Uluslararası Tarım Araştırmalarında Yenilikçi Yaklaşımlar Dergisi
International Journal of Innovative Approaches in Agricultural Research 2019, Vol. 3 (3), 529-542
https://doi.org/10.29329/ijiaar.2019.206.17

Review article

Possibilities for the Use of Black Soldier Fly (*Hermetia illucens*) in Poultry Breeding as a Feed and Waste Utilization

Evgeni Petkov [a, *]

[a] Institute of Animal Science - Kostinbrod, Bulgaria

Abstract

Black soldier fly (BSF, *Hermetia illucens*), may be a reliable source of animal protein, fats, calcium, lysine, etc. This makes it possible the products obtained by this insect to become substitutes (partly orentirely) of the soybean and fish meal. First of all, however, different issues should be solved to react on the future increase in the demands for such kind of products as feed. This means to dramatically change the technology of manufacturing and to introduce regulatory legislative frameworks in which this industry to be developed, guaranteeing its safety for the customers. This is necessary despite the fact that in BSF larvae such preconditions due to the biological and cycle characteristics are not observed, as naturally it excludes the transfer of pathogens from the bed because of the disconnection of the composted matter at the prepupae stage. This is a result of natural migration, during which the larvae are self-cleaning mechanically and chemically, while emptying their gastrointestinal tract.

Additional reliability is also assured by the fact that the adult insect does not feed, does not lay eggs directly in the compost and is not a carrier of infectious and parasitic diseases. Since it is a natural resident of the poultry manure, it can also be successfully used for its processing, on the one hand reducing the volume, and on the other decreasing the concentration of the pathogenic microflora in it, which naturally leads to its decontamination.

In terms of origin, some drawbacks have also been identified, however, the effect of which can easily be neutralized by developing the systems used and regulating the composition of the food substrate.

Keywords: Black soldier fly (Hermetia illucens), Poultry, Protein, Substitute, Feed.

Received: 31 May 2019 * **Accepted:** 10 July 2019 * **DOI:** https://doi.org/10.29329/ijiaar.2019.206.17

* **Corresponding author:**

Evgeni Petkov, Institute of Animal Science - Kostinbrod, Bulgaria.
Email: mechovet@abv.bg

INTRODUCTION

Black soldier fly (*Hermetia illucens*) is a fly (Diptera) from the family Stratiomyidae. The adult insect is black, making similar noises to the wasps and with a body length of 15-20 mm (Hardouin et al., 2003). The larvae might reach 27 mm length, 6mm width and to weigh up to 220 g in the final stage. They have a long rounded abdomen and whitish colour (Diclaro and Kafman, 2009).

In addition to the BSF, the companies on the market deal with 3 kinds of insects, thought to be a potential protein source for the animal and human diet- the housefly (*Musca domestica*), the darking beetle (*Alphitobius diaperinus*) and the mealworm (*Tenebrio molitor*). However, only the BSF and the products which can be obtained by its life cycle fit entirely into the new legislative framework.

There are many different directions of work and they are mainly as a substitute and/ or enhancer of a feed compound due to the high content of easily digestible protein. In regard to the levels of the aminoacids that are important for the poultry, Newton et al. (2005) reported that the protein concentrate made by the BSF larvae are extremely rich of threonine (0.6% - 1.41%), valine (2.23% -3.4%), isoleucine (1.51% -2%), leucine (2.61%- 3.5%) and lysine (2.21% - 3.4%).

With the improvement of the systems and the equipment for the larvae growing, the manufacturing of the products from the latter increased drastically during the last decade as well as the possibilities to include them as a feed component in some of the most resource-consuming braches of the livestock breeding, such as the poultry breeding. Particular attention is paid to the potential of the insects as a solution for the increasing feed needs (Gahukar, 2011; Nadeau et al., 2015) and in particular concerns about global food insecurity due to climate change and / or the growing population (Van Huis, 2013; Shelomi, 2016).

