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Black Soldier Fly (*Hermetiaillucens)* Larvae as a Sustainable Source of Protein in Poultry Feeding: A Review

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Abstract

Currently, poultry producers in developing countries are facing problems of high cost and poor quality of poultry feed. Insects are one of the potential protein sources for poultry feed. The use of insects as poultry feed is not in direct competition with human 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 serving as an alternative protein source in animal feeding and 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 concentrate in poultry ration. BSF larva contains high calcium and phosphorus and contains about 35-42% crude protein with 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 meat meal. Recent evidence suggests that the nutritional value of BSF larva is 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. No negative effects were reported from growing chicks fed on BSF larvae meal. 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, the inclusion of BSF larvae meal into the poultry feeding system has both economic and environmental benefits.*

Keywords: Black soldier fly larvae; chickens; protein; wastes

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). Population growth leads to a global increase in food consumption patterns, changes in lifestyles, and food preferences (van Huis, 2013). 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).

Poultry producers in developing countries, including Ethiopia are facing the problem of the high market price of protein concentrates of animal origin and oilseed cakes. Feed accounts for about 70-75% of the total cost of poultry production (Abd El-Hack *et al*. 2015), partially attributed to the high market price of conventional protein concentrates of both plant and animal origin. This situation warrants the identification and use of locally available plant or animal protein sources in poultry feeding (Vasso and Russ, 2007).

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). Under the traditional poultry production system, chickens scavenge all edible materials in their surroundings including insects, indicating that insects are natural feed ingredients of scavenging poultry. The use of insects as chicken feed is not in direct competition with the human population as a food resource (Diener *et al*., 2011).

Among the insect species, Diptera Hermetiaillucens (Black Soldier Fly) 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). The BSF larvae are able to handle a large variety of waste materials and convert them into protein and fat-rich biomass. The biology and habitat of BSF make it a promising way out to fulfill the gap between animal waste and animal feed challenges. These being the cases, the objective of this literature review were aimed to review the current research relating to the use of BSF larvae meal as a potential alternative protein source for poultry feeding and the response of chickens that fed BSF larvae meal.

Entomology and Distribution of Black Soldier Fly

The BSF, *Hermetiaillucens,* is a true fly (Diptera) of the family Stratiomyidae. The insect is indigenous to the warm tropical and temperate zones of the American continents (Newton *et al.,* 2005). Climate change and human activities facilitated its spread to other continents (Leek, 2017). 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).

They are generally considered beneficial insects and non-pest. It is one of the potential protein source feed ingredients due to its ability to convert large amounts of organic waste (1.3 billion tones annually) into protein-rich biomass (Veldkamp*et al.,* 2012). 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) and is wasp-like and 15-20 mm long (Hardouin *et al.,* 2003). 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). 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).

The larvae can feed quickly, from 25 to 500 mg of fresh matter/larva/day (Makkar *et al*., 2014) 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). 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).

Biology / Lifecycle of Black Soldier Fly

The BSF has five stages in its lifecycle: egg, larvae, prepupae, pupae, and adult. The estimated life cycle of BSF is 40 days but this length differs depending upon the environmental conditions present and the nutrition provided (Alvarez, 2012). Eggs are usually creamy yellow in color and take 4 days to incubate and hatch under optimum conditions of around 20°C to 30°C (Newton 2015). Immediately after hatching, BSF larvae have a dull, whitish color and try to hide away from light due to their photophobic nature (Newton, 2015). Larvae are a very voracious consumer of organic matter and can grow rapidly. The larvae spend most of their life feeding on food and manure wastes and rapidly turn them into fat, protein, and calcium. These nutrients are utilized by larvae to morph into pupae, and further, into adults (Newton *et al*., 2005).

The optimal temperatures of black soldier fly for efficient utilization of feed ranges from 27 to 33^{0}C (Alvarez, 2012). Lower temperatures are most likely tolerable because feeding action and metabolism of the larvae will generate some heat which allows their development in colder climates (Newton, 2015). With optimum temperatures, larvae will reach full size (20 to 25mm) in about 4 weeks but can take from 2-4 months if temperature and enough feed are not available (Newton, 2015). Larvae can tolerate and thrive at densities up to almost 3lb per sq. ft. ($14kg/m^2$) (Burtle *et al*., 2012). Optimal moisture content for the feed ranges from 60% to 90% and is very important for the development of BSF.

