egg albumin (Mwaniki *et al*., 2018b; Mwaniki *et al*., 2020). In replacement of soybean meal and oil, the laying hens were fed either 10% whole (undefeated) BSFLM or 10% dry BSF pre-pupa meal. The researchers discovered no differences in egg production performance when compared to the maize-mixed soybean experimental diets (Kawasaki *et al*., 2019). The addition of 7.5% defatted BSF larval meal in the hen's diet resulted in the same result compared to the other groups of 5% dietary defatted BSF resulted in lowered egg production (Mwaniki *et al*., 2018a). But, when soybean meal was replaced entirely with BSF larval meal in laying chicken diets for 21 weeks, laying percentage and average egg weight were significantly reduced. Furthermore, birds fed BSF larval feed produced more improperly shaped eggs than chickens fed soybean meal (Marono *et al*., 2017). Besides , the egg production of BSF chickens and control hens was 91.6 % and 82.8 % after 6 (six) weeks of feeding on BSFLM , respectively. There were no significant statistical differences (Ruhnke *et al*., 2018). The addition of BSF to the Lohmann diet improves laying performance. Researchers looked at a group of 64–74 week old Leghorn classic chickens who were approaching their laying season. Breed standards were 84.4% and 83.4% for hens fed an isocaloric BSF- and isonitrogenous-based diet with soybean partially or replaced. The breed standard was 5% lower in the control group (soybean-based diet) (Maurer *et al*., 2016).

Fish meal (6% of the diet) was employed as animal protein in 50-week laying hens. Egg weight, yolk index, egg shape index, and yolk color were unaffected by replacing 100% fish meal protein with maggot meal. However, there was only a slight effect on shell thickness and weight, which might be attributable to variations in the quantities of calcium (4.21% vs. 3.8%)and phosphorus (0.56% vs. 0. 45%), in the two diets (maggot meal and fish), respectively (Agunbiade *et al*., 2007). On the other hand, whole egg weight and shell weight were unaffected when dietary soybean was completely replaced with BSF larvae feed for 21 weeks (Secci *et al*., 2018). The entire egg weight, yolk, albumen, and shell were unaffected by a BSF-containing diet with partial soybean supplementation. Albumin levels were reduced by 7.5% in a complete soybean replacement diet (Maurer *et al*., 2016). The total replacement of soybean-based meal by BSF larvae negatively affected egg weight and mass in Lohmann Brown Classic hens fed for 21 weeks (Marono *et al*., 2017). In a 12-week choice feeding trial, eggs produced by chickens fed BSF larval meal had a considerably lower shell thickness (0.446 mm) than control birds (0.457 mm) (Ruhnke *et al*., 2018). There were no variations in shell deformation, haugh unit, albumen height, or shell reflectivity across groups. Because of the significantly reduced egg weight in laying hens fed BSF as a choice feeding, shell weight was markedly decreased by 6.3% compared to the control group; nonetheless, the egg weights (average) produced by treatment hens were >67g (Ruhnke *et al*., 2018). Secci *et al*. (2018) investigated the effect of replacing a soybean-based meal with a BSF larval meal in the feed of laying chickens for 21 weeks and found that in comparison to the group on a soya bean-based diet (SBM group), hens fed an insect-based diet produced eggs (HIM group) with a higher percentage of yolk. Redder yolks (red index 5.63 v. 1.36) were associated with HIM more than SBM. In comparison to SBM yolks, HIM yolks were richer in α-tocopherol (4.0 mg/kg vs. 2.4 mg/kg), lutein (8.6 mg vs. 4.9 mg/kg), ?-carotene (0.33 mg/kg vs. 0.19 mg/kg), and total carotenoids (15 mg/kg vs. 10.5 mg/kg). HIM yolks and SBM yolks have nearly equal fatty acid compositions. Finally, compared to SBM yolks, HIM yolks had 11% less cholesterol. According to Kawasaki *et al*. (2019), either feeding BSF larval feed or pre-pupa meal increased both albumin height and egg yolk color, considerably. The introduction of 5% and 7.5% defatted BSF larval meal in the laying chicken diets produced the same result in terms of egg yolk color (Mwaniki *et al*., 2018a). In comparison to the control group, the eggs laid by free-range chickens fed BSF dry larvae meal on a choice feeding trail had noticeably darker yolks. However, this result is expected, given that the control meal contained artificial coloring components and that the BSF group received levels that were lower than those of the control group (Ruhnke *et al*., 2018). Regarding eggshell thickness, the pre-pupa diet group showed an improvement, with substantial changes between the pre-pupa and larvae meal groups but no statistically significant differences compared to the control group. Although eggshell strength increased by 16.9% and 18% in the pre-pupa diet group compared with the control and larval meal groups, the results were insignificant (Kawasaki *et al*., 2019). In this regard, employing 5% defatted BSF larval meal in the hen diet resulted in considerably greater values of eggshell strength when compared to other groups however, using 7.5% defatted BSF resulted in slightly higher eggshell thickness than that of a control group (Mwaniki *et al*., 2018a). The appearance, taste, texture, and acceptability of eggs from hens given 50 g/kg BSF larval meal showed a considerable improvement. Furthermore, dietary interventions had little effect on the odor. The high glutamic acid content of BSF Larval meal (6.85 g/kg) may have contributed to the significant increase in the sensory profile of eggs produced by chickens fed BSF. According to a recent study, replacing half of the soybean-based meal and oil with full-fat dried BSF larval meal resulted in the generation of eggs with sensory profiles comparable to control eggs (Bejaei & Cheng, 2020).

