The Pharma Innovation Journal 2023; 12(6): 3469-3474

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 3469-3474

www.thepharmajournal.com
Received: 20-04-2023
Accepted: 18-05-2023

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A review on black soldier fly, *Hermetia illucens* as a potential source for organic waste management

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Abstract
The use of black soldier fly (BSF) as a bioconversion agent has become an emerging breakthrough in waste management. Organic wastes, such as household waste and livestock manure, can be used as a growth medium for BSF larvae and converted into favorable products. The average composting time of BSF larvae is around 12– 15 days, which is faster than that of microbes or earthworms (4–5 weeks). BSF shows potential as a feed and food ingredient because it has a high nutritional content, such as enzyme, chitin, medium-chain fatty acid, and antimicrobial peptides, and can be used as a functional food ingredient. From an economical perspective, the short composting period and the role of BSF as a feed and food alternatives can benefit producers and consumers. However, some challenges arise regarding the use of BSF larvae (BSFL) as a bioconversion agent, such as for heavy metal residues, pesticide residues, pathogens, and antimicrobial gene transmission and residues that require the best composting strategy for mitigation. The environmental safety of organic waste treated with BSFL has a good impact. Research must focus on effectively and safely enhancing the cultivation and processing of BSF and its applications as a functional food. In conclusion, BSF is a profitable alternative for organic waste bioconversion in developed and developing countries.

Keywords: Organic waste, compost, waste management, environmental safety, black soldier fly

1. Introduction

One of the huge challenges in almost all the cities in India is waste management. With the fast urbanization and agricultural land transformation into accommodation generating bulk waste in a quick span and the growing population, an upsurge in waste has become issue in developed and developing countries and may shortly become the most prominent concern for the world. The food supply chain generates 1.3 billion tons of agricultural and food waste every year (Yeona 2022) [40]. Current environmental, health, economic, and food security issues are related to the increasing use of unsustainable food and feed production, resulting in large amounts of organic waste. Thus, an economical and environmentally friendly strategy to manage organic waste is necessary. The Insects can also act as an agent that bioconverts organic wastes, such as food waste and livestock manure, can be adopted to produce nutrient-rich feed and organic fertilizer (Surendra and Kuehnle 2019) [33]. The black soldier fly (BSF) (*Hermetia illucens*) is one popular insect potentially developed as a bioconversion agent for various organic wastes and livestock manure. Its cultivation is easy, cheap, and fast, and this insect can simultaneously produce nutrient-rich animal feed, organic fertilizers (Song *et al*. 2021) [30], fuel (Kamarulzaman *et al*. 2019) [15], and other derivative products. Several studies have mentioned the success of Black Soldier Fly (BSF) larvae and pupae as feed for animals, such as fish (Bruni *et al*. 2018) [6], poultry (Cullere *et al*. 2018) [42], and pigs (Tan *et al*. 2020) [34], as a substitute for the main protein source (usually fish meal or soy- bean meal). The Black Soldier Fly (BSF) is not a vector of disease in humans and animals (Diener *et al*. 2015) [9] so it is safe for cultivation on a wide scale. Adult BSFs do not eat because their mouths do not function, and they die after laying eggs (Wardhana 2017) [38]. BSF Larva modify feces, reduce pathogenic bacteria such as *Escherichia coli* and *Salmonella enterica* (Erickson *et al*. 2004) [10[]], and contain natural antibiotics (Newton *et al*. 2005) [24]. These promising abilities must be explored to improve the production and productivity of Black Soldier Fly (BSF) for the application of their derivative products to various types of livestock and plants. This review discussed the Black Soldier Fly (BSF) life cycle, BSF bioconversion, utilization, safety aspects, the challenges and future application in producing various kinds of derivative products for organic fertilizers, nutrient-rich animal feed, bioactive compounds.