When the BSF larvae grow into full size (½-inch-long grubs) (Burtle *et al*. 2012), larvae stop feeding, they become dark and their skin becomes harder. This is the pre-pupa stage, at this point, they start searching for a dry and dark place other than a feed source to pupate and transform into an adult (Newton, 2015). It is supposed that migrating larvae leave chemical trails so that other maggots follow creating a migration path. Along with drier conditions, the pupation site also requires ambient humidity levels of approximately 60% to emerging as adults. Pupation can last 5 to 7 days depend on temperature and ambient humidity. Adults emerge after 10-14 days at 27-36^{o}C (Myers *et al*., 2008) from their pupae cases. The main purpose of adults in the life cycle is to mate and lay eggs. The adults do not feed but drink water or other liquids if available and rely on the fats stored from the larval stage for their life activity (Newton, 2015).

Adults live and mate two days after emerging from the pupal stage (Myers *et al*., 2008). Female oviposit into dry cracks and crevices near larval habitat (Newton *et al*. 2005) two days after copulation. A temperature of 25°C-35°C (Newton, 2015) and ambient light plays a vital role to initiate mating for adult flies, as it is found in the studies that mating levels of adults were highest under natural sunlight. Furman *et al*. (1959) stated that BSF mating begins in the air with aerial questing after stimulation by light (Alvarez, 2012). The adult flies are photophilic and require strong daylight spectra as well as temperatures between 25°C and 35°C to encourage mating to occur.

Production Systems of Black Soldier Fly and organic substrates

Several methods of rearing BSF have been developed till now. The designs depend on the type of substrate provided for optimal growth and development of BSF. In this type of production system, a conveyor belt made for the collection of waste is designed in such a way that manure solids were collected in the conveyer belt whereas urine plus excess water were drained off the sides of the belt into collection gutters. Then the collected manure solids were delivered to the larval culture basin. The larval culture basin contained 90,000 to 100,000mixed aged larvae/m^2. A 35^o ramp along opposing walls of the manure pit is constructed to facilitate the migration of the prepupae to the gutter at the top. This gutter then allows prepupae to pass in collection containers. During this, a portion of the prepupae is saved with the purpose to support the adult soldier fly colony. Eggs from the adult colony are used to maintain larval densities sufficient to digest the manure. The remaining prepupae are frozen until the composite is dried for feed preparation (Sheppard, 2002).

Different types of organic waste have been used for farming back soldier fly larvae in confinement. Major BSFL growth parameters such as development time, feed conversion efficiency, mortality, larvae weight, and nutrient composition are strongly affected by the growth substrate (Zheng *et al*., 2012). Therefore the commercial-scale application of the technology will demand the usage of substrates that can yield quality larvae within a short duration and reduce losses through mortality is necessary. Due to the larvae consuming a wide range of organics, the full range of substrates for rearing BSFL especially for biomass production on a commercial scale are still largely undetermined (Leek, 2017). Organic waste materials are also highly heterogeneous in nature and variable in terms of moisture and nutrient content and therefore generalized applications of findings are almost impossible (Holmes *et al*., 2012).

Nguyen *et al*. (2015) compared the development rate, size, and mortality of BSFL fed on poultry, feed, pig manure, fish renderings, and kitchen food waste and reported that larvae fed on kitchen food waste had the fastest growth, heaviest biomass, and yields attributed to higher calorie content. Kalova and Borkovcova (2013) fed BSF larvae 14 different waste types over a 14 day period and only four of the waste streams resulted in adult flies during this period among them postconsumer food waste suggesting that these diets were the most suited to larval development.