Blood Traits

In laying hens, completely replacing a soybean-based meal with a BSFLM did not affect blood glucose, total protein, or albumin. Globulin was significantly higher significant than albumin, and when compared to the control diet, the albumin-to-globulin ratio was significantly lower in the hens fed larval meal (Marono *et al*., 2017). In larvae-feeding hens, these discoveries about globulin and the albumin-to-globulin ratio resulted in an overall rise in circulating immunoglobulin, higher disease resistance, and better immune function (Marono *et al*., 2017). To determine the impact of dietary BSF larval and pre-pupa meal on blood Ca and P contents, 168-day-old laying hens were used in a five-week feeding experiment. The results showed that chickens fed a diet containing 10% prepupae meal had considerably higher serum Ca levels. Blood Ca levels were significantly higher than in control diets when dietary soybean meal was completely substituted with BSFLM in laying hen diets (Marono *et al*., 2017). Although creatinine levels in the blood of hens fed the BSF diet were lower than those in the control group who were fed soybean meal (Gariglio *et al*., 2019; Marono *et al*., 2017). A recent study showed that glutathione peroxidase enzyme and total superoxide dismutase activities were linearly increased, and malondialdehyde content in plasma was linearly decreased as dietary full-fatted BSFM inclusion levels were raised (Chu *et al*., 2020).

Diseases and Mortality

According to studies, hens fed nutritional BSFLM that had been partially defatted (12% and 24%) did not experience metabolic or health issues (Maurer *et al*., 2016). Additionally, the lack of morbidity and mortality in laying hens fed a diet supplemented with BSF demonstrated that BSF larvae had no negative effects on the health of laying hens (Borrelli *et al*., 2017; Kawasaki *et al*., 2019; Marono *et al*. 2017). Throughout the trial with five-week duration, substituting soybean oil and meal with 10% (w/w) BSFLM and 10% (w/w) pre-pupae diet had no impact on the mortality rate (Kawasaki *et al*., 2019). There was very little mortality in all the chickens fed either a partially defatted meal from BSF larvae or a soybean-based control diet (Maurer *et al*., 2016). Furthermore, no mortality was recorded in laying hens of 50 weeks fed a diet including larval meal as a partial or whole replacement for fish meal (animal protein) (Agunbiade *et al*., 2007).

Challenges of Using BSF as Poultry Feed

The use of BSF larvae (BSF) as a protein source in poultry feed is a relatively new concept, and there may be challenges in establishing a stable and reliable supply chain for large-scale production. The need to develop a BSF larvae-based feed industry has grown crucial, yet a more supportive environment is needed for BSF larvae feed to significantly impact the animal feed industry. This entails increased customer acceptance, cost-effective investment and operation, better collaboration amongst regulatory agencies, and improved support from the government (Siva Raman *et al*., 2022). Other significant obstacles still exist for the large-scale production and use of insects meal in food and feed, some related to regulations and the production system and others to treatment planning and usage practices (Diener *et al*, 2009). BSF larvae can carry pathogens and contaminants that could potentially harm poultry. It is crucial to implement strict quality control measures to ensure the food safety of poultry products. Although substantial research funding is available in this area, the development of insect production facilities is still largely hindered by stringent European rules surrounding the use of insects as animal feed (Salomone *et al*, 2017). Additionally, insect meal is now too expensive compared to other traditional sources of protein. It can increase the cost of poultry feed and make it less competitive in the market. This is a result of the lack of widespread commercial production of insect feeds (Cutrignelli *et al.,* 2018). Moreover, BSF larvae are becoming an increasingly popular protein source for human consumption, which could result in competition for the supply and drive up prices for poultry feed.

Conclusion

Insects have been introduced as a unique and promising feed item for chicken diets. According to the most recent literature, they might be utilized to replace fish or soybean meals in broiler or layer diets. Employing biological wastes to raise insects and using these larvae in the poultry diet could help the poultry sector maintain its economic viability. As a sustainable protein source in chicken diets, insects could help food security. BSF is ideal for producing large quantities because of its high rate of growth, excellent feed conversion, low mortality, resistance to disease, and protein contents. So BSF is a fantastic choice that may be used in poultry diets without affecting the development, palatability, nutrient profile, or flavor of eggs and meat. The average daily intake of BSF by the hens assigned to the BSF treatment was 15g or 16% of their diet. Full-fat BSFL can be utilized in balanced broiler diet formulations up to 20% without endangering the health or performance of the chickens, which will result in a 19% reduction in feed costs. However, more scientific research is required to determine the highest dose of BSFLM that may be utilized in broiler and layer chicken feed.

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Conflicts of Interest

The authors have disclosed no conflicts of interest.

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