BSF Life Cycle and Characteristics in Its Development

BSF is highly sustainable species capable of dealing with severe environmental conditions such as drought, shortage of feed or oxygen deficiency (Diener et al., 2011a). One great advantage of *Hermetia illucens* on other types of insects used for the production of biomass is that the imago and prepupae are not fed and therefore are not a potential carrier of diseases and pathogens coming from the compost raw material (Leclercq, 1997). Larvae are sold as pet food, fish bait, and can be easily dried for longer storage (Veldkamp et al., 2012).

Hermetia illucens is a natural resident of tropical, subtropical and temperate zones of America. The development of international transport since the Second World War has led to its naturalization in many regions of the world (Leclercq, 1997). It is widespread in tropical and more temperate regions between about 45 ° N and 40 ° S parallel (Diener et al., 2011b). For Europe it is normally found in Mediterranean countries such as Italy, Spain, Portugal and Greece. In the region of Bulgaria, it is found only in summer in the most southern parts, such as Blagoevgrad, where the fly easily migrates from the territory of central and southern Greece.

Larvae grow rapidly by consuming large quantities (from 25 to 500 mg per larva per day) of a wide range of organic fresh and decomposable materials such as decaying fruits and vegetables, coffee bean pulp, ethanol grain waste, animal manure and human excreta (Hardouin et al., 2003; Diener et al., 2011a; van Huis et al., 2013). Under ideal conditions, the development cycle lasts up to 2 months, but in case of malnutrition or lower temperature, the cycle may stretch up to 4 months. At the end of the larva stage (prepupa), the larva empties its digestive tract and stops feeding by starting preparation for migration (Hardouin et al., 2003). Then, the prepupae migrate in search of a dry and protected area for pupation (Diener et al., 2011b).

The duration of the pupation stage is about 14 days, but can be extremely variable and last up to 5 months (Hardouin et al., 2003). Female flies mate two days after hatching and lay in dry cracks and cracks adjacent to the potential source of food for worms (Diener et al., 2011a). Adults do not eat and rely on the fat accumulated by larvae (Diclaro et al., 2009).

Several methods have been developed for growing BSF depending on the different substrates used, such as pig manure (Newton et al., 2005), poultry manure (Sheppard et al., 1994) and food waste (Barry, 2004). Growing equipment use the instincts for migrating of the prepupae to capture them. Prepupae have a natural instinct to migrate outside the compost- they climb up the ramp into the container in which they grow to fall into a collecting vessel attached to one of the ends (Diener et al., 2011a).

Optimum conditions for BSF breeding include a narrow range of temperature and humidity, as well as appropriate levels of hardness, viscosity and water content in the food substrate. The temperature should be kept between 29°C and 31°C, although it may develop in a wider range, but the temperature of the compost should not fall below 24°C and exceed 42°C (Sheppard et al., 2002). Relative humidity should vary within a narrow range of between 50% and 70%. Higher relative humidity makes the diet too damp and the larvae can crawl on it, trying to obtain an adequate supply of oxygen (Barry, 2004).

It is also necessary to maintain a parental colony of adult insects (imago) all year long for breeding purposes in a greenhouse with access to natural light. The greenhouse must be at least 66 m^3 in order to ensure the minimum requirements of the whole airborne process (Barry, 2004). The maximum and optimum temperatures according to Sheppard et al. (2002) for mating and egg laying are respectively from 24 °C to 40 °C and from 27.5 °C to 37.5 ° C. Wide ranges of relative humidity are reported by some authors, such as 30-90% (Sheppard et al., 2002) or 50-90% (Barry, 2004). At the time of egg laying, it is necessary to have a container in the greenhouse, humid environments to attract older females to bring their eggs into baits previously prepared for this purpose (Barry, 2004).

The BSF larvae are used both live to feed fish and poultry, as well as in cut or dried state. Attempts were made to create defatted meal by grinding and pressing the larvae to allow draining of the intracellular fat (Kroeckel et al., 2012).

