https://doi.org/10.33472/AFJBS.6.13.2024.4484-4502

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

BLACK SOLDIER FLY FARMING: A CIRCULAR ECONOMIC APPROACH TO WASTE MANAGEMENT

Shweta Kashid[1*], Nidhi Mehendre[2], Shruti Naik[3], Eshani Kashid[4], Kalpana Joshi[5]

[1*,2,3,4,5]Department of Biotechnology, Sinhgad College of Engineering, Affiliated to Savitribai Phule Pune University, Pune, Maharashtra, India

Corresponding Author: Shweta Kashid[1*]
Department of Biotechnology, Sinhgad College of Engineering, Affiliated to Savitribai Phule Pune University, Pune, Maharashtra, India
Email:

Article Info

Volume 6, Issue 13, July 2024

Received: 04 June 2024

Accepted: 05 July 2024

Published: 31 July 2024

doi: 10.33472/AFJBS.6.13.2024.4484-4502

ABSTRACT:

An increase in population and industrialization has also led to a rise in food demand. This includes a surge in meat and seafood consumption to meet the increased protein requirements. Thus, the problem of providing nutritionally adequate feed for these protein sources with their improved quality was identified. Soy feed has been used prominently but results in an increase in deforestation due to large area requirements for cultivation and was found to be nutritionally inadequate.

Hermetia illucens, also known as the Black Soldier Fly (BSF), offers a promising alternative by converting wet waste matter into highly nutritious protein-rich feed for various animal industries. Black Soldier Fly farming, a part of green technology, is one of the most widespread forms of insect farming which helps provide useful biological products along with organic waste management. Products derived from BSF larvae encompass biodiesel as a fuel, protein for animal feed, chitin, and chitosan for the cosmetic and healthcare industry, frass - as a biofertilizer, lipids, growth media, and biochar. This paper delves into detailed explanations of various synthesis processes of the products. Thus, the review summarizes the benefits of BSF larvae and their diverse applications.

Keywords: Organic Waste Management, Biodiesel, Bioconversion, Chitin, Gut Microbiota, Insect Farming.

1. **INTRODUCTION**

Poultry and fish farms, being the important sectors of the food industry, feed the non-vegetarian population around the globe. According to a National Family Health Survey, in India, almost 73% of Indians consume meat (Muinde et al. 2023), with about 6 million tons of meat consumption in 2020 alone (cycles, Text, and A. Minhas, 2023). Thus, the feed quality and quantity are crucial to determining the quality of the meat consumed by the overall population.

The degradation of feed can be harmful to the growth of fish and poultry, further hampering consumer health (Sapkota et al. 2007). Poor quality feed reduces the amount of nutrients, also leading to lower parasite and pathogen resistance (Adesogan et al. 2020). Most of it is usually centered around soy feed which is costlier and proves detrimental to the environment due to increased deforestation (Espinosa, Tago, and Treich 2020). An increased feed requirement escalates the soy feed demand leading to increased land clearance for its cultivation (Craig et al. 2017; Zampiga, Calini, and Sirri 2021). Some industries, especially fish farms, use small dead fish as feed, which is not nutritionally adequate (Jennings et al. 2016). It is important to find an alternative that can help cater to large amounts of food requirements while maintaining good quality.

Black Soldier Fly larvae (BSFL) can be a promising solution where organic matter can be recycled with the help of these larvae, which will then act as a highly nutritious feed source for target industries (Y.-S. Wang and Shelomi 2017). *Hermetia illucens Linnaeus*, a large fly belonging to the family *Stratiomyidae,* are 13-20 mm long and originate from the northern and tropical regions of America but are now spread to the tropical and subtropical regions of the rest of the world (Hauser and Woodley 2015). They are

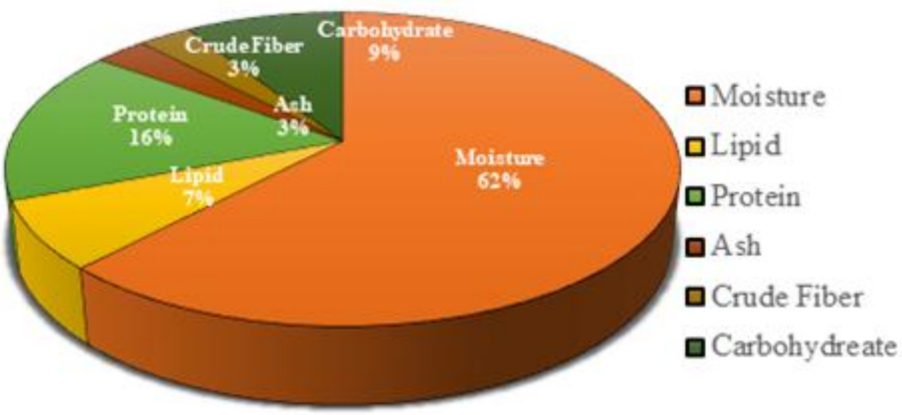

Figure 1. Proximate analysis of BSF larvae.

Entomophagy is a common practice worldwide where various insect types like crickets, mealworms, Black Soldier Flies, ants, etc. can be used as edible material in human food as well as livestock material. Cricket is estimated to have the largest share in the edible insect market (Surendra et al. 2016). However, BSF is slated to register the highest growth rate in the market between 2023-2032 due to an increase in the global aquaculture market and a subsequent rise in BSF demand. Table 1 gives us a comparison between the proximate analysis of different insect types.

Table 1. Comparative Proximate Analysis of different insect types (X. Liu et al. 2017)

Content	Larvae of BSF	Puparia	Shrimp shells	Quantitative Analytical Methods
Total protein	31.4	31.7	44.1	From UPLC-MS of total amino acids (X. Liu et al. 2017)
Total chitin	14.8	40.7	27.3	UPLC-MS (X. Liu et al. 2017)
Crude lipid	34.6	1.4	1.29	Soxhlet, ethyl ether (X. Liu et al. 2017)

UPLC-MS-Ultra-performance liquid chromatography-mass spectrometry

BSF farming is a part of green technology that provides a solution for organic waste handling while providing useful biological products (X. Liu et al. 2017). It is used for producing edible biomass — proteins, chitin, lipids, and vitamins (Shah et al. 2022). Transesterification of larvae has shown the formation of possible biodiesel which can be used as a fuel in the long run (Mangindaan, Kaburuan, and Meindrawan 2022; Mohan et al. 2023; Okoro et al. 2023). These insects have also shown an ability to produce peptides possessing antimicrobial properties against viruses, bacteria, parasites, and fungi (Yi et al. 2014). Another vital compound that can be extracted from the larvae is chitin or chitosan which has great potential in the medical and cosmetic industry (Rehman et al. 2023; LR - Veehouderij en omgeving et al. 2021).

The use of BSF larvae can reduce the feed cost while increasing feed quantity with comparatively less space required (Y.-S. Wang and Shelomi 2017). This review will summarize and focus on various aspects of BSF larvae, their farming, and applications in various industries.

2. CONSUMER AND GROWTH CYCLE OF BSF

Figure 2 illustrates the consumer cycle; organic matter is the raw material provided for the growth of the Black Soldier Fly and its larvae. These larvae are then dried or processed to produce various feed options for the poultry, pet industry, and aquaculture. By-product of the feeding process, frass, can be used as a biofertilizer for the nourishment of plants and crops. Further, enriched food products are provided to the human population. Rearing animals and consumption of food leads to the production of wet kitchen waste and organic matter. This organic matter can again be included in larval feed thus completing the consumer cycle.

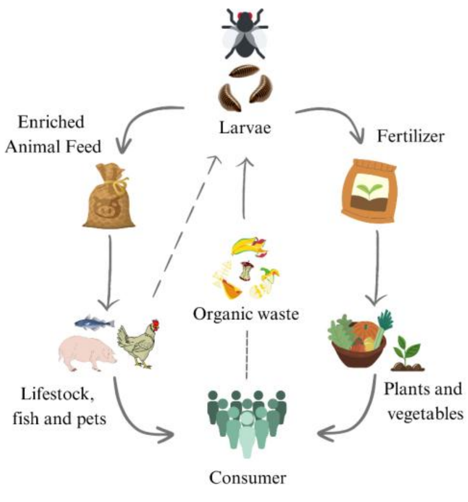

Figure 2. Consumer cycle

The life cycle of BSF shows five distinct stages:

1. Eggs
2. Larvae
3. Prepupae
4. Pupae and
5. Adult fly

The female fly lays 500-1000 eggs and requires about 3-4 days of incubation period. Hatched larvae are 5-19 mm in length and contain maximum protein and fat content. The pupal flies are born through various prepupal metamorphosis transformations which carry the highest chitin and melanin content (Guilliet et al. 2022). The complete life cycle of BSF takes a span of two weeks but it can get delayed under unfavorable circumstances.

