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THE BLACK SOLDIER FLY: THE TINY INSECT POWERING THE FUTURE OF FOOD AND FUEL

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Abstract

One of the most promising insect species for industrial, animal nutrition and sustainable waste management is the black soldier fly (BSF), *Hermetia illucens* (Diptera: Stratiomyidae). Adult BSF flies do not feed, bite or spread illness like pestiferous flies do. Food scraps, animal dung and agro industrial waste are all broken down by their larvae (BSFL), who turn them into biomass and frass that are high in protein and fat. The larvae have a high calcium content, useful medium chain fatty acids such lauric acid, 40–50% protein and 25–35% fat on a dry matter basis making them nutritionally important. These characteristics have made it possible to use them as animal feed for livestock, poultry and aquaculture. Beyond feed, BSF larvae yield chitin, antimicrobial peptides and biodiesel precursors.

Key words: Biodiesel, Black soldier fly, Insect protein, Organic waste management.

Introduction

With the world population expected to reach nearly 10 billion by 2050, a significant challenge arises in providing sustainable food for both people and animals while preserving natural resources. Conventional cattle production produces a lot of greenhouse gasses and needs

a lot of land, water and feed. As a result, finding environmentally suitable substitute proteins has emerged as a top scientific concern worldwide.

The black soldier fly (*Hermetia illucens*) has shown to be an unexpected remedy. Adult BSFs don't bite or carry disease like pest flies do and their larvae are good at recycling organic waste. They produce nutrient rich protein and fat from manure, leftover food and agricultural waste. This procedure transforms trash into value, embodying the circular economy. Because of their superior nutrition, BSF larvae (BSFL) are already utilized in aquaculture and poultry feed. They are similar to meat and fish in that they include fat, protein and necessary amino acids.

Their potential for human ingestion is currently gaining attention which will support global entomophagy trends. Globally, more than 2,000 insect species are consumed and BSFL may soon follow suit. They are perfect for large scale farming because of their versatility, quick development and self harvesting nature. In the end, the black soldier fly represents ethical, circular and sustainable food production.

Life Cycle of the Black Soldier Fly (*Hermetia illucens*)

Under warm tropical conditions, the Black Soldier Fly (BSF) goes through a complete metamorphosis with four main phases in its life cycle: egg, larva, pupa and adult. The cycle takes roughly 40 to 60 days to complete. Every step is crucial to the insect's growth and its part in the recycling process of nature.

Egg

A few days after mating, the female Black Soldier Fly produces 400–500 small eggs, marking the start of the fly's life. These rice grain like, cream colored eggs are typically found in clusters in cracks, fissures or next to organic debris that is decomposing. Instead of standing directly on waste, the female prefers dry areas near it. The eggs get darker as they get older and right before they hatch, they have a tiny black mark. Minute larvae emerge and start feeding as soon as the incubation phase which lasts approximately four to five days is over.

Larval

The BSF life cycle's most active and fruitful stage is the larval stage. The freshly hatched larvae have a little black head, a pink, curved mouth hook, soft bodies and are segmented and pale white in colour. They avoid rigid, fibrous materials like cellulose and lignin, but they are ravenous decomposers that feed voraciously on decomposing organic matter including manure, kitchen trash and other biodegradable materials. Larvae grow quickly to a length of 25–27 mm

during this stage which usually lasts 18–24 days. They have fine body hairs and turn pale brown toward the end of this stage. The effective waste recyclers found in nature, BSF larvae transform a lot of garbage into biomass that is high in nutrients. They contain around 40–45% protein and 25-35% fat making them an excellent and sustainable source of animal feed.

Prepupa

When the larvae reach the prepupal stage, they cease feeding and start to move away from the feeding area in pursuit of a dark and dry location to pupate. Large quantities of fat are stored during this time for usage later on in the non feeding pupal and adult stages. By the end of the about six to eight day prepupal phase, the insect's body has darkened in preparation for transformation.

Pupa

The prepupa sheds its skin and transitions into the pupal stage after locating a suitable dry location. The pupa has a dark, hardened exterior shell and is fully immobile, much like the prepupa. The insect experiences a tremendous transformation inside this shell. The fat reserves that were stored during the larval period provide all of the energy required for this transition. The larva transforms into a fully grown adult fly during this stage, which lasts roughly 10 to 14 days.

Adult

The life cycle of the BSF is completed when the adult emerges at the conclusion of the pupal phase. Adults are thin, wasp like flies with light yellow legs and black bodies. Males tend to look more bronze in color, while females usually have crimson abdomens. Adult flies only sip water and live for five to eight days, unlike their larval counterparts. Their only goal during this short period is to mate and procreate in order to start the next generation. One of nature's most helpful insects, adult BSF are safe for people because they don't bite or carry illness.