2. Black Soldier Fly (BSF) Life Cycle

The Black Soldier Fly (BSF) is an insect that belongs to order Diptera and family Stratiomyidae and is found in subtropical and tropical cli mates (Surendra *et al*. 2016) [32]. Its life cycle consists of five phases, namely, egg, larva (maggot), pre-pupa, pupa, and imago, (Martínez-Sánchez *et al*. 2011) [21]. Black Soldier Fly (BSF) egg and larval development are shown in Figure 1. The Black Soldier Fly (BSF) life cycle is holometabolous and starts from the egg phase. BSF fly eggs are oval with a length of 1 mm and color of pale white that gradually turns yellow until hatching time; a colony usually produces 200– 900 eggs. The adults can optimally lay eggs at a humidity of more than 60% (Tomberlin and Sheppard 2002) [36]. Female flies lay eggs near food sources, such as organic waste. Eggs hatch into larvae within 3–6 days at 24°C. BSF larva obtain energy from various organic wastes that are still full of nutrition, such as exc reta or chicken manure, palm ker nel meal (Fahmi 2015) [11]; tofu waste; kitchen waste (Newton *et al*. 2005) [24]; and fruit and vegetable waste (Žáková and Borkovcová 2013) [41]. The larva runs as a decomposer, and this stage is the longest phase in BSF life cycle; BSF Larva are also known as a bioconversion agent. BSF Larva can live in wide temperature and pH ranges (Tomberlin *et al*. 2009) [35]. The white skinned larval stage lasts for approximately 12 days. The larvae begin to turn brown and darken a week later and reach the prepupa stage (Myers *et al*. 2008).

Fig 1: Life cycle of black soldier fly, *Hermetia illucens*.

Prepupa does not require feeding and turns into a pupa by migrating to a dry and protected place. The pupa stage have maximum size and store a large amount of fat for defense during metamorphosis. The pupa stage lasts for 6–7 days until the individual becomes an imago/adult fly (Rachmawati *et al*. 2015) [29]. BSF adults only rely on body fat reserves obtained during the larval stage, so they do not act as a vector of disease and bacteria. Adult flies only need water to survive for 6–8 days (Tomberlin and Sheppard 2002).

3. Organic waste bioconversion: Bioconversion by insects is an attractive solution that can overcome the problems of organic waste management. Insect larvae can convert a large number of nutrients from organic waste (Leong and Kutty 2020) [18] by up to 70% in two weeks and store them as protein-rich biomass to replace fish meal, animal feed (Diener *et al*. 2015). Black Soldier Fly (BSF) life cycle and potential benefits are shown in Figure 2. BSFs have been propagated as organic waste converter agents because they eat a variety of organic materials four times their body weight and produce larvae containing 40% crude protein and 30% fat biomass.

