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Valorization of Black Soldier Flies at Different Life Cycle Stages

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Solid waste treatment is a major concern all around the world, especially in developing countries. Unlike plastic and metals, organic waste is invaluable and requires a high cost for treatment. Black Soldier Fly (BSF) is a novel option since not only provides waste treatment solutions but also converts organic waste into high-economic products. An in-depth understanding of this species must be required for researchers who are looking for alternative processes as well as scaling up for larger plants or commercial purposes. In this review, the valorization of BSF at different life stages has been successfully developed. After treating organic waste, the frass of BSF has been seen as an organic fertilizer. Due to the highest lipid content (47.65 %) in prepupae stages, they are used for biodiesel production. The protein content is highest in the larva stage, so it is a lower-cost replacement for conventional animal feed. Since the chitin content in BSF's cuticles makes up to 40 %, prepupae and cocoons can be seen as promising sources of chitin.

1. Introduction

Due to the rapid population growth, organic waste is always a difficult problem in many countries. According to FAO's report, the food waste estimate in 2019 for total urban in Australia was 120 kg/capita (Zhongming et al., 2021). About 30 – 40 % of food production was discharged and did not use (Schader et al., 2014). This phenomenon normally occurred in the post-harvested period, during the storing and transporting stages which leads to the growth of greenhouse gases (GHGs). In India, the agricultural post-harvest loss is around 92 million t and the GHGs emitted were about 3.3 M t/y. There is nearly 750 BUSD loss due to food wastage every year (Surendra et al., 2016). Organic waste treatments like landfill, anaerobic digestion, and composting is not only high cost but also contaminate the ground and surface water environment (Surendra et al., 2015).

Insect-based food waste treatment is becoming more widely acknowledged as a cost-effective and ecologically responsible way to recycle resource. Numerous insect species convert organic wastes including food waste, animal byproducts, and agricultural waste at high rates. Many studies have indicated that the yellow mealworm, house fly, and black army fly are very suitable for biodegrading organic waste (Shaboon et al., 2022). Compared to mealworm-like insects, grasshoppers and crickets are far more expensive to breed because they require a lot more room to produce. Houseflies pose a risk of escape, illness transmission, and significant annoyance. Among these insects, BSF (*Hermetia illucens*) used to remediate food waste is gaining popularity. BSF is an insect normally found in tropical, subtropical, and warm zone of America (Surendra et al., 2016). The BSF larvae can treat a wide range of waste items quickly while reducing bacterial growth and odor. They also compete with the housefly (*Musca domestica*), a primary illness mediator, and may decrease it (Kim et al., 2021). BSF larvae transform organic waste into protein, chitin, and fat-rich biomass throughout the treatment process. Each stage of BSF's life cycle has unique components that allow it to serve a variety of purposes. Determination of the appropriate stages for each application was not much research although the properties of BSF are complex. In this article, a review of the lifecycle characteristics of the BSF has been carried out. The applications of BSF

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were highlighted and discussed based on their life cycle. This study can be a prime for determination of the appropriate application of BSF follow their life stages for lowering the negative effects of their properties.

2. The life cycle of BSF and waste processing

BSF the black and slim flies whose length is 15 to 20 mm, are mainly distributed in tropical and subtropical areas, the western hemisphere, and nutrient-rich ecosystems (Müller et al., 2017). The life cycle of BSF has 5 main stages including eggs, larvae, prepupae, pupae, and adult flies (Smets et al., 2020). The composition of the 5 major stages of BSF was shown in Figure 1. A mature BSF has a life span of around 8 – 9 d and in this stage, the chitin content of BSF can reach up to 40 % in cuticles. The female flies deposit eggs (500 to 1,000 eggs) and they spend 4 d to 3 weeks incubation those eggs (Oliveira et al., 2015). Larva after hatching has 5-19 mm in length and high lipid and protein content of 38.86 % and 40.96 %. The larvae store a large of lipid and protein in their body for use in later stages due to the lack of chewing part of BSF adults. The BSF larvae spent 10 – 52 d developing into prepupae with six times molting. Through several stages of prepupae, larvae grow to pupae within the formation of chitin and melanin. The adult emerges from the prepupae after approximately two weeks, although it can take up to five months in poor climatic circumstances (Purkayastha and Sarkar, 2021).

