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# Performance and Carcass Characteristics of Broiler Chickens Fed Black Soldier Fly Larvae-Based Diets- A Review

**By**

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***Abstract***

*Feed is one of the main challenges of production in the poultry industry since it accounts for 60-80% of total cost of production. The scarcity and high cost of conventional protein ingredients is a convincing factor for researchers in looking for non-conventional alternative protein sources to reduce the cost of poultry feeds and poultry products. Partially defatted black soldier fly (BSF) larvae meal is considered as one of the non-conventional protein-rich, locally available feed resource which can be used in poultry feed formulation. This feedstuff has the potential to replace expensive and mostly unavailable conventional protein sources such as fish meal. The proposed study aims to determine performance, meat quality and sensory attributes of broiler chickens fed on partially defatted black soldier fly larvae-based diets. The black soldier fly larvae meal can substitute the conventional fish meal and the performance of broiler chicken measured to elucidate the contribution of the non-conventional insect-based diets in broilers. The meat of such fed chicken can be assessed for carcass characteristics (dressing percentage, cuts yield), meat quality (pH, water holding capacity, cooking loss, moisture, crude protein and fat content %,) and carcass sensory attributes (appearance, odour, taste, texture, flavour and overall acceptability). The expected results will provide useful information on the effects of the feeding of black soldier fly larvae meal as a non-conventional protein source on performance of broiler, carcass characteristics, meat quality and sensory attributes.*

***Key words:*** *Black soldier fly larvae meal, Sustainability, Environmental health, Increased chicken performance, Nutritious feeds, Mass production, Nutrient recycling.*

## Introduction

Poultry includes domesticated avian species (chickens, turkeys, guinea fowls, ducks, and geese) which are raised for eggs, meat, and feathers (Bounds & Zinyemba, 2018). Chickens, which constitute about 90% of the poultry population are, by far, the most important poultry species in all parts of the world (Alders *et al*., 2018). The rising of world population has led to increased demand for food especially animal products such as meat, eggs, dairy (FAO & OECD, 2018). To meet the demand for meat this would require an increase in chicken production and consequent augmented feed ingredients used in feed formulation. For the total cost of feed which constitutes of 60-80 %, about 95% is used to meet energy and protein requirements, about 3 to 4 % for major mineral, trace mineral and vitamin requirements, and 1 to 2% for various feed additives (Velmurugu, 2013).

Concerning the poultry industry, a major key goal of the sector is to provide feeds containing all the necessary nutrients for birds to support production and maintenance, thus allowing them to express their genetic potential (Sánchez-Muros *et al.*, 2014). Proteins are thus, a key ingredient in the success of commercial poultry farming since it has a high contribution to the production of healthy and safe chicken meat. Currently, important animal protein ingredient used for animal feed is fishmeal (Veldkamp & Bosch, 2015).The fact that it is used for both human and livestock nutrition, it is expensive. Incorporating fishmeal in poultry feeds makes them expensive and raises the cost of production. Therefore, there is an urgent need to look for and evaluate locally available non-conventional protein sources for use in animal feeds.

Black soldier fly (*Hermetia illucens*), is a common fly of the Stratiomyidae family of insects which has been proposed as

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one of the most suitable insect species to be used as alternative source of protein for animal feed. It has a rather short lifecycle of about 6-7 weeks, however, its lifecycle length depends on the environmental conditions as the BSF can slow down its activity to survive under unfavorable conditions (Banks *et al*., 2014). BSF larvae develop through five larval stages (Egg, larvae, pre-pupa, pupa and adult).The pre-pupal stage is energy, protein and fat-rich biomass suitable feed for monogastric animals such as poultry, pig rabbits, several species of fish, and shrimp (Tomberlin *et al*., 2009). Black soldier fly larvae (BSFL) are rich in both protein and lipids, and contain an amino acid profile suitable for several species (Newton *et al*., 2005).The larvae of BSF has a crude protein of 39 to 64% (Boykin, 2019). The larva of the black soldier fly contains up to 45% of lipids. The lipids of the BSF larvae are characterized with large amounts of saturated fatty acids (58–72%) which vary considerably depending on the composition of the rearing substrate (Surendra *et al*., 2016). These high levels of lipid dilute the level of crude protein content in BSFL. The defatting of the BSFL would provide a product of a relatively higher crude protein content and results in a by-product of lipid, which has potential as a biofuel (Surendra *et al.*, 2016). Additionally, preliminary analysis showed that the amino acid profile of maggot meal of PDBSF meal 'Hermetia meal' is very similar to that of fishmeal and better than soybean meal (Elwert *et al*., 2010).

