

# Black Soldier Fly (*Hermetia illucens*) as a Potential Agent of Organic Waste Bioconversion

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**ABSTRACT** The use of black soldier fly (BSF) as a bioconversion agent has become an emerging breakthrough in waste processing. 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. The safety aspects of BSF utilization, including microbial safety, chemical safety, and environmental safety, warrant clarification to ensure BSF safety. 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; therefore, this strategy can be used to reduce global warming. 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.

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## 1. INTRODUCTION

One of the huge challenges in almost all the cities in Indonesia is waste management. For example, the amount of waste in East Java in 2018 reached 5,064.88 tons/day consisting of 43.24% food waste, 17.73% wood branches and leaves, and 39.03% inorganic waste (Ministry of Environment and Forestry 2022). With the fast urbanization and agricultural land transformation into accommodation generating bulk waste in a quick span in some areas 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 (Shazia Iqbal et al. 2021). The food supply chain generates 1.3 billion tons of agricultural and food waste every year (Yeona 2022). 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 cultivation of insects as a bioconversion agent for organic wastes, such as food waste and livestock manure, can be adopted to produce nutrient-rich feed and organic fertilizer (Surendra and Kuehnle 2019). Insects can also act as an agent that bioconverts chicken and pig manure up to 50% and reduces phosphorus and nitrogen waste up to 75% (Newton et al. 2005a; Abd El-Hack et al. 2020). Several

types of insects belonging to the order of *Lepidoptera*, *Hymenoptera*, *Coleoptera*, *Hemiptera*, *Trichoptera*, *Odonata*, and *Diptera* can decompose organic wastes and reduce odors and the presence of pathogenic microbes (Surendra et al. 2020). Other insects can live in various organic wastes, such as the Hong Kong caterpillar or mealworm (*Tenebrio molitor*) (Azizah et al. 2019; Schiavone et al. 2019), locust insects (*Locusta migratoria* and *Schistocerca gregaria*) (Alegbeleye et al. 2012; van Huis 2013), crickets (*Acheta domestica* and *Gryllobates sigillatus*) (Wang et al. 2005; Navarro del Hierro et al. 2020), house fly (*Musca domestica*) (Adesina et al. 2012; Okah and Onwujiariri 2012), and black soldier fly (BSF) (*Hermetia illucens*) (Purnamasari et al. 2019).

The BSF is one popular insect potentially developed as a bioconversion agent for various organic wastes and livestock manure (*Hermetia illucens*). Its cultivation is easy, cheap, and fast, and this insect can simultaneously produce nutrient-rich animal feed (Liu et al. 2017; Stadlander et al. 2017), organic fertilizers (Liu et al. 2017; Song et al. 2021), fuel (Rehman et al. 2018; Kamarulzaman et al. 2019), and other derivative products (Caligiani et al. 2018). Several studies have mentioned the success of BSF larvae (BSFL) and pupae as feed for animals, such as fish (Bruni et al. 2018), poultry (Cullere et al. 2018), and pigs (Tan et al. 2020), as a substitute for the main protein source (usually fish meal or soybean meal). The BSF is not a vector of disease in humans

and animals (Diener et al. 2015) 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). BSFL modify feces, reduce pathogenic bacteria such as *Escherichia coli* and *Salmonella enterica* (Erickson et al. 2004), and contain natural antibiotics (Newton et al. 2005b). These promising abilities must be explored to improve the production and productivity of BSF for the application of their derivative products to various types of livestock and plants. This review discussed the BSF life cycle, BSF bioconversion, utilization, safety aspects, and future application in producing various kinds of derivative products for organic fertilizers, nutrient-rich animal feed, bioactive compounds. The challenge of BSFL utilization was also addressed.

## 2. BSF LIFE CYCLE

The BSF is an insect that belongs to order Diptera and family Stratiomyidae and is found in subtropical and tropical climates (46° North –42° South Latitude) (Surendra et al. 2016). Its life cycle consists of five phases, namely, egg, BSFL, prepupa, pupa, and imago, (Martínez-Sánchez et al. 2011). BSF egg and larval development (Maglangit and Alosbanos 2021) are shown in Figure 1. The 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 (Fahmi 2015; Wardhana 2017). The number of eggs produced is directly proportional to the body and wing size of BSFs (Gobbi et al. 2013); adults can optimally lay eggs at a humidity of more than 60% (Tomberlin and Sheppard 2002). Female flies lay eggs near food sources, such as organic waste.

Eggs hatch into larvae within 3–6 days at 24°C (Diener et al. 2011; Holmes et al. 2012). BSFL have an oval, flattened body shape about 12–17 mm long and 11 body segments with several transverse hairs. BSFL obtain energy from various organic wastes that are still full of nutrition, such as excreta or chicken manure (Newton et al. 2005b), palm kernel meal/PKM (Fahmi 2015); tofu waste (Purnamasari et al. 2019); kitchen waste (Newton et al. 2005b); and fruit and vegetable waste (Žáková and Borkovcová 2013). The larva runs as a decomposer, and this stage is the longest phase in

BSF life cycle; BSFL are also known as a bioconversion agent. BSFL can live in wide temperature and pH ranges (Myers et al. 2008; Tomberlin et al. 2009), and their digestive tract contains several bacteria, such as *Micrococcus* sp., *Bacillus* sp., *Streptococcus* sp., and *Aerobacter aerogens* (Banjo et al. 2005). The quantity and quality of the media used in larval growth affect the body's nutrient content (van Huis 2013) and larval weight (Sundu and Dingle 2002). The growth rate of BSFL is extremely fast until the 8th day. The body-weight of the larvae also continues to increase until they are about to enter the prepupa stage. The white-skinned larval stage lasts for approximately 12 days. The larvae begin to turn brown and darken a week later (Rachmawati et al. 2015) and reach the prepupa stage for the next 25–31 days (Myers et al. 2008).

Prepupa does not require feeding and turns into a pupa by migrating to a dry and protected place. In the pupa stage, BSFL are at their maximum size and store a large amount of fat for defense during metamorphosis (Newton et al. 2005a). The prepupa phase starts on the 19th day, and the pupa stage begins on the 24th day. The pupa stage takes place for the next 8 days and lasts for 6–7 days until the individual becomes an imago/adult fly (Fahmi 2015; Rachmawati et al. 2015).

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) and require optimal environmental conditions for reproduction, namely, an average daytime temperature of 31.8°C; BSF adults are tolerant of various temperatures (range: 15°C–47°C) (Diener et al. 2011). The breeding and egg laying of BSF are influenced by time, light intensity (135 mol m<sup>-2</sup> s<sup>-1</sup>) (Zhang et al. 2010), light wavelength (700 nm) (Briscoe and Chittka 2001), temperature (24°C–40°C) and relative humidity (30%–90%) (Tomberlin and Sheppard 2002).

## 3. ORGANIC WASTE BIOCONVERSION WITH BSF

Bioconversion by insects is an attractive solution that can overcome the problems of organic waste management. Bioconversion converts organic waste into high-value products, such as a source of methane energy, through fermen-

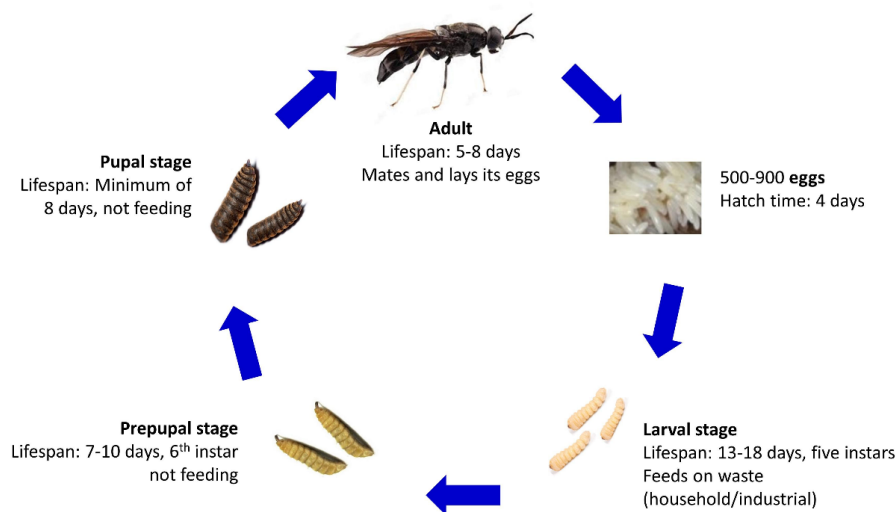


FIGURE 1. BSF egg and larval development (Maglangit and Alosbanos 2021)

TABLE 1. Organic waste reduction by BSFL.

Reducing material	Reducing the percentage of BSFL	References
Cattle waste	33%–58%	(Myers et al. 2008)
	12.7%	(Gold et al. 2020)
Poultry waste	50%–56%	(Myers et al. 2008; Siddiqui et al. 2022)
Organic waste	66%–79%	(Diener et al. 2011)
Fresh fruit waste	46.7%	(Lalander et al. 2019)
Vegetable waste	58.4%	(Gold et al. 2020)
Swine manure	86%–88%	(Awasthi et al. 2020)
Food manufacturing byproducts	52%	(Siddiqui et al. 2022)
Human feces	39.1%–48.6%	(Gold et al. 2020)

tation involving living microorganisms, such as bacteria, fungi, or insect larvae (family: *Chaliforidae*, *Mucidae*, and *Stratiomyidae*) (Newton et al. 2005a). Furthermore, insect larvae can convert a large number of nutrients from organic waste (Leong and Kutty 2020) by up to 70% in two weeks and store them as protein-rich biomass to replace fish meal (Diener et al. 2015). 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. Therefore, the conversion of organic waste by BSFL is an attractive recycling technology with many uses, such as in waste reduction and stabilization and value-added animal feed, and opens up new economic opportunities for small entrepreneurs in developing countries (Diener et al. 2015; Nguyen et al. 2015). Waste reduction by BSFL is commonly used as an indicator to determine the bioconversion efficiency of the type of waste and is calculated as the difference between the feed provided and residue and then divided by feed (Siddiqui et al. 2022). Larval survival and growth are affected by the C/N ratio, protein level, and volatile solid content of the provided substrate (Rehman et al. 2018; Gold et al. 2020). High fiber concentrations negatively affect the bioconversion efficiency and larval growth (Bohm et al. 2022). Other factors influencing bioconversion include feeding rate, larval density, and feeding frequency (Diener et al. 2011). The added synergistic microorganisms, fungi, or exogenous microbes improve the bioconversion of organic wastes and do not negatively affect the nutrient value of BSF biomass (Surendra et al. 2020). The percentage of reduction by organic waste bioconversion is shown in Table 1. By comparison, the percentage of reduction using vermicomposting is only 4%–5% of food waste (Ali et al. 2015) and 18% of cow manure (Contreras-Ramos et al. 2005). He et al. (2021) reported that bioconversion using the mealworm of rice straw and corn straw can produce carbon reduction of up to 16.3% and 13.67%. Therefore, BSFL bioconversion is the most efficient among these methods.