Social, Economic and Environmental Benefits of Black Soldier Fly

Biomass conversion

Several researchers have shown that BSFL is effective at reducing animal manure and organic waste materials by converting them into a protein and fat-rich biomass suitable for various purposes, including animal feeding, biodiesel, and chitin production (van Huis *et al*., 2013). Kim *et al.* (2011) reported that BSF was able to consume and digest raw organic waste materials (manure, kitchen waste, abattoir waste: blood and offal's) more rapidly and resourcefully than the house fly(*Musca domestica*). Newton *et al.* (2005) fed a total of 4500 larvae fresh swine manure to BSFL and the larvae converted 68kg dry weight of manure into 41.6kg dry weight residue and 26.2kg of prepupae. The author also recorded BSFL reduced 55kg of fresh manure, dry matter, to 24kg of residue, dry matter, within 14 days and the manure was reduced by 56%, with the residue having no objectionable odor. Sheppard *et al.* (1994) fed BSFL approximately 5.2 tons of fresh chicken manure and the manure was reduced to approximately 2.6 tons of residue, yielding 242kg of prepupae, with a mean weight of 0.22g. The authors also reported that BSFL reduced the manure by up to 50%, while at the same time eliminating house fly breeding. The larvae were fed different quantities of manure of waste materials 1.5 or 4.6 kg each day, with the new food either mixed in or placed on the surface (Diener *et al.,* 2011). There is a good opportunity to utilize these flies for bioconversion considering the fact that approximately 1.3 billion tons offood is wasted from the food produced each year in the world (Gustavsson *et al.,* 2011).

Odor and pollution reduction

Odor and pollution reduction are other benefits derived from BSF. This is accomplished by their abundant densities on waste material combined with their avid appetite, causing the waste material to be processed at a fast rate, while the larvae are processing this waste; they aerate and dry the material suppressing bacterial growth. The larvae modify the microflora of manure, potentially reducing harmful bacteria such as *Escherichia coli* 0157:H7 and *Salmonella enterica* (van Huis *et al*., 2013). The BSF larvae reduce the nutrient concentration and the amount of manure residue, leading to a reduction in the amount of pollution, possibly by 50-60% or more (Newton *et al.*, 2005) and causing it to be less favorable to the house fly larvae. The combination of all these characteristics causes a reduction in odors and pollution (Diener *et al.*, 2011).

Housefly control

The common housefly (*M. domestica*) tends to come into more contact with humans for a number of reasons. The common housefly feeds throughout its life due to its physiology of having functional feeding parts. This causes the fly to always be on the lookout for edible organic matter, such as human food, making the interaction between the fly and humans more common. The BSF's physiological traits of having no functional feeding parts cause it to have no attraction to homes, consequently reducing any pest-like behavior and living its life apart from humans (Barry, 2004). However, the BSF has a strong ability to reduce the number of house flies by preventing the house fly from ovipositing (the act of depositing eggs). The reduction of house flies will be a large benefit as they are prominent disease vectors, adding to the importance of their population control. The ability of colonization by BSF was reported by Sheppard *et al.* (1994) who discovered that BSF had the ability to colonize poultry and pig manure causing a reduction in common housefly populations by 94-100%.

Chitin benefit

Apart from having a desirable (soluble) protein content, insect species also contain high amounts of chitin, which is the main constituent in the insect exoskeleton. Chitin is a non-toxic, biodegradable linear polymer. Recent studies confirmed that chitin has effects on innate and adaptive immuneresponse, including the ability to recruit and activate innate immune cells and induce cytokine and chemokine production *via* a variety of cell surface receptors including macrophage mannose receptor, toll-like receptor 2 (TLR-2), and Dectin-1(Lee *et al.*, 2008).

Nutritional Profile of Black Soldier Fly Larvae

The nutritional profiles of BSF larvae as animal feed sources were reported by various authors. The DM content of fresh larvae is quite high (35-45%), which makes them easier and less costly to dehydrate than other fresh by-products (Newton *et al.*, 2008). Maurer *et al.* (2016) reported that dried full-fat BSF larvae meal contained 41.5% CP, 26.5% EE, 4.3% ash, 0.80% Ca, 0.50% P, 0.08% Na and 0.33% chloride while dried partly-defatted BSF larvae meal consisted 59.0% CP, 11.0% EE, 5.0% ash, 0.98% Ca, 0.63% P, 0.08% Na and 0.28% chloride. The result showed that partly-defatted BSF larvae have better CP, ash, Ca, and P contents than full-fat ones. Newton *et al.* (2005) found protein levels of 43.2% of BSF pre-pupae reared on pig manure while a value of 42.1% was found when reared on poultry manure (Newton *et al.*, 1977). Relatively, similar protein content (43.6%) was reported by St-Hilaire *et al.* (2007) when reared on pig manure. Results confirmed by Oonincx *et al.* (2015) showed CP values ranging between 38% and 46%, and fat values between 21% and 35%. Crude protein and fat values of larvae in a trial conducted by Driemeyer (2016) were 35.9% and 48.1%, respectively. Crude protein content in larvae increased just after hatching, and then it gradually decreased from 4–12 days of larval development, with a minimum concentration of 38% crude protein (CP) at larval phase followed by a further increase of 39.2% in mature larvae on day 14 (Sauvant *et al.*, 2004).The various values of CP contents of BSF reported by authors were due to different types of diet given to the fly and life stage of the fly.