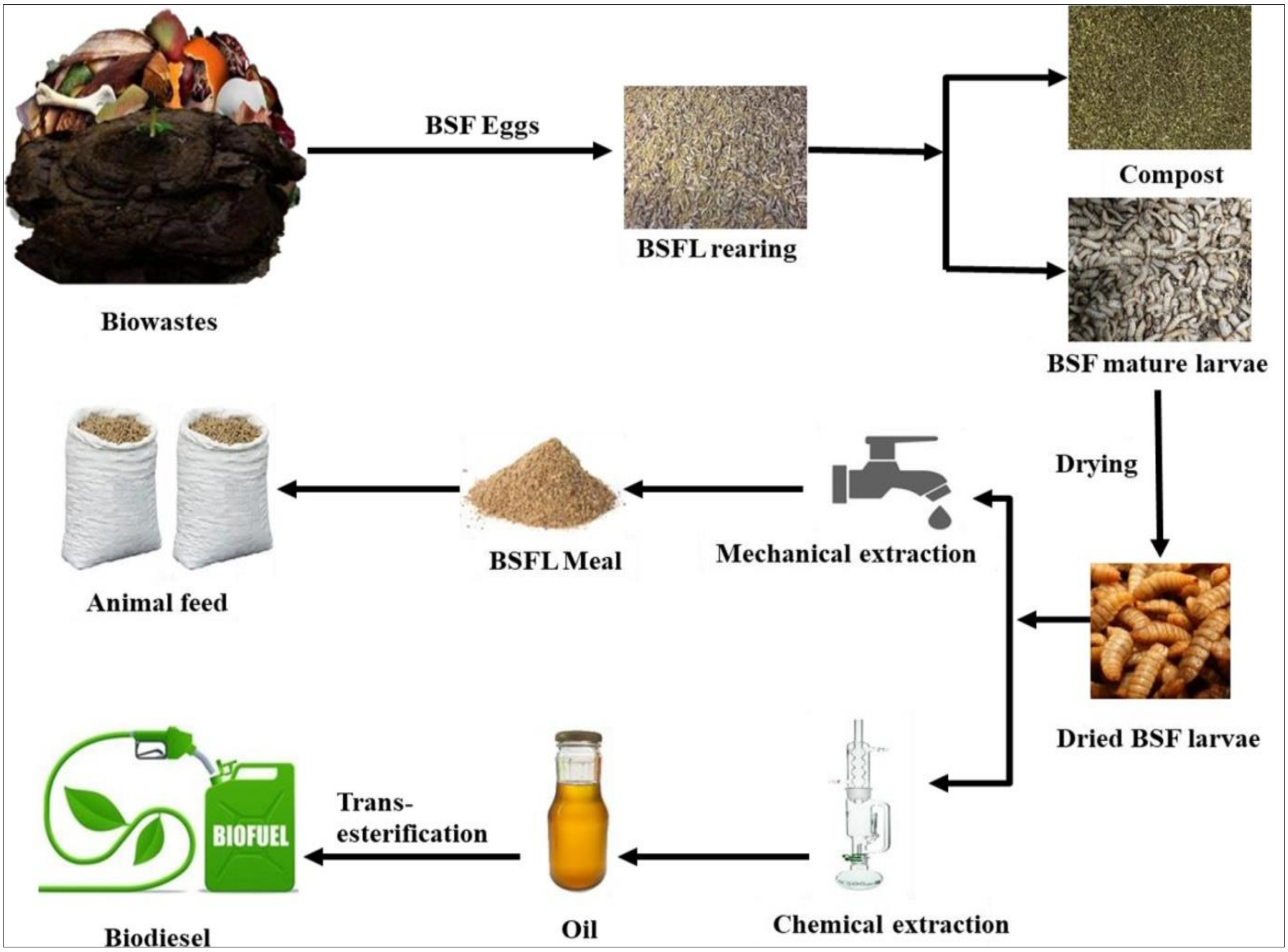

Figure 2: Schematic presentation of animal feed and liquid energy production from BSF Larva.

Therefore, the conversion of organic waste by Black Soldier Fly (BSF) Larva is an attractive recycling technology with many uses, such as in waste reduction, stabilization, value-added animal feed, and opens up new economic opportunities for small entrepreneurs in developing countries (Nguyen *et al*. 2015) [15]. Waste reduction by BSF Larval survival and growth are affected by the C/N ratio, protein level, and volatile solid content of the provided substrate (Gold *et al*. 2020) [13]. High fiber concentrations negatively affect the bioconversion efficiency and larval growth (Bohm *et al*. 2022) [5]. Other factors influencing bioconversion include feeding rate, larval density, and feeding frequency. Residues from Black Soldier Fly (BSF) larva are used as compost and have nutritional levels suitable for use as fertilizers and soil amendments. The rate of waste consumption by BSF Larva varies according to the type of waste, number of larvae, moisture content, temperature, and larval size (Alvarez *et al*. 2019). BSF Larva can reduce pathogen bacteria, such as *Escherichia* sp., *Salmonella* sp., *Vibrio* sp., and *Yersinia* sp., allowing the compost end product to meet the requirements for use as fertilizer and/or soil improver (Awasthi *et al*. 2020) [2].

4. Nutrient Composition

Among various insects that can be developed as feed, BSF has quite high protein and fat contents ranging 40%–50% and 29%–32%, respectively (Bosch *et al*. 2019). The BSF to be used as substitute for fish meal and as animal feed. Black Soldier Fly (BSF) is also rich in lauric acid (36.74%) (Fitriana *et al*. 2022) [12]. BSFL can be produced easily and quickly and can decompose various kinds of organic matter, such as livestock manure, vegetable waste, and kitchen waste (Spranghers *et al*. 2018) [31], and Agro-industrial byproducts (Meneguz *et al*. 2018) [22]. The use of different substrates will produce different biochemical compositions of larvae. Protein sourced from insects is environmentally friendly, economical, and has an important role in nature.

5. Potential Use

Feed availability is a major factor in the success of livestock business, whether in the form of poultry, ruminant, or fish farming. Fish waste is the main raw material for supporting protein, but its availability fluctuates. For increasing the sustainability of meat production, insects have emerged as innovative feed ingredients for several livestock species. Potential alternative raw materials with high protein content include maggots from BSF, which also contain animal protein.