The BSF larvae play important role in integrated waste management. The larvae efficiently turn the waste products into an edible and high quality source of animal protein that can then be fed back to those animals or others (Singh & Kumari, 2019). Black soldier flies that have received a suitable diet have feed conversion efficiency better than most conventional production animals. It can convert 50% of the dry matter content of organic wastes into insect biomass rich in protein and fat content (42% and 35%), respectively (Diener *et al*., 2009). Another benefit associated with BSF larvae is that this insect has no attraction to human food or habitat; hence, it has no potential to transmit any disease or cause a nuisance. Furthermore, they prevent houseflies and other insect from laying eggs in the material inhabited by BSFL. This minimizes incidences of human diseases transmitted by the houseflies. Although the adults do not feed, therefore do not require particular care and rearing of BSF require low investment (Newton *et al*., 2005).

## 1.2 The need to diversify feed sources

Chicken production provides an immense supply of food (meat, eggs) which is the most preferred to other kinds of animal food products for the world's population. The high rate of rising in the world population has led to increased demand for food especially animal products including meat as a result; there is also increase in poultry production and high demand for conventional protein ingredients used in feed formulation which are then becoming more expensive. The high cost of feeds which represents 60- 80% is a major limiting factor in commercial chicken production. Therefore, there is need to find locally alternative proteins sources which are cost effective. Insect species such as Black soldier fly larvae, common housefly maggots and grasshoppers, have been proposed as a high quality, efficient and sustainable alternative protein sources which can contribute to global food security via feed or as direct food sources for human consumption. However, there is limited information on the effects of feeding Black soldier fly larvae on carcass characteristics, meat quality and sensory attributes of broiler meat. This review highlights the general contribution of insect-based diets, especially black soldier fly larvae, to sustainable poultry production, food and nutrition security of partially defatted larvae meal in broiler diet.

Black Soldier fly larvae are insects naturally found in poultry, pig, and cattle manure but can also be grown on wastes that human and other animals cannot or will not digest, such as organic side streams from food production, catering and kitchen waste. They are efficient converters as they produce a protein and lipid-rich biomass from substrates that can be poorly used by monogastric animals. The larvae meal has a high content of protein (up to 37%), fat (35%), and essential amino acids with higher level of lysine methionine and threonine, minerals with higher concentrations in calcium, iron, phosphorous, zinc, and vitamin E. The nutritional profile of maggots' meal of *Hermetia illucens* is comparable to fishmeal and, in some aspects, better than soybean meal. It has been shown that BSF larvae meal could replace fish meal to upgrade the nutritive value of soybean meal in the broiler diets without any adverse effects on growth performance. These characteristics, linked to a short production cycle, make BSF larvae very good candidates alternative protein sources for poultry nutrition.

Knowledge on performance of broiler chicken fed on Black Soldier fly larvae meal based- diet will help in improving chicken production by feeding BSF as an alternative protein ingredient and also assessment of carcass characteristics, meat quality and sensory attributes of meat from chicken feed on BSF based- diet will provide information which will help to solve the problem of food and nutrition security.

It is expected that adoption of these diets will lead to improvement of broiler chicken performance, meat quality and sensory attributes of broiler chicken meat fed on partially defatted black soldier fly larvae-based diets

## 1.3 Overview of Chicken Production in Kenya

Poultry contributes 8 % to agricultural value added, with the country producing over 25 000 tons of poultry meat and 1.3 billion eggs per year (Government of Kenya (GoK, 2017)). The sector is highly heterogeneous with three major poultry production systems: free range, semi-intensive and intensive systems. A large number is comprising of small scale free-range and backyard indigenous chicken producers; a good number of small scale commercial layers and broiler farms; and few industrial integrated layer and broiler farms (Bergevoet & Van Engelen, 2014). Chickens constitute about

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98 % of the total poultry raised in Kenya where 82% consists of indigenous chicken, 6.9% of broilers ,9.3% layers, and other poultry species like ducks, geese, turkeys, pigeons, ostriches, guinea fowls, and quails make up 1.8 % of the poultry produced (FAO, 2018).

The fast-growing population that is projected to reach 96 million by 2050, rising incomes, and urbanized Kenyan population are expected to double the demands in food especially livestock products such as meat, milk, and eggs (Bergevoet & Van Engelen, 2014). As reported by Carron *et al*., (2017), consumption of poultry meat in Kenya is predicted to increase from 54.8 thousand metric tonnes in 2000 to 164.6 in 2030, and from 6 to 30.5 thousand metric tonnes in Nairobi. To meet this expected demand growth, poultry production in Kenya is expected to increase from 56.9 to 1,666 metric tonnes by 2030 (FAO, 2018), again under the assumption that trade regulations remain similar and relative prices of inputs and outputs to the poultry system remain unchanged.

