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Black Soldier Fly –The Fly Behind Sustainable Composting

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ABSTRACT

The Black Soldier Fly (Hermetia illucens), a versatile and ecologically significant insect, has drawn increasing notice for its potential to transform agricultural practices. Belonging to the family Stratiomyidae, this non-pest fly is native to tropical and subtropical regions but is now cultivated globally due to its numerous environmental and agricultural benefits. Its larvae are especially noteworthy for their capacity to efficiently decompose organic matter, converting it into nutrient-rich by-products that can be reintegrated into farming systems. Now, the challenge is that skyrocketing solid waste is a significant cause of the requirement for more landfill sites. The total agricultural residue wastes are expected to be increase per year in India. Due to the low bioconversion rate and various other environmental elements, Black soldier fly decomposition is treated as a sustainable alternative. This not only lowers waste but also supports sustainable agriculture by providing organic fertilizers and other valuable resources. Agriculture, the backbone of food systems, faces mounting pressures from population growth, urbanization, and climate change. These challenges demand innovative and sustainable approaches to guarantee food security while lowering environmental impacts. The Black Soldier Fly, with its unique biological capabilities, has become a promising solution for addressing these challenges. Its capacity to convert organic waste into useful resources makes it a pivotal tool for sustainable agriculture.

Keywords: *Black soldier fly, Compost, Decomposing, Environmental sustainability, bio degradation, Organic Fertilizer, bio remediation, nutrient recycling*

Introduction

The black soldier fly, *Hermetia illucens*, has transitioned from a mere insect to a pivotal component in sustainable waste management and agriculture (Tomberlin & Huis, 2020). Its exceptional ability to turn organic waste into worthy biomass has positioned it as a key player in the closed-loop economy (Albalawneh *et al.,* 2025). The increasing demand for livestock and poultry products has led to a surge in intensive farming, resulting in substantial manure production that poses environmental threats if not managed effectively (Zhang *et al.,* 2021). Simultaneously, the accumulation of food waste from households and industries presents a pressing environmental challenge, contributing to pollution and resource depletion (Wang & Shelomi, 2017). Conventional waste management operations like landfilling and incineration are increasingly unsustainable due to their environmental impacts and limited capacity (Kofroňová *et al.,* 2024). This has spurred the exploration of alternative waste treatment strategies, with *Hermetia illucens* larvae emerging as an encouraging approach for zero waste steps and resource reclamation (Siddiqui *et al.,* 2022, and Brodeur *et al.,* 2024). The larvae of this fly are voracious consumers of organic matter, capable of rapidly reducing waste volume and converting it into valuable protein and fat-rich biomass (Nyakeri *et al.,* 2019). The resulting larval biomass can be processed into a nutrient-rich animal feed supplement, presenting a sustainable and economically attractive alternative to conventional protein sources that contribute to deforestation and overfishing.

The larvae of the Black Soldier Fly (BSFL) are highly efficient at bio-degradation of organic matter, transforming it into nutrient-rich residue known as frass. This frass acts as a plant food rich in key nutrients like nitrogen, phosphorus, and potassium, which are pivotal for plant growth. By organic recycling it into agricultural inputs, BSF helps to curtail greenhouse gas emissions, notably methane, a by-product of traditional waste disposal methods like landfilling (Cickova *et al.,* 2015).

Organic waste management through BSF contributes to a circular economy by recycling nutrients back into farming systems. This process not only reduces the environmental burden of waste disposal but also minimizes the reliance on synthetic fertilizers. Additionally, the larvae themselves can be harvested as a protein-rich resource for animal feed, further enhancing their economic and ecological value (Smetana et al., 2016). The use of BSF in agriculture extends beyond its role as a fertilizer. By integrating BSF into farming systems, the environmental footprint of agriculture can be significantly reduced. The diversion of bio waste from landfills not only limits methane release but also conserves valuable land resources. Moreover, the production of BSF-derived products requires minimal energy inputs compared to conventional fertilizer manufacturing processes, making it a more sustainable option.