6. Bioactive Compounds

Black Soldier Fly (BSF) is generally used as feedstuff of animals, including those in aquaculture and livestock production. The use of Black Soldier Fly (BSF) as a prebiotic and antimicrobial agent has been discovered recently, and the bioactive components of BSF were found to be enzymes, chitin, peptides, and polysaccharides. The protein of Black Soldier Fly (BSF) Larva can be hydrolyzed to produce antioxidant peptides for functional foods, cosmetic industries, and pharmaceutical products (Almeida *et al*. 2022) [1].

a. Enzyme

The Black Soldier Fly (BSF) also secretes beneficial enzymes related to digestion, such as amylase, lipase, and protease, during metabolism. The proteases with high activity in the digestive tract of Black Soldier Fly (BSF) Larva include leucine arylamidase, galactosidase, mannosidase, fucosidase and galactosidase (Kim *et al*. 2021). Cellulase is another enzyme that is presumed to be produced by Black Soldier Fly (BSF) Larva, especially in its digestive tract, due to the discovery of the novel CS10 cellu- industries, such as feed, food, textile industry, and tissue engineering, and as an adsorbent in water and waste water treatment (Purkayastha and Sarkar 2020) [28]. According to Leke-Aladekoba (2018) [16], chitin from Black Soldier Fly (BSF) has an antimicrobial activity against *Staphylococcus aureus*. Giving BSF meals to laying hens can also increase egg production and egg weight and adjust the composition of the gut microbiome, especially the chitin-degrading microbes that increase the production of short-chain fatty acids (Purnamasari and Himmatul, 2022). Therefore, Black Soldier Fly (BSF) feed can be used as an excellent prebiotic for the gut microbiota (Borrelli *et al*. 2017) and reduce the use of antibiotics.

b. Chitin

As a bioconversion agent, BSF has an excellent ability to produce chitin polymers or polymer of glucosamine up to 7% of Black Soldier Fly (BSF) biomass on dry matter basis (Surendra *et al*. 2020). The chitin content of BSF varies with its life phase. In particular, the puparium and cocoon phases have the highest chitin content. Crystalline, the chitin form found in BSF, is alpha chitin. As a feed ingredient, the high chitin content of BSF can interfere with its digestibility as a monogastric feed.

c. Lauric Acid

Lauric acid is a medium-chain fatty acid (C12:00) or a saturated fatty acid that is popularly used as an antimicrobial agent, especially against gram-positive bacteria. One of the stages in the life cycle of BSF is prepupae, which are rich in protein and fatty acids; the fat in prepupae can reach as much as 0.58 g C12: 0/100 mL, which is beneficial to suppress the growth of Lactobacilli and Streptococci (Spranghers *et al*. 2018) [31]. These medium-chain fatty acids are widely used as antibacterial agents, such as a feed additive that can fight pathogenic bacteria including *Streptococcus suis*, *E. coli*, *Clostridium perfringens*, *Salmonella poona*, and *S. aureus* and functions as an immunomodulator in livestock (Jackman *et al*. 2020) [14]. Lauric acid also represses *Listeria monocytogenes*, which is a foodborne pathogen that can infect animal production, and can be converted into monolaurin that has antibacterial, antiviral, and antiprotozoal properties (Almeida *et al*. 2022) [1]. Lauric acid also improves productivity in beef and dairy cattle, including carcass percentage, IMF, and meat and milk quality (Nguyen *et al*. 2020).

d. Antimicrobial Peptides (AMPs)

AMPs perform an essential role in innate immunity as the first line of protection against pathogens, including bacteria, viruses, and fungi. AMPs are small molecules with size varying from 10 to 100 amino acid residuals and are produced by all living animals and plants (Vogel *et al*. 2018) [37]. Moretta *et al*. (2020) [23] identified AMPs in BSF Larva using bioinformatics and found that 57 putatively active peptides have the potential to be developed as antimicrobials, antifungals, anticancer and antivirals. Four peptides with an average size of 4.2 kDa can fight *Helicobacter pylori* (*Campy- lobacteria: Heliobacteria*) and *E. coli* (*Enterobacterial: En- terobacteriaceae*) and thus can be employed as a substitute for antibiotics against bacteria with increasing resistance (Alvarez *et al*. 2019). Three AMPs from BSF, namely, hidefensin-1, hidiptericin-1, and hiCG13551, were cloned and transferred to E. coli to produce transgenic antimicrobials to fight entomopathogenic bacteria in *Bombyx mori silkworm*; hidefensin-1 and hidiptericin-1 successfully inhibited the growth of *E. coli* and *Streptococcus pneumonia*, and HiCG13551 suppressed the growth of *E. coli* and *Streptococcus pneumonia* (Xu *et al*. 2020) [39]. A study of AMPs in BSF confirmed that a new peptide (defensin-like peptide, DLP) could challenge gram-positive bacteria, including MSRA (Park *et al*. 2014) [27]. The antimicrobial peptides present in BSF biomass show potential use against fungi and viruses