## 1.4 Benefits of Broiler Chicken Production

Broilers chicken production sector is possibly the fastest growing and most flexible of all livestock sectors. It has expanded by very strong demand for animal sources food due to the high increasing population worldwide (Bounds & Zinyemba, 2018) .Therefore, many farmers prefer to invest in this business since it is fundamental to the livelihoods of many worlds' poorest people. Rural poultry, in particular, is essential for the livelihood of many resource-poor farmers often being the only asset they possess. It makes up about 80 % of poultry stocks in low-income food-deficit countries and significantly contributes to: (i) Improving human nutrition, providing food (meat) with high-quality nutrients and micronutrients; (ii) generating income and savings in a short time and especially for women who are in this business thus enhancing the capacity to cope with shocks and reducing economic vulnerability; (iii) providing manure for the vegetable garden and crop production. The importance of the socio-cultural and religious functions of village poultry production for smallholder livelihoods, beyond its economic or nutritional importance, is also widely recognized (Farrell, 2013).

### *1.4.1 Providing food for Human consumption*

Poultry meat is economical and widely accepted. It permits quick and easy preparation and has several desirable nutritional and organoleptic properties. Poultry meat is not only a good source of protein, but it contains more protein (22-24 %) than red meats (Farrell, 2013). Poultry meat protein is a high-quality protein that is easy to digest and contains all the essential amino acids presently known to be required in the human diet. It is low in calories and therefore a good foodstuff for weight-control diets, convalescents, and old people who are not physically active (Dowarah, 2013).

Broiler meat contains 150 calories per 100 g of meat; it also contains less cholesterol than other foods of animal origin. Its fibers are tender, easy to chew, grind and digest, and have a mild flavor that blends well with other foods and there are no major taboos on their consumption (De Oliveira *et al*., 2016). For the above reasons, poultry meat is increasingly preferred in the diet of the people as it is improving standards of living.

### *1.4.2 High Returns in a Short Time*

Income generation is the primary goal of family poultry keeping. Eggs can provide a regular, although small income while the sale of live birds provides a more flexible source of cash as required (Bounds & Zinyemba, 2018). Modern broilers are fast-growing animals reaching market at early age and a considerably short time is required from the time of the beginning of the project to the time when a farmer can sell some products (Bounds & Zinyemba, 2018).Therefore broilers production is helping to cope with market demand for protein (meat), and a high return of investment within a very short period to farmers (Szőllősi *et al.*, 2014).

### *Providing manure*

Poultry manure contains all the essential nutrients required for crop production, and its value as an organic fertilizer and a source of plant nutrients has been recognized for centuries (Nguyen et al., 2015). It has beneficial effects on plant growth, even if the manure constitutes only a small percentage of the nutrients applied to cropland when compared to commercial fertilizer. Broiler litter is a rich source of nutrients critical to corn and soybean production. The reviewed studies demonstrated a yield increase of 6% in corn when substituting poultry litter for inorganic fertilizer and a 14% yield increase for soybeans (Nguyen et al., 2015). In addition, the improved nodulation in soybeans are resulting from the abundance of P and micro-nutrients contributed to the observed soybean yield increases (Hoover *et al*., 2015).

### 1.4.3 Overview of the Feed Industry in Kenya

Feed manufacturers in Kenya largely rely on by-products from food agro-processing industries mainly sourced from neighboring countries in the East Africa Community or imported from regional markets and other international markets. These imported ingredients are maize, maize germ/bran, wheat bran and pollard, soybean and its derivatives, sunflower cake, nut cakes, cottonseed cake, fish meal, and micro-ingredients (usually additives). Some raw materials like vitamins, mineral premixes, and amino acids also are not available locally hence imported (Bergevoet & Van Engelen, 2014).

The scarcity of raw materials due to increase in demand for the ingredients used to formulate feed (fish meal, meat meal, groundnut cake, soybean, maize, among others) and with the competition between animal and human food requirement, and other industrial needs such as bio-fuel production in the world market, those ingredients become particularly expensive (Aldington, 2013).

### 1.4.4 Nutritional Requirements of Broilers

Nutrition is an important part of poultry farming because the performances of chickens and other poultry birds depend majorly on their nutrition. (Velmurugu, 2009). Poultry convert

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feed into food products fast, efficiently, and with relatively low environmental impact compared with other livestock. The chicken production has high nutrient needs including water, energy, protein, amino acids, vitamin, minerals among others and must be in appropriate concentrations and balance and are relative to high rate of productivity (Klasing & Klasing, 2018). Table 1 and Table 2 indicate the nutritional requirements for starter, grower and finisher broilers.

