

Short Communication

## Use Of Restaurant Food Waste And Other Organic Waste In Feeding Black Soldier Fly (*Hermetia illucens*): A Review

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### ABSTRACT

Food waste and organic waste in general have become significant global challenges. This review aims to provide insight into how black soldier fly larvae can contribute to addressing this problem. These larvae have shown the ability to thrive on organic waste and convert it into useful products, such as animal feed, biodiesel, frass (which is a valuable fertilizer), and chitin. These products support the principles of circular economy. The review also examines legislative barriers that limit the use of these insects in tackling this challenge. With appropriate regulatory support and infrastructure, black soldier flies can contribute to sustainable food and organic waste management as well as resource recovery.

### Key words:

insects, organic waste, legislation, sustainability

### Abbreviations:

BSFL – black soldier fly larvae

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## INTRODUCTION

In recent decades, organic waste, and food waste in particular, have emerged as a major global challenge in terms of environmental impact and resource utilization. According to the estimates, 40% of total food waste comes from the restaurant industry alone. Roughly one-third of all food produced worldwide ends up as waste. This quantity of wasted food would be enough to feed two billion people, far exceeding the total number of undernourished individuals worldwide. This clearly points to the food service industry as a significant factor in global food waste generation ([FoodNotify Hospitality Blog, 2024](#)). Conventional solutions like landfilling are constrained by limited capacity, and they also raise environmental concerns. Common potential hazards include leachate and greenhouse gas emissions. In response to this, the world needs more sustainable waste management strategies ([Nguyen et al., 2015](#)).

An alternative approach involves the utilization of the black soldier fly (*Hermetia illucens* L.) larvae. The larvae can efficiently process a broad spectrum of organic substrates, including kitchen residues and fruit and vegetables ([Nguyen et al., 2015](#)). As highlighted in [Nguyen et al. \(2015\)](#), *H. illucens* larvae have shown the potential to reduce various types of organic waste, with culinary waste exhibiting the highest average reduction. In addition to their role in waste management, these insects also produce valuable by-products. They are rich in protein and fat (45.2 and 31.4%, respectively), which makes them an excellent alternative source of animal feed ([Nguyen et al., 2015](#)). A combination of these benefits makes this insect species a promising integrated solution for organic waste management and resource recovery.

## POTENTIAL FOR REDUCING FOOD WASTE FROM RESTAURANTS AND OTHER ORGANIC WASTE BY USING *HERMETIA ILLUSCENS* LARVAE

The increased production of solid waste, particularly food waste, represents a significant environmental and public health concern globally, and in some parts of the world, it is the largest portion of landfill waste ([Amrul et al., 2022](#); [Hariri et al., 2024](#)). The absence of widespread incineration facilities in some areas further emphasizes the urgency of developing sustainable alternatives to landfill disposal. One of the emerging solutions is the use of black soldier fly (*Hermetia illucens*) larvae (BSFL), [Figure 1](#). This idea has drawn considerable attention as an environmentally friendly and profitable method for bioconverting organic waste into valuable resources ([Siddiqui et al., 2022](#); [Magee et al., 2021](#)).

BSFL are known for their ability to process a broad range of organic waste ([Siddiqui et al., 2022](#)). Many studies have demonstrated that they can transform diverse organic waste substrates into valuable products. These substrates include household kitchen residues, restaurant leftovers, agricultural by-products, municipal organic waste, and expired food products ([Siddiqui et al., 2022](#)). Experimental studies have shown the effectiveness of BSFL in recycling household kitchen leftovers containing both plant-based and animal-based components, catering waste from restaurants, different types of rice-based meals, livestock manure, slaughterhouse waste, milling by-products, and palm oil industry residues ([Siddiqui et al., 2022](#); [Newton et al., 2005](#); [Zhou et al., 2013](#); [Nyakeri et al., 2017](#)). The remarkable ability of BSFL to efficiently use such heterogeneous substrates makes them an ideal choice for managing multiple organic waste streams.