7. Safety aspects

a. Microbial safety

The assessment of Black Soldier Fly (BSF) safety as a portion of food feed, and pharmaceutical ingredient is essential considering that humans are endusers (Barroso *et al*. 2017) [3]. Safety assessment aims to prevent the spread and contamination of infection agents to humans. BSF as a feed must be free from contamination or as a carrier that carries pathogens, pesticides, heavy metals, and pharmaceuticals (Surendra *et al*. 2020). Contamination can happen through the distribution of handling and storage of raw material of BSF. Microbiological contamination can also occur in the finished product during packaging and distribution or from the environment. Therefore, the identification and assessment of critical control points are necessary to ensure the safety of BSF naval vessels (Swinscoe *et al*. 2019). No evidence can confirm that BSF is a harbor from pathogenic viruses, but it may be a vector. As a protein source, BSF may also have the potential as an allergen (Purnamasari and Himmatul, 2022).

b. Chemical safety

Diener *et al*. (2015) [9] fed Black Soldier Fly (BSF) Larva with a diet containing heavy metals Pb, Cd, and Zn at low, medium, and high levels and later detected these heavy metals in the bodies of the larvae, prepupa, and adults. However, heavy metal zinc was not detected in the BSF larvae, prepupa, and adults when its contamination was at low levels. Black Soldier Fly (BSF) can also accumulate naturally heavy metals (cadmium, lead, mercury, and arsenic) in feed ingredients, such as in seaweed with the highest retention percentage of 93% for Cd and the lowest of 22% for arsenic (Biancarosa *et al*. 2018) [4].

8. Economical aspects

Composting using Black Soldier Fly (BSF) requires a shorter time (12–15 days) than composting using microbes or earthworms (4–5 weeks). The final product also varies from humus to protein, biodiesel, sugar, and grease sugar. Waste treatment using BSFL is a promising concept where a circular economy with maintained environmental and economic stability can be attained, especially among lower middle class economies ((Purnamasari and Himmatul, 2022). An economic opportunity is to organically produce BSFL products and their derivatives that are healthy, safe, and nutritious.

9. Challenges and Potential in the future

The potential of Black Soldier Fly (BSF) as a source of protein for livestock and humans generates not only opportunities but also challenges because Black Soldier Fly (BSF), which is an insect, is not recognizable or not yet accepted by all groups as a food ingredient and is considered taboo or unattractive. As a bioconversion agent, Black Soldier Fly (BSF) Larva is widely cultivated using organic wastes from agriculture and households. Black Soldier Fly (BSF) is allowed for use as animal feed, but its application in human food is being debated (Gold *et al*. 2018). In the event of using BSFL as human food, postharvest processing must be conducted to ensure that it is free from contamination. Concerns of food safety and the insects' shape have negative impacts on con- sumption frequency. Some reports showed that insects can cause allergies of varying allergy levels, whether consumed directly or through processed food derived from insects. The allergy is probably due to the identified tropomyosin in Black Soldier Fly (BSF) and crustaceans (Leni *et al*. 2020) [17]. Some studies indicated that the antibiotic resistance gene (ARG) has emerged due to aerobic manure composting (Cao *et al*. 2020). Black Soldier Fly (BSF) composting approach can decrease the ARG by 95% in poultry ma- nure after 12 days and reduce lincomycin by 84.9% after 12 days of bioconversion (Luo *et al*. 2022) [20]. As food and feed and functional products, Black Soldier Fly (BSF) and its derivatives can provide benefits to producers and consumers. In addition to financial benefits, the functional properties of BSF render it a healthy bioactive natural resource. Given that the environmental safety of organic waste treated with Black Soldier Fly (BSF) has a good environmental impact, this strategy can be one of the main efforts to mitigate global warming. Cheap protein sources are also beneficial for fish, beef cattle, dairy, and poultry farmers. In addition to the bioremediation of livestock manure (fecal sludge), Black Soldier Fly (BSF) can be used in entomoremediation for heavy metal wastes, such as Zn and Cd (Bulak *et al*. 2018) [7]. Research must focus on safely and effectively improving the processing and cultivation of BSF and its applications as a functional food. The development and enhancement of BSFL genetic quality must be carried out by identifying potential genes that regulate various traits for BSF production, such as manipulating protein as a source of food and functional food or fat material for biodiesel.