Economically, BSF offers multiple revenue streams, from the sale of frass as an organic fertilizer to the use of larvae in animal feed and biodiesel production. These applications make BSF a versatile and profitable addition to agricultural value chains (Antonius *et al.,* 2019).

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Cickova *et al.* (2015) highlighted that many insects, including BSF, play a crucial part in recycling organic matter in nature. By consuming organic by-products and incorporating nutrients into their bodies, those not only lesser the environmental waste but also produce organic fertilizers that have the potential to replace conventional chemical inputs. The BSF stands out among these insects due to its adaptability to various organic substrates, including food waste, plant residues, and rotting fruits.

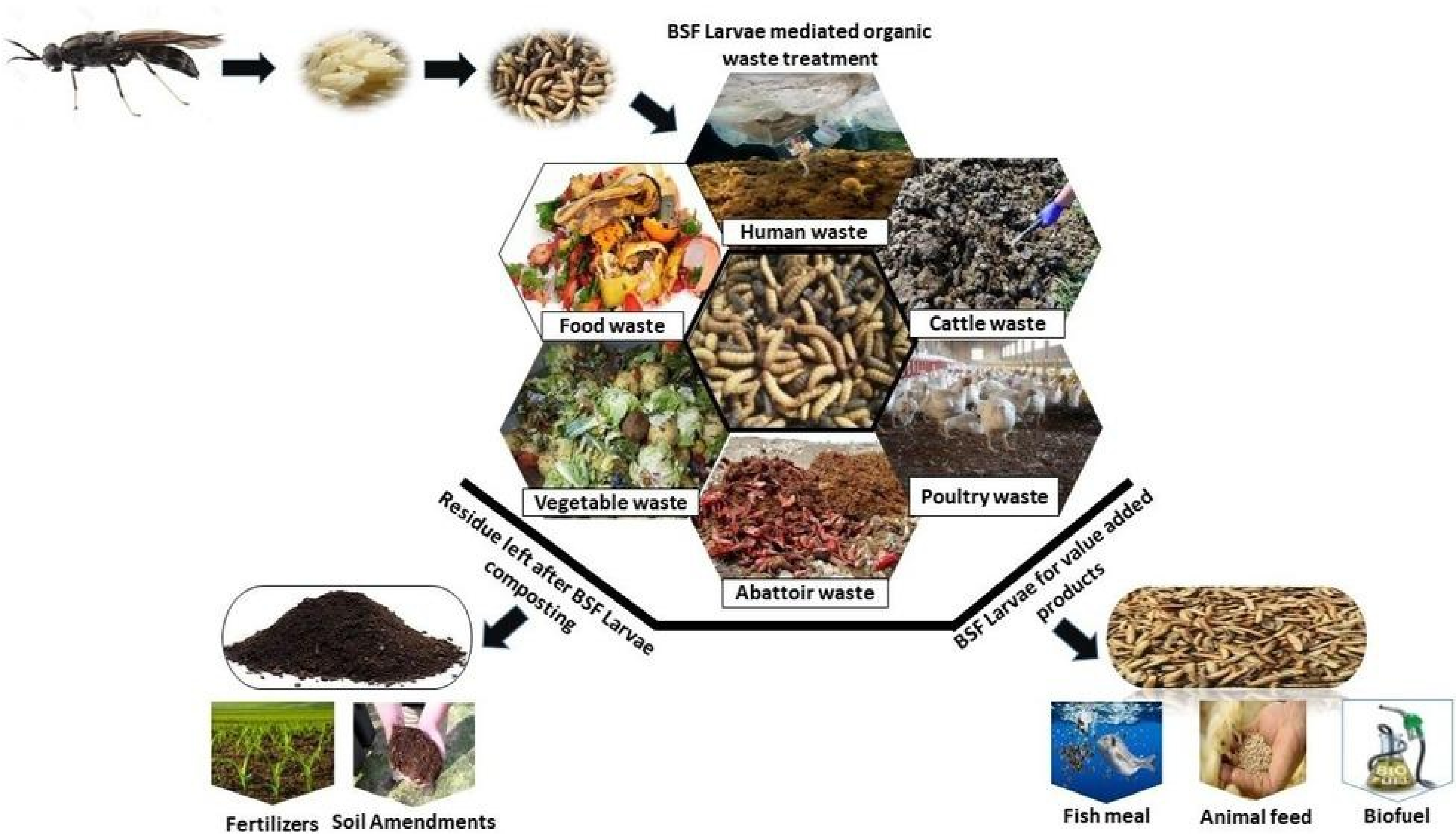
The potential applications of BSF extend beyond waste recycling. Their larvae are a sustainable source of protein, making them valuable as provender for the creation of biodiesel and biologically active substances. BSF-derived frass (BSFF) has been explored as manure in various crops, including basil and sorghum (Newton, 2005), asparagus bean (Anggraeni *et al.,* 2010), corn (Alattar *et al.,* 2016), onion (Zahn, 2017), and lettuce (Kebli and Sinaj, 2017).