Residues from BSFL are used as compost and have nutritional levels suitable for use as fertilizers and soil amendments. The rate of waste consumption by BSFL varies according to the type of waste, number of larvae, moisture content, temperature, and larval size (Alvarez et al. 2019). BSFL 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). Table 2 shows the emission potential of several greenhouse gases (GHGs) during composting by some bioconversion agents. BSFL produces less and cleaner GHG than vermicompost and traditional composting in agricultural waste and food waste substrate. GHG emission is also determined by other factors, such as C/N ratio, pH, composting time, substrate, and aeration rate (Rehman et al. 2018; Li et al. 2020; Lindberg et al. 2022a).

#### 4. BSF 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). These nutrients include essential amino acids; thus, allowing BSF to be a substitute for fish meal and MBM for animal feed. BSF is also rich in lauric acid (36.74%) (Fitriana et al. 2022). BSFL can be produced easily and quickly (Mawaddah et al. 2018) and can decompose various kinds of organic matter, such as livestock manure, vegetable waste, and kitchen waste (Spranghers et al. 2018), and agroindustrial byproducts (Meneguz et al. 2018). 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. Insects have high feed conversion rates and can be reared and mass-produced (Li et al. 2015) and can reduce virus survival (Lalander et al. 2015). Antibacterial studies in Korea showed that methanol extract from BSFL has antibiotic properties against gram-negative bacteria but is not effective against gram-positive bacteria (Kim et al. 2011).

Omega-3 and -6 fatty acids are present in BSF biomass and could be enriched by manipulating the composition of substrates, such as microalgae, seaweed, and fish offal (Surendra et al. 2020). BSF accumulates manganese (Mn) and micronutrient calcium (Ca) up to 6% of dry matter (Spranghers et al. 2018). BSFL has relatively high protein content and can be potentially used as protein sources (Table 3). Compared with other insects usually used for animal feed, such as Jamaican field cricket and mealworm with crude protein levels of 67.7% and 64.5%, respectively, BSFL has lower crude protein level at 44.7%–44.9%. Despite this disadvantage, BSFL adults aged 2 weeks have the lowest methane emission compared with Jamaican field cricket, mealworm, and soybean during rumen fermentation (Jayanegara et al. 2017).

#### 5. POTENTIAL USE OF BSF AS FEED

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. The effect of BSFL on animal performance is shown in Table 4. Potential alternative raw materials with high protein content include maggots from BSF, which also contain animal protein. As a component of a complete diet, BSFL meal contains the recycled lost nutrients because the residual fatty acids and amino acids of organic wastes are incorporated into the biomass high in fat and protein (Henry et al. 2015) and even functional molecules (Iaconisi et al. 2017).

BSFL meal can be applied in livestock diets as a replacement part or even a complete substitute for conventional protein sources, such as soybean meal and fishmeal. However, insect meal has a high ratio of omega 6 and monounsaturated fat, and fish meal is rich in EPA (14%) and DHA (16%) (Barroso et al. 2017). Heavy metals and nonessential elements do not accumulate in BSFL but rather in the residues (Bohm et al. 2022).

## 6. BIOACTIVE COMPOUND IN BSF

Owing to its nutritional content, BSF is generally used as feedstuff of animals, including those in aquaculture and livestock production. The use of 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 bioactive content is a component that has potential to be developed in addition to BSF as a protein-rich feed source. The protein of BSFL can be hydrolyzed to produce antioxidant peptides for functional foods (Zhu et al. 2020), cosmetic industries, and pharmaceutical products (Almeida et al. 2022).

### 6.1 Enzyme

The 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 BSFL include leucine arylamidase,  $\alpha$ -galactosidase,  $\alpha$ -mannosidase,  $\alpha$ -fucosidase, and  $\alpha$ -galactosidase (Kim et al. 2021). Cellulase is another enzyme that is presumed to be produced by BSFL, especially in its digestive tract, due to the discovery of the novel CS10 cellulase gene in BSF, which is expected to be an excellent opportunity for cellulase enzyme producers in the industry (Lee et al. 2014). Several studies also reported cellulase and ligninase enzyme activity, such as corncob fermentation with BSFL to reduce lignin by 2% and cow manure processing using BSFL to reduce hemicellulose level by 5% and cellulose content by 17% (Li et al. 2015; Gold et al. 2018).

### 6.2 Chitin

As a bioconversion agent, BSF has an excellent ability to produce chitin polymers or polymer of glucosamine up to 7% of BSF biomass on dry matter basis (Surendra et al. 2020). The chitin content of BSF varies with its life phase. Chitin content in various stages of BSF with different method analysis are shown in Table 5. 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. Nafisah et al. (2019) stated that physical activity, such as exoskeleton separation and fermentation using chitinolytic bacteria, can increase protein content and reduce fiber content by 65.02%.

The crystallinity index of chitin varies from 49.4% (BSFs) to 25.20% (BSF pupa). The chitins from BSF have good thermal stability with a maximum degradation of chitin BSF imago and BSF pupae at 363°C and 371°C, respectively (Purkayastha and Sarkar 2020). Soetemans et al. (2020) reported that the thermal property of chitin varies in different life stages with 366.1°C, 356.6°C, and 356.7°C for puparia, flakes, and adult BSF, respectively. Given the characteristics of chitin obtained from BSF, this insect has a huge opportunity to be developed for application in various

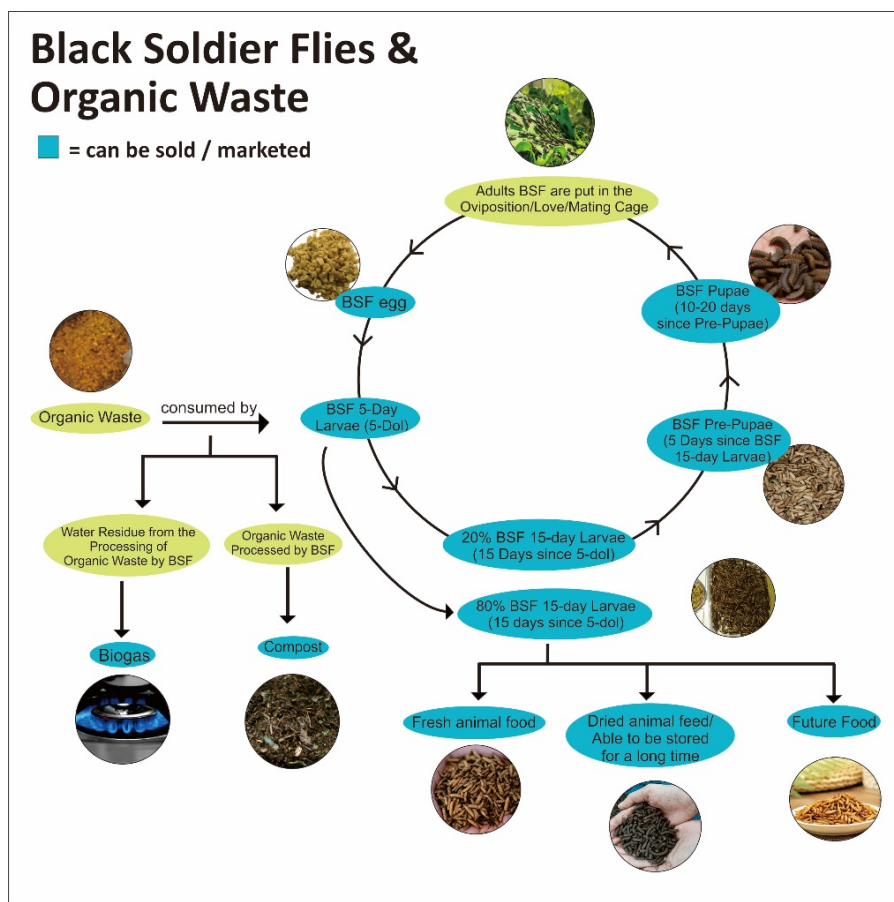


FIGURE 2. BSF life cycle and potential benefits.

TABLE 2. Green gases emission produces by different composting methods.

Variables	BSFL	Vermicomposting	Composting
<b>Agriculture waste</b>			
Total C loss (%)	-	53.2 (Yang et al. 2017)	48.9 (Yang et al. 2017)
Total N loss (%)	-	15.5 (Yang et al. 2017)	27.8 (Yang et al. 2017)
CH <sub>4</sub> emission (g/kg)	0.08; 0.49; 0.76 (Pang et al. 2020)	2.28 (Yang et al. 2017)	10.52 (Yang et al. 2017)
N <sub>2</sub> O emission (mg/kg)	1.03; 0.91; 1.36 (Pang et al. 2020)	5.76 (Yang et al. 2017)	12.29 (Yang et al. 2017)
NH <sub>3</sub> emission	-	-	-
Total CHG emission (kg CO <sub>2</sub> -eq/ton dm)	3.12; 16.93; 26.15 (Pang et al. 2020)	8.1 (Yang et al. 2017)	22.8 (Yang et al. 2017)
<b>Food waste</b>			
NH <sub>3</sub> emission (g/kg)	0.15–1.68 g/kg (Pang et al. 2020) ; Below detection limit (Lindberg et al. 2022b)	4 ± 1 (Lleó et al. 2013); 15.3–34.0 Hwang et al. (2020)	2.61 (Komilis and Ham 2006) ; 2.37 (Yang et al. 2013)
CH <sub>4</sub> (g/kg)	1.0–3.0 (Lindberg et al. 2022b) ; 0.06–0.79 (Lindberg et al. 2022a)	46.4–69.5 (Hwang et al. 2020)	88.1 (Hwang et al. 2020)
NO <sub>2</sub> (g/kg)	0.19–1.0 (Lindberg et al. 2022b); 0.06–0.50 (Lindberg et al. 2022a)	0.27 (Hwang et al. 2020)	4.73 (Hwang et al. 2020)

- Not reported

TABLE 3. Nutrient content of BSF larvae fed with different substrates.

Substrate	Nutrient composition	References
Food waste	Crude Protein 32.80%–44.06%; Crude Fiber 30.42%–40.96%	(Fitriana et al. 2022)
Abattoir waste	Crude Protein 44%–44.4%	(Lalander et al. 2019)
Digested sludge	Crude Protein 42.3%–42.9%	(Lalander et al. 2019)
Pig manure	Crude protein 42.83% Crude lipid 36.52%	(Wang et al. 2020b)
Chicken manure	Crude protein 41.72% Crude lipid 36.18%	(Shumo et al. 2019)

industries, such as feed, food, textile industry, and tissue engineering, and as an adsorbent in water and wastewater treatment (Leni et al. 2017; Purkayastha and Sarkar 2020).

According to Leke-Aladekoba (2018), chitin from 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. Therefore, BSF feed can be used as an excellent prebiotic for the gut microbiota (Borrelli et al. 2017) and reduce the use of antibiotics.