Fish Meal Substitute

Some authors are working to prove the possibilities of the larvae of the BSF to substitute for other rather expensive animal products such as fish meal and dry whey, which, however, due to some peculiarities cannot be used in large amounts. For example, in the study of Elwert et al. (2010), we observe similar trends confirming that the weight of broiler chickens (Ross 308) fed different diets containing between 4.7% and 6.6% of the BSF larvae is comparable to the weight of chickens fed a diet containing 3% fish meal as a source of animal protein.

According to Cullere et al. (2016), the addition of BSF larvae does not adversely affect the taste of breast meat. However, there is more recent data from the same author about increase the levels of not so desirable saturated and monounsaturated fatty acids in meat obtained from broilers by eating a diet containing the larvae of the BSF (Cullere et al., 2017). Similar effects have not been established by other authors about the use of defatted BSF larvae as it reduces the negative impact on the fatty acid profile of the meat obtained (Schiavone et al., 2017).

In both cases, the authors conclude that the larvae of the BSF are a promising source of protein for feeding birds by providing satisfactory values of the principal zootechnical and slaughter indices, while at the same time not impairing the quality of the meat obtained (Cullere et al., 2016; Cullere et al., 2017; Schiavone et al., 2017).

The percentage of protein in the defatted meal of the BSF after the chemical extraction of fat is comparable to most fish meals. Such a product type is not as rich in sodium, phosphorus and chlorides, which is a disadvantage of fishmeal. Considering the high content of lysine (which is important in poultry breeding), most authors (Makkar et al., 2014; Diener et al., 2009) are of the opinion that the products of the BSF larvae are able to compete the nutritional qualities of fish meal, turning into somewhat better substitute.

According to Spranghers et al. (2017), this is the result of the recently introduced methods for chemical defatting of BSF larvae, resulting in the final product being able to reach protein content above 60% with no significant concentration of residual lipids.

Soybean Meal Substitute

The meal made of the BSF larvae may be used in poultry feeds to partially or completely replace feed components such as corn or soybeans (Bradley et al., 1984). Hale (1973) proved that broiler chickens fed with corn soybean mixture (65%: 35%) and those fed with a mixture containing 35% of the larvae of BSF (65%) have the same rate of growth. In later studies of Schiavone et al. (2016), it has been confirmed that the addition of a similar product is a promising source of protein in the preparation of poultry feeds, concluding that the inclusion of the BSF larvae can guarantee satisfactory performance indicators, even if the soybean meal is completely replaced in laying hens' feed without any negative effects on the health or performance of the hens. According to a similar study by Maurer et al. (2016), even a slight effect on egg productivity was observed.

In general, the nutrients (fats and proteins) from the substrate are concentrated in the insects (Spranghers et al., 2017), with the increase in final product values reaching more than 10 times the values of the primary raw material (especially in the non-fatty residue). The percentage of protein in larvae or prepupae meal is comparable to that of other feed additives of plant origin, and the percentage of crude fat is higher than most fish meals and soybean meals known in the market (Diener et al., 2009; Makkar et al., 2014).

Processing the Manure

The use of insects in agriculture or, more precisely, their cultivation on manure may increase its value and, possibly, its exploitation. In spite of a wide variety of insects that could potentially be used for the processing of manure, according to Sheppard et al. (1994), Diener et al. (2009), Caparros Megido et al. (2015) only *Hermetia illucens* are able to meet the hygienic requirements for a similar type of production that is guaranteed to be safe in the direct application as a feed additive for animal feed.