A simple setup is required for the growth and incubation of BSF with less space and maintenance. Considering their biological behavior, a quiet calm place is preferred for its growth (Rehman et al. 2023; Guilliet et al. 2022). Large bins or tubs with tiny holes are used for growing stage flies and are covered with a mesh at the top for anchorage. A bunch of 2-3 inches thick corrugated sheets are used where the female flies lay eggs and are kept for incubation for the next 2-3 days (G. D. P. Da Silva and Hesselberg 2020; Amrul et al. 2022). One-third of the bin is covered with organic matter, rotten vegetables, and sludge to feed the flies (X. Liu et al. 2017; Siddiqui et al. 2022; Dzepe et al. 2021). The complete set-up for BSF growth is easy to build and has two main components, namely: Larvero- for larval growth, and Fly house- for adult flies (Amrul et al. 2022).

The larvae utilize the food and deplete the initial weight by 50%, faster than conventional composting (Siddiqui et al. 2022). BSFL, a polyphagous insect, feeds on different kinds of substrates based on the enzymes produced in its gut comprising three parts namely: foregut- where the main digestion takes place, midgut- may act as temporary food storage, and hindgut- which stores the feces (Yi et al. 2014; Klammsteiner et al. 2020). Various substrates specific to different microbial groups present in the insect gut are mentioned in Table 2 below.

Table 2. Action of BSFL gut microflora on the substrate

Sr. No.	Microbial species (spp.)	Metabolic Activity
1.	*Orbus* spp., *Pseudomonas* spp., *Campylobacter* spp. (Yu et al. 2023)	Amino acid metabolism
2.	*Dysgnomonas* spp. (Yu et al. 2023)	Protein digestion and absorption
3.	*Issatchenkia* spp. (Yu et al. 2023)	Pepsin activity
4.	*Pediococcus* spp., *Campylobacter* spp., *Lactobacillus* spp. (Yu et al. 2023)	Trypsin activity
5.	*Lactobacillus* and *Bacillus* spp. (Gold, von Allmen, et al. 2020)	Peptidase activity
6.	*Firmicutes* spp. (Ao et al. 2021)	Swine and cattle manure
7.	*Proteobacteria and Bacteroidetes* (Ao et al. 2021; Yu et al. 2023)	Poultry manure and food waste
8.	*Enterococcus, Cellulomonas, Pichia* yeasts, *Fusarium* spp (Klüber et al. 2022; Yu et al. 2023)	Lignocelluloses in palm kernel meal

9.	*Actinomycetes* spp (Jiang et al. 2019)	Lignin and chitin
10.	*Providencia* spp. (Barson and Antonara 2018)	Protein and lipid conversion in the gut
11.	*Klebsiella* spp.(M. Wu and Li 2015)	Pectinolytic activity
12.	*Morganella* spp.(Barson and Antonara 2018)	Production of biogenic amines

Various studies performed on BSF insects and its gut, have shown no impact on gut microbes across various changing dietary parameters, pointing us towards the presence of dominant gut bacterial genera (Bonelli et al. 2020)- *Actinomycetes, Enterococcus, Dysgonomonas, Providencia, Morganella, Firmicutes, Proteobacteria, Bacteroidetes, klebsiella,* and *Pseudomonas.* They provide various functional abilities like substrate digestion, resistance to diet changes, essential catabolic actions, and production of antimicrobial peptides against extrinsic bacterial colonies (Yu et al. 2023). Specialized crypts or paunches promote bacterial persistence despite differences in extrinsic changes and help in host-microbe interaction (Klammsteiner et al. 2020). Yu et al (Yu et al. 2023) have found other functions of gut microbes like food detoxification and immune system stimulation which also influence the oviposition rate in BSF (Yu et al. 2023).

Various environmental and feeding factors decide the reproduction, growth rates, and life span of the insects. The performance of bioconversion and the BSFL biomass quality is improved using combinations of wastes with a variety of nutrients (Gold, Cassar, et al. 2020; Seyedalmoosavi et al. 2022). A pH of 2-4 is optimal for the increase in larval protein content as the alkalization stimulates protease activity. The temperature and light intensity also play a key role in increasing the chances of mating and oviposition of the flies. Optimum temperature ranging from 31-36 °C is maintained for the rearing of the flies (Mohan et al. 2023; Akpesse et al. 2022; Oyatogun et al. 2020).

The life cycle of BSFL is depicted in Figure 3. The adult fly lacks a digestive system and mouth parts; thus, they are only used in reproductive functions (Gold et al. 2018). The larval stage is important because at this stage the insect has the highest intracellular fat and protein content (Bonelli et al. 2020; Seyedalmoosavi et al. 2022). The fly metamorphosizes to the pupal stage where chitin and melanin are present at the highest level due to the presence of the dark metallic black body (Hiruma and Kaneko 2013; Soetemans, Uyttebroek, and Bastiaens 2020; Triunfo et al. 2022).

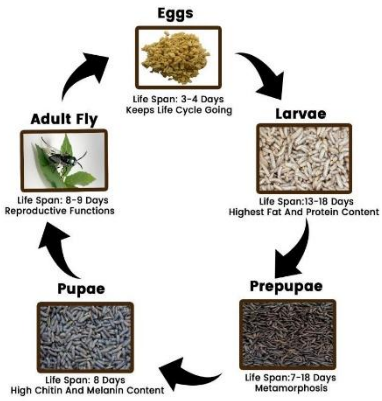

Figure 3. The life cycle of BSF

3. BSFL PRODUCTS AND SYNTHESIZING METHODS

3.1 Fresh larvae

For centuries, insects have been included in human diets across Asia, Latin America, and Africa, benefiting around 2 billion people. As the challenge of feeding over 9 billion people by 2050 remains, insects are gaining attention as a significant alternative protein source (Lange and Nakamura 2021). The efficient farming of fresh BSF larvae is crucial to obtaining a valuable protein and nutrient source for animal feed. The insects are fed live to animals in poultry and fish farms providing the essential nutrients for their nourishment.

3.2 Dead Larvae

Insects, especially the Black Soldier Fly (*Hermetia illucens*), are gaining attention as sustainable food sources. Proper handling of deceased BSF larvae is essential for their further utilization (Huang, C., W. Feng, J. Xiong, T. Wang, W. Wang, C. Wang, and F. Yang 2018). Drying is a common method for long-term storage and ease of handling (St-Hilaire et al. 2007). The sensory attributes of dried larvae significantly influence their market worth, particularly in the pet food industry (Meticulous Market Report 2022; Rahman 2007). Dehydration reduces water activity, prolongs storage by preventing enzymatic degradation and microbial spoilage increasing protein content (Ms. Prerana Patil 2022). The techniques utilized for dried larvae are given below:

3.2.1 Sun-dried: It is a natural method that involves exposing larvae to consistent and uniform sunlight. A sustainable, low-energy approach preserves high protein and fat levels essential for livestock and aquaculture feed (Chong et al. 2021). (P. Da Silva et al. 2019).

3.2.2 BSFL dryer: This uses low-temperature steam to process the larvae which results in significant color, reduced water content, grind convenience, and longer shelf life. The contact with steam causes heat and mass transfer and the subsequent drying of larvae (Alp and Bulantekin 2021).

3.2.3 Sand roasting: A traditional method, popular among street food vendors and villagers in Asian countries such as India, Indonesia, and China, commonly applied to create value-added snacks from cereals or nuts (Kora 2019).

3.2.4 Microwave heating: Utilizes electromagnetic energy to increase the motion of water molecules within fresh larvae, resulting in high vapor pressure and causing the larvae to puff (Lentz, Tang, and Resurreccion 2020).

3.2.5 Freeze-dried: Insects are slowly killed and preserved for a long duration, allowing a reduction in their metabolism. The resulting dried larvae exhibit prolonged storage stability and retain high protein content, making them a valuable resource for various applications (Saucier et al. 2022).

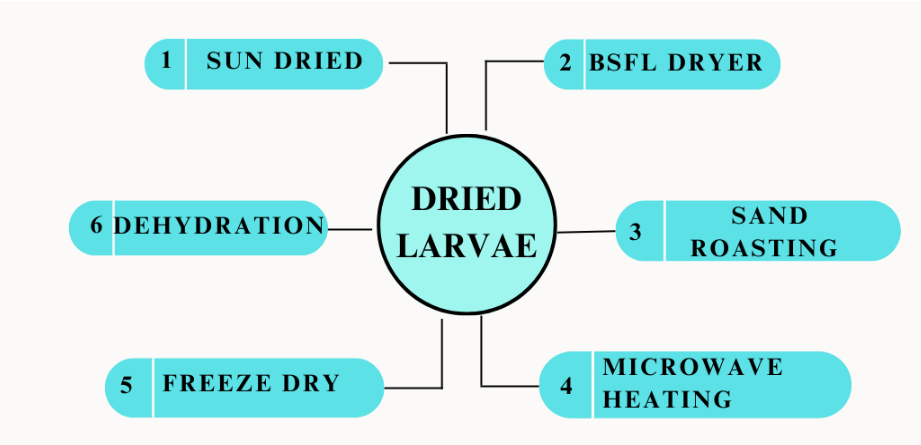

Figure 4. Various ways of drying BSFL.