**Table 1. Nutritional requirements for different chicken categories**

| | starter Broiler | Grower Broiler | finisher Broiler |
|---|---|---|---|
| **Nutrient** | **Composition** | | |
| Metabolizable Energy (ME) | 2900-3100 Kcal/kg | 3000-3300kcal/kg | 3100-3300 Kcal/kg |
| Crude Protein (CP) | 21-24% | 18-23% | 17-22% |
| Crude Fiber (CF) | 5% | 8% | 8% |
| Calcium | 0.85-1.05% | 0.80-1.00% | 0.3-0.5% |
| Methionine | 0.37% | 0.33% | 0.3% |
| Lysine | 1.10% | 0.85% | 0.9% |
| Sodium | 0.01-0.3% | 0.01-0.3% | 0.01-0.3% |
| *Source:* | *Lamot, (2002)* | *Shariatmadari, (2009)* | *Shariatmadari, (2009)* |

## 1.5 Broiler Feed Availability and Nutrition

Feeding of broilers is commonly used conventional feedstuffs from agro-industrial by-products which comprise energy source, protein source, vitamins, and minerals. Energy sources normally constitute the highest proportion (about 50–60%) of livestock diets, followed by plant protein sources (about 10–20%), next is the fiber and animal protein sources (10–15%), and the lowest rates of inclusions usually is for minerals and additives as feed ingredients (Velmurugu, 2013). Globally, maize (corn) is the most commonly used energy source, and soybean meal or cake is a common plant protein source, while fishmeal is the major animal protein ingredient used in livestock rations. These three feed ingredients are known to be the conventional livestock feed ingredients, and they usually constitute a part of livestock concentrate feeds (Velmurugu, 2013). They have been facing market competition with human food demands, especially in developing countries, and this trend has been tagged as "feed-food competition" therefore lead to increased feed cost (Aldington, 2013). To cope with the feed-food competition, it has been necessary to look at the use of locally available, cheaper alternative feedstuffs for use in livestock feed formulations. A wide range of non-conventional feedstuffs is proposed to be used in livestock feeding globally (Concentrate, 2007).

**Table 2. Nutritional requirements for Grower Broiler**

| **Nutrient** | **Composition** |
|---|---|
| Metabolizable Energy (ME | 3000-3300 Kcal/kg |
| Crude Protein (CP) | 18-23% |
| Crude Fiber (CF) | 8% |
| Calcium | 0.80-1.00% |
| Methionine | 0.33% min |
| Lysine | 0.85% min |
| Sodium | 0.01-0.3% |

Source: (Velmurugu, 2013

## 1.6 Non- Conventional Feedstuffs for Broilers

The utilization of non-conventional feed resources is justified by serious feed deficits, the rising cost of production, continuing low animal productivity, and inability of the components of the animal industries to meet national targets, especially of animal proteins (Singh & Kumari, 2019). Most animals, in particular, monogastric such as poultry require proteins to compensate for the inability to synthesize specific amino-acids. However, conventionally used protein ingredients are not ecologically or economically sustainable (Garba & Soli, 2017). Therefore, a solution to develop a sustainable and productive household aviculture system includes the use of local, easily available, and cheap protein sources, preferably not used for other purposes. Insects, which are a natural food source of free-range poultry, provide a sustainable alternative to traditional protein sources (Allegretti *et al.*, 2017). Insect larvae and pupae are typically rich in protein (40-70% dry weight), mono- and/or polyunsaturated fatty acids, other valuable nutrients such as iron, copper, magnesium, manganese, phosphorous, selenium, zinc, B vitamins and essential amino acids such as lysine and tryptophan.

## 1.7 Insects as animal feed

Insects have been proposed as a high quality, efficient and sustainable alternative protein source which can contribute to global food security via feed or as a direct food source for

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human (Van Huis, 2016). Insects 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. They are also interesting in terms of low greenhouse gas emissions, high feed conversion efficiency, low land use, and their ability to transform low value organic side streams into high value protein products (Veldkamp & Bosch, 2015). The candidate insect species used as feedstock for pets, livestock and fish are the Black soldier fly *Hermetia illuscens* (Diptera: Stratiomyidae), the common housefly *Musca domestica* (Diptera: Muscidae) and to some lesser extent mealworms, locusts/grasshoppers/crickets and silkworms.

Awoniyi *et al*., (2003) findings showed that replacement of fish meal by housefly maggot meal at 25% in broiler chicken diet affect positively the broiler chicken in terms of average weekly body weight gain and protein efficiency ratio. Cullere *et al*., (2019) studied the effect of the replacing soybean oil with BSF larvae fat in broiler finisher diet, on the quality and sensory traits of their meat and they have found satisfactory productive performance and meat quality from a nutritional and sensory point of view .In addition to these studies, Nginya *et al*., (2019) have done a study by feeding grasshopper as protein source to indigenous chicken replacing fish meal and found improved FCR with increasing replacement of fish meal by grasshopper meal and carcass characteristics were not affected and also sensory attributes of meat appeared to be improved slightly by feeding grasshopper meal.

### 1.8 Nutrient composition of insects

Insects, which are natural food sources of free-range poultry and fish, provide a sustainable alternative to traditional protein sources. Insect larvae and pupae are typically rich in protein (40-70%), mono and /or polyunsaturated fatty acid, other valuable nutrients such as iron, copper, magnesium, manganese, selenium, Zinc and essential amino acids such as lysine and tryptophan (Rumpold & Schlüter, 2013). Researchers have done studies on several insects and showed their nutrients composition.

