Sustainable Aquaculture Innovation: The Role of Black Soldier Fly in Fish Feed

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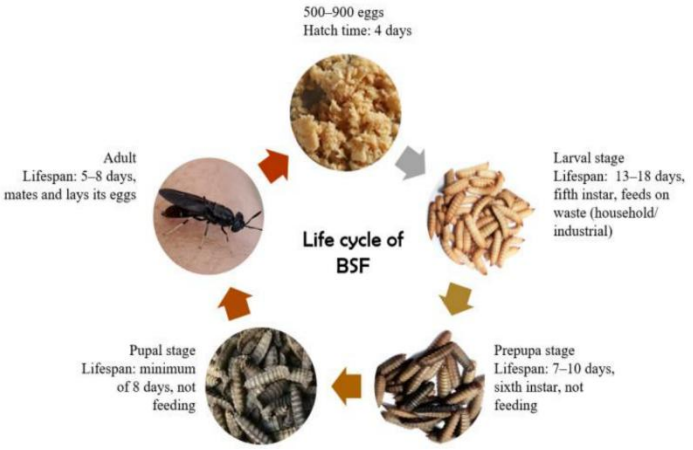
Introduction

Aquaculture is a major food producing sector which requires large quantities of fish meal and fish oil for aqua farming. Fish meal and fish oil consists of valuable natural nutrients such as proteins, amino acids and fatty acids. However, based on the nutritional qualities fish meal and soya meal have been recognized as a rich source of protein in aquaculture till date (Sánchez-Muros *et al*., 2014). Most importantly, the usage of fish meal in aquaculture has been replaced with alternate protein sources due to their production cost, demand of raw materials and various environmental issues. The insect black soldier fly (*Hermetia illucens*) larval (BSFL) meal is being recognized as a feed ingredient in aquafeeds for their protein rich content similar to fish meal (FM). BSFL meal has been utilized as a fish meal or soy meal substitution in aquaculture to improve the nutrition (Kannan Mohan,2022). The black soldier fly is often associated with the outdoors and livestock, usually around decaying organic matter such as animal waste or plant material. Since the black soldier fly larvae consumes decaying matter, they have been used to reduce animal manure in commercial swine and poultry facilities (Newton 2005). Although they are not known as a disease vector, adult soldier flies are a potential mechanical vector of various pathogens.

The life cycle of Black Soldier Flies showcases their efficiency in waste conversion and protein production, making them invaluable for sustainable farming. It begins with females laying eggs near decaying organic matter, providing food for larvae that hatch within 3–4 days under ideal conditions. The larval stage, lasting 14–18 days, is the most critical, as larvae consume large amounts of organic waste, transforming it into protein and biofertilizer. Afterward, the pupal stage, lasting 5–10 days, facilitates the metamorphosis into adults, which live for 5–8 days and focus solely on reproduction, relying on energy reserves from the larval phase. By optimizing conditions for each stage, farmers can ensure continuous production and maximize the benefits of this sustainable system.



(Maglangit, F.; Alosbanos, R.S, 2022)

The Role of Black Soldier Fly in Aquaculture

Alternative Protein Source

Black Soldier Fly (BSF) larvae are an excellent source of high-quality protein, making them an ideal ingredient for animal feed. They are rich in essential amino acids, fats, and micronutrients, which are crucial for the growth and health of livestock, poultry, and aquaculture species. Studies have shown that BSF larvae contain protein levels ranging from 35–50% on a dry matter basis, alongside beneficial fats and minerals, such as calcium and phosphorus, which enhance the nutritional profile of feed products (Makkar *et al*., 2014). Their production is also environmentally sustainable, as larvae efficiently convert organic waste into biomass, reducing reliance on traditional feed sources like soy and fishmeal.