3.3 Protein

The protein content of BSF larvae significantly influences their use as animal feed and protein-rich supplements. Protein fractionation involves separating various protein components from the larvae. Initial defatting to extract crude protein and subsequent fractionation processes to purify specific proteins, using techniques like chromatography and precipitation (Oonincx et al. 2015).

Literature studies investigated the protein production efficiency of BSF larvae when fed with various organic wastes as summarized below in Table 3.

Table 3: Percentage of protein obtained from BSF larvae using various feed substrates

	Feed Substrates	**Crude protein (in %)**
Nutritional Composition of BSF larvae	Chicken feed	41.2% (Spranghers et al. 2017)
	Restaurant scrap	43.1% (Spranghers et al. 2017)
	Vegetable and fruit waste	39.9% (Giannetto et al. 2020)
	Cow manure	41.2% (S. Y. Wang et al. 2020)
	Pig manure	42.8% (S. Y. Wang et al. 2020)

3.4 Oil/ BSFL lipid

Some methods applied for efficient extraction of fats are mechanical pressing or petroleum ether extraction followed by alteration through acid-catalyzed esterification and alkaline-catalyzed transesterification (Mohan et al. 2023). The oil extraction process involves defatting the larvae to remove non-lipid components (Siddiqui et al. 2022). Furthermore, fractionation via fractional distillation of the crude insect extract after defatting enables the separation of valuable protein and fat constituents (Oyatogun et al. 2020; Buszewski 2000).

3.5 Biodiesel

BSF oil can be transformed into biodiesel through a process known as transesterification. Enzymatic transesterification, employing lipases as catalysts, has shown promise as an efficient and environmentally friendly method for producing biodiesel from BSF oil (Mohan et al. 2023). Figure 5 shows the detailed process for biodiesel extraction.

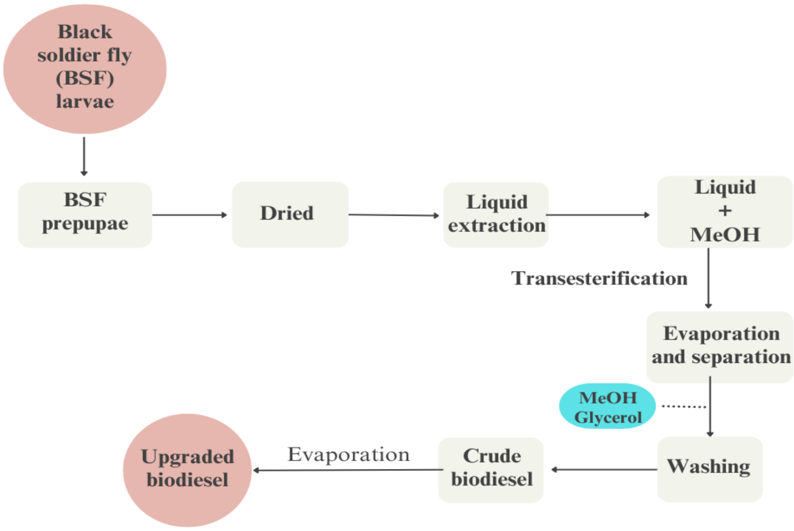

Figure 5. Biodiesel production from BSFL

3.6 Chitin

Chitin, a polysaccharide found in the exoskeleton of insects, has numerous applications in the pharmaceutical and medical industries (Farinha and Freitas 2020). The extraction process involves defatting and fractionation to isolate chitin. Also, deacetylation can be applied to enhance its usability (Złotko et al. 2021). During molting, larvae periodically shed their skin that is collected from the rearing unit and the waste treatment (Hiruma and Kaneko 2013; Singh Kaleka, Kaur, and Kour Bali 2019). The extraction process from larval skins is carried out in three key steps: pre-treatment, demineralization, and deproteinization. Chitin conversion to chitosan requires a vigorous alkaline treatment (Hahn et al. 2020; Marguerite Rinaudo; Waśko et al. 2016). For pre-treatment, the raw material is cleaned with detergent and water, oven-dried at 105°C, and ground into fine particles. Demineralization treatment involves an acidic wash with 1.5 M hydrochloric acid for 2 hours at 25°C, converting decomposing minerals into water-soluble salts (Oyatogun et al. 2020). There are various methods of chitin extraction with different steps for protein removal as depicted in Figure 6.

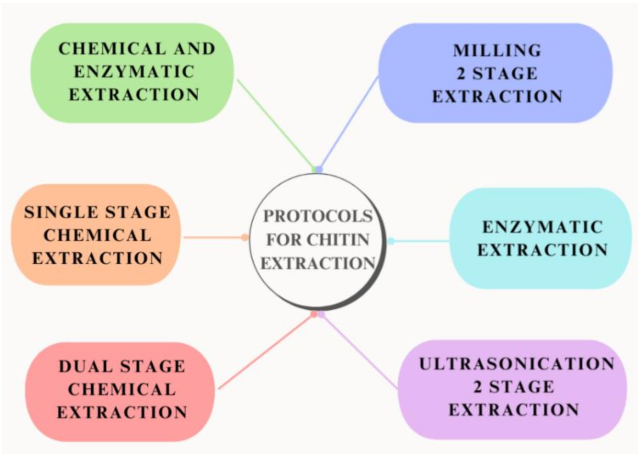

Figure 6. Methods of Chitin Extraction

4. APPLICATIONS OF BSFL

4.1 Waste processing

Waste processing is the way of efficiently handling the waste, sorting and composting it (Britannica, T. Editors of Encyclopaedia 2020). The BSF larvae are excellent tools for managing organic waste. They feed on large chunks of organic matter and grow, which in turn can be used for various other products (Siddiqui et al. 2022). As suggested in some reports, larvae were successful in reducing 43% nitrogen and 67% phosphorus content in cow manure (Amrul et al. 2022). BSF larvae are known to ingest animal waste and manure to convert 50% of it into useful byproducts (Scala et al. 2020). This exceptional composting ability of the larvae in the optimum temperature range of 24-30^oC benefits not only in providing good quality products but also in organic waste treatment. BSF has thus been a conserving alternative among researchers for organic waste treatment.

4.2 BSF as a protein source

There is an increase in protein feed demand in the food industry. Due to reduced plant-based protein sources and restrictions on various animal protein sources, industries are looking for alternatives (Henchion et al. 2017). One of the promising ones is BSF larvae. Organic wastes are converted into protein and fat biomass by BSF which can be used as substitutes for conventional proteins and animal diets (Amrul et al. 2022; Gasco, Biancarosa, and Liland 2020). It is safe for animal consumption due to being pest-free (Lu et al. 2022). Larval composition is 30% fat and 40% protein but is dependent on the manure/substrate provided (X. Liu et al. 2017; Barragan-Fonseca, Dicke, and Van Loon 2017; Ewald et al. 2020; Pérez-Pacheco et al. 2022). It was found that larvae feeding on fruits and vegetables provide less protein content as compared to those feeding on animal and organic waste content (Gold, Cassar, et al. 2020; Banks, Gibson, and Cameron 2014; Cappellozza et al. 2019). These saprophytic insects can thus be good candidates for human and animal protein sources.

4.3 Biodiesel

For a few decades, the Earth has been facing major crises in energy sources. BSF being a rich source of lipids/fats can provide an alternative to solve the energy crisis. In addition to protein-rich content BSF larvae also contain high fat (Eriksen 2022; Barragán-Fonseca 2018). In order to increase the fat content in the larvae it is important to provide substrate with rich fat content during larval feel (X. Liu et al. 2017). The fat is extracted from the BSF larvae by defatting the insects and can be further converted into biodiesel for energy purposes. Further, the extracted fat is processed and converted into biodiesel via transesterification. Using BSF to convert lignocellulosic biomass into biodiesel is a cost-effective method for energy production (Amrul et al. 2022; Zheng et al. 2012). It was found that BSF biodiesel led to reduced combustion with lower environmental emissions with better fuel efficiency (Mohan et al. 2023; Jung et al. 2022). Moreover, research has shown that biodiesel produced from BSF fat meets the international standards for biodiesel quality (Surendra et al. 2016; Zheng et al. 2012; Jung et al. 2022). Thus, BSF biodiesel production can be considered one of the effective methods of energy production.