#### *Housefly Maggots*

Housefly maggots (also called a maggot meal, housefly maggots, magmeal) are a source of protein and lipids. Their contents are high but extremely variable where CP content varies between 40 and 60% and lipid content is even more variable and ranges from 9 to 26% (Aniebo *et al.*, 2010). Maggots contain a low (usually lower than 9%) but not negligible amount of crude fibre (CF) but higher values have been reported for acid detergent fibre (ADF). Phosphorus (P) contents in housefly maggots are of similar order as in black soldier fly larvae but calcium (Ca) levels are lower by about 15 times. Lysine content in housefly maggots, similar to that in black soldier fly larvae is also high (from 5 to 8.2 g/ 100 g CP with an average of 6.1 g/100 g CP) (Makkar *et al*., 2014).

#### *Silkworm*

Silkworm has other common names such as silkworm pupae (SWP), silkworm meal, spent silkworm pupae and defatted silkworm pupae meal. The SWP is a waste product of the silk industry that could be used as a top-class unconventional protein and energy source for poultry diets after proper processing at a reasonable cost (Khan, 2018). The reported proximate compositions for SWP on fresh basis were found in the range of moisture (65–70%), CP (12–16%), EE (11–20%), carbohydrate (1.2–1.8%), and ash (0.8–1.4%) (Tomotake *et al.*, 2010). The high CP content in the defatted silkworm meal (75%) with 44% total EAAs makes it an ideal candidate for preparing protein concentrate isolates with enhanced protein quality that can be used in poultry diets.

#### *Grasshoppers*

Grasshoppers are also insects used as alternative protein sources and can be harvested from their varied habitats such as croplands, grasslands, wetlands, and paddocks (Khusro *et al*., 2012). There are numerous species of grasshoppers in East Africa and the known 270 provide a wide spectrum for selection for food and feed (Hunter and Elder, 1999; Egonyu et al., 2021; Jago, 1990; Kietzka et al., 2021; Latchininsky et al., 2011; Makkar et al., 2022; Siddiqui et al., 2023; van Huis, 2022). Some of these swarm or increase in numbers especially in the rainy season when they can be trapped or harvested. The nutrient composition of grasshopper meal was assessed by many scientists; the CP content was varying from 29 to 77.1% due to various species, developmental stages, and different processing methods (Shrivastava *et al*., 2019). A study done by Nginya *et al.*, (2019) show that African Grasshopper have 50.5 % CP, 15.3% CF, 6.40% ash, 18.8% EE, and 5240 kcal/kg GE on DM basis and vary with the types van Huis., (2022); Makkar et al., (2022).

#### *Crickets* (*Gryllus testaceus* Walker)

Crickets also named cricket meal, house cricket, field cricket, or Mormon cricket inhabit paddy fields and fallow lands. It can survive and grow well on a variety of organic materials (Makkar *et al.*, 2014). Crickets are reported to have a high CP in the range of 55 to 73% and sufficient EAAs, except for methionine and lysine, which can be supplied directly in the feed. Barroso *et al*., ( 2014) reported that the CP and EE of field cricket (DM basis) was 58.3% and 10.3%, respectively which is comparable with those of conventional protein feed supplements. SBM (46.8 and 1.84%, respectively), meat meal (48.5 and 8.47%, respectively) and FM (60.2 and 4.11%, respectively).

#### *Termites*

Termite is a social insect sometimes referred to as a white ant, yet it is not in any way an ant that belongs to the family of Termitoidae and infraorder of Isoptera. Termite is categorized into fertile male (king), fertile female (queen), sterile male (worker), and sterile female (soldiers) (Paoletti *et al*., 2010). Ntukuyoh *et al.*, (2012) examined the proximate composition, mineral, vitamin, and anti-nutrient contents of termite queen,

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workers, and soldiers of *Macrotermes bellicosus*. The proximate composition revealed that the crude protein content of the soldiers was higher unlike that of queen and workers. The highest mineral content was sodium found in queen, while the least mineral was manganese found in the termite soldiers. Termites are rich in vitamin A, vitamin C, fat while anti-nutrient components were low. Termites are recommended to be used as a source of protein in poultry diets since they are found to have high protein content varying from 20.00 to 46.3 percent (Moreki & Tiroesele, 2012).