Black Soldier Fly Larvae (BSFL) have shown great potential as a sustainable alternative to fishmeal in aquafeed, providing comparable nutrition while supporting the growth and health of fish and shrimp. BSFL are rich in essential proteins, lipids, and micronutrients, meeting the dietary requirements of aquaculture species. Research has demonstrated that BSFL-based diets can replace fishmeal partially or completely without negatively impacting growth rates, feed conversion ratios, or overall health in species such as tilapia and shrimp (Henry *et al*., 2015). Moreover, BSFL contain antimicrobial peptides and lauric acid, which can enhance immunity and disease resistance in aquatic organisms. By reducing

dependency on fishmeal, BSFL not only alleviate pressure on wild fish stocks but also promote more sustainable and cost-effective aquaculture practices.

Sustainability

Black Soldier Fly Larvae (*Hermetia illucens*) have demonstrated exceptional efficiency in transforming organic waste into high-value nutrients suitable for various applications. They serve as a sustainable source of protein and essential nutrients for pet foods, aquaculture, and poultry feeds, supporting animal growth and health. Additionally, the residue left after larval digestion acts as a nutrient-rich fertilizer, enhancing soil quality and fertility. This dual-purpose system makes BSFL an eco-friendly solution for waste management and agricultural productivity (Siddiqui *et al*., 2022; Surendra *et al*., 2020).

Nutritional Aspects of Black soldier Fly Larvae

Composition

The composition of Black Soldier Fly Larvae (BSFL) makes them an ideal sustainable and nutritionally rich feed ingredient for aquaculture. With protein content ranging from 40–50%, BSFL provide highly digestible protein, including essential amino acids like lysine, methionine, and threonine, which are critical for growth and health in fish and shrimp. Their protein has a high biological value, supporting muscle development and balanced nutrition when used to replace fishmeal. Additionally, BSFL contain 25–30% lipids, offering a dense energy source, particularly through medium-chain fatty acids like lauric acid, which has antimicrobial properties that enhance disease resistance and promote gut health. BSFL also provide essential micronutrients such as calcium, phosphorus, magnesium, and trace elements like zinc, iron, and manganese, supporting skeletal development, immune function, and metabolic processes. Moreover, their fiber and chitin content, though minimal, supports gut health and may act as an immunostimulant, further enhancing their potential in aquaculture nutrition (Van Huis *et al*., 2013).

Black soldier fly (BSF) larvae (*Hermetia illucens*) are gaining attention as a nutrient-dense and sustainable protein source for animal feed. Their nutritional profile is influenced by various factors, including the larvae's diet, stage of development, and rearing environment.

Proximate Composition of Black soldier fly

Crude Protien: Black soldier fly (BSF) larvae generally consist of 35–45% crude protein on a dry matter basis, though some research has documented levels as high as 63% (Lu *et al*., 2022).

Fat content: The fat content of black soldier fly (BSF) larvae typically ranges from 15–35%, depending on their diet (Liland *et al*., 2017).

Ash content: The ash content of black soldier fly (BSF) larvae, which reflects their mineral composition, ranges from 9% to 28%.

Amino acid profile: Black soldier fly (BSF) larvae offer a balanced amino acid profile, containing vital amino acids like lysine, methionine, and threonine, which makes them an excellent choice for animal nutrition (Lu *et al*., 2022).

Mineral content

Calcium and Phosphorus: Black soldier fly (BSF) larvae are rich in calcium (5–8%) and phosphorus (0.6–1.5%), which are essential nutrients that support healthy bone development in animals.

Vitamins: Black soldier fly (BSF) larvae are a natural source of essential vitamins, including riboflavin (B2), pantothenic acid (B5), and biotin (B7). Their vitamin content can be further enhanced through dietary adjustments, such as adding seaweed to their feed, which has been shown to boost vitamin E levels.

Benefits of BSF in Aquaculture Nutrition

Black soldier fly (BSF) larvae (*Hermetia illucens*) present numerous advantages in aquaculture nutrition, making them a viable and eco-friendly substitute for conventional feed ingredients.