The growing global population, projected to reach 9.7 billion by 2050, necessitates a 70% increase in food production. The concomitant rise in the call for food, in conjunction with rapid urbanization and changing dietary preferences, is creating unprecedented pressure on agricultural systems and natural resources. Simultaneously, waste management has emerged as a critical environmental challenge; generation of garbage is expected to increase from 2.01 billion tons in 2016 to 3.40 billion tons by 2050. The interconnection of these challenges demands innovative, resource-efficient both food security and waste management in an integrated manner. (Dhanush Kenchanna *et al.,* 2024)

Despite the growing interest in organic fertilizers, their adoption in intensive agriculture remains limited. Organic fertilizers often require large quantities to achieve results comparable to synthetic inputs, which can be challenging for farmers to implement. However, BSFL frass stands out due to its concentrated nutrient profile and additional benefits, such as promoting soil microbial activity and enhancing nutrient uptake efficiency (Kebli & Sinaj, 2017).

Research comparing BSFL frass to other organic and synthetic fertilizers has highlighted its potential to enhance crop growth and yield while maintaining environmental sustainability. Alattar et al. (2016) demonstrated its effectiveness in improving corn yield, and Zahn (2017) reported similar results in onion production. These findings underscore the need for further studies to optimize frass application rates and methods for different crops and agroecological conditions.

Conversion of waste into compost by Black Soldier Fly



Anshika Singh and Kanchan Kumari (2019)

Black Soldier Fly Larvae Frass as a Food Waste Solution

Global Challenge of Solid Trash

- Increasing Waste Generation: The world's biggest challenge with solid waste, forecast to rise from 2 billion tonnes in 2016 to 3.4 billion tonnes by 2050.
- Pressure of Food Waste: More than half of all solid waste produced worldwide is food waste, which has a substantial negative impact on the environment and the economy. This emphasizes how urgently 43 efficient methods for managing garbage are needed.
- Black Soldier Fly Larvae (BSFL) as a Solution
- Innovative Approach: Feeding food waste to insect larvae, particularly black soldier fly larvae (BSFL), has emerged as an innovative and attractive waste management strategy.

- BSFL Composting: BSFL bio conversion is a simple, space-efficient, and cost-effective process. Larvae receive a single meal or periodically, and their self-harvesting nature reduces the need for adeptness, making it beneficial for a loop economy and sustainable operations in various income countries.
- Waste Reduction Capability: BSFL can consume a wide range of decaying natural materials, including bio waste, and can eliminate over 50% of total organic waste in as little as two weeks under ideal conditions.
- Valuable Products: BSFL uniquely converts organic waste into proteinaceous and lipid-rich biomass suitable for animal consumption, and also produces a significant by-product: frass.
- Black soldier fly larvae (BSFL) frass possesses special features that make eco eco-friendly, especially concerning nutrient cycling from food waste substrates. Its promising potential extends beyond just soil amendments and organic manure.