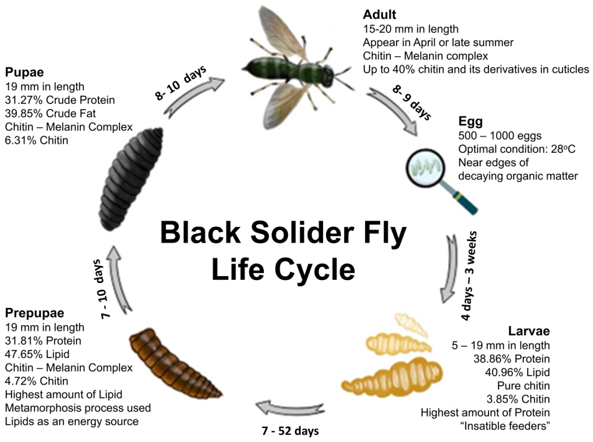

Figure 1: The composition of BSF in different life cycle stages

In waste processing, sorting organic and inorganic trash must be done as the first step. Although BSF larvae are typically quite tolerant of eating different organic wastes, it is still crucial to determine whether the facility's organic waste is fit for larval consumption. According to (Müller et al., 2017), larvae and bacteria reduced 43 % nitrogen and 67 % phosphorus in cow manure. Larvae ingest animal fences and convert 50 % of them into valuable larval biomass. In 14 d, 24 kg of swine manure will be consumed by 45,000 larvae. Larvae have the potential ability to convert chicken manure to 42 % protein and 35 % fat (Oliveira et al., 2015). Climate conditions had a noticeable impact on BSF performance in waste processing. The ideal temperature was in the range of 24 °C to 30 °C. Over 30 °C, BSF larvae could find a cooler place for feeding, while the temperature lower 24 °C make larvae eating less because their metabolism would slow down. The second component was a shaded area because if exposed to light, larvae may travel to the deeper layer of food. The ideal situation that was most conducive to digestion was a food-water content of 60 to 90 %. The key element was also the nutrient-dense meal. For the larva, a food supply with a high protein and carbohydrate content would be ideal. Waste that has been decomposed by bacteria or fungus was more likely to be readily absorbed by the larva. Performance of the larva would be impacted by food particle size. Nutrients will be absorbed more readily if the substrate is in the form of tiny particles, liquid, or slurry due to the inability to chew (Kastolani, 2019).

3. The valorization of BSF at different life cycle stages

Depending on life stages, BSF had different applications because its composition varies, which leads to the various applications of BSF. The valorization of BSF based on the life cycle was shown in Figure 2.