***Black Soldier Fly Larvae***

***Description of Black soldier fly larvae***

Black soldier fly larvae (*Hermetia illucens*) also called black soldier fly larvae meal, black soldier fly prepupae meal, soldier fly prepupae meal, black soldier fly maggot meal, is a harmless fly (Diptera) of the *Stratiomyidae* family. The adult fly is black, wasp-like and 15-20 mm long. The larvae can reach 27 mm in length, 6 mm in width, and weigh up to 220 mg in their last larval stage (Rindhe *et al.*, 2019). They are a dull, whitish color, the larvae can be used in different forms; live, chopped, or dried and ground (Makkar *et al*., 2014). In ideal conditions, larvae become mature in 2 months, but the larval stage can last up to 4 months when not enough feed is available. At the end of the larval stage (prepupa), the larva empties its digestive tract and stops feeding and moving. The prepupae then migrate in search of a dry and protected pupation site (Diener *et al.*, 2011). The duration of the pupal stage is about 14 days but can be extremely variable and last up to 5 months (Shumo *et al.*, 2019). The females mate two days after emerging and oviposit into dry cracks and crevices adjacent to a feed source. The adults do not feed and rely on the fats stored from the larval stage for their short survival (Diener *et al.*, 2011).

***Nutritive Value of Black Soldier Fly Larvae***

There is a considerable variation in the nutrient composition of BSF larvae meal reported in the literature. This variation is related to the type of fly attractant and substrate used during the production process processing, drying or storage methods used (Nyakeri *et al.*, 2017). However, studies have shown that BSF larvae meal can be a good source of animal protein in fish and poultry diets. The reported crude protein varied from as high as 64% to as low as 39.16% (De Marco et al., 2015).The nutritional profile of BSF larvae is comparable to fishmeal and, in some aspects, better than soybean meal. The author suggested that BSF larvae meal could replace a fish meal to upgrade the nutritive value of soybean meal in the broiler rations without any adverse effect on the weight gain, feed consumption, and feed: gain ratio (Nyakeri *et al.*, 2017). The larva of the black soldier fly contains contain large amounts of lipids up to 45%. In general, the fatty acid profile of BSF prepupae is high in medium chain fatty acids (MCFA) lauric acid (C12:0, ~>50% of total fat). But, the fatty acid composition of the larvae depends on the fatty acid composition of the diet fed on the larvae. For example, larvae fed on cow manure contained 21% 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 (St-Hilaire et al., 2007). An analysis of dried Black Soldier Fly larvae elucidates that it contains different nutrients as are indicated in Table 3.

**Table 3.** Comparison of the nutritional value of Black Soldier fly larvae meal vis-à-vis conventional fish and soy meals

| Constituents (% DM) | BSF larvae meal | Fish meal | Soymeal |
|---|---|---|---|
| Crude Protein | 56.9 | 70.6 | 51.8 |
| Lipid | 26.0 | 9.9 | 2.0 |
| Calcium | 7.56 | 4.34 | 0.39 |
| Phosphorus | 0.90 | 2.79 | 0.69 |
| Methionine | 2.1 | 2.7 | 1.32 |
| Cysteine | 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 | 3.35 |
| Lysine | 6.6 | 7.5 | 6.18 |
| Threonine | 3.7 | 4.1 | 3.78 |
| Tryptophan | 0.5 | 1.0 | 1.36 |
| 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)

| Mineral | Mean value |
|---|---|
| Calcium | 75.6 |
| Phosphorus | 9.0 |

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| | |
|---|---|
| Potassium | 6.9 |
| Sodium | 1.3 |
| Magnesium | 3.9 |
| Iron | 1.37 |
| Manganese | 246 |
| Zinc | 108 |

Source: (Cullere et al., 2016)

The mineral content of BSF larvae meal is shown in Table 3 where it shows some micro and macro minerals and their quantities. The calcium content of the larvae is extremely high. This is due to calcium carbonate impregnated into the exoskeleton matrix. Other minerals, such as magnesium, potassium, iron, manganese, and zinc, are also well represented in the BSF larvae meal nutritional profile and contribute to the high ash content. The only mineral with values below average compared to most feeder insects is sodium (Finke, 2013)**.**

***Uses of Black soldier fly larvae***

BSF larvae have been used for a number of different purposes where many studies have shown that black soldier fly can be fed to many different kinds of small livestock, amphibians, and fish. Since the larvae is good source of protein, fat content, and essential amino acids. As an animal feed, BSF larvae can be fed live, chopped, or dried and ground forms (Park, 2016). The author suggested that BSF larvae meal could partially replace Soybean meal and fish meal in the broiler diets without any adverse effect on the body weight gain (BWG), feed intake (FI) and feed conversion ratio (FCR) (Onsongo *et al*., 2018) .Up to 50% fish meal can be replaced with BSFL without affecting the fish production and feed utilization (Barroso *et al.,* 2014). Black soldier larvae meal was found to be a suitable ingredient in growing pig diets, being especially valuable for its amino acid, lipid, and Ca contents (Makkar *et al.*, 2014).