10. Conclusion

Black Soldier Fly (BSF) is a popular insect and has potential as a bioconversion agent for reducing and recycling organic biomass. The potential of BSF as a source of feed and food (edible product) has also been increasingly explored in food technology and animal feed, especially as a source of protein. Ease of maintenance and simple handling are important for products that are financially profitable and safe for the environment. BSF can be used to produce bioactive and prebiotic components, such as antimicrobial peptide, chitin, and enzymes, and even as a raw material for biodiesel. The safety of BSF must be considered from the microbiological, chemical, and environmental aspects. The study of production methods, utilization, and potential of BSF warrants further and deep exploration to efficiently generate products that are truly profitable, environmentally friendly, and economical.

12. References

1. Almeida C, Murta D, Nunes R, Baby AR, Fernandes, Barros L, *et al*. Characterization of lipid extracts from the *Hermetia illucens* larvae and their bioactivities for potential use as pharmaceutical and cosmetic ingredients. Heliyon. 2022;8(5):e09455. doi:10.101 6/j.heliyon.2022.e09455.
2. Awasthi MK, Liu T, Awasthi SK, Duan Y, Pandey A, Zhang Z. Manure pretreatments with black soldier fly *Hermetia illucens* L. (Diptera: Stratiomyidae): A study to reduce pathogen content. Science of The Total Environment. 2020;737:139842. doi:10.1016/j.scitotenv.2020.139842.
3. Barroso FG, Sánchez-Muros MJ, Segura M, Morote E, Torres A, Ramos R, *et al*. Insects as food: Enrichment of larvae of *Hermetia illucens* with omega 3 fatty acids by means of dietary modifications. Journal of Food Composition and Analysis. 2017;62:8–13. doi: 10.1016/j.jfca.2017.04.008.
4. Biancarosa I, Liland NS, Biemans D, Araujo P, Bruckner CG, Waagbø R, *et al*. Uptake of heavy metals and arsenic in black soldier fly (*Hermetia illucens*) larvae grown on seaweed-enriched media: Heavy metals in black soldier fly larvae grown on seaweed. Journal of the Science of Food and Agriculture. 2018;98(6):2176–2183. doi:10.1002/jsfa.8702.
5. Bohm K, Hatley GA, Robinson BH, Gutiérrez-Ginés MJ. Black Soldier Fly-based bioconversion of biosolids creates high-value products with low heavy metal concentrations. Resources, Conservation and Recycling. 2022;180:106149. doi:10.1016/j.resconrec.2021.106149.
6. Bruni L, Pastorelli R, Viti C, Gasco L, Parisi G. Characterisation of the intestinal microbial communities of rainbow trout (Oncorhynchus mykiss) fed with *Hermetia illucens* (black soldier fly) partially defatted larva meal as partial dietary protein source. Aquaculture. 2018;487:56–63. doi:10.1016/j.aquaculture.2018.01.006.
7. Bulak P, Polakowski C, Nowak K, Waśko A, Wiącek D, Bieganowski A. *Hermetia illucens* as a new and promising species for use in entomoremediation. Science of The Total Environment. 2018;633:912–919. doi:10.101 6/j.scitotenv.2018.03.252.
8. Musniati N, Sartika RAD. The existence of livestock as a dominant risk factor of pneumonia among Indonesian children aged 12-59 months. Int. J Agric. Extension Social Dev 2019;2(1):07-10. DOI: 10.33545/26180723.2019.v2.i1a.16
9. Diener S, Zurbrügg C, Tockner K. Bioaccumulation of heavy metals in the black soldier fly, *Hermetia illucens* and effects on its life cycle. Journal of Insects as Food and Feed. 2015;1(4):261–270. doi:10.3920/JIFF2015.0030.
10. Erickson MC, Islam M, Sheppard C, Liao J, Doyle MP. Reduction of Escherichia coli O157:H7 and Salmonella enterica Serovar Enteritidis in Chicken Manure by Larvae of the Black Soldier Fly. Journal of Food Protection. 2004;67(4):685–690. doi:10.4315/0362-028X-67.4.685.
11. Fahmi MR. Optimalisasi proses biokonversi dengan menggunakan mini-larva *Hermetia illucens* untuk memenuhi Kebutuhan pakan ikan, 2015. doi:10.13057/psnmb i/m010124.
12. Fitriana EL, Laconi EB, Astuti DA, Jayanegara A.