### 6.3 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* (Sprangers et al. 2018). The lauric acid content of BSF with various feeding strategies are shown in Table 6. 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; Widianingrum et al. 2019). Lauric acid also represses *Listeria monocytogenes*, which is a foodborne pathogen that can infect animal production (Çenesiz and Çiftci 2020), and can be converted into monolaurin that has antibacterial, antiviral, and antiprotozoal properties (Almeida et al. 2022).

The addition of lauric acid in the end also improves livestock productivity, such as feed efficiency, average daily gain, egg mass, and animal health in pig and poultry (Irawan et al. 2020; Elrod et al. 2019; Madeira et al. 2020). Lauric acid also improves productivity in beef and dairy cattle, including carcass percentage, IMF, and meat and milk quality (Nguyen et al. 2020; Wang et al. 2020a).

Lauric acid from BSF is safe for cattle and can be used to fight against the adult nymphs or larvae of *Rhipicephalus (Boophilus) microplus* (dos Santos et al. 2020). As an antiviral, it can also retrain African swine fever virus, herpes simplex virus type I, and coronavirus (Jackman et al. 2020; Aldridge 2020). Lauric acid can also be used as an anticoccidial (Price et al. 2013). Other essential fatty acid in BSF larva oil are palmitic, linoleic, and oleic acid often used as emulsifiers, emollients, and stabilizers of cosmetic formulation (Almeida et al. 2022).

### 6.4 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). Owing to their vast biodiversity, insects are among the most prosperous and most innovative origin for AMPs. Moretta et al. (2020) identified AMPs in BSFL 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* (*Campylobacteria: Heliobacteria*) and *E. coli* (*Enterobacteria: Enterobacteriaceae*) and thus can be employed as a substitute for antibiotics against bacteria with increasing resis-

tance (Alvarez et al. 2019). Three AMPs from BSF, namely, hiddefensin-1, hidiptericin-1, and hiCG13551, were cloned and transferred to *E. coli* to produce transgenic antimicrobials to fight entomopathogenic bacteria in *Bombyx mori silkworm*; hiddefensin-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). 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). Another type of AMP is cecropin-like peptide 1, which can fight against gram-negative bacteria (Park and Yoe 2017). AMPs in BSFL are associated with more than 50 genes, 26 of which are classified as defensins. Therefore,

attention must be paid to gut microbiota adaptation in live-stock because the modification of feed given will modulate the gut microbiota population (Vogel et al. 2018). The antimicrobial peptides present in BSF biomass show potential use against fungi and viruses.

## 7. SAFETY ASPECT OF BSF UTILIZATION

### 7.1 Microbial safety

The popularity of BSF for organic waste bioconversion into quality products, including products with high protein content, and a source of polymers and beneficial bioactive materials, has continued to grow and is increasing globally. Therefore, the assessment of BSF safety as a portion of food,

TABLE 4. Nutrient content of BSF larvae fed with different substrates.

Animal	Treatment	Result	Reference
Broiler	substituting 250 g/kg (w/w) of the basal diet with BSFL meal	BSFL meals are excellent sources of AME for broilers and a valuable source of digestible amino acids	(De Marco et al. 2015)
Layer hen	replacement of soybean meal with BSFL meal on laying hens, from 24 to 45 week of age	led to a more favorable feed conversion ratio in hens	(Marono et al. 2017)
	A protein replacement of 25% with BSF larvae in the diet of laying hens	Positively affected on egg mass, Albumin to globulin ratio decreased, cholesterol and triglycerides decreased	(Abd El-Hack et al. 2020)
Quail	substitution of soya bean meal and oil with defatted black soldier fly larvae meal	feasible and provide the meat of comparable quality to that of quails fed a conventional diet	(Cullere et al. 2018)
	replacement to the common soya bean meal and soyabean oil with BSFL Meal up to 15%	Increase digestibility of nutrients, productive performance, carcass, and meat quality	(Cullere et al. 2016)
Duck	defatted BSF larva meal into the diets of Muscovy ducks	did not affect the slaughtering performance of the birds or the meat quality parameters	(Gariglio et al. 2021)
Swine	suitable ingredient in growing pig diets	its relative deficiency in methionine + cystine and threonine requires the inclusion of those amino acids for the preparation of balanced diets. The ash content of the meal is also high, and this requires attention	(Tan et al. 2020)
Fish	partially defatted black soldier fly larvae meal and mechanically extracted black soldier fly larvae oil (BSFLO)	The digestibility of diets containing BSFL meal or BSFL oil was significantly superior to in the Reference diet. The maximum inclusion of each BSFL meal and BSFL oil recommended in rainbow trout diets is 13% and 10%	(Dumas et al. 2018)
	suitable to replace up to 50% of dietary Fish Meal protein with Defatted BSFL Meal	boosted antioxidant status, decreased the hepatopancreas lipid and serum cholesterol content of juvenile Jian carp ( <i>Cyprinus carpio</i> var. <i>Jian</i> )	(Li et al. 2017)
	partial replacement of Fish Meal protein up to 50% by Defatted BSFL Meal protein 50%–100% replacement of Soybean Oil with this n-3 enriched BSF Oil	reduced the feeding cost by 15.5% of European sea bass, <i>Dicentrarchus labrax</i> positively influences the performance and health status of juvenile mirror carp, improvement in the serum biochemical profile as immune status indicator, less inflammatory state of the liver and head kidney	(Abdel-Tawwab et al. 2020) (Xu et al. 2020)

TABLE 5. Chitin content in various stages of BSF with different method analysis.

Sources	Gravimetric (Soetemans et al. 2020)	Glucosamine (Soetemans et al. 2020)	Gravimetric (Wang et al. 2020a)	HCL-NaOH (Brigode et al. 2020)	ADF-ADL (Brigode et al. 2020)
Larvae	9.5%	7.8%	3.6		
Prepupa	9.1%	10.9	3.1		
Pupa	10.3%	10.7	14.1	25.39	21.19
Shedding	31.1%	23.7			
Cocoon	23.8%	22.4			
Flies	5.6	8.4	2.9	7.75	26.78
Flakes				20.69	7.94

feed, and pharmaceutical ingredient is essential considering that humans are end-users (Barroso et al. 2017; Lock et al. 2016). Safety assessment aims to prevent the spread and contamination of infection agents to humans. A study of BSF gut microbiota revealed that the use of BSF as feed requires the pretreatment of the feedstock and postharvest to prevent and depreciate pathogenic contamination (Khamis et al. 2020). 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). BSF as a bioconversion tool converts organic waste into a protein source, so many concerns arise about its safety (Swinscoe et al. 2019). Livestock producers must maintain cleanliness and safety from farm to fork (FAO 2008).

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). BSF production also affects its safety; for example, differences in BSF feed produce different macrobiotics in larvae. A food safety study provided feed that was inoculated with mycotoxins [aflatoxin B1, ochratoxin A or zearalenone, and deoxynivalenol (DON)] above the maximum limit (Reg (EC) 1881/2006; EC 2006) and found that these mycotoxins were secreted and did not accumulate in the body of BSFL (Varotto Boccazzi et al. 2017; Camenzuli et al. 2018). 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. In some cases, the larva can even have viable Salmonella at the end of the rearing (Erickson et al. 2004). A recent study reported that BSFL did not show any significant reduction in Salmonella in the contaminated substrate during rearing (De Smet et al. 2021). By contrast, the substrate inoculated with *S. aureus* showed a decrease after 6 days and was counted below limit detection (Gorrens et al. 2022). Regardless, some investigations reported that extracts of BSFL have antimicrobial effects (Park et al. 2014; Xia et al. 2021). Being free of contamination is beneficial to maintain the utilization's safety aspect of a substrate.

## 7.2 Chemical safety

When BSF is used as a bioconversion agent, heavy metal contamination is possible if the organic waste used as BSF feed is contaminated with heavy metals. Diener et al. (2015) fed BSFL 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. 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). The accumulation of cadmium in BSF prepupa must be considered as an animal feed ingredient Diener et al. (2015). Exposure to heavy metal Cu and Cd also influences the fresh body weight of BSFL; exposure to Cu at 100–400 mg/kg did not influence the fresh weight of BSFL, exposure to Cu at 800 mg/kg significantly decreased the fresh body weight, and exposure to Cd at 100–800 mg/kg did not influence the fresh body weight (Wu et al. 2020). Heavy metal concentrations in BSF vary in each life stage. The larval stages has 7–170.5 µg/g Cd and 3.8–141.7 µg/g Pb, and the prepupa has 7.9–142.9 µg/g Cd and 1.5–40.1 µg/g Pb (Diener et al. 2015).

The feed produce is also important in the application of BSF as animal feed. For organic waste, it must be free from heavy metal contamination. Even low Cd concentration in feed can leave residues above the EU threshold (2 mg/kg Cd); low levels of Pb contamination are still below the threshold for Pb for feed (10 mg/kg Pb) (Diener et al. 2015). BSFL can also tolerate feed containing 6% plastic fragments or cardboard packaging without directly affecting their growth. The Bioaccumulation factor (BAF) of this contamination was identified, and the highest BAF was obtained from mixed cardboard packaging produced by vegetarian products (van der Fels-Klerx et al. 2020). BSFL bioconversion can create high-value biomass with low heavy metal concentrations and can reduce waste volume of up to 40% in 20 days (Bohm et al. 2022).

## 7.3 Environmental impact

Utilizing insects as feed can influence food stock, and a slight environmental but precise inspection of the resource is needed to examine the environmental safety, impact, and economics (Bosch et al. 2019). The use of BSF as a bioconversion agent is beneficial from an environmental aspect because it can convert various kinds of waste, including lime waste, vegetables, fruit, livestock manure, household waste, agricultural waste, and other organic wastes, into components of economic value, such as proteins, lipids, peptides, amino acids, and chitin. This method can be an alternative waste treatment that can have a positive impact on the environment and ecology (Liu et al. 2019a). BSF also suppresses the multiplication of houseflies, which often harm the environment and humans by causing pollution and carrying diseases (Bradley and Sheppard 1984). The application of BSFL as a bioconversion agent is a profitable alternative for developing countries that still face challenges in processing abundant organic waste (Mertenat et al. 2019). BSF can also help prevent global warming. Composting using BSF has 47 times lower CO<sub>2</sub> emissions than open windrow composting, which is accompanied by almost twice the risk of global warming compared with using BSF per 1 ton of biowaste (wet weight).

The use of BSFL as a substitute for fish meal tubs can reduce global warming potential by up to 30% (Mertenat et al. 2019). Its requirement for electricity source is only half of the composting. The BSF can reduce the accumulation of volatile fatty acids by 25.58%–80.08% and can in-

TABLE 6. The lauric acid content of BSF with various feeding strategies.