According to Newton *et al.* (1977), the fat content of BSF larvae was 28.0% on pig manure, 35%on cattle manure, and 34.8% on poultry manure. The lipids of larvae fed on cow manure contained21% of lauric acid, 16% of palmitic acid, 32% of oleic acid, and 0.2% of omega-3 fatty acids, while these proportions were, respectively 43%, 11%, 12%, and 3% for larvae fed 50% fish offal and 50% cow manure (Makkar *et al*., 2014).

The BSF larva is a better or comparable amino acid profile to that of soybean meal (SBM) (Tran *et al*., 2015). The lysine and methionine content of BSF larvae proteins are comparable to that of meat meal (Ravindran *et al.*, 1999). Cullere *et al.* (2016) reported that the most abundant essential amino acids were valine and leucine, whereas alanine and glutamic acid were rich in defatted BSF larvae meal. The content of amino acids in BSF varies throughout their lifespan and appears to be related to its CP content as the highest level of amino acids contents was mostly expressed in the early stages of larval development then gradually decreased. In dry matter (DM), the adult stage of larvae was characterized by the highest content of amino acids (g/kg) (Liu *et al.*, 2017).
Generally, black soldier fly larvae meal CP are comparable to others insect meals and to that of soybean meal but slightly lower than that in fish meal.

The BSF larva is high in calcium and phosphorus (Newton *et al.*, 2005). The ash content varied between different samples of BSF pre-pupae depending on their feed substrate. Newton *et al.* (2005) found an ash content of 16.6% when the BSF pre-pupae were reared on pig manure and 14.6% on poultry manure (Newton *et al.*, 1977). Moreover, an ash content of 15.5% was reported by St-Hilaire*et al.* (2007) when pre-pupae were fed pig manure. However, a low ash value of 7.8% was recorded by Driemeyer (2016) when BSF pre-pupae were reared on pig manure.

Table 1: Comparison of black soldier fly larvae with some insects' meals and soybean meal and fish meal

Types of insect	Chemical composition					References
	CP	CF	EE	Ash	GE	
Mealworm	52.8	-	36.1	3.1	26.8	Finke, 2002
House cricket	63.3	-	17.3	5.6	-	Finke, 2002
Black Solder Fly Larvae	42.1	8	26	20.6	-	St-Hilaire *et al*., 2007
Housefly maggot Meal	50.4	5.7	18.9	10.1	22.9	Adesina *et al*., 2011
House fly pupae	70.8	15.7	15.5	7.7	24.3	Pretorius, 2011
Locust or grasshopper meal	57.3	8.5	8.5	6.6	21.8	Alegbeleye *et al*., 2012
SWP meal (non-defatted)	60.7	3.9	25.7	5.8	25.8	Jintasataporn, 2012
Fish meal	70.6	_	9.9	-	-	FAO, 2011
Soybean meal	51.8	-	2.0	-	-	FAO, 2011

CF=crude fiber; CP= crude protein; EE= ether extract; GE= gross energy, SWP=silkworm pupae

Table 2. Amino acid compositions (g/16 g nitrogen) of black soldier fly larvae meals versus conventional meal