BSF larva is one of the most common variants of the last few decades (Sheppard et al., 1994; Newton et al., 2005). This is due to some peculiarities in the fertilization and cycle that affect the actual conversion of manure from livestock breeding or green plant mass into an animal-friendly product containing approximately 40% protein and 35% fat (Myers et al., 2008; van Huis, 2013). This is due to the acidification of the compost, which has been reported by a number of authors (Sheppard et al., 2002; St-Hilaire et al., 2007b; Sheppard et al., 2014; Nyakeri et al., 2017) since it is known that the low pH (below 5.5) in the feed substrate hinders the development of most pathogenic microorganisms, conditionally pathogenic microorganisms, fermentation processes, and the development of competing species such as house fly.

According to some authors (Diener et al., 2009; van Huis, 2013) BSF larvae are the most useful chicken feed because they contain extremely high levels of fatty acids such as lauric acid (21% of total lipids), palmitic (16% of total lipids), oleic acid (32% of total lipids) and ω-3 fatty acids (FA, 0.2%) (Gnaedinger et al., 2015; Makkar et al., 2014). However, according to St-Hilaire et al. (2007a), the final levels of individual fatty acids can be easily manipulated depending on the nutrient substrate used.

Disadvantages

Non-homogeneity of the nutritional composition for individual batches of larvae and prepupae meal - inconsistency of the chemical composition in the various batches of dried larvae, especially with respect to protein and fats, according to most authors (Newton et al., 2005; Diener et al., 2009; St-Hilaire et al., 2007a; Sheppard et al., 2014; Spranghers et al., 2017). It is influenced much by what the larvae consume during their lifetime. Some authors (Oonincx et al., 2015) believe that the use of higher protein substrates results in a higher concentration of protein in the larvae of the BSF, but the same is not observed for fat since the increase in concentration of the fat in the food substrate does not lead to an increase in the fat concentration in the final products.

There are many sources of variation, even in experimental models of extraction of protein from the BSF larvae. Methods used to extract proteins from the larvae or prepupae (Liu et al., 2017), no matter if the final values include chitin protein (within the range of 2% to 5%, according to Spranghers et al., 2017) may influence the results of the nutrient values in the final product (Bussler et al., 2016). By adjusting the protein content according to Spranghers et al. (2017), it is advisable to eliminate the chitin content.

Differences in protein content between batches that come from differences in feeding of the BSF larvae can be quite stark. For example, some authors (Krockel et al., 2012; De Marko et al., 2015) report the final protein and fats in BSF larvae (owned by the same company) ranging from 31.7% to 47.6% and 11.8-34.3%, respectively. According to Zhou et al. (2013), the genotype of the various BSF lines in the world additionally contributes to such a difference in end products.

Eventually, Nyakeri et al. (2017), consider that the mean values of the main nutritional components of BSF larvae meal to be taken for both cultivated lines and wild specimens are 40.8 ± 3.8% and 28.6 ± 8.6%, respectively for the protein and fat.

Another disadvantage of the BSF is its high energy and water consumption in countries with moderate continental climate. The minimum temperature requirements of the BSF are about 24°C, which makes the production in the colder parts of Europe a very energy-consuming process. Also, the life cycle varies from a few weeks to several months, depending on the temperature, the quality and the quantity of the food (Veldkamp et al., 2012). High temperature reproduction requirements for the adult form of BSF (28-32°C - according to Sheppard, 1983 or 30°C - according to Yu et al., 2014) further contribute to this. This has to be done in tropical and sub tropical countries to be profitable.

BSF has strong need for fresh water and a wastewater management system for growing in countries with a drier climate and shortage of water. The production of BSF larvae also has great water needs as the content of water in waste should not be lower than 70% (Yu et al., 2014). In addition, a drainage system is required to remove stagnant fluid from the work rooms that is released during nutrition of larvae with juicy nutrient substrates (Diener et al., 2011b).

Prospects and Challenges

Major obstacles to the sector are the establishment of regulatory mechanisms in the EU and the development of new production technologies. For this purpose, it is not only necessary to review the role of insecticide-compatible components, but also their derivatives within a comprehensive sustainable protein strategy. This would also mean going beyond the topic by looking for combinations with other persistent protein sources - such as algae, plant waste high-protein shrubs, as well as the involvement of technology companies. Different players are required here: food and feed businesses, research centers in the field, technology players who could actually help analyze the different ways to automate these processes. This would significantly improve the efficiency and productivity of human work in them.