Environmental footprint of Black Soldier Fly Larvae (BSFL)

Parameter	Value	Citation
CO2 Emissions	655 g CO2 per 1 kg dry matter consumed	(Xiang *et al.*, 2024)
CH4 Emissions	0.80 mg CH4 per 1 kg dry matter consumed	(Xiang *et al.*, 2024)
N2O Emissions	2.26 mg N2O per 1 kg dry matter consumed	(Xiang *et al.*, 2024)
Waste Reduction Index (WRI)	4.77 ± 2.98 g/day for kitchen waste	(Zulkifli *et al.*, 2023)
Bioconversion Efficiency	67% substrate reduction for fruit waste	(Karthikeyani *et al.*, 2024)
Greenhouse Gas Emissions	Over 90% reduction compared to conventional composting	(Pang *et al.*, 2020)
Nitrogen Reduction	53% reduction in swine manure	(Matos *et al.*, 2021)
Phosphorus Reduction	42% reduction in swine manure	(Matos *et al.*, 2021)
Global Warming Potential (GWP)	6.687 kg CO2 eq per 100 kg dried BSFL production	(Nugroho *et al.*, 2023)

Advantages of BSFL frass.

- BSFL frass contains chitin, which is a promising soil amendment for improving soil quality, plant growth, and plant resilience. Schmitt,2020.
- Rich in nutrients (macro, micronutrients, and organic matter), Bortolini *et al*,2020.
- High phosphorus concentrations from Black Soldier Fly (BSF) frass can indirectly promote nitrogen (N) accumulation in plants by enhancing overall plant growth and nutrient uptake. Attiogbe *et al.,* 2019.
- Black Soldier Fly (BSF) frass, which is the excrement and uneaten organic matter left behind by BSF larvae, contains chitin. Chitin, a component of the insect's exoskeleton, can stimulate the production of antimicrobial peptides in plants. These peptides act as a natural defense mechanism, helping plants resist pathogens. Klammsteiner *et al.,* 2020.
- "Increasing the population of beneficial microbes in the soil enhances plant nutrient absorption. Choi *et al.,* 2019.
- Black soldier fly larvae (BSFL) offer significant environmental benefits in bioremediation by reducing landfill waste and greenhouse gas emissions. Gold *et al.,* 2020.

The use of Black Soldier Fly Larvae (BSFL) has emerged as a promising solution for addressing environmental challenges such as bioremediation, reduction of landfill waste, and mitigation of greenhouse gas emissions. This approach leverages the larvae's ability to efficiently convert organic waste into valuable biomass, thereby lessening the impact on the environment associated with regular waste management practices. This response provides a comprehensive analysis of the environmental benefits of BSFL, supported by insights from relevant research papers.

Reduction of Landfill Waste

Reducing the amount of organic waste dumped in landfills is one of BSFL's most important environmental effects. Methane, a powerful greenhouse gas, is produced when organic waste, including food waste, breaks down in landfills. BSFL considerably lessens the requirement for landfilling by turning this garbage into larval biomass.

Bioremediation and Pollution Reduction

BSFL are not only effective in reducing waste and greenhouse gas emissions but also play a plays a vital part in bioremediation. Bioremediation entails using living organisms to remove pollutants from the environment, and BSFL have been proven to be particularly effective in this regard.

Decomposition of Organic Matter

The larvae's capacity to break down organic materials is a key element in their bioremediation potential. Studies have demonstrated that BSFL can decompose a wide range of organic substrates, including kitchen waste, fruit and vegetable waste, and even mixed livestock manure (Li et al., 2023). This decomposition process not only reduces the volume of let over but also converts it into a nutrient-rich biomass that can be used as fertilizer.