Effects of various organic substrates on growth performance and nutrient composition of black soldier fly larvae: A meta-analysis. Bioresource Technology Reports. 2022;18:101061. doi:10.1016/j.biteb.2022.101061.
13. Gold M, Cassar CM, Zurbrügg C, Kreuzer M, Boulos S, Diener S, *et al*. Biowaste treatment with black soldier fly larvae: Increasing performance through the formulation of biowastes based on protein and carbohydrates. Waste Management. 2020;102:319–329. doi:10.101 6/j.wasman.2019.10.036.
14. Jackman JA, Boyd RD, Elrod CC. Medium-chain fatty acids and monoglycerides as feed additives for pig production: towards gut health improvement and feed pathogen mitigation. Journal of Animal Science and Biotechnology. 2020;11(1):44. doi:10.1186/s40104-020-004 46-1.
15. Kamarulzaman MK, Hafiz M, Abdullah A, Chen AF, Awad OI. Combustion, performances and emissions characteristics of black soldier fly larvae oil and diesel blends in compression ignition engine. Renewable Energy. 2019;42:569–580. doi:10.1016/j.renene.2019.04.126.
16. Leke-Aladekoba AA. Comparison of extraction methods and characterisation of chitin and chitosan with antimicrobial and antioxidant properties form black soldier fly (Hermetia illucens) meal. [Doctoral thesis]. [Halifax, Nova Scotia]: Dalhousie University, 2018.
17. Leni G, Tedeschi T, Faccini A, Pratesi F, Folli C, Puxeddu I, *et al*. Shotgun proteomics, insilico evaluation and immunoblotting assays for allergenicity assessment of lesser mealworm, black soldier fly and their protein hydrolysates. Scientific Reports. 2020;10(1):1228. doi:10.1038/s41598-020-57863-5.
18. Leong SY, Kutty SRM. Characteristic of *Hermetia illucens* Fatty Acid and that of the Fatty Acid Methyl Ester Synthesize Based on Upcycling of Perishable Waste. Waste and Biomass Valorization. 2020;11(10):5607–5614. DOI: 10.1007/s12649-020-01018-0.
19. Listya Purnamasari, Himmatul Khasanah. Black Soldier Fly (*Hermetia illucens*) as a Potential Agent of Organic Waste Bioconversion. ASEAN Journal on Science & Technology for Development.2022;39(2)69–83. DOI 10.29037/ajstd.780.
20. Luo X, Yang Q, Lin Y, Tang Z, Tomberlin JK, Liu W, *et al*. Black soldier fly larvae effectively degrade lincomycin from pharmaceutical industry wastes. Journal of Environmental Management. 2022;307:114539. doi: 10.1016/j.jenvman.2022.114539.
21. Martínez-Sánchez A, Magaña C, Saloña M, Rojo S. First record of *Hermetia illucens* (Diptera: Stratiomyidae) on human corpses in Iberian Peninsula. Forensic Science International. 2011;206(1-3):e76–e78. doi:10.1016/j.forsciint. 2010.10.021.
22. Meneguz M, Schiavone A, Gai F, Dama A, Lussiana C, Renna M, Gasco L. Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (*Hermetia illucens*) larvae: Rearing substrate effects on performance, 2018.
23. Moretta A, Salvia R, Scieuzo C, Di Somma A, Vogel H, Pucci P, *et al*. A bioinformatic study of antimicrobial peptides identified in the Black Soldier Fly (BSF) *Hermetia illucens* (Diptera: Stratiomyidae). Scientific Reports. 2020;10(1):16875. doi:10.1038/ s41598-020-74017-9.
24. Newton L, Craig S, Wes D W, Gary B, Robert D. Using the black soldier fly, Hermetia illucens, as a valueadded tool for the management of swine manure. Technical report. Animal and poultry waste management center, north carolina state university. Raleigh, report. Animal and poultry waste management center, NC, 2005.
25. Nguyen TTX, Tomberlin JK, Vanlaerhoven S. Ability of Black Soldier Fly (Diptera: Stratiomyidae) Larvae to Recycle Food Waste. Environmental Entomology. 2015;44(2):406–410. doi:10.1093/ee/nvv002.
26. Nutritional composition of black soldier fly. Journal of the Science of Food and Agriculture. 98(15):5776–5784. doi:10.1002/jsfa.9127.
27. Park SI, Chang BS, Yoe SM. Detection of antimicrobial substances from larvae of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae): Antimicrobial activity of *H. illucens*. Entomological Research. 2014;44(2):58–64. doi:10.1111/1748-5967.12050.
28. Purkayastha D, Sarkar S. Physicochemical Structure Analysis of Chitin Extracted from Pupa Exuviae and Dead Imago of Wild Black Soldier Fly (Hermetia illucens). Journal of Polymers and the Environment. 2020;28(2):445–457. doi:10.1007/s10924-019-01620-x.
29. Rachmawati R, Buchori D, Hidayat P, Hem S, Fahmi MR. Perkembangan dan Kandungan Nutrisi Larva *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) pada Bungkil Kelapa Sawit. Jurnal Entomologi Indonesia. 2015;7(1):28. doi:10.5994/jei.7.1.28.
30. Song S, Ee AWL, Tan JKN, Cheong JC, Chiam Z, Arora S, Lam WN, *et al*. Upcycling food waste using black soldier fly larvae: Effects of further composting on frass quality, fertilising effect and its global warming potential. Journal of Cleaner Production. 2021;288:125664. doi:10.1016/j.jclepro.2020.125664.
31. Spranghers T, Michiels J, Vrancx J, Ovyn A, Eeckhout M, De Clercq P, *et al*. Gut antimicrobial effects and nutritional value of black soldier fly (*Hermetia illucens* L.) prepupae for weaned piglets. Animal Feed Science and Technology. 2018;235:33–42. doi:10.1016/j.anif eedsci.2017.08.012.
32. Surendra K, Olivier R, Tomberlin JK, Jha R, Khanal SK. Bioconversion of organic wastes into biodiesel and animal feed via insect farming. Renewable Energy. 2016;98:197– 202. doi:10.1016/j.renene.2016.03.022.
33. Surendra KC, Kuehnle A. Embracing AgTech for Food Security and Beyond. Industrial Biotechnology. 2019;15(6):323–324. doi:10.1089/ind.2019.29194.skc.
34. Tan X, Yang H, Wang M, Yi Z, Ji F, Li J, Yin Y. Amino acid digestibility in housefly and black soldier fly prepupae by growing pigs. Animal Feed Science and Technology. 2020;263:114446. doi:10.1016/j.anifeedsci.2020.114446.
35. Tomberlin JK, Adler PH, Myers HM. Development of the Black Soldier Fly (Diptera: Stratiomyidae) in Relation to Temperature. Environmental Entomology. 2009;38(3):930–934. doi:10.1603/022.038.0347.
36. Tomberlin JK, Sheppard DC. Factors Influencing Mating and Oviposition of Black Soldier Flies (Diptera: Stratiomyidae) in a Colony. Journal of Entomological Science. 2002;37(4):345–352. doi:10.18474/0749-8004-