The BSF larvae play important role in integrated waste management. They are effective decomposers of organic waste as such; they can be used to breakdown large quantities of post-consumer waste or animal manure. The larvae efficiently turn the waste products into an edible and high quality source of animal protein that can then be fed back to those animals or others (Singh & Kumari, 2019). Another benefit associated with BSF larvae is that the adults are not attracted to human habitation and thus pose a significantly lower risk of disease transmission than other fly species. Furthermore, they prevent houseflies and other insects from laying eggs in the material inhabited by BSFL (Newton *et al*., 2005).

***Advantages of rearing BSF larvae over other insects***

Black soldier fly larvae have advantages of over other insect species used for biomass production in that the adult does not feed and, therefore, does not require particular care. It is also not a potential carrier of the disease, the larvae are sold for pets and fish bait, and they can be easily dried for longer storage (Gold *et al.*, 2018). A disadvantage of the black soldier fly for biodegradation is that it requires a warm environment, which may be difficult or energy-consuming to sustain in temperate climates. Also, the duration of the life cycle ranges between several weeks to several months, depending on ambient temperature, and the quality and quantity of the diet (Tomberlin *et al.,* 2009).

In contrast ,other insects such as grasshoppers, caterpillars, and mealworms, require to be produced on plants or plant products (Kenis *et al.*, 2014). House flies are easy to rear on different substrates and maggots can be produced in large quantities, as shown by recently developed industrial production systems in other parts of the world (Coghlan, 2012). The nutritional properties and qualities of the house fly maggot are well known, and its suitability for some poultry species (e.g. guinea fowl, quails) is documented (John, 2015). However, using house flies also implies some safety issues since these are known to carry various animal and human diseases (Makkar *et al*., 2014). While for termites, even if they are recommended to be used as a source of protein in poultry diets, they cannot be easily mass-reared and are known to produce methane, an important greenhouse gas. Therefore, large production systems cannot be envisaged (Ho *et al*., 2013). Some termite species are known to be toxic to poultry but the information is lacking for most species (Šobotník *et al*., 2012).

***Effects of Feeding BSF larvae Meal on Broilers Chicken Performance and meat quality***

There are several measures that can be used to evaluate the performance of a flock of broilers: growth rate, days to market, mortality, and feed efficiency. The performance of animals depends on feed composition and feed intake, as well as digestion and absorption processes. Broiler performance is also affected by different factors like dietary factors and non-dietary factors such as the ambient temperature of the poultry house, litter quality, diseases among others. The nutritional profile of BSF larvae is comparable to FM and, in some aspects, better than SBM. The author suggested that BSF larvae meal could replace FM to upgrade the nutritive value of SBM in the broiler diets without any adverse effect on the body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR) (Makkar *et al*., 2014). According to Attivi *et al*., (2020) the inclusion of 100% BSF replacing fish meal resulted in reduced feed intake but body weight gain and feed efficiency enhanced. The use of non-conventional protein sources (Black Soldier fly larvae meal) as substitutes for fish meal in poultry feed improved broiler productive performance without any deleterious effect and can be considered as a suitable alternative for fish meal (De Marco *et al.*, 2015). Okah & Onwujiariri, (2012) demonstrated superior performance with the replacement of 50% of a 4.00% dietary fish meal with maggot meal in a finisher broiler chicken's diet.

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Researchers have conducted studies on effect of feeding insects based diets on carcass quality where Elahi *et al*. (2020) studied the effect of replacing soybean meal with house fly maggot meal on growth performance, carcass characteristics and meat quality of broiler chicks. They concluded that housefly maggot can partially replace soybean meal without affecting carcass composition and meat quality while Popova *et al*., (2020) findings showed the inclusion of 5% of full fat black soldier fly larvae meal in the diet affected considerably the quality characteristics and fatty acids profile of meat in broilers at 35 days of age. Another study showed effective partial replacement of soya bean meal and soya bean oil with defatted black soldier fly larvae meal in the diet for growing broiler quails (Cullere *et al*., 2016). After conducting a study on feeding of BSF in place of soybean meal in Jumbo quail diets, Mbhele *et al*., (2019) concluded that BSFL meal could replace soybean products in Jumbo quail diets at an optimal inclusion level of 54 g/kg without compromising their productive performance, health status, and meat quality.

The larva of the black soldier fly contains contain large amounts of lipids (up to 45%) which may affect meat quality and fatty acids profile (Popova et al., 2020). The lipid composition shows an extreme quantitative and qualitative variability, depending on the chemical composition of the rearing substrate (Surendra et al., 2016) In addition, Black soldier fly larvae contains 58% to 72% saturated fatty acids (SFA) and 19% to 40% mono (MUFA) and polyunsaturated fatty acids (PUFA) of the total fat content (Makkar et al., 2014). Up to now, defatted BSFL meal has been appeared as the most feed ingredient for the feed industry because it is very rich in protein ,thus making it a possible substitute for soybean meal and /or fish meal (Schiavone et al., 2017). Defatting processes produce black soldier fly larvae meal with crude fat content as low as 5% DM depending on fat extraction and it has been shown to increase crude protein from 40-44% DM in whole BSFLM (Makkar et al., 2014) to as high as 65.5 % DM (Schiavone et al., 2017). Furthermore, defatted BSFLM was shown to have higher or comparable digestible amino acids concentration to typical animal and plant protein sources used in poultry feed (Schiavone et al., 2017).Defatting of BSF meal can be done mechanically by chopping the frozen larvae and pressing them to extract extracellular fat or use petroleum ether to chemically extract fat to increase protein fraction, improve meal shelf life and to create a fat stream for biodiesel and other applications (Surendra et al., 2016).