Nutritional Value

A sustainable, nutrient rich source of protein and fat, black soldier fly (*Hermetia illucens*) larvae can compete with or even outperform conventional feed sources like fishmeal and soybean meal. Depending on the raising substrate and processing technique, their crude protein composition varies from 40 to 50% and their lipid content from 25 to 35% (dry matter basis). They include vital amino acids that promote muscle growth and metabolism, including leucine, lysine, valine and histidine. They have antibacterial and energy boosting properties because to their medium chain fatty acids particularly lauric acid. Additionally, the larvae offer a healthy

proportion of unsaturated and saturated fats, which facilitates the absorption of nutrients. They improve immune and bone health since they are rich in minerals including calcium, phosphorus, magnesium, zinc and iron.

The nutritional value is further enhanced by vitamins B_1, B_2 and C. Their exoskeleton contains chitin and chitosan which function as bioactive fibres with antibacterial and antioxidant properties. Cellular repair is aided by nucleotides like uridine monophosphate and inosine. Larvae raised on garbage have a higher fat content, whilst those raised on manure have a higher protein content. Processing techniques maintain quality while having a minor impact on composition. All things considered, BSF larvae are a dense, safe and environmentally friendly source of protein that is perfect for aquaculture, livestock and future human diets, all of which promote a sustainable biocircular economy.

Rearing of BSF

Breeding, larval rearing, and processing are the three stages of BSF rearing.

Breeding:

- Adults require roomy flight cages with either artificial or natural light for mating.
- Water is supplied by misting devices.
- Females lay their eggs in cardboard flutes that are placed near damp substrates.

Larval Rearing

- Examples of substrates include food waste, manures and agro industrial waste.
- Plastics and hazardous elements shouldn't be found in waste.
- Substrates are ground into a fine powder before being inoculated with larvae.
- Each container holds 5,000–10,000 larvae depending on the system's size.

Processing

- Mature larvae must be harvested, cleaned and dried in order to be converted into meal or oil.
- Grass is packaged as fertilizer after being cleaned.

Optimized rearing conditions:

A temperature range of 27 to 30°C and a relative humidity of 60 to 70% are suitable for raising Black Soldier Fly. In addition, successful mating activity requires light intensity greater than 200 μ mol m^2/s.

Organic Waste Management by Black Soldier Flies

Larvae of the BSF are essential to the treatment of organic waste. They flourish on a variety of substrates like

- **Municipal organic waste** (household food scraps, restaurant waste).
- **Agro-industrial waste** (fruit processing residues, brewery byproducts, palm oil residues).
- **Livestock manure** (poultry, pig, cattle).

Mechanisms of Waste Reduction

Larvae consume large amounts of food, breaking down and digesting organic materials. Their actions limit pathogen loads, lessen moisture and odour and stop house flies which are disease carrying insects from proliferating. By lowering *Salmonella* and *Escherichia coli* in manure, BSFL can improve biosecurity.

Waste Reduction Efficiency

The Black Soldier By reducing the dry weight of municipal waste by 65–75%, fly larvae contribute significantly to the management of organic waste. About 20% of the trash is effectively transformed into useful larval biomass during this process. The larvae also significantly reduce manure in poultry waste systems, reducing it by at least 50%. As a high value organic fertilizer, frass the leftover substrate enhanced with microbial byproducts and larvae exuviae improves crop yields and soil health.

Applications of BSF

1. Animal Feed

- **Aquaculture**: BSFL meal effectively substitutes fishmeal in the diets of trout, carp, catfish and shrimp without hindering growth.
- **Poultry:** Enhanced meat quality and amino acid composition in broilers and quails, with no adverse effects observed in laying hens.
- **Swine:** A partial substitution of soybean meal promotes normal growth.
- **Pet Food:** Widely utilized in the diets of reptiles, amphibians and exotic birds.

2. Human Consumption

While not common, Black Soldier Fly larvae (BSFL) have been eaten in Sabah, Malaysia. Challenges include cultural views and the connection to waste. Transforming them into powders, oils or textured protein could enhance their acceptance. The nutritional benefits such as high

protein levels, significant calcium content and the presence of antimicrobial fatty acids, highlight their potential for incorporation into human diets.

3. Industrial Uses

Biodiesel: Oil from BSFL is transformed into biodiesel with yields similar to those of plant oils.

Chitin and Chitosan: These compounds are extracted for applications in bioplastics, pharmaceuticals and agriculture.

Organic Fertilizers: Frass improves soil fertility.

Conclusion

One essential insect for sustainable waste and food systems is the black soldier fly. Its larvae convert organic waste into nutrient rich biomass, which is then used as a feed fertilizer and a precursor to biofuel. BSF has unparalleled potential to address the worldwide issues of food security, waste management and climate change because of its balanced nutritional composition, disease suppressive properties and minimal environmental impact. Although overcoming legal, cultural and technological obstacles is necessary to scale its use, BSF has the potential to play a key role in a robust and circular bioeconomy with further study and development.

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