4.4 Frass

BSF larvae treatment of organic waste produces a mixture of BSFL excretion, frass, and shed exoskeletons. (Amrul et al. 2022; Basri et al. 2022). This mixture with the left-over organic matter constitutes the biofertilizer- frass. Frass can be utilized to increase the soil's nutritional quality and water-holding capacity (Poveda 2021). It can decrease our dependence on costly mineral fertilizers, which have harmful effects on environmental health and soil quality. (Basri et al. 2022; Team Acrres et al. 2023). The high levels of macronutrients (potassium, nitrogen, phosphorus) are readily available in frass as they are present in the insect's diet (Anyega et al. 2021; Beesigamukama, Subramanian, and Tanga 2022). Multiple trials have demonstrated that the utilization of frass accelerates plant growth (Anyega et al. 2021). It could increase and improve soil's organic matter while the chitin in frass increases plant disease resistance against harmful pathogens (Basri et al. 2022).

4.5 Animal feed

The demand for meat, fish, and eggs has increased, leading to a higher need for animal feed. BSFL provides a sustainable alternative, with variable protein and fat content (Siddiqui et al. 2022; Lu et al. 2022). After defatting, BSFL has around 60% crude protein content. BSF larvae also contain saturated fatty acid methyl esters like palmitic, lauric, and myristic acids (T. Liu et al. 2022; Ewald et al. 2020). Lauric acid, with the highest percentage, converts into monolauric acid (Suryati et al. 2023) used in food industries as it shares a similar nutritional content to that of coconut fat and palm oil (McCarty and DiNicolantonio 2016). BSFL is rich in minerals like iron, manganese, zinc, phosphorus, copper, and calcium as they are very important in feed (Shah et al. 2022; Barragán-Fonseca 2018). Their higher calcium content than fishmeal makes them beneficial for livestock feed (Lu et al. 2022). Thus, BSFL can be a major source of nutritionally adequate, pest-free, and safe animal feed (Surendra et al. 2016; N. Wu et al. 2020; Lievens et al. 2021).

4.6 Growth media

BSFL is also suitable for use as growth media to carry out soilless agriculture, offering a viable alternative to commercial peat for potted plant cultivation. One of the studies (Setti et al. 2019) indicated that Black Soldier Fly Larvae Processing Residue (BSPR) can be a unique ingredient of growth media. When used in 20% contribution, BSPR was shown to significantly increase crop production. According to one of the literature, 80% commercial peat in combination with 20% BSFL frass as a component growing media has been found to be beneficial to crop growth and development without causing any abiotic stresses, especially causing an increase in the total dry weight of the crop.

4.7 Biochar

Biochar is charcoal made by burning agricultural and organic wastes in a controlled manner which will reduce pollution and safely store carbon. Researchers are closely studying the production of biochar from insect frass because it contains significant amounts of chitosan. This discovery has the potential to reduce the cost of commercial absorbents (Mojiri, Andasht Kazeroon, and Gholami 2019). Chitosan, a natural bio-sorbent derived from chitin, has the ability to purify wastewater containing dyes in water-based solutions. There is a need to verify the economic feasibility of this approach. Biochar from BSFL contains high levels of nitrogen, which can be achieved rarely (Bulak et al. 2023). It also carries numerous macro elements as compared to biomass obtained from plant residues making it more effective for agricultural use (Bulak et al. 2023; Hu et al. 2023).

4.8 Chitin

Chitin, a biopolymer with unique properties, consists of N-acetyl-D-glucosamine and some D-glucosamine (Soetemans, Uyttebroek, and Bastiaens 2020). It can be converted to chitosan through deacetylation, enhancing its solubility in acidic environments. Both chitin and chitosan have various applications in medicine, agrochemicals (No and Meyers 2000), waste treatment (Shahidi, Arachchi, and Jeon 1999), food (Cosme and Vilela 2021), beverages (Triunfo et al. 2022), etc. BSF insects shed chitin-rich skin during metamorphosis, with the highest chitin content in the adult stage (Britannica, T. Editors of Encyclopaedia 2024). Chitin, chitosan, and their derivatives have various antimicrobial activities against a large group of organisms (Hadj Saadoun et al. 2020; Sharp 2013) and possess anti-cancer properties of chitosan. Chitosan is valued for its biocompatibility, biodegradability, and non-toxicity, making it suitable for gene and drug delivery in chemotherapy, as well as tissue engineering.

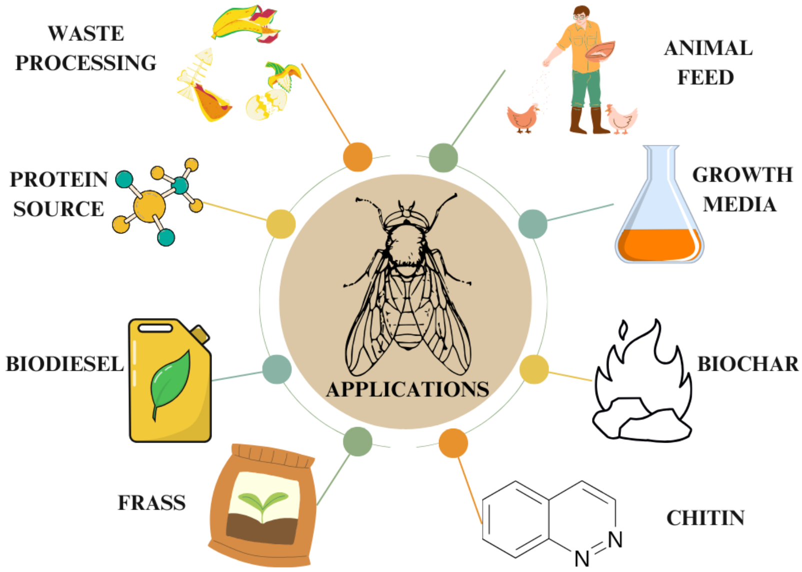

Figure 7. Versatile applications using Hermetia illucens

5. CONCLUSION

BSFL was found to be a promising solution in organic waste conversion to high-value products. The various forms of BSF such as Fresh larvae, dead larvae, prepupae, pupae, lipids, proteins, and chitin can be utilized efficiently in various applications. The BSFL frass is considered a biofertilizer that improves soil's nutritional quality and water-holding capacity. The residues of this treatment have unique characteristics which are an ingredient of growth media. The shedding of insect skin is rich in chitin and can produce chitosan possessing anticancer properties. BSF larvae are a rich source of protein and lipids which can result in promising alternatives to protein feed sources and biodiesel as an alternative energy source. Thus, BSFL is a dynamic creature with various applications and composting agents for a green environment.

Acknowledgment
The authors are very grateful to Savitribai Phule Pune University (SPPU), Pune, India as well as the Department of Biotechnology at Sinhgad College of Engineering, Pune, India.

Funding
Not Applicable

References

1. Adesogan, Adegbola T., Arie H. Havelaar, Sarah L. McKune, Marjatta Eilittä, and Geoffrey E. Dahl. 2020. "Animal Source Foods: Sustainability Problem or Malnutrition and Sustainability Solution? Perspective Matters." *Global Food Security* 25 (June): 100325. doi:10.1016/j.gfs.2019.100325.
2. Akpesse, Akpa Alexandre Moïse, Celine Nobah Epse Kacou Wodjé, Otchoumou Atcho Roxane Danielle, Tenon Coulibaly, Dohouonan Diabaté, Thérèse Appoh Perrine Kissi, Kouakou Hervé Koua, and Kouassi Philippe Kouassi. 2022. "Optimization of the Production of Black Soldier Flies Hermetia Illucens by Controlling Biological

Parameters in Côte d'Ivoire." *JOURNAL OF ADVANCES IN BIOLOGY* 15 (September): 11–19. doi:10.24297/jab.v15i.9274.