Amino acids	BSF Larvae	Fishmeal	Soybean meal
Essential			
Methionine	2.1	2.7	1.32
Cystine	0.1	0.8	1.38
Valine	8.2	4.9	4.50
Isoleucine	5.1	4.2	4.16
Leucine	7.9	7.2	7.58
Phenylalanine	5.2	3.9	5.16
Tyrosine	6.9	3.1	3.35
Histidine	3.0	2.4	3.06
Lysine	6.6	7.5	6.18
Threonine	3.7	4.1	3.78
Tryptophan	0.5	1.0	1.36
Non-essential			
Serine	3.1	3.9	5.18
Arginine	5.6	6.2	7.64
Glutamic acid	10.9	12.6	19.92
Aspartic acid	11.0	9.1	14.14
Proline	6.6	4.2	5.99
Glycine	5.7	6.4	4.52
Alanine	7.7	6.3	4.54

(Source: Makkar *et al*., 2014)

Table 3. Mineral compositions of black soldier fly larvae meal

Mineral	Mean value
Calcium (g/kg)	75.6
Phosphorus (g/kg)	9.0
Potassium (g/kg)	6.9
Sodium (g/kg)	1.3
Magnesium (g/kg)	3.9
Iron (g/kg)	1.37
Manganese (mg/kg)	246
Zinc (mg/kg)	108
Copper (mg/kg)	6

(Source: Newton *et al.,* 1977)

Effects of BSF larvae on Broilers

The performance of broilers that fed BSF larvae meals was evaluated by different authors. Oluokun (2000) compared BSF larvae with SBM and FM on broiler production. The author suggested that maggot meal could replace FM to upgrade the nutritive value of SBM in the broiler diets without any adverse effect on the body weight (BW) gain, feed intake, and feed conversion ratio (FCR). The feeding of dried BSF larvae as a substitute for SBM resulted in a similar BW gain but a lower feed intake as compared to the control indicating an improved FCR (Makkar *et al.,* 2014).

Cousins (1985) reported that broilers fed a BSF-based starter diet showed daily gain and body weight at 10 days old, roughly similar to those fed the fish meal control diet (24.6 vs. 24.5 g/day, 286 vs. 285 g, respectively). These results were consistent with other studies that did not indicate any differences in daily gain or final weight during the grower phase in broiler quails fed either a control diet or BSF larvae meal diet (Cullere *et al.,* 2016). Dabbou *et al*. (2018) reported that body weight and average daily gain during starter growing periods were increased due to the inclusion of BSF into the broiler chicken diets, while the average daily gain decreased linearly during the finisher stage, which may be attributed to some negative effects of dietary BSF larvae meal on gut morphology when administrated at a high level (10%).

In growing broiler quail, Cullere *et al*. (2016) tested three diets as control, 10% defatted BSF larvae meal (substituted 28.4% soybean oil and 16.1% SBM) and 15% defatted BSF larvae meal (substituted 100% soybean oil and 24.8% SBM). The author found that quails showed the same BW gain, feed intake FCR, and mortality rate in all dietary groups. Apparent digestibility of nutrients (DM, Organic Matter, CP, EE, and starch) was overall comparable among the three groups except for EE, whose digestibility was the highest (P<0.001) in control (92.9%) and 15% BSF meal (89.6%) groups. Feed choice trial showed that broiler quails did not express a preference toward control or 15% BSF meal diets and breast meat weight and yield did not differ among all groups. The author confirmed that BSF at an inclusion level of up to 15% as a replacement for SBM and soybean oil had no problematic effects on digestibility, productive performance as well as carcass and meat quality of quail broilers.

Effects of BSF larvae on Layers

Maurer *et al*. (2016)conducted a feeding trial with a partly defatted meal of dried BSF larvae in small groups of laying hens. Experimental diets contained 12 and 24% meals replacing 50 or 100% of soybean cake used in the control diet, respectively. After three weeks of the experiment, there were no significant differences between feeding groups with regard to egg production, feed intake, egg weight, and feed efficiency. There was a tendency (P=0.05) for lower albumen weight in the 24% meal group; yolk and shell weights did not differ. There were also no mortality or sign of health disorders occurred. The DM of feces increased with increasing proportions of meal in the diet, with a significant difference between 24% meal and the control groups (P=0.05). Increases of black fecal pads were observed in the 12% and 24% meal groups. Higher DM of feces and a larger proportion of dark, firm fecal pads with 24% gave reason to assume that in this diet the proportion of meal was too high. The causes of these differences are not fully understood.