	Lauric acid content (%)	Reference
Chicken feed	0.05 ± 0.01	(Schreven et al. 2021)
Crambe press cake	0.20 ± 0.04	(Schreven et al. 2021)
Crambe seed meal	2.92 ± 0.07	(Schreven et al. 2021)
Flax cake	0.76 ± 0.18	(Hoc et al. 2020)
Food waste	36.96	(Mohamad et al. 2020)
Bacterial dried cell	48.70	(Mohamad et al. 2020)
Preconsumer waste	27.8	(Hong T. et al. 2018)

crease the final composting yield by increasing phosphorus as much as 42.30%–64.16%, total nitrogen (Kjeldahl analysis) by 45.41%–88.17%, and total nutrients by 26.51%–33.34%. BSF can also produce sugar products derived from BSFL grease and convert dairy manure into biodiesel. A total of 1248.6 grams of fresh manure was converted to 273.4 grams dry manure and produced 1200 BSFL for 21 days; 70.8 grams of dry BSFL was processed with petroleum ether to produce 15.8 grams of biodiesel and 86.2 grams of sugar (Li et al. 2011). With the above potentials, the BSF can be an alternative that is safe for the environment and can mitigate global warming.

## 8. ECONOMICAL ASPECT OF BIOCONVERSION ORGANIC WASTE USING BSFL

The feed accounts for the largest cost in livestock production; a main example is protein feed, which is often obtained from soybean meal and fish meal. For example, the feed cost is 85.31% of the total cost in the dairy business, 77.41%–80.97% for broiler chickens, and 74.42% for layer chickens (Haloho et al. 2013; Suwarta et al. 2012). This nutritional source can be obtained by substituting various local products and feed ingredients; however, the need for protein sources for livestock has not been satisfied (Frempong et al. 2019). The substitution of soy-based feed with BSF meal has a remarkably effect on the cost of feed. The price of feed per bird fed is lower with BSF meal (1 US \$ per bird) than with soybean meal (1.17 US \$ per bird) in the starter phase. Similarly, in the finisher phase, the cost is 1.63 US \$ for the BSF meal and 1.90 US \$ for the soybean meal. With low prices, the performance (body weight gain, FCR, average daily feed intake, and carcass weight) of broiler or cattle fed soybean meal and BSF meal does not significantly differ (Onsongo et al. 2018). From an economical perspective, BSF production varies greatly depending on the location, feed source, scale of production, and purpose of BSF production. It is also influenced by the production model factor using a tray or batch (Pleissner and Smetana 2020). Dry BSF production of 7.14 tons requires costs of 79,358.15 € and 5,281.56 € for equipment and daily operational costs. BSF production is deemed feasible if the dry BSF product is directly commercialized as a downstream product without further processing. However, processing through extraction and purification into certain chemicals, for example, the isolation of bioactive components (fatty acids, pigments, and chitin), can significantly increase revenue (Pleissner and Smetana 2020). BSF production costs include indirect cost, labor, consumables, and equipment that account for 13%, 45%, 12%, and 30% of the total cost, respectively (Zurbrügg et al. 2018).

Composting using BSF requires a shorter time (12–15 days) than composting using microbes or earthworms (4–5 weeks). The final product also varies from hummus to protein, biodiesel, sugar, and grease sugar. However, additional treatments are sometimes required to mature the final products from BSF composting (Madeira et al. 2020; Choudhury et al. 2018). 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 (Zurbrügg et al. 2018). In Asia, various studies on the use of BSFL have been carried out to streamline its production and application in waste processing; BSF in biodiesel production, secretion of metabolites from BSFL, rearing tech-

niques, animal feed substitution have already been studied in China, Republic of Korea, Malaysia, Indonesia, Japan, and Vietnam (Kim et al. 2021). Studies on BSFL are still ongoing for the synthesis of economically valuable products and premium products that can be profitable. An economic opportunity is to organically produce BSFL products and their derivatives that are healthy, safe, and nutritious.

## 9. CHALLENGES AND POTENTIAL OF BSF IN THE FUTURE

The potential of BSFL as a source of protein for livestock and humans generates not only opportunities but also challenges because BSFL, which is an insect, is not recognizable or not yet accepted by all groups as a food ingredient and is considered taboo or unattractive. The safety of insect-origin food is still being studied. Some contemporary cultures have used insects as cuisines (Durst et al. 2010). The Food and Drug Administration in collaboration with the Association of American Feed Control Officials (AAFCO) through a Memorandum of Understanding imposed regulations in America regarding BSFL, specifically on how to produce, label, package, distribution, sell, import, and export it for food and feed. In August 2016, AAFCO agreed that dried BSFL could be cultivated as a feed and composting agent with a minimum fat content of 32% and 34% protein (Patterson et al. 2021).

As a bioconversion agent, BSFL is widely cultivated using organic wastes from agriculture and households. BSFL is allowed for use as animal feed, but its application in human food is being debated (Liu et al. 2019b; 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 (Liu et al. 2019b). Several factors that influence insect decisions for food are feelings of disgust, household income and region, insect phobia, knowledge level, and social demographic factors, such as age and household size. Moreover, the perceived positive attributes associated with edible insects, the preferences of children in the household, and age and knowledge level have positive impacts on consumption frequency. Concerns of food safety and the insects' shape have negative impacts on consumption frequency. Some reports showed that insects can cause allergies of varying allergy levels, whether consumed directly or through processed food derived from insects. In China, consuming pupae silkworm caused acute allergies; in Botswana, someone was admitted to the hospital due to acute allergy from *Gonimbrasia belina* caterpillar (Okezie et al. 2010; Chung et al. 2001). The allergy is probably due to the identified tropomyosin in BSFL and crustaceans (Leni et al. 2020).

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Some studies indicated that the antibiotic resistance gene (ARG) has emerged due to aerobic manure composting (Zhang et al. 2016; Cao et al. 2020). BSFL composting approach can decrease the ARG by 95% in poultry manure after 12 days (Cai et al. 2018) and reduce lincomycin by 84.9% after 12 days of bioconversion (Luo et al. 2022). Another study also reported that BSFL decreased 97% of tetracycline after 12 days compared with the traditional method (Cai et al. 2018). However, another report stated that BSFL bioconversion does not have an influence in lowering ARG (Cifuentes et al. 2020). Niu et al. (2022) revealed that the density of BSFL during conversion influenced compost quality and was associated with ARG abundance. Elevated ARG level was found in gut of high-density BSFL during manure conversion and found to be best in the density of 100 larvae in 100-gram manure. These ARGs, including tetX and mcr-1, were reported from hosts, such as *Escherichia*, *Alcaligenes*, *Klebsiella*, and *Providencia* from fresh feces.

As food and feed and functional products, 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 BSFL 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), BSFL can be used in entomoremediation for heavy metal wastes, such as Zn and Cd (Bulak et al. 2018). 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 (Zhu et al. 2019).

## 10. CONCLUSIONS

BSFL is a popular insect and has potential as a bioconversion agent for reducing and recycling organic biomass. The potential of BSFL 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 BSFL must be considered from the microbiological, chemical, and environmental aspects, including its low GHG emission during bioconversion. The study of production methods, utilization, and potential of BSFL warrants further and deep exploration to efficiently generate prod-

ucts that are truly profitable, environmentally friendly, and economical.

## AUTHORS' CONTRIBUTIONS

L.P and H.K conceived the project and mainly performed the writing and literature review.

## COMPETING INTERESTS

The authors declare no competing interests.

## REFERENCES

- Abd El-Hack M, Shafi M, Alghamdi W, Abdelnour S, Shehata A, Noreldin A, Ashour E, Swelum A, Al-Sagan A, Alkhatieb M, Taha A, Abdel-Moneim AM, Tufarelli V, Ragni M. 2020. Black Soldier Fly (*Hermetia illucens*) Meal as a Promising Feed Ingredient for Poultry: A Comprehensive Review. *Agriculture*. 10(8):339. doi:10.3390/agriculture10080339.
- Abdel-Tawwab M, Khalil RH, Metwally AA, Shakweer MS, Khallaf MA, Abdel-Latif HM. 2020. Effects of black soldier fly (*Hermetia illucens* L.) larvae meal on growth performance, organs-somatic indices, body composition, and hemato-biochemical variables of European sea bass, *Dicentrarchus labrax*. *Aquaculture*. 522:735136. doi:10.1016/j.aquaculture.2020.735136.
- Adesina M, Adejinmi O, Omole A, Fayenuwo J, Osunkeye O. 2012. Performance of broilers' finishers fed graded levels of Cassava peel -maggot meal- based diet mixtures. *Journal of Agriculture, Forestry and the Social Sciences*. 9(1):226-231. doi:10.4314/joafss.v9i1.25.
- Aldridge M. 2020. Review of the antiviral activity and pharmacology of monoglycerides and implications for treatment of COVID-19. preprint. *Open Science Framework*. doi:10.31219/osf.io/qdsef.
- Alegbeleye WO, Obasa SO, Olude OO, Otubu K, Jimoh W. 2012. Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell. 1822) fingerlings: Evaluation of the nutritive value of the variegated grasshopper. *Aquaculture Research*. 43(3):412-420. doi:10.1111/j.1365-2109.2011.02844.x.
- Ali U, Sajid N, Khalid A, Riaz L, Rabbani MM, Syed JH, Malik RN. 2015. A review on vermicomposting of organic wastes. *Environmental Progress & Sustainable Energy*. 34(4):1050-1062. doi:10.1002/ep.12100.
- Almeida C, Murta D, Nunes R, Baby AR, Fernandes P, Barros L, Rijo P, Rosado C. 2022. Characterization of lipid extracts from the *Hermetia illucens* larvae and their bioactivities for potential use as pharmaceutical and cosmetic ingredients. *Heliyon*. 8(5):e09455. doi:10.1016/j.heliyon.2022.e09455.
- Alvarez D, Wilkinson KA, Treilhou M, Téné N, Castillo D, Sauvain M. 2019. Prospecting Peptides Isolated From Black Soldier Fly (Diptera: Stratiomyidae) With Antimicrobial Activity Against *Helicobacter pylori* (Campylobacteriales: Helicobacteraceae). *Journal of Insect Science*. 19(6):17. doi:10.1093/jisesa/iez120.
- Awasthi MK, Liu T, Awasthi SK, Duan Y, Pandey A, Zhang Z. 2020. Manure pretreatments with black soldier fly *Hermetia illucens* L. (Diptera: Stratiomyidae): A study to reduce pathogen content. *Science of The Total Environment*. 737:139842. doi:10.1016/j.scitotenv.2020.139842.

