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Black soldier fly (*Hermetia illucens*): An alternative protein source for poultry feeding

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Abstract
Recently, poultry producers in developing countries are facing problems of high cost and poor quality of poultry feed. Insects could be a potential replacement of protein rich ingredients in poultry diets. The use of insects as poultry feed is not in direct competition with human being for food consumption. The objective of this paper is to review the current work related to the use of Black Soldier Fly (BSF) larvae meal as an alternative protein source in poultry feeding. Black soldier fly is a harmless insect acting as an alternative protein source in animal feeding and grown in the disposal of organic wastes, by-products and side streams. The results of numerous studies showed that BSF larvae meal could safely and economically be used as protein source in poultry ration. BSF larva contains high calcium and phosphorus and about 35-42% crude protein with high biological value and comparable amino acid profile to that of soybean meal (SBM). The lysine and methionine contents of BSF larva are comparable to that of fish meal. Many authors suggested that BSF larvae meal could replace a fish meal or upgrade the nutritive value of SBM in broiler diets without any adverse effect on the production performance. The use of BSF larvae in layers diet resulted in enhanced laying performance and egg qualities. Generally, all the available literature confirms the feasibility of total or partial replacement of fish meal and SBM with BSF larvae meal without any negative effects. Most of the publications reviewed indicated that the growth of chicks fed with BSF larvae meal was either equivalent or superior to SBM in nutritive value as measured by the production performance of growing and laying birds. Therefore, inclusion of BSF larvae meal into the poultry feeding system has both economic and environmental benefits for sustainable poultry production.

Keywords: Black soldier fly larvae meal, broiler, layer, protein source

1. Introduction
The global human population is expected to rise to about 9 billion by the year 2050, possibly accompanied by a 70% increase in the demand for animal proteins (FAO 2011) [15].The trend of people has been changed from vegetable-based protein to animal-based protein foodstuff, including milk, fish, meat, and eggs, and this inclination is predictable to heighten over time (Hunter *et al*., 2017) [21]. Moreover, conventional feedstuffs are being replaced by unconventional feed resources (Belghit *et al*., 2019) [8]. Livestock sector can play a major role in sagging inadequate living standards and enhancing food security (Armanda *et al*., 2019) [4]. Poultry production is an area of livestock production, where animal protein production for human consumption is relatively rapid. The increasing intensity of poultry production requires protein concentrate of high biological values (Hossain and Blair, 2007) [20]. Feed accounts for about 70-75% of the total cost of poultry production, partially attributed to the high market price of conventional protein concentrates of both plant and animal origin (Abd El-Hack *et al*., 2015) [1]. Cost-effective feed and their accessibility could impart an efficacious role in farming (Dumont *et al*., 2019) [14]. Soybean and fish meal are two conventional feed stuffs that increase the expenses of the feeds because human beings are also the consumer of soybean and fish (Kelemu *et al*., 2015) [24]. Fishmeal is being used in nurturing livestock and is also the most important source of protein for fish husbandry (Olsen, 2011) [39]. Intensification of soybean cultivation exclusively in the tropic areas could trigger land grabbing and deforestation as well as other adverse public and ecological concerns. Therefore, imperative solutions should be designed to substitute conservative costly feed ingredients with cheaper, eco-friendly, high protein quality ones with ease of digestibility (Goldansaz *et al*., 2017) [17].

Insects are one of the promising potential poultry feed resources as they contain valuable nutrients and compounds that modulate animal microbiota and optimize animal health. Consumers seem to be willing to accept food of animal products produced with the use of insect materials as feed (Mancuso *et al.*, 2016) [29]. The use of insects as chicken feed is not in direct competition with the human population as a food resource (Diener *et al*., 2011) [12].

Insect species

1. Black soldier fly (BSF) larvae (*Hermetia illucens*)
2. Common house fly (*Musca domestica*)
3. Silk worm pupae meal
4. Mealworm (*Tenebrio molitor*) have been used widely as auspicious unconventional feedstuffs of protein for animal feed (Van Huis, 2017) [53]. These insect species have the potential to turn the organic wastes into high protein biomass and the remaining substrates act as natural fertilizers for crops (Shelomi, 2020) [48].