Reduction of Pollutants

BSFL has been shown to minimise the levels of various pollutants in organic waste. For instance, the larvae can reduce the total nitrogen content in swine manure by up to 53% and phosphorus by up to 42% (Matos et al., 2021). This reduction in nutrient content not only decreases the effects of garbage disposal on the environment but also produces a more balanced fertilizer product.

Environmental Impact Assessment

To fully understand the environmental benefits of BSFL, doing a life cycle assessment is crucial. (LCA) that evaluates the whole procedure from trash gathering to the production of final products. LCAs have been conducted to assess the environmental impacts of BSFL sanitation services systems.

Effect of Black soldier fly larval frass combined with other manures on soil properties, Soil Fertility and Crop Performance.

BSF-derived frass has shown promise as a natural fertilizer that enhances soil fertility and promotes plant health. Frass is not only a source of macronutrients but also contains secondary nutrients (e.g., calcium, magnesium, sulfur) and micronutrients (e.g., iron, copper, zinc), which are often deficient in high-input agricultural systems.

The use of BSFL frass improves soil structure, microbial activity, and water-holding capacity, considering all for achieving high yields, particularly in nutrient-demanding vegetable crops (Anggraeni, 2010).

In vegetable production, where the need for sustainable and chemical-free practices is increasing, BSF products offer an eco-friendly alternative. Their application can reduce the dependency on agrochemicals, aligning with global efforts to promote organic and sustainable farming practices. For instance, investigations have reported positive effects of BSFL frass on crops like basil, sorghum, and asparagus beans (Newton et al., 2005; Anggraeni, 2010).

Klammsteiner *et al.* (2020) performed an experiment using black soldier fly frass as a soil additive and its suitability. They applied frass from larvae raised on different diets in nitrogen-equivalent amounts as soil amendment, comparing it to NH_4NO_3 fertilizer as a control. The analysis showed that the soil properties showed no difference between mineral fertilizer and frass, except for nitrate and dissolved nitrogen contents.

Guo *et al.* (2021) experimented on the influence of black soldier fly faeces and distiller's grains on the physico-chemical properties of saline alkali soil. The results showed that the application of 4% distiller's grains significantly reduced soil pH (5.52%) compared to the control. The results showed that application of 2% black soldier fly faeces in combination with 2% distiller's grains significantly increased the contents of available nitrogen, phosphorus, potassium, and organic matter in saline alkali soil, and also the nitrate nitrogen level was improved, which was 95.7% higher than that of the control.

Menino *et al.* (2021) studied black soldier fly larvae frass (BSFLF) as a bio-manure with seven treatments: T_0 (control), T_{25}, T_{50}, T_{75}, T_{100}, $T_{125,}$ and T_{150} of the total required amount of N supplied by BSFLF. The report from the experiment showed a considerable increase in OM, $P_2O_{5,}$ and K_2O had been noticed when BSFF was applied in treatment T_{100}.

Nutrient composition of frass from black soldier fly larvae composting of different biodegradable wastes.

BSF larvae fed with a mixture of okra and wheat bran resulted in 47.8 g kg $^{-1}$ N and 0.98 g kg $^{-1}$ K content in frass. Sarpong et al. (2019) performed a comparative study with BSF larvae fed with municipal solid waste of varying composition (2, 2.5, 3.0, 3.5 to 4 kg) and a control. They reported that the N, P, and K contents in the frass after the larvae consumed the substrate reached the respective concentrations of 4.8, 0.9, and 0.6 g kg-1 [1] respectively, and also the heavy metals content had reduced to an acceptable level. BSF larvae were fed on a carbohydrate source (bread waste). These larvae generated frass containing 15.2 g kg $^{-1}$ of N, while small additions (5–15%) of a protein rich waste stream (fish waste) resulted in increase in the nutrient content ranging from 18.4 to 23.8 g kg $^{-1}$, demonstrating that the BSF larvae diet can be adjusted to modify the formulation of the end product (Lopes *et al.,* 2019).