Waste reduction efficiency is a crucial aspect of BSFL performance in food waste management systems. Several studies have shown reductions in both the volume and mass of organic waste treated by larvae. BSFL can significantly decrease the initial weight and volume of organic waste ([Siddiqui et al., 2022](#); [Hariri et al., 2024](#)). For instance, [Ibadurrohman et al. \(2020\)](#) reported that BSFL could recycle up to 75% of biological wastes, producing 800 g of insect larvae from 4 kg of substrate. [Nguyen et al. \(2015\)](#) found different reduction rates depending on the substrate type. They tested poultry feed, pig liver, pig manure, fruit and vegetables, and kitchen waste and concluded that kitchen waste had the highest average reduction rate. These results suggest that restaurant waste could be upcycled using BSFL. Additional small-scale experiments have also been conducted. They reported waste reduction rates of 39% for fruit, 35% for vegetable waste, 35% for bakery waste, and 38% for kitchen waste ([Siddiqui et al., 2022](#)). [Irfana et al. \(2021\)](#) reported similar findings, but in their experiment, the reduction rate of fruit waste was slightly higher, reaching 57%. They also observed that reduction efficiency varied between raw and cooked vegetable substrates. [Magee et al. \(2021\)](#) reported waste volume reductions ranging from 37% to 79% across various pre-consumer food waste streams in the UK. One of the more recent studies, conducted by [Hariri et al. \(2024\)](#), showed that BSFL reared on food waste reached higher reduction rates than those reared on chicken feed. Even better results were achieved by adding effective microorganisms (EM). This study demonstrates that BSFL waste reduction can be optimized by adding microorganisms as supplements to the substrate.

The efficiency of food waste bioconversion depends on several interacting factors ([Amrul et al., 2022](#)). The nutritional composition of the substrate strongly influences larval growth. Fat content is particularly important because substrates rich in lipids are digested more easily ([Siddiqui et al., 2022](#); [Cetinkaya and Yardimci, 2008](#)). [Rasdi et al. \(2022\)](#) explored the growth of BSFL on carbohydrate, protein, and fruit-based waste. They showed that BSFL growth differs significantly depending on whether the substrate is rich in fiber, protein, or carbohydrates. [Cheng et al. \(2017\)](#) suggested that moisture content is also an important parameter. It influences larval survival, growth, and the efficiency of residue separation. The same authors identified an optimal moisture range for separating residue after larval treatment, which is between 70 and 75%. In order to further improve the conversion efficiency, the substrate can be pre-treated using different techniques, and the process can be optimized. Pre-treatment methods aim to increase substrate accessibility and surface area ([Siddiqui et al., 2022](#); [Peguero et al., 2022](#); [Salerno et al., 2009](#)). Using a mixed diet based on different food waste proved to be more suitable for commercialization than using a single waste type. This provides a more balanced nutrient intake for BSFL and a higher survival rate ([Gold et al., 2020a](#); [Gold et al., 2020b](#)). [Gold et al. \(2020a\)](#) reported that mixing different waste streams can significantly improve survival rates, reaching 97–100%. All of these studies indicate that maximizing the potential of BSFL requires optimization of multiple factors.

The bioconversion process is influenced by the BSFL gut microbiome. It speeds up the digestion and recycling of organic waste. Studies have identified dominant bacterial species such as *Bacteroidetes*, *Firmicutes*, and *Proteobacteria* in the BSFL midgut. Complex organic matter is decomposed by enzymes produced by those bacteria. Some bacteria have even demonstrated lignocellulolytic abilities ([Siddiqui et al., 2022](#); [Yu et al., 2023](#); [Sun et al., 2015](#)). [Yu et al. \(2011\)](#) demonstrated that the addition of bacterial supplements to the BSFL diet can be beneficial. Adding *Bacillus subtilis*, *Arthrobacter*, and *Rhodococcus* to the BSFL feed potentially leads to faster larval growth

and increased harvestable biomass (Yu et al., 2011; Siddiqui et al., 2022). It must be noted, however, that the BSFL gut microbiome can also contain potentially pathogenic bacteria such as *Staphylococcus*, *Pseudomonas*, and *Campylobacter* (Siddiqui et al., 2022; She et al., 2023).