- Azizah AN, Pranoto P, Budiastuti MS. 2019. Pemanfaatan sampah organik sebagai media pakan larva *Tenebrio molitor* (ulat hongkong). Symposium of Biology Education (Symbion). 2. doi:10.26555/symbion.3550.
- Banjo AD, Lawal OA, Olusola OO. 2005. Bacteria Associated with *Hermetia Illucens*. (Linnaeus) Diptera: Stratiomyidae. Asian Journal of Microbiology, Biotechnology & Environmental Sciences Paper. 7(3):352–354.
- Barroso FG, Sánchez-Muros MJ, Segura M, Morote E, Torres A, Ramos R, Guil JL. 2017. 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. 62:8–13. doi:10.1016/j.jfca.2017.04.008.
- Biancarosa I, Liland NS, Biemans D, Araujo P, Bruckner CG, Waagbø R, Torstensen BE, Lock EJ, Amlund H. 2018. 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. 98(6):2176–2183. doi:10.1002/jsfa.8702.
- Bohm K, Hatley GA, Robinson BH, Gutiérrez-Ginés MJ. 2022. Black Soldier Fly-based bioconversion of biosolids creates high-value products with low heavy metal concentrations. Resources, Conservation and Recycling. 180:106149. doi:10.1016/j.resconrec.2021.106149.
- Borrelli L, Coretti L, Dipineto L, Bovera F, Menna F, Chiariotti L, Nizza A, Lembo F, Fioretti A. 2017. Insect-based diet, a promising nutritional source, modulates gut microbiota composition and SCFAs production in laying hens. Scientific Reports. 7(1):16269. doi:10.1038/s41598-017-16560-6.
- Bosch G, van Zanten H, Zamprogna A, Veenenbos M, Meijer N, van der Fels-Klerx H, van Loon J. 2019. Conversion of organic resources by black soldier fly larvae: Legislation, efficiency and environmental impact. Journal of Cleaner Production. 222:355–363. doi:10.1016/j.jclepro.2019.02.270.
- Bradley SW, Sheppard DC. 1984. House fly oviposition inhibition by larvae of *Hermetia illucens*, the black soldier fly. Journal of Chemical Ecology. 10(6):853–859. doi:10.1007/BF00987968.
- Brigode C, Hobbi P, Jafari H, Verwilghen F, Baeten E, Shavandi A. 2020. Isolation and physicochemical properties of chitin polymer from insect farm side stream as a new source of renewable biopolymer. Journal of Cleaner Production. 275:122924. doi:10.1016/j.jclepro.2020.122924.
- Briscoe AD, Chittka L. 2001. The Evolution of Color Vision in Insects. Annual Review of Entomology. 46:471–510.
- Bruni L, Pastorelli R, Viti C, Gasco L, Parisi G. 2018. 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. 487:56–63. doi:10.1016/j.aquaculture.2018.01.006.
- Bulak P, Polakowski C, Nowak K, Waśko A, Wiącek D, Bieganski A. 2018. *Hermetia illucens* as a new and promising species for use in entomoremediation. Science of The Total Environment. 633:912–919. doi:10.1016/j.scitotenv.2018.03.252.
- Cai M, Ma S, Hu R, Tomberlin JK, Thomashow LS, Zheng L, Li W, Yu Z, Zhang J. 2018. Rapidly mitigating antibiotic resistant risks in chicken manure by *Hermetia illucens* bioconversion with intestinal microflora: Insect-microbe mitigate antibiotic resistant risk. Environmental Microbiology. 20(11):4051–4062. doi:10.1111/1462-2920.14450.
- Caligiani A, Marseglia A, Leni G, Baldassarre S, Maistrello L, Dossena A, Sforza S. 2018. Composition of black soldier fly prepupae and systematic approaches for extraction and fractionation of proteins, lipids and chitin. Food Research International. 105:812–820. doi:10.1016/j.foodres.2017.12.012.
- Camenzuli L, Van Dam R, de Rijk T, Andriessen R, Van Schelt J, Van der Fels-Klerx H. 2018. Tolerance and Excretion of the Mycotoxins Aflatoxin B1, Zearalenone, Deoxynivalenol, and Ochratoxin A by *Alphitobius diaperinus* and *Hermetia illucens* from Contaminated Substrates. Toxins. 10(2):91. doi:10.3390/toxins10020091.
- Cao R, Wang J, Ben W, Qiang Z. 2020. The profile of antibiotic resistance genes in pig manure composting shaped by composting stage: Mesophilic-thermophilic and cooling-maturation stages. Chemosphere. 250:126181. doi:10.1016/j.chemosphere.2020.126181.
- Choudhury AR, Natarajan AK, Kesavarapu S, Veeraraghavan A, Dugyala SK, Rao K, Thota KR. 2018. Technical Feasibility of *Hermetia illucens* in Integrated Waste Management, Renovated with Sewage Water, an Overview. OALib. 05(04):1–27. doi:10.4236/oalib.1104421.
- Chung K, Baker JR, Baldwin JL, Chou A. 2001. Identification of carmine allergens among three carmine allergy patients. Allergy. 56(1):73–77. doi:10.1034/j.1398-9995.2001.00693.x.
- Cifuentes Y, Glaeser SP, Mvie J, Bartz JO, Müller A, Gutzeit HO, Vilcinskas A, Kämpfer P. 2020. The gut and feed residue microbiota changing during the rearing of *Hermetia illucens* larvae. Antonie van Leeuwenhoek 2020 113:9. 113(9):1323–1344. doi:10.1007/S10482-020-01443-0.
- Contreras-Ramos SM, Escamilla-Silva EM, Dendooven L. 2005. Vermicomposting of biosolids with cow manure and oat straw. Biology and Fertility of Soils 41:3. 41(3):190–198. doi:10.1007/S00374-004-0821-8.
- Cullere M, Tasoniero G, Giaccone V, Acuti G, Marangon A, Dalle Zotte A. 2018. 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. 12(3):640–647. doi:10.1017/S175173117001860.
- Cullere M, Tasoniero G, Giaccone V, Miotti-Scapin R, Claeys E, De Smet S, Dalle Zotte A. 2016. Black soldier fly as dietary protein source for broiler quails: Apparent digestibility, excreta microbial load, feed choice, performance, carcass and meat traits. Animal. 10(12):1923–1930. doi:10.1017/S1751731116001270.
- De Marco M, Martínez S, Hernandez F, Madrid J, Gai F, Rotolo L, Belforti M, Bergero D, Katz H, Dabbou S, Kovitvadhi A, Zoccarato I, Gasco L, Schiavone A. 2015. Nutritional value of two insect larval meals (*Tenebrio molitor* and *Hermetia illucens*) for broiler chickens: Apparent nutrient digestibility, apparent ileal amino acid digestibility and apparent metabolizable energy. Animal Feed Science and Technology. 209:211–218. doi:10.1016/j.anifeedsci.2015.08.006.
- De Smet J, Vandeweyer D, Van Moll L, Lachi D, Van Campenhout L. 2021. Dynamics of *Salmonella* inoculated during rearing of black soldier fly larvae (*Hermetia illucens*). Food Research International. 149:110692. doi:10.1016/j.foodres.2021.110692.

- Diener S, Zurbrugg C, Roa Gutiérrez F, Nguyen HD, Morel A, Koottatep T, Tockner K. 2011. Black soldier fly larvae for organic waste treatment - prospects and constraints. Proceedings of the executive summary WasteSafe 2011.
- Diener S, Zurbrugg C, Tockner K. 2015. Bioaccumulation of heavy metals in the black soldier fly, *Hermetia illucens* and effects on its life cycle. *Journal of Insects as Food and Feed*. 1(4):261–270. doi:10.3920/JIFF2015.0030.
- dos Santos LB, Favero FC, Conde MH, Freitas MG, Santos-Zanuncio VS, Carollo CA, de Almeida Borges F. 2020. Clinical safety of lauric acid for cattle and its in vitro and in vivo efficacy against rhipicephalus microplus. *Veterinary Parasitology*. 280:109095. doi:https://doi.org/10.1016/j.vetpar.2020.109095.
- Dumas A, Raggi T, Barkhouse J, Lewis E, Weltzien E. 2018. The oil fraction and partially defatted meal of black soldier fly larvae (*Hermetia illucens*) affect differently growth performance, feed efficiency, nutrient deposition, blood glucose and lipid digestibility of rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*. 492:24–34. doi:10.1016/j.aquaculture.2018.03.038.
- Durst PB, Johnson DV, Leslie RN, Shono K. 2010. Edible Forest Insects, Human Bite Back. Proceedings of workshop on Asia-Pacific resources and their potential for development. Bangkok, Thailand: Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific.
- Elrod C, Boyd R, Jackman J. 2019. From Membrane Biophysics to the Farm: Applications of Fatty Acid and Monoglyceride Chemistry to Animal Health. p. 70–71.
- Erickson MC, Islam M, Sheppard C, Liao J, Doyle MP. 2004. 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*. 67(4):685–690. doi:10.4315/0362-028X-67.4.685.
- Fahmi MR. 2015. Optimalisasi proses biokonversi dengan menggunakan mini-larva *Hermetia illucens* untuk memenuhi kebutuhan pakan ikan. doi:10.13057/psnmbi/m010124.
- FAO. 2008. The Codex code of practice on good animal feeding SECTION 6. <https://www.fao.org/3/i1379e/i1379e06.pdf>.
- Fitriana EL, Laconi EB, Astuti DA, Jayanegara A. 2022. Effects of various organic substrates on growth performance and nutrient composition of black soldier fly larvae: A meta-analysis. *Bioresource Technology Reports*. 18:101061. doi:10.1016/j.biteb.2022.101061.
- Frempong NS, Nortey TN, Paulk C, Stark CR. 2019. Evaluating the Effect of replacing fish meal in broiler diets with either Soybean meal or poultry by-product Meal on Broiler Performance and total feed cost per kilogram of gain. *Journal of Applied Poultry Research*. 28(4):912–918. doi:10.3382/japr/pfz049.
- Gariglio M, Dabbou S, Gai F, Trocino A, Xiccato G, Holodova M, Gresakova L, Nery J, Bellezza Oddon S, Biasato I, Gasco L, Schiavone A. 2021. Black soldier fly larva in Muscovy duck diets: effects on duck growth, carcass property, and meat quality. *Poultry Science*. 100(9):101303. doi:10.1016/j.psj.2021.101303.
- Gobbi P, Martínez-Sánchez A, Rojo S. 2013. The effects of larval diet on adult life-history traits of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). *European Journal of Entomology*. 110(3):461–468. doi:10.14411/eje.2013.061.
- Gold M, Cassar CM, Zurbrugg C, Kreuzer M, Boulos S, Diener S, Mathys A. 2020. Biowaste treatment with black soldier fly larvae: Increasing performance through the formulation of biowastes based on protein and carbohydrates. *Waste Management*. 102:319–329. doi:10.1016/j.wasman.2019.10.036.
- Gold M, Tomberlin JK, Diener S, Zurbrugg C, Mathys A. 2018. Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. *Waste Management*. 82:302–318. doi:10.1016/j.wasman.2018.10.022.
- Gorrens E, De Smet J, Vandeweyer D, Bossaert S, Crauwels S, Lievens B, Van Campenhout L. 2022. The bacterial communities of black soldier fly larvae (*Hermetia illucens*) during consecutive, industrial rearing cycles. *Journal of Insects as Food and Feed*:1–16. doi:10.3920/JIFF2021.0150.
- Haloho RD, Santoso SI, Marzuki S. 2013. Analisis Profitabilitas pada Usaha Peternakan Sapi Perah di Kabupaten Semarang. *Ragam Jurnal Pengembangan Humaniora*. 13(1):65–72. <https://jurnal.polines.ac.id/index.php/ragam/article/view/468>.
- He L, Zhang Y, Ding MQ, Li MX, Ding J, Bai SW, Wu QL, Zhao L, Cao GL, Ren NQ, Yang SS. 2021. Sustainable strategy for lignocellulosic crop wastes reduction by *Tenebrio molitor* Linnaeus (mealworm) and potential use of mealworm frass as a fertilizer. *Journal of Cleaner Production*. 325:129301. doi:10.1016/j.jclepro.2021.129301.
- Henry M, Gasco L, Piccolo G, Fountoulaki E. 2015. Review on the use of insects in the diet of farmed fish: Past and future. *Animal Feed Science and Technology*. 203:1–22. doi:10.1016/j.anifeeds.2015.03.001.
- Hoc B, Genva M, Fauconnier ML, Lognay G, Francis F, Caparros Megido R. 2020. About lipid metabolism in *Hermetia illucens* (L. 1758): on the origin of fatty acids in prepupae. *Scientific Reports*. 10(1):11916. doi:10.1038/s41598-020-68784-8.
- Holmes LA, Vanlaerhoven SL, Tomberlin JK. 2012. Relative Humidity Effects on the Life History of *Hermetia illucens* (Diptera: Stratiomyidae). *Environmental Entomology*. 41(4):971–978. doi:10.1603/EN12054.
- Hong T, Chandiramani N, Restrepo-Cano J, Sarathy M. 2018. New approach to improving fuel and combustion characteristics of black soldier fly oil. *Chemical Engineering Transactions*. 65:31–36. doi:10.3303/CET1865006.
- Hwang HY, Kim SH, Shim J, Park SJ. 2020. Composting Process and Gas Emissions during Food Waste Composting under the Effect of Different Additives. *Sustainability*. 12(18):7811. doi:10.3390/su12187811.
- Iaconisi V, Marono S, Parisi G, Gasco L, Genovese L, Maricchiolo G, Bovera F, Piccolo G. 2017. Dietary inclusion of *Tenebrio molitor* larvae meal: Effects on growth performance and final quality treats of blackspot sea bream (*Pagellus bogaraveo*). *Aquaculture*. 476:49–58. doi:10.1016/j.aquaculture.2017.04.007.
- Irawan AC, Astuti DA, Wibawan IWT, Hermawati W. 2020. Supplementation of black soldier fly (*Hermetia illucens*) on productivity and blood hematology. *Jurnal Ilmu-Ilmu Peternakan*. 30(1):50–68. doi:10.21776/ub.jiip.2020.030.01.06.
- Jackman JA, Boyd RD, Elrod CC. 2020. 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*. 11(1):44. doi:10.1186/s40104-020-00446-1.