Black Soldier Fly

Black Soldier Fly (*Hermetia illucens*) is the most promising candidate for large-scale industrial production. The BSF is a harmless insect with the potential to solve two of modern agriculture's growing problems, namely; serving as a potential alternative protein source in the poultry industry and disposal of organic wastes, by-products, and side streams (Taiwo and Otoo, 2013) [51].

Entomology and Distribution

The BSF (*Hermetia illucens*) belongs to the order *Diptera* and in the *Stratiomyidae* family (Awasthi *et al*., 2020) [6]. The insect is indigenous to the warm tropical and temperate zones of the American continents (Newton *et al.*, 2005) [37]. Climate change and human activities facilitated its spread to other continents (Leek, 2017) [27]. As a result, the Black Soldier Fly is now native to almost 80% of the world between latitudes 46°N and 42°S (Martinez-Sanchez *et al.*, 2011) [31]. Black soldier fly larvae are naturally found in poultry, pig, and cattle manure but can also be grown on organic wastes such as coffee bean pulp, vegetables, catsup, carrion, and fish offal. The BSF larvae (also called BSF larvae meal, BSF prepupae meal and BSF maggot meal) are used live, chopped or dried and ground forms. Adult BSF only looks for a mate, breed, and lays about 500 eggs in crevices near composting waste (Diener *et al.*, 2011, Nguyen *et al.*, 2015) [12, 38] and is wasp-like and 15-20 mm long (Hardouin *et al.*, 2003) [18]. Primarily black, the female's abdomen is reddish at the apex and has two translucent spots on the second abdominal segment. The adult fly does not have mouthparts and doesn't even feed during its short lifespan. They do not bite or sting, feed only as larvae and are not associated with disease transmission. Adult flies are easily distinguished by their long antennae (Gennard, 2012) [16]. During its adult life, the insect doesn't feed therefore the larvae are quite large (220 mg) to store all nutrients necessary to support the adult (Makkar *et al.*, 2014) [28]. The larvae can feed quickly, from 25 to 500 mg of fresh matter/larva/day (Makkar *et al*., 2014) [28] and this rate depends on the size of the maggot and the type of food being consumed. During the last larval stage, the larvae crawl away from the waste into a dark area to pupate. This migratory phenomenon is utilized in rearing facilities to self-collect (Diener *et al.*, 2011) [12]. Although BSF can tolerate weather extremes, they best thrive in temperature ranges of between 29 and 31 °C and relative humidity of 50-70% (Makkar *et al.*, 2014) [28].

Lifecycle

Life cycle starts from an egg, which also marks the end of the previous life stage *i.e.*, the female dies after laying eggs (Dortmans *et al*., 2017) [13]. A female fly lays 400 to 800 eggs in tiny, dry and well-sheltered cavities and close to a food source, preferably decomposing organic matter. This is to protect the eggs from predators and prevent dehydration of the egg packages from direct sunlight alongside increasing the chances of the survival of the larvae upon hatching (Dortmans *et al*., 2017) [13]. After hatching, the cream-like larvae take up large amounts of decomposing organic matter and increase from few millimeters to approximately 2.5 cm in length and 0.5 cm in width (Dortmans *et al*., 2017) [13]. The voracious feeding allows for the storage of enough fats and proteins to aid in the process of pupation, fly emergence, mating and oviposition. Larval development takes a period of 14 to 16 days under optimal conditions (Shumo *et al*., 2019) [49]. The optimum temperature required by BSF ranges between 26°C and 27°C (Dortmans *et al*., 2017) [13]. Temperatures above 30°C trigger the larvae to move away from the substrate in search of cooler areas while temperatures below 24°C reduce the metabolic activity of the insect leading to reduced growth (Holmes *et al*., 2012; Dortmans *et al*., 2017) [19,13]. The optimum relative humidity for growth of the BSF larvae ranges between 60-70%, while the recommended substrate moisture ranges between 52-70% (Holmes *et al*., 2012) [19]. Nevertheless, the BSF larvae have the ability to prolong their life cycle during unfavorable conditions (Shumo *et al*., 2019) [49].