BSFL bioconversion not only reduces waste, but also yields valuable by-products that can be used in agriculture, energy, and industry (Siddiqui et al., 2022; Hariri et al., 2024). The prepupal stage of BSFL is known for its high protein content, ranging from 34 to 46.2%. Some studies reported protein content reaching 63% when corrected for moisture content (Oonincx et al., 2015; Diener et al., 2009; Lu et al., 2022; Spranghers et al., 2017). One of the more recent studies has shown that BSFL grown on food waste had an enhanced amino acid profile compared with commercial feed (Hariri et al., 2024). Besides proteins, they are also a valuable source of lipids and chitin. These characteristics make BSFL a sustainable, high-quality source of animal feed (Siddiqui et al., 2022; Barragan-Fonseca et al., 2017; Lu et al., 2022). Farming BSFL generates virtually no waste, as even the residues can be used. This residue, known as frass, contains chitin. It is used as a natural fertilizer because it has a favorable nitrogen and phosphorus content (Siddiqui et al., 2022; Magee et al., 2021; Amrul et al., 2022). Studies show that BSFL frass can improve soil quality as well as plant health, as some authors have reported that citin increases plants' resistance to pests and diseases (Siddiqui et al., 2022; Choi and Hassanzadeh, 2019). Besides improving plant health, chitin also has an economic value. It has applications in many sectors, including medicine, cosmetics, and biotechnology (Waško et al., 2016). BSFL also contain a significant amount of lipids. These lipids are a viable alternative to traditional sources used in biodiesel production (Li et al., 2011; Zheng et al., 2012; Kim et al., 2021).

Scale and operational goals dictate which rearing approach is used for waste management (Siddiqui et al., 2022; Amrul et al., 2022). Natural colonization systems are used for small households or communities based on local needs (Nyakeri et al., 2017). On the other hand, artificial mass breeding systems are designed for commercial companies that treat large amounts of organic waste under optimized and stable conditions. These artificial systems can even be integrated with sewage treatment processes, ensuring a consistent feed input (Siddiqui et al., 2022). To achieve optimal BSFL performance, it is necessary to adjust abiotic factors, especially temperature and relative humidity (Siddiqui et al., 2022; Salam et al., 2022). Siddiqui et al., (2022) and Magee et al. (2021) reported that the ideal temperature for larval survival is 30°C, while the optimal temperature range for population growth is 28-30°C.

From an environmental point of view, bioconversion of organic waste using BSFL has several advantages over conventional waste management strategies. One of these is its lower environmental impact compared with landfilling and incineration (Magee et al., 2021; Amrul et al., 2022; Salomone et al., 2017). For example, Siddiqui et al. (2022) reported lower greenhouse gas emissions. The second advantage is that BSFL-based systems produce biomass intended for animal feed with a much smaller ecological footprint than conventional protein sources (Siddiqui et al., 2022).

Although many positive aspects are evident, the adoption of the BSFL-based systems on a large scale is hindered by several factors. One of the main barriers is the regulatory and legislative framework, which limits which waste streams can be used as insect feed (Siddiqui et al., 2022; Amrul et al., 2022). In addition, logistics also presents a challenge. It is difficult to find a dependable, economically viable source of substrate with consistent quality and sufficient availability on a large scale (Siddiqui et al., 2022). This challenge also influences the economic feasibility of BSFL-based waste management, as its cost-effectiveness is also dependent on the type and quality of the substrate used (Siddiqui et al., 2022).



Figure 1. BSFL at their larval stage (<https://www.mannainsect.com/>)

## LEGISLATIVE CHALLENGES

Science has shown that feeding black soldier flies with organic waste could potentially reduce its volume, especially food waste. One of the main challenges is the regulatory framework. Legislation varies across the world, so this section compares different policy priorities. As examples, the USA, the EU, and several Asian countries are used because they represent different approaches to insect farming regulations.