- Jayanegara A, Yantina N, Novandri B, Laconi EB, Nahrowi N, Ridla M. 2017. Evaluation of some insects as potential feed ingredients for ruminants: chemical composition, in vitro rumen fermentation and methane emissions. *Journal of the Indonesian Tropical Animal Agriculture*. 42(4):247. doi:10.14710/jitaa.42.4.247-254.
- Kamarulzaman MK, Hafiz M, Abdullah A, Chen AF, Awad OI. 2019. Combustion, performances and emissions characteristics of black soldier fly larvae oil and diesel blends in compression ignition engine. *Renewable Energy*. 142:569–580. doi:10.1016/j.renene.2019.04.126.
- Khamis FM, Ombura FLO, Akutse KS, Subramanian S, Mohamed SA, Fiaboe KKM, Saijuntha W, Van Loon JJA, Dicke M, Dubois T, Ekesi S, Tanga CM. 2020. Insights in the Global Genetics and Gut Microbiome of Black Soldier Fly, *Hermetia illucens*: Implications for Animal Feed Safety Control. *Frontiers in Microbiology*. 11:1538. doi:10.3389/fmicb.2020.01538.
- Kim CH, Ryu J, Lee J, Ko K, Lee Jy, Park KY, Chung H. 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.
- Kim W, Bae S, Park K, Lee S, Choi Y, Han S, Koh Y. 2011. Biochemical characterization of digestive enzymes in the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). *Journal of Asia-Pacific Entomology*. 14(1):11–14. doi:10.1016/j.aspen.2010.11.003.
- Komilis DP, Ham RK. 2006. Carbon dioxide and ammonia emissions during composting of mixed paper, yard waste and food waste. *Waste Management*. 26(1):62–70. doi:10.1016/j.wasman.2004.12.020.
- Lalander C, Diener S, Zurbrügg C, Vinnerås B. 2019. Effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (*Hermetia illucens*). *Journal of Cleaner Production*. 208:211–219. doi:10.1016/j.jclepro.2018.10.017.
- Lalander CH, Fidjeland J, Diener S, Eriksson S, Vinnerås B. 2015. High waste-to-biomass conversion and efficient *Salmonella* spp. reduction using black soldier fly for waste recycling. *Agronomy for Sustainable Development*. 35(1):261–271. doi:10.1007/s13593-014-0235-4.
- Lee CM, Lee YS, Seo SH, Yoon SH, Kim SJ, Hahn BS, Sim JS, Koo BS. 2014. Screening and Characterization of a Novel Cellulase Gene from the Gut Microflora of *Hermetia illucens* Using Metagenomic Library. *Journal of Microbiology and Biotechnology*. 24(9):1196–1206. doi:10.4014/jmb.1405.05001.
- Leke-Aladekoba AA. 2018. Comparison of extraction methods and characterisation of chitin and chitosan with antimicrobial and antioxidant properties from black soldier fly (*Hermetia illucens*) meal. [Doctoral thesis]. [Halifax, Nova Scotia]: Dalhousie University.
- Leni G, Caligiani A, Marseglia A, Baldassarre S, Maistrello L, Sforza S. 2017. Fractionation of black soldier fly biomolecules for feed/food or technological applications. doi:10.13140/RG.2.2.28396.26244.
- Leni G, Tedeschi T, Faccini A, Pratesi F, Folli C, Puxeddu I, Migliorini P, Gianotten N, Jacobs J, Depraetere S, Caligiani A, Sforza S. 2020. Shotgun proteomics, in-silico evaluation and immunoblotting assays for allergenicity assessment of lesser mealworm, black soldier fly and their protein hydrolysates. *Scientific Reports*. 10(1):1228. doi:10.1038/s41598-020-57863-5.
- Leong SY, Kutty SRM. 2020. 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*. 11(10):5607–5614. doi:10.1007/s12649-020-01018-0.
- Li Q, Zheng L, Qiu N, Cai H, Tomberlin JK, Yu Z. 2011. Bioconversion of dairy manure by black soldier fly (Diptera: Stratiomyidae) for biodiesel and sugar production. *Waste Management*. 31(6):1316–1320. doi:10.1016/j.wasman.2011.01.005.
- Li S, Ji H, Zhang B, Zhou J, Yu H. 2017. Defatted black soldier fly (*Hermetia illucens*) larvae meal in diets for juvenile Jian carp (*Cyprinus carpio* var. Jian): Growth performance, antioxidant enzyme activities, digestive enzyme activities, intestine and hepatopancreas histological structure. *Aquaculture*. 477:62–70. doi:10.1016/j.aquaculture.2017.04.015.
- Li W, Li Q, Zheng L, Wang Y, Zhang J, Yu Z, Zhang Y. 2015. Potential biodiesel and biogas production from corncob by anaerobic fermentation and black soldier fly. *Biore-source Technology*. 194:276–282. doi:10.1016/j.biortech.2015.06.112.
- Li Y, Han Y, Zhang Y, Fang Y, Li S, Li G, Luo W. 2020. Factors affecting gaseous emissions, maturity, and energy efficiency in composting of livestock manure digestate. *Science of The Total Environment*. 731:139157. doi:10.1016/j.scitotenv.2020.139157.
- Lindberg L, Ermolaev E, Vinnerås B, Lalander C. 2022a. Process efficiency and greenhouse gas emissions in black soldier fly larvae composting of fruit and vegetable waste with and without pre-treatment. *Journal of Cleaner Production*. 338:130552. doi:10.1016/j.jclepro.2022.130552.
- Lindberg L, Vinnerås B, Lalander C. 2022b. Process efficiency in relation to enzyme pre-treatment duration in black soldier fly larvae composting. *Waste Management*. 137:121–127. doi:10.1016/j.wasman.2021.10.033.
- Liu C, Wang C, Yao H. 2019a. Comprehensive Resource Utilization of Waste Using the Black Soldier Fly (*Hermetia illucens* (L.)) (Diptera: Stratiomyidae). *Animals*. 9(6):349. doi:10.3390/ani9060349.
- Liu T, Awasthi MK, Chen H, Duan Y, Awasthi SK, Zhang Z. 2019b. Performance of black soldier fly larvae (Diptera: Stratiomyidae) for manure composting and production of cleaner compost. *Journal of Environmental Management*. 251:109593. doi:10.1016/j.jenvman.2019.109593.
- Liu X, Chen X, Wang H, Yang Q, ur Rehman K, Li W, Cai M, Li Q, Mazza L, Zhang J, Yu Z, Zheng L. 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.
- Lleó T, Albacete E, Barrena R, Font X, Artola A, Sánchez A. 2013. Home and vermicomposting as sustainable options for biowaste management. *Journal of Cleaner Production*. 47:70–76. doi:10.1016/j.jclepro.2012.08.011.
- Lock E, Arsiwalla T, Waagbø R. 2016. Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmo salar*) postsmolt. *Aquaculture Nutrition*. 22(6):1202–1213. doi:10.1111/anu.12343.
- Luo X, Yang Q, Lin Y, Tang Z, Tomberlin JK, Liu W, Huang Y. 2022. Black soldier fly larvae effectively degrade lincosycin from pharmaceutical industry wastes. *Journal of Environmental Management*. 307:114539. doi:10.1016/j.jenvman.2022.114539.
- Madeira MS, Alfaia CM, Lopes PA, Pestana J, Coelho D, Fontes CMGA, Prates JAM. 2020. Ameliorating Pork Marbling and Quality with Novel Feeding Approaches.