37.4.345.
37. Vogel H, Müller A, Heckel DG, Gutzeit H, Vilcinskas A. Nutritional immunology: Diversification and dietdependent expression of antimicrobial peptides in the black soldier fly Hermetia illucens. Developmental & Comparative Immunology. 2018;78:141–148. doi:10.1016/j.dci. 2017.09.008.
38. Wardhana AH. Black Soldier Fly (Hermetia illucens) as an Alternative Protein Source for Animal Feed. Indonesian Bulletin of Animal and Veterinary Sciences. 2017;26(2):069. doi:10.14334/wartazoa.v26i2.1327.
39. Xu J, Luo X, Fang G, Zhan S, Wu J, Wang D, Huang Y. Transgenic expression of antimicrobial peptides from black soldier fly enhance resistance against entomopathogenic bacteria in the silkworm, Bombyx mori. Insect Biochemistry and Molecular Biology. 2020;127:103487. doi:10.1016/j.ibmb.2020.103487.
40. Yeona H. Measures to Reduce Agri-food Waste at the Retail and Consumption Stages. Technical report. Korea Rural Economic Institute, 2022.
41. Žáková M, Borkovcová M. Comparison of field and lab application of *Hermetia illucens* larvae. MendelNet 2013. MendelNet. were calculated. Correlation coefficients were calculated as per the formulae suggested by Falconer. 2013;1981:798–801.
42. Cullere M, Tasoniero G, Giaccone V, Acuti G, Marangon A, *et al.* Black soldier fly as dietary protein source for broiler quails: Meat proximate composition, fatty acid and amino acid profile, oxidative status and sensory traits. Animal. 2018;12(3):640–647. doi:10.1017/S175 1731117001860.