(1) Nutritional Profile

High Protein Content: Black soldier fly larvae (BSFL) are an excellent source of protein, offering amino acid profiles similar to those found in fish meal. This makes them essential for supporting the growth and overall health of aquaculture species.

High Fat Content: The larvae are packed with valuable lipids, such as lauric and palmitic acids, which play a vital role in meeting the energy requirements of fish and promoting their overall well-being (Wang *et al*., 2017).

(2) Sustainable Production- Black soldier fly larvae can thrive on a wide range of organic waste,

making them an eco-friendly option while serving as a sustainable source of protein.

(3) **Economic viability-** Incorporating black soldier fly larvae into feed can help cut production expenses, as they can be locally sourced and lessen the dependence on costly conventional feed ingredients.

(4) **Positive impact on growth performance-** Research indicates that including black soldier fly larvae in aquafeeds promotes healthy growth and efficient feed utilization in farmed animals (Surendra *et al*., 2016)

Production process of black soldier fly larvae

(1) Feeding on Organic Waste

The first stage in farming black soldier flies involves feeding the larvae organic waste, such as food scraps, agricultural by-products, or manure. These larvae excel at efficiently digesting and breaking down a wide range of organic materials, including those unsuitable for human consumption (Diener *et al*., 2011).

Choosing the Right Substrate

Organic waste is selected based on its availability and compatibility with the larvae's needs. Commonly used substrates include fruit and vegetable scraps, slaughterhouse waste, and leftover food.

Maintaining Optimal Conditions

For the larvae to thrive, their environment should be carefully managed. Ideal conditions include temperatures between 25–30°C and humidity levels of 60–70%, which support efficient feeding and rapid growth (Tomberlin *et al*., 2002).

Advantages of Using Organic Waste

Feeding BSFL with organic waste offers a dual benefit: it provides the larvae with a sustainable nutrient source while significantly reducing waste buildup and cutting down on methane emissions from landfills.

(2) Transforming Waste into Nutrient-Rich Biomass

Throughout their larval stage, black soldier fly larvae consume organic waste and transform it into a nutrient-dense biomass rich in protein, fats, and other essential nutrients.

Bioconversion Efficiency: BSFL are remarkably effective at breaking down organic material, capable of reducing waste by 50–70%, depending on the type of substrate used (Van Huis *et al*., 2013).

Nutritional Value

The biomass produced by the larvae typically comprises 40–50% protein and 20–30% fat, making it a highly nutritious and sustainable alternative to traditional feed ingredients like fishmeal and soybean meal (Makkar *et al*., 2014).

Beneficial By-Products

The leftover material after the larvae processes the waste, known as frass, is a nutrient-rich organic fertilizer that can enhance soil health (Gold *et al*., 2020).

(3) Harvesting, Drying, and Processing

When the larvae mature, typically within 14–18 days, they are harvested and processed to produce high-quality feed ingredients.

Harvesting Techniques

Larvae are separated from their substrate using mechanical methods, such as sieves, ensuring efficient collection.

Drying and Processing Methods

To prevent spoilage, the harvested larvae are dried using methods like oven-drying or sun-drying to reduce moisture content. After drying, they undergo grinding and defatting to produce protein-rich meal (Barroso *et al*., 2014).

End Products and Their Uses

The processed larvae yield several valuable products, including BSF meal as a protein source, BSF oil for energy, and functional feed additives derived from BSF to promote better animal health (Henry *et al*., 2015).

Health and Performance of Aquatic Species Fed with BSF Larvae

Black Soldier Fly larvae (BSFL) have gained recognition as an effective and sustainable feed option in aquaculture due to their excellent nutritional content. Numerous studies have explored how BSF larvae affect the growth, survival, and overall health of fish and other aquatic species.

(1) Growth and Survival Rates

Studies show that fish fed with BSF larvae achieve similar or even better growth compared to those given traditional feed like fishmeal or soybean-based diets. The high protein levels and essential

amino acids in BSF larvae are critical for the proper development and well-being of aquatic animals.