The European Union has the strictest restrictions. The EU generally prohibits the utilization of food waste in animal feeding due to concerns over disease transmission and the use of animal protein ([Pinotti et al., 2023](#); [Pinotti and Ottoboni, 2021](#); [Shurson et al., 2023](#)). While recent legislation has permitted some processed animal proteins (PAP), many materials are still explicitly forbidden. It is legal to use porcine and avian PAP in aquaculture feeds, as well as insect PAP in fish, pig, and poultry diets. However, the use of ruminant-derived proteins, catering waste, former foodstuffs containing meat or fish, meat and bone meal, human and animal manure, and sewage sludge is still banned ([Pinotti et al., 2023](#); [Pinotti and Ottoboni, 2021](#); [Shurson et al., 2023](#)). Pet food made from food waste appears to be the most promising pathway within current EU rules ([Pinotti et al., 2023](#)). Even though EU laws are restrictive, it is still possible to process at least some types of waste using the BSFL method.

Serbia is working towards harmonizing its food and feed legislation with the EU, but currently there is no specific document that regulates the use of BSFL as food or feed. Their use is regulated through the general food and feed safety frameworks. The main legal act is the Law on Food Safety, which establishes general safety requirements. Insects are treated as novel food, which means that special permission is required. Since Serbia is trying to align with the EU practices, BSFL are not allowed for human consumption. The regulatory framework is based on several documents, including the Rulebook on the Quality of Feed and the Rulebook on Animal By-products Not Intended for Human Consumption. They define feed as a product of plant, animal, or other origin used for animal nutrition, which allows an indirect interpretation of insect proteins. In practice, Serbia is aligning with EU Regulation (EU) 2017/893, which permits the use of BSFL in animal feed under controlled conditions.

In the U.S., the Swine Health Protection Act (SHPA) regulates food waste feeding. This act prohibits feeding untreated waste containing meat products to swine. It requires such waste to be cooked at 100 °C for 30 minutes before feeding ([Shurson et al., 2023](#); [Stat. 2229 - Public Law No. 96-468 \(10/17/1980\)](#)). The use of waste as feed must be licensed and is subject to inspection ([Shurson et al., 2023](#)). Additionally, the FDA BSE/Ruminant Feed Ban Rule strictly forbids adding mammalian tissue to ruminant diets. It allows only rendered by-products under specific conditions and approved food waste. Furthermore, this rule also requires mandatory labeling and detailed record-keeping in order to ensure traceability and prevent cross-contamination ([Shurson et al., 2023](#)). Although some food waste processing methods, such as dehydration, pelleting, and extrusion, may exceed minimum thermal requirements, these processes must still conform to SHPA standards. Processed food waste may be classified as rendered products for regulatory purposes, depending on oversight by state authorities, USDA-APHIS, or the FDA ([Shurson et al., 2023](#)).

Some Asian countries have less restrictive laws. Japan, Taiwan, S. Korea, and China are good examples. They promote upcycling of food waste to animal feed ([Shurson et al., 2023](#)). To ensure that safety protocols are followed, Japan has established regulatory guidelines and a certification system (Eco-feed) with multi-stage inspection, evaluation, and certification processes ([Shurson et al., 2023](#)). China has adopted a directive stressing adherence to a "no-treat, no-feed" policy. This means that direct feeding of untreated food waste to pigs is banned. China implements strict measures, including record-keeping, monitoring, traceability, closed-loop operations, and financial support systems ([Shurson et al., 2023](#)). Other countries could benefit from the approaches adopted in Japan, Korea, and China. This would allow them to upcycle a broader range of food waste while maintaining high food and feed safety and quality standards.

## CONCLUSION

Black soldier fly larvae (*Hermetia illucens*) are a promising strategy for addressing the growing challenge of restaurant food waste and other types of organic waste. Many studies indicate that *Hermetia illucens* can transform a wide variety of organic substrates into valuable products while minimizing environmental impact. Some of these products are animal feed, biodiesel mass, organic fertilizer, and chitin. However, both EU and U.S. laws restrict the application of these products, especially in animal nutrition. Examining and adapting regulatory and operational models that are already implemented in some Asian countries could help overcome these limitations. Nations such as Japan, China, and South Korea demonstrate that it is possible to develop systems that upcycle food waste into animal feed while maintaining high safety and quality standards. BSFL have demonstrated their potential to contribute to a more resource-efficient waste management system provided that regulatory conditions are met.

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