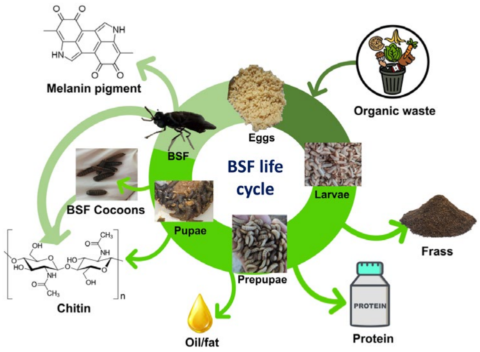

Figure 2. The valorization of BSF at different life stages

3.1 BSF frass as an organic fertilizer

The BSF larvae frass was considered an organic fertilizer with many applications. Compared to the production of other fertilizers, the BSF larval frass exhibited lower environmental impacts in terms of water use, energy use, global warming potential, and other categories (Smetana et al., 2019). The frass produced by BSF larvae was also emphasized as one of the process' key outputs, and it may be used to substitute traditional Nitrogen fertilizers, lessening the global warming potential associated with the usage of any conventional Nitrogen fertilizer (Salomone et al., 2017). According to Agustiyani et al. (2021), when using BSF frass, statistics related to plant height, number of leaves, wet weight of the upper plant (canopy), and root weight of Pakchoi plant were higher compared to NPK treatment. However, depending on the feed substrates, the physicochemical characteristics of the frass have significant changes (Table 1). Besides, post-treatment of BSF larvae frass should be carried out to increase its stability. International Platform of Insects for Food and Feed published a guideline document in 2021 that creates a prime for the development of the standard of EU-wide insect frass. Based on this document, there are modifications in EU Regulation 142/2011, classified insect frass as "insect excrements" and required that frass used as fertilizer be heat treated at 70 °C for 60 min (Lopes et al., 2022). Although the number of studies on BSF frass is growing, more research is needed to improve the quality of frass as an organic fertilizer and make it a better alternative to chemical fertilizers for plant development.

Table 1: The chemical composition of BSF frass in various feed substances

Waste	Chemical composition				Ref
	C	N	P	K	
Chicken manure	23.6	2.3	1.1	1.8	(Tao Liu et al., 2019)
Brewery spent grain	35.2	2.1	1.2	0.2	(Beesigamukama et al., 2020)
Pig manure	26.8	2.4	2.1	1.0	(Tao Liu et al., 2019)
Household waste	35.8	2.2	0.5	0.7	(Kawasaki et al., 2020)
Fresh Okara	37.1	5.1	0.3	1.9	(Chiam et al., 2021)
Commercial Fertilizer	45.1	3.0	1.23	1.49	(Beesigamukama et al., 2020)

3.2 BSF as a distinct chitinous biomass

Chitin, an abundant and valuable natural material, has seen desired application in various fields including the biomedical, pharmaceutical, agricultural, textile, and food industries (Smets et al., 2020). Because chitin and its derivatives content in BSF cuticles make up to 40 % (Khayrova et al., 2020), the pupae and cocoons are a promising source of chitin as shown in Figure 2. Chitin in black soldier fly is α-chitin like shrimp chitin compared to β-chitin in squid pen (Soetemans et al., 2020). Because of the variation in the amount of chitin and physicochemical characteristics in crustacean waste, chitin in insects is considered an alternative source in industries (Smets et al., 2020). At earlier stages, including 5th instar larvae, the black soldier fly contains pure chitin, afterward, melanin is formed and linked with chitin by a strong covalent bond and creates chitin-melanin complexes, which is different from various chitin sources as crustaceans (Khayrova et al., 2020). Melanin which is a heterogeneous polymer from the oxidation and polymerization of phenols and intermediate phenols is divided into three main types: eumelanin, pheomelanin, and allomelanin (Basturk et al., 2021). The color of eumelanin and allomelanin are black to brown compared to yellow to red pigment of pheomelanin (Pralea et al., 2019). Eumelanin, which is a special type of insect melanin, is through deacetylated amino groups bound to chitin (Sugumaran, 1998). Although having an intricate linkage with chitin, the melanin can still remove to obtain the pure chitin by using hydrogen peroxide for degrading melanin (Basturk et al., 2021). Besides, the presence of both chitin- and chitin-melanin complexes in BSF creates a novel polymer with various applications such as radionuclide sorbents (Bakulin et al., 2011), and antioxidant material (Ushakova et al., 2019).