Hopley (2015) tested the ability of layer hens to be reared on BSF larvae and BSF pre-pupae meal and whether this had any effect on the production parameters and egg quality and concluded that the production parameters were favorable and that the chickens on larvae meal had a lower FCR. Al-Qazzaz *et al.* (2016) found that the egg quality parameters were either comparable or superior to that of the control treatment and concluded that BSF larvae as a viable protein source for layer hens.In laying hens, the inclusion of 7.5% defatted BSF larvae meal into their diet from weeks 19 to 27 of age showed significantly higher body weight than other groups (Mwaniki *et al.,* 2018). AccordingtoKawasaki *et al*. (2019) studies on laying hens fed a diet supplemented either with whole (non-defatted) 10% BSF larvae meal or with 10% BSF pre-pupa meal for 5 consecutive weeks did not show significant differences among treated birds and those fed the basal diet. However, Borrelli *et al.* (2017) reported that the complete replacement of soybean meal by BSF larvae meal in laying hens reduced their body weight (2.09 vs. 1.89 kg, respectively) after a 21-week feeding period.

Van Schoor (2017) tested the effect that BSF pre-pupae meal on layer production parameters and egg quality. Results were also positive; egg quality was not affected by the inclusion of the prepupae meal and at the inclusion of 10%, production parameters were also not affected. The rate of degradation (shelf-life) of the eggs was also not affected by the inclusion of the pre-pupae meal. The author concluded that BSF pre-pupae meal may be used as an alternative protein source in layer hen diets with no significant effects on the egg quality, shelf life and production parameters. Mwaniki *et al*. (2018) also reported that, in laying hens, inclusion of 7.5% defatted BSF larvae meal into their diet from weeks 19 to 27 of age showed significantly higher body weight than other groups.Provision of BSF larvae also had a positive effect on the feather condition of laying hens with intact beaks (*Star et al.,* 2020).

Generally, from the above results reported by various authors, it may be concluded that BSF larvae meal could replace FM or SBM in the broiler and laying hen diets without any adverse effect on performance.

Conclusion

Based on the comprehensive research finding obtained from different researchers, it is possible to come up with a concrete conclusion that BSF larvae meals are a valid, cost-effective, and highly nutritive alternative source of animal protein feed. It is potentially utilized as a substitute for expensive conventional protein source feeds or as a supplement. According to the current review, BSF larvae contains 35-42% CP, are rich in minerals and fat, have a better or comparable amino acid profile, and have efficient food conversion factor compared to conventional fish and soybean meals which are reported to be very expensive and unaffordable for poultry producers. Generally, the results of studies confirmed the feasibility of total or partial replacement of FM with BSF larvae or prepupae meal. No negative effects have been reported on the growth performances as well as the quality of eggs of chicken that fed BSF larvae meal. Most of the studies have reported similar or even better growth rates in chicks fed BSF larvae when compared to SBM or SBM plus FM. The costs of conventional feed materials such as SBM and FM are very high and their availability is limited. The inclusion of this insect meal in poultry diets may lower the cost of feeds without any adverse effects on the performance of the chicken, thus potentially improving the profitability of the poultry sector.

Implications to Ethiopian Context

Currently, Black Soldier Fly rearing is done at a small scale in east African countries like Kenya, Uganda, and Tanzania. In Ethiopia, there is limited information available on the existence, status, abundance, and distribution of BSF to use as a potential alternative sustainable protein-rich ingredient for poultry and fish feeds. It requires identifying BSF at the country level, establishing intensive insect rearing, and large-scale production through the utilization of bio-waste and organic side stream to enhance poultry production and productivity ultimately for improving food security of the country. This can be achieved when different stakeholders do participate and share responsibilities. The government should create awareness on how to establish Black Soldier Fly rearing farms up on utilizing locally available Black Soldier Fly species, bio-waste, and organic side streams to different stakeholders engaged in livestock production systems and collaborate working with various governmental and non-governmental organizations. To reduce the environmental effect of protein-rich animal feed derived from plant and animal sources, black soldier fly larvae should be encouraged as a substitute for conventional protein source feed or supplementation.

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