The optimum temperature required for BSF growth is between 26 to 27C, relative humidity range from 60-70%, substrate moisture should be 52-70% and light intensity range between 135-200. temperature above 30 c trigger the larvae to move away from substrate for searching cooler areas while below 24C reduce the metabolic activity of the insect leading to reduced growth. (Barragan *et al*., 2017) [7]. The pupae stage is symbolized by the replacement of the larval mouth-parts with a hook-shaped structure and the change in colour from cream to dark brown-charcoal grey. The pupa uses its hook-shaped structure to move out and away from the substrate into a shaded and protected environment safe from predators (Zurbrügg *et al*., 2018) [54]. The pupation stage takes between two to three weeks and is marked by the transformation of the pupa into a fly. The emergent fly does not feed and is only dependent on water for development along the life cycle (Zurbrügg *et al*., 2018) [54]. During this phase, the adult searches for a partner, copulates and the female lays eggs. The flies have been found to prefer copulating in shaded areas during the morning light and females lay their eggs in well-shaded dark crevices near substrates (Au Julius, 2021) [5]. Light intensity affects both the mating and egg fertilization of BSF (Zurbrügg *et al*., 2018) [54]. However, it has been suggested that light spectral composition plays a more important role in fertilization than light intensity. Light-emitting diodes producing wavelengths in the UV, blue and green ranges have proved to increase the proportion of fertilized eggs (Oonincx *et al*., 2016) [43].

Nutritive profile

Nutritional profile of BSF larvae in terms of proximate values are more or less comparable to soybean and fish meal except fat (%) which is observed higher in BSF larvae amongst all three compound. (Onsongo *et al*., 2018) [42]. Body composition of BSF larvae depends upon the substrate were they grown. For example, larvae fed fish offal have higher protein content while fat content was higher in kitchen or restaurant waste. (Barragan *et al*., 2017) [7]. Protein and fat% of BSF larvae is highly influenced by processing methods. Highly defatted meal contain higher CP% and lowest EE% as compared to fully fat and partially defatted BSF meal. (Cardinaletti *et al*., 2019, Schiavone*et al*., 2017) [9,46]. The content of limiting Amino Acids *viz.* Methionine and Lysine in BSF larvae are more or less comparable to fishmeal and higher than soybean meal. (Makkar *et al.*, 2014) [28]. On different rearing substrates amino acid profile of BSF larvae remains almost same including Lysine and Methionine. (Spranghers *et al.*, 2017) [50]. Fatty acid profile of BSF larvae possess a good balance of saturated and unsaturated fatty acid to meet the nutritional requirement of poultry. (Larouche, 2019) [26]. BSF larvae have superior mineral content and it is mainly influenced by the type of substrate where they reared. For example, micro minerals are higher in kitchen waste as compare to cattle manure and spent grain. (Shumo *et al*., 2019) [49].

Effects of BSF meal on Broilers

Growth performance and feed efficiency

Inclusion of animal origin protein (fish meal and larvae meal) in broiler diets improved the weight gain, feed intake and FCR over diet contained plant origin (soybean meal) protein only (Oluokun, 2000) [41]. Anankware *et al*., (2018) [3] observed that diet having animal protein source were significantly better than combination of animal & plant protein source in terms of feed intake, weight gain & water intake. Moreover, it performs better in terms of FCR and mortality.Improved live weight and BWG were observed in broiler when diet having 10% partially defatted HI larvae. However, at finisher stage, reduced performance of broiler was observed due to increase the inclusion level of HI larvae in diet. It may be due to chitin present as exoskeleton in larval body of BSF which reduce the digestibility in broiler (Dabbou *et al*., 2018) [11]. Final weight and ADG of broiler at later stage were significantly differed between diet containing 5% BSFPM and 10% BSFPM replaced with SFM (Onsongo *et al*., 2018) [42]. Hermatia meal diet with amino acid fortification improved the final BW and FCR as compared to control and HM alone diet (Valten *et al*., 2018) [52]. Addition of 0.2% HI meal as feed additives in diet increased the FI. However, FCR remain unchanged during the entire trial (Jozefiak *et al*., 2018) [22]. Total or partial replacement of Soybean Oil with BSL fat did not affect the growth performance of broiler chicken. However, result of free choice test showed that birds did not show any preference towards the control and treatment diet. It means that inclusion of BSL fat does not affect the palatability of poultry diet (Schiavone *et al*., 2017) [44]. Kim *et al*., 2020 [25] stated that all the growth parameters were remained same. However, improved FCR was observed in coconut and BSFL oil diet compared to corn oil diet. It may be due to the higher amount of medium chain fatty acid present in coconut and BSF oil which improves the nutrient digestion in chicken.