In some of the countries with tropical climate, the wild forms of the BSF have long been used as a means of successfully managing manure and human faeces (Sheppard et al., 2002), reducing the smell and insect populations (Sheppard, 1983). In fact, in those parts of the world, *H. illuscens* is local species and is actively used throughout the year, and no special facilities are required to hold a large number of larvae or breeding flocks. In tropical countries open systems are used to allow flies to colonize the poultry or other manure in the farm, while providing a pathway for removing the bumps from the compost mass during their natural migration (St-Hilaire et al., 2007b; Sheppard et al., 2014; Nyakeri et al., 2017). This, according to Mutafela (2015), can be accomplished by simply spraying the pre-prepared food substrate on the floor of the structure and waiting for flies to come in to bring the eggs to specially prepared eggs or egg traps.

Home farming systems are one of the possibilities for insect breeding because "mini-animals" can be grown on far less space than mammals or birds (Ferreira et al., 1995; Paoletti, 2005). The future of insects and their farming as animal feed, however, depends on the systems of growing in the industry. For the time being, there is a lack of adequate logistics and capacities for the supply of insect feed additives worldwide, relying on the fact that gradual supply often leads to the gradual and gradual acceptance of novel foods from the relevant markets (Paoletti, 2005). While according to Maurer et al. (2016), production of larvae from BSF and other insect products does not reach large quantities, they will not be available as feed, as their delivery will always be a problem and this necessitates the first step to be done by and on behalf of the industry.

At present, the expansion of the branch is achieved by increasing the production area, which, of course, is not the right way. This old tactic has been successfully implemented so far, due to the small volumes of production. In an opening of the insect market as a consequence of lifting the ban on using the insects as a feed component, the lack of mechanized solutions will lead to worker hunger in the sector and the industry's inability to respond to demand.

Various low-cost cultivation systems, such as CORS (Saprophage Organic Residue Remodeling), have been developed for the use of organic waste substrates to feed their BSF larvae (Diener et al., 2009; Aldana et al., 2016). The only advantage of these systems is that no new facilities or buildings are required (Sheppard et al., 2002; Sheppard et al., 2014), however, they would not be able to respond in the near future to a sharp increase in production.

BSF larvae pilot and full scale industrial plants have been tested and established as effective, but technical issues to increase existing BSF larvae systems are still ongoing, although there is still no question of ways to standardize production and produce (Azagoh et al., 2015; Čičková et al., 2015; Pastor et al., 2015). Scientists have yet to open the topic of introducing the long-awaited reactor-type system to replace the existing batch types of BSF farming systems up to now.

Legislation of new products

After years of insecurity for the insect sector, the new European legislation, adopted two years ago on innovative food ingredients, has firmly included insects into its legal scope. According to it, insects and their derivatives are "unregulated innovative food ingredients" for the European legislation if they were not used in the EU before 1997. Now companies that already offer insects and their products for feed or human use on the Community market have two years to submit the documents for approval of the products they are developing.

At an earlier stage, some rules also existed, with the EU and Bulgaria regulated by Regulation (EC) No 999/2001 adopted on 2 May 2002. According to the legal framework, insect protein can only be used to feed fish, pets, fur animals and zoo animals (www.babh.government.bg). According to some non-governmental organizations such as IPIFF (International Platform of Insects for Food and Feed), a change in EU legislation to allow the use of insects in feed for poultry and pigs is expected by the end of 2020.

As far as international bodies are concerned, insects are not included in the United Nations Codex Alimentarius, with the exception of food additives (Van Huis et al., 2013b). This is also a problem in the US, where insects are described as a "defect" that can only be found in foods until a certain point but not explicitly indicated as food (FDA, 2010). However, to date, insects are sold in the US and other countries, such as new products for humans and animals (www.labs.russell.wisc.edu).