Due to high nutritional value of black soldier fly larvae in proteins, availability, and low price, insects are accepted to be a potentially sustainable protein feed resource in poultry nutrition. Generally, results of studies confirm the feasibility of total or partial replacement of Soybean or FM meal with insect meal (BSF) (Khan, 2018). However, limited information is available on the effects of replacing fish meal with BSFL meal on meat quality traits, sensory properties and the acceptability of products from animals fed on BSF larvae meal by consumers. Hence this study will provide the information on effects of feeding BSF larvae- based diets on broiler carcass quality and consumers' acceptance.

## 1.9 Factors determining broiler meat quality

The initial and final quality judgment by consumers before and after purchasing a meat product is influenced by meat appearance, texture, juiciness, odor, mouth feel characteristics, etc. These quality parameters are dependent on many predetermining factors that affected the live animal before being converted from muscle to meat (Ramadhan *et al*., 2012).

### *1.9.1 Color and pH*

The appearance is the most important quality attribute of cooked or raw poultry meat because consumers associate it with the product's freshness, and they decide whether or not to buy the product based on their opinion of its attractiveness. (Guidi & Castigliego, 2010).The color of meat primarily comes from the red myoglobin molecules found in muscle tissue. However, there are many factors such as breed, nutrition, muscle type, postmortem changes, processing methods, and packaging that can affect meat color (Wideman *et al*., 2016).

In normal living muscle the pH is approximately 7.2 while the pH of meat can range from 5.2 to 7.0. The pH of muscle/meat is a measurement of acidity. The Glycogen is broken down to lactic acid when muscle turns into meat. The highest quality products tend to fall in the pH range of 5.7 to 6.0. The pH has a direct bearing on the meat quality attributes such as tenderness, water-holding capacity, color, juiciness, and shelf life (Mir *et al*., 2017).

### *1.9.2 Water-Holding Capacity*

Water-Holding Capacity (WHC) is the amount of water the meat can hold during the application of external forces such as cutting, heating, grinding, and pressing. When added water, including phosphates and salts, the correct term would be the water-binding capacity (Warner, 2014). Meat is comprised of about 75% water. An increase in the water content of muscles, enhancing tenderness, juiciness, firmness, and appearance; improve the quality and economical value of meat. WHC of meat can be affected by genotype, feeding, fasting and stunning (Cheng & Sun, 2010).

### *1.9.3 Cooking Loss*

Cooking loss is a combination of liquid and soluble matters lost from the meat during cooking (Marino *et al*., 2013). The cooking of meat plays a vital role to achieve a palatable and safe product since it enhances the hygienic quality of meat by inactivation of pathogenic microorganisms and to enhance its flavor, tenderness, and taste, and increase shelf life. (Kondjoyan *et al.*, 2014).Cooking loss is calculated as the percent weight difference between fresh and cooked samples concerning the weight of fresh meat samples (Jouquand *et al*., 2015).

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### 1.10 Sensory Evaluation

Sensory evaluation may be described as a scientific discipline used to evoke, measure, analyze and interpret reactions to those characteristics of foods and other materials with the use of human senses(sight, smell, taste, touch, and hearing) and sometimes in combination with instrumental methods (Ramadhan *et al*., 2012). People measure appearance, aroma, taste, texture, and sound while instruments measure the physical or chemical characteristics of a product that can relate to the sensory experience. The people (consumers) can be used in subjective consumer tests as they give a rapid response that is easy to interpret and they provide qualitative and quantitative information. They can be trained (for objective product orientated tests) and used as analytical instruments (Birwal & BK, 2015) .

The main sensory perceptions are appearance, (shape, size, surface texture, brightness), odour (smell, aroma), taste (the basic tastes), flavor (taste, aroma and trigeminal response) and texture (body, mouth feel, hardness/softness) (Ramadhan *et al.,* 2012).

## Conclusion

Insect-based feedstuffs are the alternative to high quality ingredients for chicken feeds and are promising to be locallyproduced to be incorporated in animal feeds. Black soldier flies fit in well to utilize wastes and converst them into high quality insect feed material that are alternative to the expensive fish meal.

## Conflict

The authors agree to submission of the manuscript for publication.

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