- In: Freitas Duarte A, Lopes da Costa L, editors. *Advances in Animal Health, Medicine and Production*. Cham: Springer International Publishing. p. 161–177. doi: [10.1007/978-3-030-61981-7\\_8](https://doi.org/10.1007/978-3-030-61981-7_8).
- Maglangit F, Alosbanos RS. 2021. Black soldier fly. <https://encyclopedia.pub/entry/7597>.
- Marono S, Loponte R, Lombardi P, Vassalotti G, Pero M, Russo F, Gasco L, Parisi G, Piccolo G, Nizza S, Di Meo C, Attia Y, Bovera F. 2017. Productive performance and blood profiles of laying hens fed *Hermetia illucens* larvae meal as total replacement of soybean meal from 24 to 45 weeks of age. *Poultry Science*. 96(6):1783–1790. doi:[10.3382/ps/pew461](https://doi.org/10.3382/ps/pew461).
- Martínez-Sánchez A, Magaña C, Saloña M, Rojo S. 2011. First record of *Hermetia illucens* (Diptera: Stratiomyidae) on human corpses in Iberian Peninsula. *Forensic Science International*. 206(1–3):e76–e78. doi:[10.1016/j.forsciint.2010.10.021](https://doi.org/10.1016/j.forsciint.2010.10.021).
- Mawaddah S, Hermana W, Nahrowi N. 2018. Pengaruh Pemberian Tepung Deffated Larva BSF (*Hermetia illucens*) terhadap Performa Produksi Puyuh Petelur (*Coturnix coturnix japonica*). *Jurnal Ilmu Nutrisi dan Teknologi Pakan*. 16(3):47. doi:[10.29244/jintp.16.3.47-51](https://doi.org/10.29244/jintp.16.3.47-51).
- Meneguz M, Schiavone A, Gai F, Dama A, Lussiana C, Renna M, Gasco L. 2018. 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 and nutritional composition of black soldier fly. *Journal of the Science of Food and Agriculture*. 98(15):5776–5784. doi:[10.1002/jsfa.9127](https://doi.org/10.1002/jsfa.9127).
- Mertenat A, Diener S, Zurbrugg C. 2019. Black Soldier Fly biowaste treatment – Assessment of global warming potential. *Waste Management*. 84:173–181. doi:[10.1016/j.wasman.2018.11.040](https://doi.org/10.1016/j.wasman.2018.11.040).
- Ministry of Environment and Forestry. 2022. PERATURAN MENTERI LINGKUNGAN HIDUP DAN KEHUTANAN REPUBLIK INDONESIA NOMOR 6 TAHUN 2022.
- Mohamad L, Dina F, Hasan HA, Sudesh K, Baidurah S. 2020. Effect of feeding strategy on the protein and fatty acid contents of black soldier fly prepupae (*Hermetia illucens*) for the potential applications as animal feed and promising alternative protein-rich food. *IOP Conference Series: Materials Science and Engineering*. 716(1):012006. doi:[10.1088/1757-899X/716/1/012006](https://doi.org/10.1088/1757-899X/716/1/012006).
- Moretta A, Salvia R, Scieuzo C, Di Somma A, Vogel H, Pucci P, Sgambato A, Wolff M, Falabella P. 2020. A bioinformatic study of antimicrobial peptides identified in the Black Soldier Fly (BSF) *Hermetia illucens* (Diptera: Stratiomyidae). *Scientific Reports*. 10(1):16875. doi:[10.1038/s41598-020-74017-9](https://doi.org/10.1038/s41598-020-74017-9).
- Myers HM, Tomberlin JK, Lambert BD, Kattes D. 2008. Development of Black Soldier Fly (Diptera: Stratiomyidae) Larvae Fed Dairy Manure. *Environmental Entomology*. 37(1):11–15. doi:[10.1093/ee/37.1.11](https://doi.org/10.1093/ee/37.1.11).
- Nafisah A, Nahrowi, Mutia R, Jayanegara A. 2019. Chemical composition, chitin and cell wall nitrogen content of Black Soldier Fly (*Hermetia illucens*) larvae after physical and biological treatment. *IOP Conference Series: Materials Science and Engineering*. 546(4):042028. doi:[10.1088/1757-899X/546/4/042028](https://doi.org/10.1088/1757-899X/546/4/042028).
- Navarro del Hierro J, Gutiérrez-Docio A, Otero P, Reglero G, Martin D. 2020. Characterization, antioxidant activity, and inhibitory effect on pancreatic lipase of extracts from the edible insects *Acheta domestica* and *Tenebrio molitor*. *Food Chemistry*. 309:125742. doi:[10.1016/j.foodchem.2019.125742](https://doi.org/10.1016/j.foodchem.2019.125742).
- Newton G, Sheppard D, Watson D, Burtle G, Dove C, Tomberlin J, Thelen E. 2005a. The black soldier fly, *hermetia illucens*, as a manure management/resource recovery tool. *Symposium on the state of the science of Animal Manure and Waste Management*. volume 1. Cite-seer. p. 57.
- Newton L, Craig S, Wes D W, Gary B, Robert D. 2005b. Using the black soldier fly, *Hermetia illucens*, as a value-added tool for the management of swine manure. Technical report. ANIMAL AND POULTRY WASTE MANAGEMENT CENTER, NORTH CAROLINA STATE UNIVERSITY. RALEIGH, NC.
- Nguyen SH, Nguyen HDT, Hegarty RS. 2020. Defaunation and its impacts on ruminal fermentation, enteric methane production and animal productivity. *Live-stock Research for Rural Development*. 32(4):1–9.
- Nguyen TTX, Tomberlin JK, Vanlaerhoven S. 2015. Ability of Black Soldier Fly (Diptera: Stratiomyidae) Larvae to Recycle Food Waste. *Environmental Entomology*. 44(2):406–410. doi:[10.1093/ee/nvv002](https://doi.org/10.1093/ee/nvv002).
- Niu SH, Liu S, Deng WK, Wu RT, Cai YF, Liao XD, Xing SC. 2022. A sustainable and economic strategy to reduce risk antibiotic resistance genes during poultry manure bioconversion by black soldier fly *Hermetia illucens* larvae: Larval density adjustment. *Ecotoxicology and Environmental Safety*. 232:113294. doi:[10.1016/j.ecoenv.2022.113294](https://doi.org/10.1016/j.ecoenv.2022.113294).
- Okah U, Onwujiariri EB. 2012. Performance of finisher broiler chickens fed maggot meal as a replacement for fish meal. *J. Agricultural Technol.* 8(2):471–477.
- Okezie OA, Kgomotso KK, Letswiti MM. 2010. Mopane worm allergy in a 36-year-old woman: a case report. *Journal of Medical Case Reports*. 4(1):42. doi:[10.1186/1752-1947-4-42](https://doi.org/10.1186/1752-1947-4-42).
- Onsongo VO, Osuga IM, Gachuri CK, Wachira AM, Miano DM, Tanga CM, Ekesi S, Nakimbugwe D, Fiaboe KKM. 2018. Insects for Income Generation Through Animal Feed: Effect of Dietary Replacement of Soybean and Fish Meal With Black Soldier Fly Meal on Broiler Growth and Economic Performance. *Journal of Economic Entomology*. 111(4):1966–1973. doi:[10.1093/jee/toy118](https://doi.org/10.1093/jee/toy118).
- Pang W, Hou D, Nowar EE, Chen H, Zhang J, Zhang G, Li Q, Wang S. 2020. The influence on carbon, nitrogen recycling, and greenhouse gas emissions under different C/N ratios by black soldier fly. *Environmental Science and Pollution Research*. 27(34):42767–42777. doi:[10.1007/s11356-020-09909-4](https://doi.org/10.1007/s11356-020-09909-4).
- Park SI, Chang BS, Yoe SM. 2014. Detection of antimicrobial substances from larvae of the black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae): Antimicrobial activity of *H. illucens*. *Entomological Research*. 44(2):58–64. doi:[10.1111/1748-5967.12050](https://doi.org/10.1111/1748-5967.12050).
- Park SI, Yoe SM. 2017. A novel cecropin-like peptide from black soldier fly, *Hermetia illucens*: Isolation, structural and functional characterization: A cecropin-like peptide from *H. illucens*. *Entomological Research*. 47(2):115–124. doi:[10.1111/1748-5967.12226](https://doi.org/10.1111/1748-5967.12226).
- Patterson P, Acar N, Ferguson A, Trimble L, Sciubba H, Koutosos E. 2021. The impact of dietary Black Soldier Fly larvae oil and meal on laying hen performance and egg quality. *Poultry Science*. 100(8):101272. doi:[10.1016/j.psj.2021.101272](https://doi.org/10.1016/j.psj.2021.101272).
- Pleissner D, Smetana S. 2020. Estimation of the econ-