3. Alp, Duygu, and Özcan Bulantekin. 2021. "The Microbiological Quality of Various Foods Dried by Applying Different Drying Methods: A Review." *European Food Research and Technology* 247 (6): 1333–1343. doi:10.1007/s00217-021-03731-z.
4. Amrul, Nur Fardilla, Irfana Kabir Ahmad, Noor Ezlin Ahmad Basri, Fatihah Suja, Nurul Ain Abdul Jalil, and Nur Asyiqin Azman. 2022. "A Review of Organic Waste Treatment Using Black Soldier Fly (Hermetia Illucens)." *Sustainability* 14 (8): 4565. doi:10.3390/su14084565.
5. Anyega, Abel O., Nicholas K. Korir, Dennis Beesigamukama, Ghemoh J. Changeh, Kiatoko Nkoba, Sevgan Subramanian, Joop J. A. Van Loon, Marcel Dicke, and Chrysantus M. Tanga. 2021. "Black Soldier Fly-Composted Organic Fertilizer Enhances Growth, Yield, and Nutrient Quality of Three Key Vegetable Crops in Sub-Saharan Africa." *Frontiers in Plant Science* 12 (June): 680312. doi:10.3389/fpls.2021.680312.
6. Ao, Yue, Chongrui Yang, Shengchen Wang, Qingyi Hu, Li Yi, Jibin Zhang, Ziniu Yu, Minmin Cai, and Chan Yu. 2021. "Characteristics and Nutrient Function of Intestinal Bacterial Communities in Black Soldier Fly (Hermetia Illucens L.) Larvae in Livestock Manure Conversion." *Microbial Biotechnology* 14 (3): 886–896. doi:10.1111/1751-7915.13595.
7. Banks, Ian J., Walter T. Gibson, and Mary M. Cameron. 2014. "Growth Rates of Black Soldier Fly Larvae Fed on Fresh Human Faeces and Their Implication for Improving Sanitation." *Tropical Medicine & International Health* 19 (1): 14–22. doi:10.1111/tmi.12228.
8. Barragán-Fonseca, Karol B. 2018. "Flies Are What They Eat : Tailoring Nutrition of Black Soldier Fly (Hermetia Illucens L.) for Larval Biomass Production and Fitness." Wageningen University. doi:10.18174/449739.
9. Barragan-Fonseca, K.B., M. Dicke, and J.J.A. Van Loon. 2017. "Nutritional Value of the Black Soldier Fly (*Hermetia Illucens* L.) and Its Suitability as Animal Feed – a Review." *Journal of Insects as Food and Feed* 3 (2): 105–120. doi:10.3920/JIFF2016.0055.
10. Barson, William J., and Stella Antonara. 2018. "144 - Proteus, Providencia, and Morganella Species." In *Principles and Practice of Pediatric Infectious Diseases (Fifth Edition)*, edited by Sarah S. Long, Charles G. Prober, and Marc Fischer, Fifth Edition, 833-835.e1. Elsevier. doi:https://doi.org/10.1016/B978-0-323-40181-4.00144-4.
11. Basri, Noor Ezlin Ahmad, Nur Asyiqin Azman, Irfana Kabir Ahmad, Fatihah Suja, Nurul Ain Abdul Jalil, and Nur Fardilla Amrul. 2022. "Potential Applications of Frass Derived from Black Soldier Fly Larvae Treatment of Food Waste: A Review." *Foods* 11 (17): 2664. doi:10.3390/foods11172664.
12. Beesigamukama, Dennis, Sevgan Subramanian, and Chrysantus M. Tanga. 2022. "Nutrient Quality and Maturity Status of Frass Fertilizer from Nine Edible Insects." *Scientific Reports* 12 (1): 7182. doi:10.1038/s41598-022-11336-z.
13. Bonelli, Marco, Daniele Bruno, Matteo Brilli, Novella Gianfranceschi, Ling Tian, Gianluca Tettamanti, Silvia Caccia, and Morena Casartelli. 2020. "Black Soldier Fly Larvae Adapt to Different Food Substrates through Morphological and Functional Responses of the Midgut." *International Journal of Molecular Sciences* 21 (14): 4955. doi:10.3390/ijms21144955.
14. Britannica, T. Editors of Encyclopaedia. 2020. "Refuse. Encyclopedia Britannica," June. https://www.britannica.com/topic/refuse.
15. Britannica, T. Editors of Encyclopaedia. 2024. "Metamorphosis | Insect Development, Adaptation & Evolution | Britannica," January. https://www.britannica.com/science/metamorphosis.

16. Bulak, Piotr, Kinga Proc-Pietrycha, Monika Kaczor, Katarzyna Złotko, Cezary Polakowski, Dariusz Wiącek, Hanna Waniak-Nowicka, et al. 2023. "A Novel Type of Biochar from Chitinous Hermetia Illucens Waste with a Built-in Stimulating Effect on Plants and Soil Arthropods." *Scientific Reports* 13 (1): 8306. doi:10.1038/s41598-023-35460-6.
17. Buszewski, B. 2000. "SOLVENTS: DISTILLATION." In *Encyclopedia of Separation Science*, edited by Ian D. Wilson, 4199–4204. Oxford: Academic Press. doi:https://doi.org/10.1016/B0-12-226770-2/07751-6.
18. Cappellozza, Silvia, Maria Giovanna Leonardi, Sara Savoldelli, Domenico Carminati, Anna Rizzolo, Giovanna Cortellino, Genciana Terova, et al. 2019. "A First Attempt to Produce Proteins from Insects by Means of a Circular Economy." *Animals: An Open Access Journal from MDPI* 9 (5): 278. doi:10.3390/ani9050278.
19. Chong, Chien Hwa, Adam Figiel, Antoni Szummy, Aneta Wojdyło, Bee Lin Chua, Chun Hong Khek, and Ma Chee Yuan. 2021. "Chapter 5 - Herbs Drying." In *Aromatic Herbs in Food*, edited by Charis M. Galanakis, 167–200. Academic Press. doi:https://doi.org/10.1016/B978-0-12-822716-9.00005-6.
20. Cosme, Fernanda, and Alice Vilela. 2021. "Chitin and Chitosan in the Alcoholic and Non-Alcoholic Beverage Industry: An Overview." *Applied Sciences* 11 (23). Multidisciplinary Digital Publishing Institute: 11427. doi:10.3390/app112311427.
21. Craig, Steven, Louis Helfrich, David D Kuhn, and Michael H Schwarz. 2017. "Understanding Fish Nutrition, Feeds, and Feeding." *Virginia Cooperative Extension*, July. http://hdl.handle.net/10919/80712.
22. cycles, Statistics Can Display More up-to-Date Data Than Referenced in the Text, and A. Minhas,. 2023. *Topic: Meat and Seafood in India*. https://www.statista.com/topics/5350/meat-and-seafood-in-india/.
23. Da Silva, G D P, and T Hesselberg. 2020. "A Review of the Use of Black Soldier Fly Larvae, Hermetia Illucens (Diptera: Stratiomyidae), to Compost Organic Waste in Tropical Regions." *Neotropical Entomology* 49 (2): 151–162. doi:10.1007/s13744-019-00719-z.
24. Da Silva, Pascoal, Nuno Ribeiro, Maria Nazaré Coelho Pinheiro, and Rui Costa. 2019. "Modelling Drying Kinetics of Black Soldier Fly (*Hermetia Illucens, L.*) Larvae." Edited by A. Mohamad, J. Taler, A.C. Benim, R. Bennacer, S.-H. Suh, R. De Lieto Vollaro, A. Vallati, and G. Battista. *E3S Web of Conferences* 128: 09011. doi:10.1051/e3sconf/201912809011.
25. Dzepe, Daniel, Paulin Nana, Hervé Mube Kuietche, Janaina Mitsue Kimpara, Ornela Magatsing, Timoléon Tchuinkam, and Rousseau Djouaka. 2021. "Feeding Strategies for Small-Scale Rearing Black Soldier Fly Larvae (Hermetia Illucens) as Organic Waste Recycler." *SN Applied Sciences* 3 (2): 252. doi:10.1007/s42452-020-04039-5.
26. Eriksen, Niels Thomas. 2022. "Dynamic Modelling of Feed Assimilation, Growth, Lipid Accumulation, and CO2 Production in Black Soldier Fly Larvae." *PloS One* 17 (10): e0276605. doi:101371/journal.pone.0276605.
27. Espinosa, Romain, Damian Tago, and Nicolas Treich. 2020. "Infectious Diseases and Meat Production." *Environmental & Resource Economics* 76 (4): 1019–1044. doi:10.1007/s10640-020-00484-3.
28. Ewald, Nils, Aleksandar Vidakovic, Markus Langeland, Anders Kiessling, Sabine Sampels, and Cecilia Lalander. 2020. "Fatty Acid Composition of Black Soldier Fly Larvae (Hermetia Illucens) – Possibilities and Limitations for Modification through Diet." *Waste Management* 102 (February): 40–47. doi:101016/j.wasman.2019.10.014.
29. Farinha, Inês, and Filomena Freitas. 2020. "Chapter 2 - Chemically Modified Chitin, Chitosan, and Chitinous Polymers as Biomaterials." In *Handbook of Chitin and Chitosan*,

edited by Sreerag Gopi, Sabu Thomas, and Anitha Pius, 43–69. Elsevier. doi:https://doi.org/101016/B978-0-12-817966-6.00002-9.