Haematological parameters

Dabbou *et al*. (2018) [11] reported that all the hematological and serum parameters fell within the normal physiological range in different dietary treatments. However, GPx activity was significantly higher as level of HI inclusion increased. This shows that insect meal may provide dietary Tocopherol to birds which enhance the antioxidant activity and same trend was observed in phosphorus concentrate upto HI10 inclusion level. Incorporation of BSF larvae @ 12 & 10% with soymeal performs better in terms of MCV and PLT as compared to control (Anankware *et al.*, 2018) [3]. Total or partial replacement of soybean oil with BSF larvae fat did not affect the health status of broiler chickens. The result of H/L ratio indicates that experimental birds did not come in stressed condition during the entire trial (Schiavone *et al.*, 2017) [44]. At finisher stage, HDL and Total cholesterol were lowered in diet having 5% BSFL oil as compared to coconut oil may be due to higher amount of linolenic acid present in BSF oil which reduce the cholesterol activity in serum, whereas TAC was higher in diet with 5% BSFL oil (Kim *et al*., 2020) [25].

Carcass Quality

Oluokun, (2000) [41] observed that diet having soybean meal with 5.6% BSF larvae meal improved the carcass yield as well as kidney, liver, gizzard weight and abdominal fat as compared to other dietary treatments. The gizzard weight was increased may be due to bulkiness of feed whereas liver and kidney were increased because they were related to metabolism of excess energy. All the carcass parameters except empty intestine weight and abdominal fat weight were significantly higher in treatment diet having BSFL with fishmeal than other dietary groups (Anankware *et al*., 2018) [3]. Onsongo *et al*. (2018) [42] found that Diet having 10% BSFPM performs better in terms of carcass parameters than all other diets.Increased live weight and carcass weight were observed when diet having 10% partially defatted HI larvae meal & then after it became reduced when inclusion of HI larvae increased(Schiavone *et al*., 2018) [45].Breast yield percentage was gradually increase as the replacement of fish meal with maggot meal was increased up to 100% (Miaga *et al*., 2020) [33]. Inclusion of 8% BSF larvae in experimental diet did not affect the carcass trait of either male or female broiler chicken (Moula *et al*., 2018) [34]. All the carcass trait in broiler chicken were remain unchanged in control and treatment diet having total or partial replacement of Soybean oil with BSFL fat (Schiavone *et al*., 2017) [44]. Total or partial replacement of SBO with BSFLO did not affect the organ yield except the relative weight of gizzard (Kim *et al*., 2020) [25].

Meat quality

Schiavone *et al*. (2017) [44] stated that meat pH, thawing loss and proximate composition of breast meat remained unchanged between control and treatment diets. In another study, yellowness value of breast meat was decreased as inclusion level of partially defatted HI larvae increased. This may be due to decrease the content of corn gluten meal from treatment diets(Schiavone *et al*., 2018) [45]. All the sensory traits of breast meat of chicken fed with different substitution of Soybean Oil with HI larvae fat were remain same. It means that consumer preference toward the meat consumption does not altered by BSFL fat inclusion (Cullere *et al*., 2016) [10]. Yellowness value of breast meat was higher in diet having coconut and BSFL oil due to presence of carotenoid content (Kim *et al*., 2020) [25].