Still, the perception of the law as an unwanted ingredient in food is an obstacle to introducing market regulation of this industry, leaving products of BSF or any other insect in the gray sector (Shelomi, 2015). While insects are not added to Codex Alimentarius as food and not just as impurities, they will have considerable difficulty in becoming legally marketed food, regardless of how consumers perceive it.

No regulation has been set up on how different food substrates can be used for BSF food, as it can process a very wide range of organic materials, including animal manure, kitchen waste and agricultural waste. Some of these wastes do not have a market price, such as rice straw, which is high in lignin and pulp, which is why they do not matter as a feed material for livestock and pose a challenge because of their inclusion in the economy and legislation on the one hand as waste as a raw material (Zeng et al., 2012; Manurung et al., 2016).

Some of these wastes, such as fecal masses and litter, are also potentially biologically hazardous pollutants according to the law, although they can be processed quite successfully by the BSF larvae. This will create regulatory problems for such type of production that will involve them in taking responsibility for the safety of the final products and the issues of regulation of the proposed food from animals fed with similar feed components (Maurer et al., 2016). Areas such as Europe, where there are no traditions and policies in this direction and which prioritize risk avoidance (Knowles et al., 2007; Siegrist, 2008; Shelomi, 2015; Laurenza and Carreno, 2015), impose stricter rules on insects as a "novel food" to be considered before insect-stuffed products are placed on the market (EPCEU Regulation EU 2015/2283).

In the publicly available UN database of food and agriculture worldwide, by 2017 there was only one text that specifically mentions BSF. The Regulation (EU) 2017/893, issued by the European Commission on 17 May 2017, lists seven species of insects currently grown in the European Union, including *Hermetia illucens*. Also some safety conditions for the production of insects as pet food and pets are introduced:

- they must not be pathogenic or have other adverse effects on the health of plants, animals or humans;
- they should not be recognized as carriers of human, animal or plant pathogens and should not be protected or identified as invasive alien species.
- In the aforementioned Regulation, there are also restrictions on the substrates with which the larvae of these insects can be fed:
- substrates must contain products of non-animal origin;
- a limited set of animal products that include fishmeal, melted fats, blood and non-ruminant gelatin, milk, eggs, honey, etc. waste).

Any other forms of waste are expressly prohibited under Regulation EU 2017/893.

These limitations eliminate the risk of prion contamination of BSF larvae but significantly restrict its use when closing food chains and reaching a waste-free production.

Conclusion

We can conclude that the BSF can be used as a reliable source of animal protein capable of replacing partially or wholly soybean meal and fishmeal. Also due to the peculiarities of its life cycle, the larval form can reduce the waste products in production and the concentration of the pathogenic microflora in them, due to its nuisance to the food substrate and the influence of the low pH of the substrate it causes. On the other hand, the particularities in its biological cycle exclude the transfer of pathogens due to disruption of the composition of the compost material at the stage of prepupae due to natural migration and emptying of the gastrointestinal tract. For additional reliability contributes also the fact that the adult form does not feed, does not hatch in compost, is not a carrier of infectious and parasitic diseases.

In terms of origin, some drawbacks have also been identified, however, the effect of which can easily be neutralized by developing the systems used and regulating the composition of the nutrient substrate. Such shortcomings are inconsistency in the chemical composition of the batches due to the influence of the food substrate on the final product and unfavorable fatty acid composition that is largely determined by the composition of the food substrate, the high energy and water consumption of production.

Despite the characteristics of this production, it would be necessary to take several important steps, namely: to develop new types of reactor systems through close cooperation between R & D centers, corporations and interested manufacturing enterprises; to introduce regulations and legal frameworks through which future companies developing in this niche market can offer their products so that their customers can be assured of their security.

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