- omy of heterotrophic microalgae- and insect-based food waste utilization processes. *Waste Management*. 102:198–203. doi:10.1016/j.wasman.2019.10.031.
- Price KL, Lin X, van Heugten E, Odle R, Willis G, Odle J. 2013. Diet physical form, fatty acid chain length, and emulsification alter fat utilization and growth of newly weaned pigs1. *Journal of Animal Science*. 91(2):783–792. doi:10.2527/jas.2012-5307.
- Purkayastha D, Sarkar S. 2020. 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*. 28(2):445–457. doi:10.1007/s10924-019-01620-x.
- Purnamasari L, Sucipto I, Muhlison W, Pratiwi N. 2019. Komposisi Nutrien Larva Black Soldier Fly (*Hermetia illucens*) Dengan Media Tumbuh, Suhu dan Waktu Pengerangan yang Berbeda. *Prosiding Seminar Nasional Teknologi Peternakan dan Veteriner 2019. Pusat Penelitian dan Pengembangan Peternakan*. p. 675–680. doi:10.14334/Pros.Semnas.TPV-2019-p.675-680.
- Rachmawati R, Buchori D, Hidayat P, Hem S, Fahmi MR. 2015. Perkembangan dan Kandungan Nutrisi Larva *Hermetia illucens* (Linnaeus) (Diptera: Stratiomyidae) pada Bungkil Kelapa Sawit. *Jurnal Entomologi Indonesia*. 7(1):28. doi:10.5994/jei.7.1.28.
- Rehman Ku, Liu X, Wang H, Zheng L, Rehman Ru, Cheng X, Li Q, Li W, Cai M, Zhang J, Yu Z. 2018. Effects of black soldier fly biodiesel blended with diesel fuel on combustion, performance and emission characteristics of diesel engine. *Energy Conversion and Management*. 173:489–498. doi:10.1016/j.enconman.2018.07.102.
- Schiavone A, Dabbou S, Petracci M, Zampiga M, Sirri F, Biasato I, Gai F, Gasco L. 2019. Black soldier fly defatted meal as a dietary protein source for broiler chickens: effects on carcass traits, breast meat quality and safety. *Animal*. 13(10):2397–2405. doi:10.1017/S1751731119000685.
- Schreven S, Yener S, van Valenberg H, Dicke M, van Loon J. 2021. Life on a piece of cake: performance and fatty acid profiles of black soldier fly larvae fed oilseed by-products. *Journal of Insects as Food and Feed*. 7(1):35–49. doi:10.3920/JIFF2020.0004.
- Shazia Iqbal, Tayyaba Naz, Munaza Naseem. 2021. CHALLENGES AND OPPORTUNITIES LINKED WITH WASTE MANAGEMENT UNDER GLOBAL PERSPECTIVE: A MINI REVIEW. *Journal of Quality Assurance in Agricultural Sciences*:9–13. doi:10.52862/jqaas.2021.1.1.2.
- Shumo M, Osuga IM, Khamis FM, Tanga CM, Fiaboe KKM, Subramanian S, Ekesi S, van Huis A, Borgemeister C. 2019. The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Scientific Reports*. 9(1):10110. doi:10.1038/s41598-019-46603-z.
- Siddiqui SA, Ristow B, Rahayu T, Putra NS, Widya Yuwono N, Nisa' K, Mategoko B, Smetana S, Saki M, Nawaz A, Nagdalian A. 2022. Black soldier fly larvae (BSFL) and their affinity for organic waste processing. *Waste Management*. 140:1–13. doi:10.1016/j.wasman.2021.12.044.
- Soetemans L, Uyttebroek M, Bastiaens L. 2020. Characteristics of chitin extracted from black soldier fly in different life stages. *International Journal of Biological Macromolecules*. 165:3206–3214. doi:10.1016/j.ijbiomac.2020.11.041.
- Song S, Ee AWL, Tan JKN, Cheong JC, Chiam Z, Arora S, Lam WN, Tan HTW. 2021. 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*. 288:125664. doi:10.1016/j.jclepro.2020.125664.
- Sprangers T, Michiels J, Vrancx J, Ovyen A, Eeckhout M, De Clercq P, De Smet S. 2018. Gut antimicrobial effects and nutritional value of black soldier fly (*Hermetia illucens* L.) prepupae for weaned piglets. *Animal Feed Science and Technology*. 235:33–42. doi:10.1016/j.anifeedsci.2017.08.012.
- Stadtlander T, Stamer A, Buser A, Wohlfahrt J, Leiber F, Sandrock C. 2017. *Hermetia illucens* meal as fish meal replacement for rainbow trout on farm. *Journal of Insects as Food and Feed*. 3(3):165–175. doi:10.3920/JIFF2016.0056.
- Sundu B, Dingle J. 2002. Use of enzymes to improve the nutritional value of palm kernel meal and copra meal I. Introduction II. Their quality and utilisation. *Proceedings of the AUSTRALIAN POULTRY SCIENCE SYMPOSIUM*. volume 11. University of Sydney. p. 1–13.
- Surendra K, Olivier R, Tomberlin JK, Jha R, Khanal SK. 2016. Bioconversion of organic wastes into biodiesel and animal feed via insect farming. *Renewable Energy*. 98:197–202. doi:10.1016/j.renene.2016.03.022.
- Surendra K, Tomberlin JK, van Huis A, Cammack JA, Heckmann LHL, Khanal SK. 2020. Rethinking organic wastes bioconversion: Evaluating the potential of the black soldier fly (*Hermetia illucens* (L.)) (Diptera: Stratiomyidae) (BSF). *Waste Management*. 117:58–80. doi:10.1016/j.wasman.2020.07.050.
- Surendra KC, Kuehnle A. 2019. Embracing AgTech for Food Security and Beyond. *Industrial Biotechnology*. 15(6):323–324. doi:10.1089/ind.2019.29194.sk.
- Suwarda, Irham, Hartono S. 2012. Struktur Biaya dan Pendapatan Usaha Ternak Ayam Broiler di Kabupaten Sleman. *AGRIKA: Jurnal Ilmu-ilmu Pertanian*. 6(1):65–85. <https://publishing-widyagama.ac.id/ejournal-v2/index.php/agrika/article/view/133/132>.
- Swinscoe I, Oliver D, Gilburn A, Lunestad B, Lock EJ, Ørnstrud R, Quilliam R. 2019. Seaweed-fed black soldier fly (*Hermetia illucens*) larvae as feed for salmon aquaculture: assessing the risks of pathogen transfer. *Journal of Insects as Food and Feed*. 5(1):15–27. doi:10.3920/JIFF2017.0067.
- Tan X, Yang H, Wang M, Yi Z, Ji F, Li J, Yin Y. 2020. Amino acid digestibility in housefly and black soldier fly prepupae by growing pigs. *Animal Feed Science and Technology*. 263:114446. doi:10.1016/j.anifeedsci.2020.114446.
- Tomberlin JK, Adler PH, Myers HM. 2009. Development of the Black Soldier Fly (Diptera: Stratiomyidae) in Relation to Temperature. *Environmental Entomology*. 38(3):930–934. doi:10.1603/022.038.0347.
- Tomberlin JK, Sheppard DC. 2002. Factors Influencing Mating and Oviposition of Black Soldier Flies (Diptera: Stratiomyidae) in a Colony. *Journal of Entomological Science*. 37(4):345–352. doi:10.18474/0749-8004-37.4.345.
- van der Fels-Klerx H, Meijer N, Nijkamp M, Schmitt E, van Loon J. 2020. Chemical food safety of using former foodstuffs for rearing black soldier fly larvae (*Hermetia illucens*) for feed and food use. *Journal of Insects as Food and Feed*. 6(5):475–488. doi:10.3920/JIFF2020.0024.
- van Huis A. 2013. Potential of Insects as Food and Feed in Assuring Food Security. *Annual Review of Entomology*.

- 58(1):563–583. doi:10.1146/annurev-ento-120811-153704.
- Varotto Boccazzi I, Ottoboni M, Martin E, Comandatore F, Vallone L, Spranghers T, Eeckhout M, Mereghetti V, Pinotti L, Epis S. 2017. A survey of the mycobiota associated with larvae of the black soldier fly (*Hermetia illucens*) reared for feed production. *PLOS ONE*. 12(8):e0182533. doi:10.1371/journal.pone.0182533.
- Vogel H, Müller A, Heckel DG, Gutzeit H, Vilcinskis A. 2018. Nutritional immunology: Diversification and diet-dependent expression of antimicrobial peptides in the black soldier fly *Hermetia illucens*. *Developmental & Comparative Immunology*. 78:141–148. doi:10.1016/j.dci.2017.09.008.
- Wang D, Zhai SW, Zhang CX, Bai YY, An SH, Xu YN. 2005. Evaluation on Nutritional Value of Field Crickets as a Poultry Feedstuff. *Asian-Australasian Journal of Animal Sciences*. 18(5):667–670. doi:10.5713/ajas.2005.667.
- Wang H, Rehman Ku, Feng W, Yang D, Rehman Ru, Cai M, Zhang J, Yu Z, Zheng L. 2020a. Physicochemical structure of chitin in the developing stages of black soldier fly. *International Journal of Biological Macromolecules*. 149:901–907. doi:10.1016/j.ijbiomac.2020.01.293.
- Wang SY, Wu L, Li B, Zhang D. 2020b. 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.
- Wardhana AH. 2017. Black Soldier Fly (*Hermetia illucens*) as an Alternative Protein Source for Animal Feed. *Indonesian Bulletin of Animal and Veterinary Sciences*. 26(2):069. doi:10.14334/wartazoa.v26i2.1327.
- Widianingrum DC, Noviani CT, Salasia SIO. 2019. Antibacterial and immunomodulator activities of virgin coconut oil (VCO) against *Staphylococcus aureus*. *Heliyon*. 5(10):e02612. doi:10.1016/j.heliyon.2019.e02612.
- Wu N, Wang X, Xu X, Cai R, Xie S. 2020. Effects of heavy metals on the bioaccumulation, excretion and gut microbiome of black soldier fly larvae (*Hermetia illucens*). *Ecotoxicology and Environmental Safety*. 192:110323. doi:10.1016/j.ecoenv.2020.110323.
- Xia J, Ge C, Yao H. 2021. Antimicrobial Peptides from Black Soldier Fly (*Hermetia illucens*) as Potential Antimicrobial Factors Representing an Alternative to Antibiotics in Livestock Farming. *Animals*. 11(7):1937. doi:10.3390/ani11071937.
- Xu J, Luo X, Fang G, Zhan S, Wu J, Wang D, Huang Y. 2020. Transgenic expression of antimicrobial peptides from black soldier fly enhance resistance against entomopathogenic bacteria in the silkworm, *Bombyx mori*. *Insect Biochemistry and Molecular Biology*. 127:103487. doi:10.1016/j.ibmb.2020.103487.
- Yang F, Li G, Zang B, Zhang Z. 2017. The Maturity and CH<sub>4</sub>, N<sub>2</sub>O, NH<sub>3</sub> Emissions from Vermicomposting with Agricultural Waste. *Compost Science & Utilization*. 25(4):262–271. doi:10.1080/1065657X.2017.1329037.
- Yang F, Li GX, Yang QY, Luo WH. 2013. Effect of bulk-ing agents on maturity and gaseous emissions during kitchen waste composting. *Chemosphere*. 93(7):1393–1399. doi:10.1016/j.chemosphere.2013.07.002.
- Yeona H. 2022. Measures to Reduce Agri-food Waste at the Retail and Consumption Stages. Technical report. Korea Rural Economic Institute.
- Zhang J, Chen M, Sui Q, Tong J, Jiang C, Lu X, Zhang Y, Wei Y. 2016. Impacts of addition of natural zeolite or a nitrification inhibitor on antibiotic resistance genes during sludge composting. *Water Research*. 91:339–349. doi:10.1016/j.watres.2016.01.010.
- Zhang J, Huang L, He J, Tomberlin JK, Li J, Lei C, Sun M, Liu Z, Yu Z. 2010. An Artificial Light Source Influences Mating and Oviposition of Black Soldier Flies, *Hermetia illucens*. *Journal of Insect Science*. 10(202):1–7. doi:10.1673/031.010.20201.
- Zhu D, Huang X, Tu F, Wang C, Yang F. 2020. Preparation, antioxidant activity evaluation, and identification of antioxidant peptide from black soldier fly (*Hermetia illucens* L.) larvae. *Journal of Food Biochemistry*. 44(5). doi:10.1111/jfbc.13186.
- Zhu Z, Rehman Ku, Yu Y, Liu X, Wang H, Tomberlin JK, Sze SH, Cai M, Zhang J, Yu Z, Zheng J, Zheng L. 2019. De novo transcriptome sequencing and analysis revealed the molecular basis of rapid fat accumulation by black soldier fly (*Hermetia illucens*, L.) for development of insectivall biodiesel. *Biotechnology for Biofuels*. 12(1):194. doi:10.1186/s13068-019-1531-7.
- Zurbrugg C, Dortmans B, Fadhila A, Verstappen B, Diener S. 2018. From pilot to full scale operation of a waste-to-protein treatment facility. *Detritus*. 1(0):18–22. doi:10.26403/detritus/2018.22.
- Çenesiz AA, Çiftci n. 2020. Modulatory effects of medium chain fatty acids in poultry nutrition and health. *World's Poultry Science Journal*. 76(2):234–248. doi:10.1080/00439339.2020.1739595.
- Žáková M, Borkovcová M. 2013. Comparison of field and lab application of *Hermetia illucens* larvae. *MendelNet 2013*. MendelNet. p. 798–801.