Effect of BSF on layers

Performance of Hen

Al Qazzaz *et al*. (2016) [2] informed that HDEP, HHEP, Egg mass, egg weight, yolk color, Shell thickness, shell weight and fertility rate were significantly altered by dietary inclusion of BSF larvae. It indicates that presence of chitin in larval body may affect the performance of hens. The productive performance of laying hens fed with defatted HI larvae meal as total replacement of SBM was lower than that of SBM diet. This may be due to reduced feed intake in treatment group (Morono *et al*., 2017) [30]. An experiment on 19 week old shaver white leghorn pullets up to 27 week and result showed that improved HDEP, feed intake and final body weight were observed in diet having 7.5% defatted BSFL meal than other dietary groups (Mwaniki *et al*., 2018) [35]. From 28 week old shave white leghorn pullets upto 43 week showed that HDEP, egg mass, feed intake and FCR remain unaffected by increasing the inclusion level of BSFLM upto 15%. It indicates that inclusion of defatted BSFLM does not altered the performance of laying hens at later stage (Mwaniki *et al*., 2020) [36]. Performance of layers remain same when diet containing total or partial replacement of SBM with HI meal (Maurer *et al*., 2016) [32]. Inclusion of 10% BSF larvae or BSF prepupae in the experimental diet did not affect the production performance of laying hens (Kawasaki *et al*., 2020) [23].

Egg quality

Maurer *et al*. (2016) [32] observed that all the egg quality parameters remain unaffected by dietary treatment with inclusion of HI larvae meal. Hens fed defatted HI larvae meal produced an uneven size of egg as compare to SBM diet. It may be due to reduced feed intake was observed in this trial which lower the protein intake and affect the egg weight (Morono *et al*., 2017) [30]. Albumin from defatted HI larvae meal group was significantly lighter than SBM group. It indicates that albumin is most susceptible to new protein source. In the same study proximate composition of yolk and albumin were unaffected by dietary treatments. With regard to tocopherol and carotenoids, egg yolks of HIM group were richer in γ-tocopherol, lutein and β-carotene content than those fed SBM diet. So, this finding creates the interest towards the nutritional manipulation of egg for human consumption (Secci *et al*., 2020) [47]. Improved yolk colour, SBS and shell thickness were observed in dietary treatments as compared to control (Mwaniki *et al*., 2018) [35]. The same study was carried out on 28 week shaver white leghorn pullets up to 43 week and result showed that yolk colour was significantly higher as level of BSFLM increased (Mwaniki *et al*., 2020) [36]. Diet having 10% BSF prepupae performs betters for egg quality parameters rather than control and BSF larvae meal. It indicates that mineral content in prepupae was higher than larvae stage (Kawasaki *et al*., 2020) [23].

Effects on economic efficiency

The inclusion of black soldier pupae meal in poultry ration has resulted in gradual decrease in cost of feeding/kg. The birds receiving black soldier pupae meal in their ration have shown improved efficiency as compared to the control group. Onsongo *et al*. (2018) [42] stated that total feed cost was gradually reduced as the inclusion level of BSFPM increased in diet. Thus, Cost Benefit Ratio and Return over Investment was maximum in diet group having BSF pupae meal replaced with Soybean meal as compared to others dietary groups.

Conclusion

With increasing the demand of chicken as animal protein source for human consumption and high market value of conventional protein source to rear the poultry, BSF meal might be only alternative protein source in poultry feeding. BSF meal contains 35-42% CP, rich in minerals and fat and have efficient food conversion factor compared to conventional fish and soybean meals. Amino acid profile (*viz*. Lysine, methionine) of BSF meal is comparable to fish meal and better than soybean meal with good balance of fatty acid profile (*viz*. oleic, linoleic, α-linolenic) to meet nutritional demand of poultry. Incorporation of BSF larvae meal (upto 10%) resulted similar or even better growth performance, weight gain and FCR in broilers. Hematological, carcass parameters and meat quality of broiler were not affected by BSFM incorporation in diet, moreover it maintain health status of birds and consumer preference of meat. Production performance of hens (*viz*. HDEP, HHEP etc.) and quality of eggs (*viz*. yolk colour, albumin, shell thickness etc.) fed BSF meal were sustained with improvement in economics. The inclusion of BSF meal in poultry diets may lower the cost of feeds without any adverse effects on the performance of the chicken & potentially improving the profitability of the poultry sector. Thus, BSF meals are a valid, cost-effective and highly nutritive alternative source of animal protein feed.

Conflict of Interest

Not available

Financial Support

Not available

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