30. Gasco, Laura, Irene Biancarosa, and Nina S. Liland. 2020. "From Waste to Feed: A Review of Recent Knowledge on Insects as Producers of Protein and Fat for Animal Feeds." *Current Opinion in Green and Sustainable Chemistry* 23 (June): 67–79. doi:10.1016/j.cogsc.2020.03.003.
31. Giannetto, Alessia, Sabrina Oliva, Carlos Frederico Ceccon Lanes, Fabio de Araújo Pedron, Domenico Savastano, Cosimo Baviera, Vincenzo Parrino, et al. 2020. "Hermetia Illucens (Diptera: Stratiomydae) Larvae and Prepupae: Biomass Production, Fatty Acid Profile and Expression of Key Genes Involved in Lipid Metabolism." *Journal of Biotechnology* 307 (January): 44–54. doi:10.1016/j.jbiotec.2019.10.015.
32. Gold, Moritz, Cecille Marie Cassar, Christian Zurbrügg, Michael Kreuzer, Samy Boulos, Stefan Diener, and Alexander Mathys. 2020. "Biowaste Treatment with Black Soldier Fly Larvae: Increasing Performance through the Formulation of Biowastes Based on Protein and Carbohydrates." *Waste Management* 102 (February): 319–329. doi:10.1016/j.wasman.2019.10.036.
33. Gold, Moritz, Jeffery K. Tomberlin, Stefan Diener, Christian Zurbrügg, and Alexander Mathys. 2018. "Decomposition of Biowaste Macronutrients, Microbes, and Chemicals in Black Soldier Fly Larval Treatment: A Review." *Waste Management* 82 (December): 302–318. doi:10.1016/j.wasman.2018.10.022.
34. Gold, Moritz, Fabienne von Allmen, Christian Zurbrügg, and Alexander Mathys. 2020. "Identification of Bacteria in Two Food Waste Black Soldier Fly Larvae Rearing Residues." *Frontiers in Microbiology* 11 (November). Frontiers. doi:10.3389/fmicb.2020.582867.
35. Guilliet, Joseph, Guillaume Baudouin, Pollet Nicolas, and Filee Jonathan. 2022. *The Natural History of the Black Soldier Fly, Hermetia Illucens: Insights From Complete Mitochondrial Genome Sequences*. Preprint. In Review. doi:10.21203/rs.3.rs-1250528/v1.
36. Hadj Saadoun, Jasmine, Anna Valentina Luparelli, Augusta Caligiani, Laura Macavei, Lara Maistrello, Erasmo Neviani, Gianni Galaverna, Stefano Sforza, and Camilla Lazzi. 2020. "Antimicrobial Biomasses from Lactic Acid Fermentation of Black Soldier Fly Prepupae and Related By-Products." *Microorganisms* 8 (November). doi:10.3390/microorganisms8111785.
37. Hahn, Thomas, Aileen Roth, Ruomin Ji, Eric Schmitt, and Susanne Zibek. 2020. "Chitosan Production with Larval Exoskeletons Derived from the Insect Protein Production." *Journal of Biotechnology* 310 (February): 62–67. doi:10.1016/j.jbiotec.2019.12.015.
38. Hauser, Martin, and Marshall Woodley. 2015. "The Historical Spread of the Black Soldier Fly, Hermetia Illucens (L.) (Diptera, Stratiomyidae, Hermetiinae), and Its Establishment in Canada." *Journal of the Kansas Entomological Society* 146 (December): 51–54.
39. Heinzen, Tarah. 2015. "Recent Developments in the Quantification and Regulation of Air Emissions from Animal Feeding Operations." *Current Environmental Health Reports* 2 (1): 25–32. doi:10.1007/s40572-014-0038-4.
40. Henchion, Maeve, Maria Hayes, Anne Maria Mullen, Mark Fenelon, and Brijesh Tiwari. 2017. "Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium." *Foods* 6 (7): 53. doi:10.3390/foods6070053.
41. Hiruma, Kiyoshi, and Yu Kaneko. 2013. "Hormonal Regulation of Insect Metamorphosis with Special Reference to Juvenile Hormone Biosynthesis." In *Current Topics in*

Developmental Biology, 103:73–100. Elsevier. doi:10.1016/B978-0-12-385979-2.00003-4.

42. Hu, Tian, Jiating Wei, Li Du, Jibao Chen, and Jun Zhang. 2023. "The Effect of Biochar on Nitrogen Availability and Bacterial Community in Farmland." *Annals of Microbiology* 73 (1): 4. doi:10.1186/s13213-022-01708-1.
43. Huang, C., W. Feng, J. Xiong, T. Wang, W. Wang, C. Wang, and F. Yang. 2018. "Science Blog of Black Soldier Fly - EVO Conversion Systems - The Black Soldier Fly Company." https://www.evoconsys.com/blog/impact-of-drying-method-on-black-soldier-fly-larvae-associated-nutrition.
44. Jennings, Simon, Grant D Stentiford, Ana M Leocadio, Keith R Jeffery, Julian D Metcalfe, Ioanna Katsiadaki, Neil A Auchterlonie, et al. 2016. "Aquatic Food Security: Insights into Challenges and Solutions from an Analysis of Interactions between Fisheries, Aquaculture, Food Safety, Human Health, Fish and Human Welfare, Economy and Environment." *Fish and Fisheries* 17 (4): 893–938. doi:10.1111/faf.12152.
45. Jiang, Cheng- Liang, Wei- Zheng Jin, Xin- Hua Tao, Qian Zhang, Jun Zhu, Shi- Yun Feng, Xin- Hua Xu, Hong- Yi Li, Ze- Hua Wang, and Zhi- Jian Zhang. 2019. "Black Soldier Fly Larvae (*Hermetia Illucens*) Strengthen the Metabolic Function of Food Waste Biodegradation by Gut Microbiome." *Microbial Biotechnology* 12 (3): 528–543. doi:10.1111/1751-7915.13393.
46. Jung, Sungyup, Jong-Min Jung, Yiu Fai Tsang, Amit Bhatnagar, Wei-Hsin Chen, Kun-Yi Andrew Lin, and Eilhann E. Kwon. 2022. "Biodiesel Production from Black Soldier Fly Larvae Derived from Food Waste by Non-Catalytic Transesterification." *Energy* 238 (January): 121700. doi:10.1016/j.energy.2021.121700.
47. Kim, Chul-Hwan, JunHee Ryu, Jongkeun Lee, Kwanyoung Ko, Ji-yeon Lee, Ki Young Park, and Haegeun Chung. 2021. "Use of Black Soldier Fly Larvae for Food Waste Treatment and Energy Production in Asian Countries: A Review." *Processes* 9 (1): 161. doi:10.3390/pr9010161.
48. Klammsteiner, Thomas, Andreas Walter, Tajda Bogataj, Blaž Stres, and Heribert Insam. 2020. "The Core Gut Microbiome of Black Soldier Fly (Hermetia Illucens) Larvae Raised on Low-Bioburden Diets." *Frontiers in Microbiology* 11 (May). Frontiers. doi:10.3389/fmicb.2020.00993.
49. Klüber, Patrick, Stephanie Müller, Jonas Schmidt, Holger Zorn, and Martin Rühl. 2022. "Isolation of Bacterial and Fungal Microbiota Associated with Hermetia Illucens Larvae Reveals Novel Insights into Entomopathogenicity." *Microorganisms* 10 (2): 319. doi:10.3390/microorganisms10020319.
50. Kora, Aruna Jyothi. 2019. "Applications of Sand Roasting and Baking in the Preparation of Traditional Indian Snacks: Nutritional and Antioxidant Status." *Bulletin of the National Research Centre* 43 (1): 158. doi:10.1186/s42269-019-0199-2.
51. Lange, Klaus W., and Yukiko Nakamura. 2021. "Edible Insects as Future Food: Chances and Challenges." *Journal of Future Foods* 1 (1): 38–46. doi:10.1016/j.jfutfo.2021.10.001.
52. Lentz, Ronald R., Juming Tang, and Fermin P. Resurreccion. 2020. "1 - Electromagnetic Basis of Microwave Heating." In *Development of Packaging and Products for Use in Microwave Ovens (Second Edition)*, edited by Ulrich Erle, Peter Pesheck, and Matthew Lorence, 3–71. Woodhead Publishing in Materials. Woodhead Publishing. doi:10.1016/B978-0-08-102713-4.00001-3.
53. Lievens, S., G. Poma, J. De Smet, L. Van Campenhout, A. Covaci, and M. Van Der Borght. 2021. "Chemical Safety of Black Soldier Fly Larvae (*Hermetia Illucens*), Knowledge Gaps and Recommendations for Future Research: A Critical Review." *Journal of Insects as Food and Feed* 7 (4): 383–396. doi:10.3920/JIFF2020.0081.