Klammsteiner *et al. (*2020) supplied three feeding materials to BSF larvae, viz., chicken feed, grass waste, and fruit/vegetable waste. They observed that pH and EC variations in chicken feed frass (6.22, 5.67 mS cm^{-1}), grass-cuttings frass (5.40, 3.06 mS cm^{-1}), and fruit/vegetables frass (5.58, 2.36 mS cm^{-1}). While N content ranged between 18.3 (fruits and vegetables), 24.4 (Grass-cuttings), and 25.9 g kg^{-1} (chicken feed), respectively.

Beesigamukama *et al.* (2020b) noticed that the frass produced by BSF larvae when fed with brewer's spent grains had 21 g kg $^{-1}$ N, 11.6 g kg $^{-1}$ P, and 1.7 g kg $^{-1}$ K.

The results obtained by Palma *et al.* (2020) when BSF larvae were fed on almond by-products of different compositions. The obtained frass had 12.3–22.3 g kg^{-1} N, 0.22–0.82 g kg^{-1} P, and 17.9– 44.6 g kg^{-1} K. These differences in nutrient concentration were due to carbohydrate, protein, and fibre contents of the feed substrates.

Arabzadeh *et al.* (2022) studied two different plant-based diets (fruit/vegetable/bakery waste supplemented with brewery waste (FVBB) and Gainesville (GV) diet to feed BSFL under laboratory conditions. The nutrient composition of GV and FVBB frass had NPK values of 2.0–1.94–3.65 and 2.70–1.27–3.0, respectively.

Combined effect of BSFL compost, organic manure on growth and yield in different crops

Liu et al. (2018) reported that black soldier fly larvae (BSFL) have the potential to effectively convert manure into high-quality fertilizer. The results showed that the BSFL composting reduced the organic matter by 20.31–22.18% in contrast to the control. The employment of BSFL significantly increased the total phosphorus (TP), total nitrogen (TKN), and total nutrients by 42.30 –64.16%, 45.41–88.17%, and 26.51–33.34%, respectively. And also concluded that employing BSFL could improve the quality of the product and the maturity degree of the composting. Therefore, the BSFL could be added as a high-efficiency transformation agent for converting organic manure into stable compost.

Beesigamukama et al. (2020) investigated Black soldier fly frass (BSFFF) as a new fertilizer for improving maize growth, yield, and nitrogen use efficiency under field conditions. The work revealed that the tallest plants and highest chlorophyll concentrations were found in maize grown in BSFFF-treated plots, which also yielded 14% higher grain yields than plots treated with similar rates of commercial organic fertilizers. Furthermore, BSFFF application at 7.5 t ha-1 significantly increased N uptake by up to 23% when compared to the equivalent rate of commercial manure. These results show that BSFFF is a viable and sustainable substitute for commercial fertilizers in the pursuit of increased maize production.

Wu *et al.* (2020) conducted a study on the effects of black soldier fly compost on rice growth. The data explained that the dry matter mass and the yield of rice treated with 4% BSF feces were the highest, compared with the control, which was increased by 40.20% and 49.59%, respectively. While the application of 8% BSF feces inhibited the rice plant height, above-ground dry matter mass, and rice yield, which were reduced by 9.98%, 22.59% and 22.66%, respectively. The 4% BSF feces promoted the growth and yield in rice.

Agustiyani *et al.* (2021) conducted an experiment with the application of compost and frass from Black Soldier Fly Larvae (*Hermetia illucens* L.) on the growth of Pakchoi (Brassica rapa L.). Also, to observe the effect of frass (insect feces) from Black Soldier Fly larvae (BSFL) as soil amendments at different application rates in comparison with other organic fertilizers on Pakchoi (*Brassica rapa* L). And the results concluded that the highest total plant weight was achieved with Compost+LOB (24.4 g), followed by 10% BSF frass (23.3 g).