Growth Performance

Research on species such as tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus*) indicates notable improvements in weight gain and feed conversion efficiency (FCE) when BSF larvae are part of their diet (Gasco *et al*., 2016).

Survival Rates

Fish that consume BSF larvae also display high survival rates, with studies confirming that there are no negative effects on their health, even when BSF meal constitutes up to 50% of their total feed (Kolawole and Mustapha, 2023).

Health and Disease Resistance

Fish that are fed BSF larvae generally exhibit improved health and greater resistance to diseases compared to those on traditional diets. This is due to the beneficial nutritional profile of BSF larvae, which supports immune function and overall vitality.

Immune Function

Several studies indicate that BSF larvae can enhance the immune response in fish. For example, fish given diets with BSF meal showed higher antioxidant levels and stronger immune defenses, which help them fight off diseases (Makkar *et al*., 2014).

Disease Resistance

In one particular study, fish fed with BSF larvae demonstrated better resistance to bacterial infections, likely due to the presence of bioactive compounds found in the larvae (Wang *et al*., 2017).

Regulatory Hurdles and Safety Concerns in BSF Larvae as Fish Feed

While Black Soldier Fly (BSF) larvae hold great potential as an alternative feed source in aquaculture, there are several challenges that need to be addressed regarding their safety, quality, and regulatory approval. One major concern is the potential presence of contaminants in the organic waste used to feed the larvae, such as heavy metals or harmful pathogens, which could compromise the safety of the larvae as feed. Additionally, regulatory barriers exist in many regions, as BSF-based products must meet certain certifications before they can be considered safe for use in aquaculture, and the lack of standardized quality control measures may slow down their commercialization. While short-term studies have shown positive results, more long-term research is needed to better understand the full effects of BSF larvae on fish diets, especially in terms of nutrient absorption, growth, and overall health. To unlock the full potential of BSF larvae in aquaculture, further research and the development of clear regulatory guidelines are essential.

The Promising Future of BSF Larvae in Aquaculture

The future of Black Soldier Fly (BSF) larvae in aquaculture looks promising, driven by ongoing advancements in BSF production technologies designed to enhance efficiency and scalability. Innovations in rearing systems, such as automated feeding, improved environmental controls, and large-scale bioconversion methods, are making BSF farming more cost-effective and sustainable. As these technologies continue to improve, the potential for BSF larvae to be integrated into mainstream aquaculture practices is growing, particularly as a replacement for traditional fishmeal and soy-based feeds. The scalability of BSF farming presents a significant opportunity for regions experiencing rapid population growth and increasing demand for sustainable food sources, especially in areas like Asia and Africa, where organic waste management and protein shortages are major concerns. However, for large-scale adoption to succeed, challenges such as regulatory hurdles and certification processes must be addressed, along with ongoing research into the long-term effects of incorporating BSF larvae into fish diets.

Conclusion

Black Soldier Fly (BSF) larvae are quickly becoming a transformative solution for sustainable aquaculture, offering an alternative to traditional feed ingredients like fishmeal and soy. Packed with high levels of protein, fats, and essential nutrients such as amino acids, vitamins, and minerals, BSF larvae serve as an ideal replacement for fishmeal in aquafeeds. This shift helps alleviate pressure on wild fish populations and addresses environmental concerns by transforming organic waste into valuable biomass, offering an eco-friendlier option.

Moreover, using BSF larvae supports cost-effective and sustainable farming by improving fish health, growth, and disease resistance. While there are some regulatory and safety issues that still need to be explored, the ongoing development of BSF farming

technologies and their potential integration into mainstream aquaculture holds great promise for creating more resilient, sustainable, and affordable farming practices. With further progress and clearer regulatory frameworks, BSF larvae have the potential to reshape the aquaculture industry and play a significant role in global food security in the near future.

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