54. Liu, Tao, Thomas Klammsteiner, Andrei Mikhailovich Dregulo, Vinay Kumar, Yuwen Zhou, Zengqiang Zhang, and Mukesh Kumar Awasthi. 2022. "Black Soldier Fly Larvae for Organic Manure Recycling and Its Potential for a Circular Bioeconomy: A Review." *The Science of the Total Environment* 833 (August): 155122. doi:10.1016/j.scitotenv.2022.155122.
55. Liu, Xiu, Xuan Chen, Hui Wang, Qinqin Yang, Kashif Ur Rehman, Wu Li, Minmin Cai, et al. 2017. "Dynamic Changes of Nutrient Composition throughout the Entire Life Cycle of Black Soldier Fly." *PloS One* 12 (8): e0182601. doi:10.1371/journal.pone.0182601.
56. LR - Veehouderij en omgeving, Team Acrres, Team Schimmels, Onkruiden en Plagen, Ilse Groeneveld, Hellen Elissen, Klaas Van Rozen, and Rommie Van Der Weide. 2021. *The Profitability Potential of Black Soldier Fly (BSF) Larvae Raised on Pig Manure at Farm Level*. Wageningen: Stichting Wageningen Research, Wageningen Plant Research, Business Unit Field Crops. doi:10.18174/549892.
57. Lu, Shengyong, Nittaya Taethaisong, Weerada Meethip, Jariya Surakhunthod, Boontum Sinpru, Thakun Sroichak, Pawinee Archa, et al. 2022. "Nutritional Composition of Black Soldier Fly Larvae (Hermetia Illucens L.) and Its Potential Uses as Alternative Protein Sources in Animal Diets: A Review." *Insects* 13 (9): 831. doi:10.3390/insects13090831.
58. Mangindaan, Dave, Emil Robert Kaburuan, and Bayu Meindrawan. 2022. "Black Soldier Fly Larvae (Hermetia Illucens) for Biodiesel and/or Animal Feed as a Solution for Waste-Food-Energy Nexus: Bibliometric Analysis." *Sustainability* 14 (21): 13993. doi:10.3390/su142113993.
59. Marguerite Rinaudo, Serge Pérez. "From Chitin to Chitosan." *Glycopedia*. https://glycopedia.eu/wp-content/uploads/2019/09/from_chitin_to_chitosan-2-c08.pdf.
60. McCarty, Mark F., and James J. DiNicolantonio. 2016. "Lauric Acid-Rich Medium-Chain Triglycerides Can Substitute for Other Oils in Cooking Applications and May Have Limited Pathogenicity." *Open Heart* 3 (2): e000467. doi:10.1136/openhrt-2016-000467.
61. Meticulous Market Report. 2022. *Black Soldier Fly Market by Product*. Meticulous research. https://www.globenewswire.com/en/news-release/2022/06/24/2468653/0/en/Black-Soldier-Fly-Market-Worth-3-96-Billion-by-2033-Exclusive-Report-by-Meticulous-Research.html.
62. Mohan, Kannan, Palanivel Sathishkumar, Durairaj Karthick Rajan, Jayakumar Rajarajeswaran, and Abirami Ramu Ganesan. 2023. "Black Soldier Fly (Hermetia Illucens) Larvae as Potential Feedstock for the Biodiesel Production: Recent Advances and Challenges." *The Science of the Total Environment* 859 (Pt 1): 160235. doi:10.1016/j.scitotenv.2022.160235.
63. Mojiri, Amin, Reza Andasht Kazeroon, and Ali Gholami. 2019. "Cross-Linked Magnetic Chitosan/Activated Biochar for Removal of Emerging Micropollutants from Water: Optimization by the Artificial Neural Network." *Water* 11 (3): 551. doi:10.3390/w11030551.
64. Ms. Prerana Patil. 2022. "Water Activity and Food Preservation – Nutrition Meets Food Science," August 29. https://nutritionmeetsfoodscience.com/2022/08/29/water-activity-and-food-preservation/.
65. Muinde, John, Chrysantus M. Tanga, John Olukuru, Clifford Odhiambo, Henri E. Z. Tonnang, and Kennedy Senagi. 2023. "Application of Machine Learning Techniques to Discern Optimal Rearing Conditions for Improved Black Soldier Fly Farming." *Insects* 14 (5): 479. doi:10.3390/insects14050479.
66. No, H. K., and S. P. Meyers. 2000. "Application of Chitosan for Treatment of Wastewaters." *Reviews of Environmental Contamination and Toxicology* 163: 1–27. doi:10.1007/978-1-4757-6429-1_1.

67. Okoro, Oseweuba Valentine, Victor Preat, Keikhosro Karimi, Lei Nie, Frederic Debaste, and Amin Shavandi. 2023. "Optimizing the Subcritical Water Valorization of Insect (Hermetia Illucens l.) Farming Waste for Biodiesel Production." *Chemical Engineering Research and Design* 196 (August): 413–426. doi:10.1016/j.cherd.2023.06.043.
68. Oonincx, Dennis G. A. B., Sarah Van Broekhoven, Arnold Van Huis, and Joop J. A. Van Loon. 2015. "Feed Conversion, Survival and Development, and Composition of Four Insect Species on Diets Composed of Food By-Products." Edited by Nikos T Papadopoulos. *PLOS ONE* 10 (12): e0144601. doi:10.1371/journal.pone.0144601.
69. Oyatogun, G. M., T. A. Esan, E. I. Akpan, S. O. Adeosun, A. P. I. Popoola, B. I. Imasogie, W. O. Soboyejo, et al. 2020. "Chapter 11 - Chitin, Chitosan, Marine to Market." In *Handbook of Chitin and Chitosan*, edited by Sreerag Gopi, Sabu Thomas, and Anitha Pius, 341–381. Elsevier. doi:https://doi.org/10.1016/B978-0-12-817966-6.00011-X.
70. Pérez-Pacheco, Rafael, Demián Hinojosa-Garro, Fernando Ruíz-Ortíz, Juan Carlos Camacho-Chab, Benjamín Otto Ortega-Morales, Nancy Alonso-Hernández, Alicia Fonseca-Muñoz, et al. 2022. "Growth of the Black Soldier Fly Hermetia Illucens (Diptera: Stratiomyidae) on Organic-Waste Residues and Its Application as Supplementary Diet for Nile Tilapia Oreochromis Niloticus (Perciformes: Cichlidae)." *Insects* 13 (4): 326. doi:10.3390/insects13040326.
71. Poveda, Jorge. 2021. "Insect Frass in the Development of Sustainable Agriculture. A Review." *Agronomy for Sustainable Development* 41 (1): 5. doi:10.1007/s13593-020-00656-x.
72. Rahman, Shafiur, ed. 2007. *Handbook of Food Preservation*. 2nd ed. Food Science and Technology. Boca Raton: CRC Press.
73. Rana, K. M., Md Salam, Shaharior Hashem, and Md Islam. 2015. "Development of Black Soldier Fly Larvae Production Technique as an Alternate Fish Feed." *International Journal of Research in Fisheries and Aquaculture* 5 (January): 41–47.
74. Rehman, Kashif Ur, Clemens Hollah, Karin Wiesotzki, Rashid Ur Rehman, Asif Ur Rehman, Jibin Zhang, Longyu Zheng, Theresa Nienaber, Volker Heinz, and Kemal Aganovic. 2023. "Black Soldier Fly, *Hermetia Illucens* as a Potential Innovative and Environmentally Friendly Tool for Organic Waste Management: A Mini-Review." *Waste Management & Research: The Journal for a Sustainable Circular Economy* 41 (1): 81–97. doi:10.1177/0734242X221105441.
75. Sapkota, Amy R., Lisa Y. Lefferts, Shawn McKenzie, and Polly Walker. 2007. "What Do We Feed to Food-Production Animals? A Review of Animal Feed Ingredients and Their Potential Impacts on Human Health." *Environmental Health Perspectives* 115 (5): 663–670. doi:10.1289/ehp.9760.
76. Saucier, L., C. M'ballou, C. Ratti, M.-H. Deschamps, Y. Lebeuf, and G.W. Vandenberg. 2022. "Comparison of Black Soldier Fly Larvae Pre-Treatments and Drying Techniques on the Microbial Load and Physico-Chemical Characteristics." *Journal of Insects as Food and Feed* 8 (1): 45–64. doi:10.3920/JIFF2021.0002.
77. Scala, Andrea, Jonathan A. Cammack, Rosanna Salvia, Carmen Scieuzo, Antonio Franco, Sabino A. Bufo, Jeffery K. Tomberlin, and Patrizia Falabella. 2020. "Rearing Substrate Impacts Growth and Macronutrient Composition of Hermetia Illucens (L.) (Diptera: Stratiomyidae) Larvae Produced at an Industrial Scale." *Scientific Reports* 10 (1): 19448. doi:10.1038/s41598-020-76571-8.
78. Setti, Leonardo, Enrico Francia, Andrea Pulvirenti, Silvia Gigliano, Massimo Zaccardelli, Catello Pane, Federica Caradonia, Sara Bortolini, Lara Maistrello, and Domenico Ronga. 2019. "Use of Black Soldier Fly (Hermetia Illucens (L.), Diptera: Stratiomyidae) Larvae Processing Residue in Peat-Based Growing Media." *Waste Management* 95 (July): 278–288. doi:10.1016/j.wasman.2019.06.017.