Anyega *et al.* (2021) compared the yields of French beans for 2 seasons, tomatoes, and kales in greenhouse and open-field settings. The results indicate that for tomatoes, kale, and French beans, the vegetable yields obtained by combining BSFFF and NPK were 4.5, 2.4, and 5.4 times higher than the yield from the control treatment, respectively.

Menino *et al.* (2021) look into the Agricultural value of Black Soldier Fly larvae frass as bio fertilizer on ryegrass. The work was conducted in a greenhouse with ryegrass, using seven treatments of BSFF. The results showed a significant effect of BSFF on the overall ryegrass production.

Reswita *et al.* (2022) Studied Effect of Giving Frass *Hermetia Illucen L.* on Soil Physical Chemical Properties, Chlorophyll Content and Yield of Upland Rice (*Oryza Sativa L.*). It is proved that the application of Frass can improve the physical and chemical properties of Ultisol soil and increase the grain weight of 100 seeds. The combination of giving Frass 30% with 25% NPK had a significant effect on increasing the total chlorophyll content of upland rice. It was concluded that the application of 30% Frass combined with 25% NPK fertilizer had a demarking effect on the chlorophyll content of upland rice and had the potential to reduce the use of chemical fertilizers by 25%.

Siddiqui *et al.,* (2022) reported that, Black soldier fly larvae (BSFL), *Hermetia illucens* have shown to turn organic waste into high-quality nutrients for pet foods, fish and poultry feeds, as well as residue fertilizer for soil amendment.

Susanto *et al.,* (2022) aimed to evaluate the impact of Black Soldier Fly (BSF) frass on plant growth in comparison to synthetic fertilizers. Corn and pak choi were the two crop species used as test plants, and they were grown in field conditions. The results of the study revealed that applying 50% BSF frass to the test plants led to improved growth and development compared to the control treatment.

Tanga *et al.* (2022) evaluated the comparative impact of BSFFF, NPK, and commercial organic fertilizer on growth, nitrogen use efficiency, yield, nutritional quality, and profitability of maize under greenhouse conditions. The findings revealed that BSFFF increased maize grain yield at higher rates: 2-25, 25- 113, and 153-212% than NPK, BSG, and Evergrow, respectively.

Terrell (2022) examined the black soldier fly (*Hermetia illucens*) composting for urban agriculture specialty crop production. Black soldier fly larvae (*Hermetia illucens*; BSF) have been recognized as an efficient organism used to break down organic matter and produce a soil amendment comparable to traditional fertilizers.

Boudabbous *et al.* (2023) revealed that Black Soldier Fly (*Hermetia illucens*) Larvae Frass Organic Fertilizer Improves Soil Quality and the Productivity of Durum Wheat and concluded that Durum wheat plants grown in pots treated with BSFL frass had the highest height, dry root weight, and chlorophyll indicators. The PCA analysis identified grain yield, yield component, and soil nutrients as major drivers for the variability among samples. Our results highlight the potential of BSFL frass to improve soil health and wheat yields in an environmentally friendly way.

Maria Y. Chavez *et al.,* (2024) reported that in small amounts, 10–20%, BSFL frass can serve as a good replacement for peat in leafy green crops.

Nicholas Romano *et al.,* (2023) performed experiment and results show that not only can BSFL frass partially replace synthetic fertilizer, but showed a growth benefit compared to the sole use of either synthetic fertilizer or BSFL frass.

Matthias J. Salomon *et al.,* (2024) Insect frass shows significant potential as a nutrient-rich organic fertiliser, and Physico-chemical analysis of two commercial BSFL frass products showed high concentrations of plant nutrients, often exceeding those in traditional composts.

Noor Ezlin Ahmad Basri *et al.* (2022) had concluded that BSFL frass has many special characters that are good for the environment, particularly soil and plant nutrition cycling from food waste substrate. In addition to soil amendments and organic fertiliser, BSFL frass has other uses, including animal feed, growth media, biochar, and feedstock for vermicomposting and biogas plants. Although the qualities of food waste substrate could affect BSFL frass quality, pre-treatment of food waste and post-treatment of BSFL frass could produce high-quality frass.