3.3 BSF as lipid and protein source for biodiesel production, animal feed, and personal care

Besides the benefits of organic waste processing, the BSL is also a huge lipid and protein source with various applications. The levels of lipids between different developmental stages that always remained at high levels varied considerably. The content of lipids was highest in the prepupae stages (47.65 %) and declined in the pupae (39.85 %) stage because a metamorphosis process used lipids as an energy source (Xiu Liu et al., 2017). BSF larvae and prepupae with high fatty acid content are valuable feedstock for biodiesel production (Hong et al., 2018). In China, (Zheng et al., 2012) produced 43.8 g of biodiesel from 2000 BSF larvae that met the standard EN 12214 of the European Committee for Standardization. (Li et al., 2011) was verified the fat from BSF can be utilized as biodiesel. (Nguyen et al., 2018) was reported optimal condition of transesterification of BSF larvae which gave biodiesel yield of 94.14 %. The properties of biodiesel met the EN 14214 standard. The time expenditure for biodiesel production from BSF is lower than the one of palm oil or sugar cane while the quality of BSF-derived biodiesel is higher (Siddiqui et al., 2022). These studies demonstrated the potential to produce biodiesel from BSF larvae.

With the high fat and protein content, BSF larvae are good nutrition sources for animal feed. In comparison with conventional animal feed, using BSF prepupae give a lower cost for investment. BSF larvae contain a large amount of protein (37 to 63 % dry matter) and lipid (7 – 39 % dry matter). BSF larva could be seen as an alternative to replace meat and soybean proteins (Kumar et al., 2022). According to (Onsongo et al., 2018), 25 % better return on investment and 16 % higher cost-benefit ratio when replacing the soybean fish meal of broiler chicken with 42 and 55.5 % BSF prepupae in the starter and the finisher diet. (Kawasaki et al., 2019) also using BSF larvae and prepupae fed by household wastes to replace soybean meal and oil in the diet of chicken. The results demonstrate that when prepupae was used as a feed, the egg weight and eggshell thickness were higher. There are many studies on using in the diet of many fish and swine species as African catfish (Fawole et al., 2020), Atlantic salmon (Bruni et al., 2020), and finishing pigs (Crosbie et al., 2021). Although there are several advantages to utilizing BSF as animal feed, its practicality in the animal feed business should be evaluated in comparison to other feed sources owing to its composition changes when mixed with diverse organic waste. As a result, a standardized technique for the mass production of insects is required.

In cosmetics, palm kernel and coconut oil for the saponification process can be replaced by fat extracted from BSF (Verheyen et al., 2018). In addition, the extracted lipids are considered a new type of feedstock for oleochemicals procedure, namely surface-active components (Smets et al., 2020). Because of the high quantities of lauric acid (>60 %) in their fatty acid profile, they were determined to be less appropriate than locust or cricket oils. To boost their marketability, all of the bug oils studied (BSFL, locust, and cricket) required odor, color, phospholipid, and free fatty acid removal.

4. Conclusion and future direction

Food waste treatment using BSF has gained great attention due to its advantages such as sustainability and the possible application of BSF-derived resources. In this study, the characteristic of BSF was summarised by establishing the life cycle. The applications of the larvae, prepupae, pupae, and adult BSF were also proposed. Although the formation of the chitin – melanin complex is a barrier to the isolation of chitin, pupae and BSF cocoons are still an appropriate source for the synthesis of chitin. Further, the unique structure of the chitin – melanin complex also created more advanced applications. BSF larvae and prepupae, a rich lipid and protein biomass can be used as a source of biodiesel, animal feed, and even in the cosmetics industry. There are many challenges in using BSF that need to be taken into consideration to estimate its true potential. The BSF breeding at a larger scale should be carried out due to the significant difference between bench and industrial scale. The implementation of BSF could require high feed substrate content, so the suitable feedstock or using a mixture of different substrates should be evaluated to find the fit for each application. Simultaneously, the feasibility of rearing techniques is also needed to conduct by life cycle assessment, techno-economy. Due to the differences in BSF larvae composition in various feed substances, the utilization of BSF larvae for animal feed or its fat for biodiesel production should be more studied in the future. The standard procedure for the isolation of lipids and proteins should be set up to ensure the quality of products for improving their application. More research is needed in the future to develop procedures for extracting high-value compounds such as lauric acid, chitin, and nanochitin. The use of BSF frass as a fertilizer might be a viable alternative to traditional fertilizers. As a result, greater research into frass treatment is recommended, as opposed to commercial composting, to improve the quality of frass and its fertilizing benefits.

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