79. Seyedalmoosavi, Mohammad M., Manfred Mielenz, Teun Veldkamp, Gürbüz Daş, and Cornelia C. Metges. 2022. "Growth Efficiency, Intestinal Biology, and Nutrient Utilization and Requirements of Black Soldier Fly (Hermetia Illucens) Larvae Compared to Monogastric Livestock Species: A Review." *Journal of Animal Science and Biotechnology* 13 (1): 31. doi:10.1186/s40104-022-00682-7.
80. Shah, Assar Ali, Pajaree Totakul, Maharach Matra, Anusorn Cherdthong, Yupa Harnboonsong, and Metha Wanapat. 2022. "Nutritional Composition of Various Insects and Potential Uses as Alternative Protein Sources in Animal Diets." *Animal Bioscience* 35 (2): 317–331. doi:10.5713/ab.21.0447.
81. Shahidi, Fereidoon, Janak Kamil Vidana Arachchi, and You-Jin Jeon. 1999. "Food Applications of Chitin and Chitosans." *Trends in Food Science & Technology* 10 (2): 37–51. doi:10.1016/S0924-2244(99)00017-5.
82. Sharp, Russell. 2013. "A Review of the Applications of Chitin and Its Derivatives in Agriculture to Modify Plant-Microbial Interactions and Improve Crop Yields." *Agronomy* 3 (4): 757–793. doi:10.3390/agronomy3040757.
83. Siddiqui, Shahida Anusha, Bridget Ristow, Teguh Rahayu, Nugroho Susetya Putra, Nasih Widya Yuwono, Khoirun Nisa', Bosco Mategeko, et al. 2022. "Black Soldier Fly Larvae (BSFL) and Their Affinity for Organic Waste Processing." *Waste Management (New York, N.Y.)* 140 (March): 1–13. doi:doi.org/10.1016/j.wasman.2021.12.044.
84. Singh Kaleka, Amritpal, Navkiran Kaur, and Gaganpreet Kour Bali. 2019. "Larval Development and Molting." In *Edible Insects [Working Title]*. IntechOpen. doi:10.5772/intechopen.85530.
85. Soetemans, Lise, Maarten Uyttebroek, and Leen Bastiaens. 2020. "Characteristics of Chitin Extracted from Black Soldier Fly in Different Life Stages." *International Journal of Biological Macromolecules* 165 (December): 3206–3214. doi:10.1016/j.ijbiomac.2020.11.041.
86. Spranghers, Thomas, Matteo Ottoboni, Cindy Klootwijk, Anneke Ovyn, Stefaan Deboosere, Bruno De Meulenaer, Joris Michiels, Mia Eeckhout, Patrick De Clercq, and Stefaan De Smet. 2017. "Nutritional Composition of Black Soldier Fly (Hermetia Illucens) Prepupae Reared on Different Organic Waste Substrates." *Journal of the Science of Food and Agriculture* 97 (8): 2594–2600. doi:10.1002/jsfa.8081.
87. St-Hilaire, Sophie, Katie Cranfill, Mark A. McGuire, Erin E. Mosley, Jeffery K. Tomberlin, Larry Newton, Wendy Sealey, Craig Sheppard, and Stephen Irving. 2007. "Fish Offal Recycling by the Black Soldier Fly Produces a Foodstuff High in Omega-3 Fatty Acids." *Journal of the World Aquaculture Society* 38 (2): 309–313. doi:10.1111/j.1749-7345.2007.00101.x.
88. Surendra, K.C., Robert Olivier, Jeffery K. Tomberlin, Rajesh Jha, and Samir Kumar Khanal. 2016. "Bioconversion of Organic Wastes into Biodiesel and Animal Feed via Insect Farming." *Renewable Energy* 98 (December): 197–202. doi:10.1016/j.renene.2016.03.022.
89. Suryati, Tuti, Euis Julaeha, Kindi Farabi, Hanies Ambarsari, and Ace Tatang Hidayat. 2023. "Lauric Acid from the Black Soldier Fly (Hermetia Illucens) and Its Potential Applications." *Sustainability* 15 (13): 10383. doi:10.3390/su151310383.
90. Team Acrres, LR - Veehouderij en omgeving, Hellen Elissen, Rommie Van Der Weide, and Luuk Gollenbeek. 2023. *Effects of Black Soldier Fly Frass on Plant and Soil Characteristics : A Literature Overview*. Wageningen: Wageningen Plant Research. doi:10.18174/587213.
91. Triunfo, Micaela, Elena Tafi, Anna Guarnieri, Rosanna Salvia, Carmen Scieuzo, Thomas Hahn, Susanne Zibek, et al. 2022. "Characterization of Chitin and Chitosan Derived from

Hermetia Illucens, a Further Step in a Circular Economy Process." *Scientific Reports* 12 (1): 6613. doi:10.1038/s41598-022-10423-5.
92. Wang, Sheng Yin, Lingli Wu, Baoling Li, and Dayu Zhang. 2020. "Reproductive Potential and Nutritional Composition of Hermetia Illucens (Diptera: Stratiomyidae) Prepupae Reared on Different Organic Wastes." *Journal of Economic Entomology* 113 (1): 527–537. doi:10.1093/jee/toz296.
93. Wang, Yu-Shiang, and Matan Shelomi. 2017. "Review of Black Soldier Fly (Hermetia Illucens) as Animal Feed and Human Food." *Foods* 6 (10): 91. doi:10.3390/foods6100091.
94. Waśko, Adam, Piotr Bulak, Magdalena Polak-Berecka, Katarzyna Nowak, Cezary Polakowski, and Andrzej Bieganowski. 2016. "The First Report of the Physicochemical Structure of Chitin Isolated from Hermetia Illucens." *International Journal of Biological Macromolecules* 92 (November): 316–320. doi:10.1016/j.ijbiomac.2016.07.038.
95. Wu, Min, and Xuefeng Li. 2015. "Chapter 87 - Klebsiella Pneumoniae and Pseudomonas Aeruginosa." In *Molecular Medical Microbiology (Second Edition)*, edited by Yi-Wei Tang, Max Sussman, Dongyou Liu, Ian Poxton, and Joseph Schwartzman, Second Edition, 1547–1564. Boston: Academic Press. doi:https://doi.org/10.1016/B978-0-12-397169-2.00087-1.
96. Wu, Nan, Xiaobo Wang, Xiaoyan Xu, Ruijie Cai, and Shiyu Xie. 2020. "Effects of Heavy Metals on the Bioaccumulation, Excretion and Gut Microbiome of Black Soldier Fly Larvae (Hermetia Illucens)." *Ecotoxicology and Environmental Safety* 192 (April): 110323. doi:10.1016/j.ecoenv.2020.110323.
97. Yi, Hui-Yu, Munmun Chowdhury, Ya-Dong Huang, and Xiao-Qiang Yu. 2014. "Insect Antimicrobial Peptides and Their Applications." *Applied Microbiology and Biotechnology* 98 (13): 5807–5822. doi:10.1007/s00253-014-5792-6.
98. Yu, Yongqiang, Jia Zhang, Jinshui Zheng, Minmin Cai, Longyu Zheng, and Jibin Zhang. 2023. "Enhanced Protein Degradation by Black Soldier Fly Larvae (Hermetia Illucens L.) and Its Gut Microbes." *Frontiers in Microbiology* 13 (January). Frontiers. doi:10.3389/fmicb.2022.1095025.
99. Zampiga, M., F. Calini, and F. Sirri. 2021. "Importance of Feed Efficiency for Sustainable Intensification of Chicken Meat Production: Implications and Role for Amino Acids, Feed Enzymes and Organic Trace Minerals." *World's Poultry Science Journal* 77 (3). Taylor & Francis: 639–659. doi:10.1080/00439339.2021.1959277.
100. Zheng, Longyu, Yanfei Hou, Wu Li, Sen Yang, Qing Li, and Ziniu Yu. 2012. "Biodiesel Production from Rice Straw and Restaurant Waste Employing Black Soldier Fly Assisted by Microbes." *Energy* 47 (1): 225–229. doi:10.1016/j.energy.2012.09.006.
101. Złotko, Katarzyna, Adam Waśko, Daniel M. Kamiński, Iwona Budziak-Wieczorek, Piotr Bulak, and Andrzej Bieganowski. 2021. "Isolation of Chitin from Black Soldier Fly (Hermetia Illucens) and Its Usage to Metal Sorption." *Polymers* 13 (5): 818. doi:10.3390/polym13050818.