Matthias J. Salomon *et al.* (2024) did a Physico-chemical analysis of two commercial BSFL frass products and reported that under the conditions of greenhouse, an application rate of 100 kg N ha^{-1} in the form of BSFL frass is advised. Overall, insect frass proves to be an efficient organic fertiliser, but with some limitations.

Jeffrey Beasley *et al.* (2023) claimed that Black Soldier Fly Frass Supported Plant Growth and Reduces Nitrogen Leaching during Coleus Production. In the production of container-grown coleus, BSFF produced marketable coleus when applied at 0.3 kg/m^{-3} N and demonstrated reduced N leaching of 87% compared with SF-coleus during a 6-week production period under greenhouse conditions. Therefore, BSFF is a suitable nutrient for growing coleus without compromising growth and leaf quality.

Gold *et al.* (2020) quoted that BSFL larvae, besides being a source of proteins to livestock, have been known to be the best organic fertilizer for crops and a better tool for managing our environment. With the rising effects of climate change, BSF can be used to lower greenhouse gas emissions and reported that black Soldier Fly Frass for Improved Soils, Crop Yields and Environment among Smallholders-Mixed Farming System in Kenya.

Tanga *et al.* (2021) proved that the agronomic N use competence of maize grown using BSFL was 2 and 3 times more than that of BSG and Evergrow, respectively. Maize grown using BSFL and NPK had greater crude protein and crude fibre content.

Gurung *et al.* (2024) conclude that manure-derived black soldier fly (BSF) frass holds significant potential as biofertilizer, particularly for chilli plants (*Capsicum annuum L.),* while also highlighting its role in sustainable litter management and closed-loop economy benefits. Manure-derived BSFL frass is a viable organic fertilizer that can boost chilli plant growth and positively influence soil microbial communities, contributing to sustainable agriculture and waste management practices.

Menino *et al.* (2021) did a greenhouse experiment with ryegrass, using seven treatments of *Hermetia illucens* L larvae frass (BSF), and the results showed a significant effect of BSF on the overall ryegrass production.

Tomato yields with BSFFF + NPK were 22–135% higher than sole NPK and 22–124% higher than other fertilizer treatments under greenhouse conditions, and 38–135% higher in open-field conditions. Sole BSFFF also yielded significantly more than BSG and Evergrow. Anyega *et al.* (2021)

Anyega *et al.* (2021) found that Kales grown with BSFFF + NPK showed markedly higher yields than BSG and Evergrow, and also higher than sole BSFFF and NPK in greenhouse settings. French bean pod yields were significantly influenced by fertilizer treatments, with BSFFF + NPK leading to significantly higher yields than most other treatments. Alone, BSFFF increased French bean yields by 70% and 65% compared to BSG and Ever grow in greenhouse and open-field experiments, respectively.

Conclusion

The use of Black Soldier Fly Larvae in bioremediation, reduction of landfill waste, and decrease in greenhouse gas emissions represents a promising approach to addressing the most pressing environmental challenges of our time. By leveraging the larvae's ability to proficiently convert organic waste into valuable biomass, we can significantly reduce the environmental footprint of waste management practices. As research continues to uncover the full potential of BSFL, their role in sustainable waste management is expected to grow.

Future Scope of Study

At the intersection of sustainable protein production, circular bioeconomy, and waste management is the black soldier fly composting paradigm. We can turn this technology from specialized pilot projects into widely used solutions by advancing research in bioconversion optimization, product diversification, digital integration, and thorough environmental assessment. This will reduce costs, lessen the effects on the climate, and create new value chains. BSF composting has the potential to become a key component of global sustainable development in the upcoming years with concentrated effort and interdisciplinary cooperation.

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Conflict of Interest

The authors declare there is no Conflict of Interest.

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