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Composting Swine Manure Using The Biotechnology of Hermetia Illucens, The Black Soldier Fly Larvae: A Review

[1] Laurențiu Liviu Urechescu, [2] Adnan Arshad, [3] Elena Maria Drăghici

[1, 2, 3] University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania

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Corresponding Author: **Laurențiu Liviu Urechescu**

Abstract

The sustainable management of swine manure is a significant challenge in agriculture due to its environmental and economic implications. The use of *Hermetia illucens* larvae, commonly known as Black Soldier Fly Larvae (BSFL), offers an innovative approach to composting pig manure. This review explores the efficacy of BSFL as a biotechnology in decomposing swine manure, highlighting the larvae's ability to reduce waste volume by up to 80% while producing valuable by-products such as protein-rich larval biomass and nutrient-rich frass. The environmental benefits of BSFL composting include lower greenhouse gas emissions and pathogen reduction compared to traditional composting methods. Additionally, the economic potential of BSFL composting is significant, as the larvae can be processed into high-quality animal feed, and the frass can be used as an organic fertilizer. Despite these advantages, challenges remain in optimizing the composting process and ensuring the safety and quality of BSFL-derived products. This review concludes that BSFL composting represents a promising, sustainable alternative for swine manure management, with potential benefits for both the environment and agricultural economics. Further research and development are needed to fully harness this technology's true potential.

Keywords: Black Soldier Fly, Larvae, Review, Composting, Swine Manure, Hermetia Illucens

1. Introduction

According to Worldometer the global population in September 2024 reached 8,175,420,840 people. The global population produces a vast amount of waste each day, encompassing municipal solid waste (household waste), industrial waste, medical waste, and electronic waste (e-waste). With population growth, the volume of waste keeps rising, exerting significant pressure on current waste management systems.

Improper waste disposal leads to environmental pollution, affecting land, water, and air. Common disposal methods like landfills emit methane, a powerful greenhouse gas that fuels climate change. Plastic waste has emerged as a major environmental issue, with significant amounts polluting oceans and threatening marine life.

Recycling rates differ widely around the world. Some countries have well-developed recycling systems that reduce waste by converting materials like plastic, glass, and metal into new products. However, in many areas, insufficient recycling infrastructure results in a larger share of waste being sent to landfills or incinerated.

As urbanization increases, cities face growing challenges in managing waste. Dense populations in urban areas generate more waste, requiring efficient collection, transportation, and disposal systems. Many cities struggle with inadequate infrastructure, leading to issues like illegal dumping and open burning.

Technological advancements are helping to address some of these challenges. Innovations in waste-to-energy (WTE) processes, smart waste management systems (using IoT), and advancements in recycling technology offer potential solutions. However, the adoption of these technologies varies widely according to budgets invested in these technologies.

The management of swine manure is a critical concern in modern agriculture due to its substantial environmental and economic implications. As global pork production increases, the amount of manure generated by intensive pig farming has become a significant environmental challenge. Traditional methods of manure management, such as direct land application and conventional composting, are associated with issues like nutrient leaching, greenhouse gas emissions, and pathogen proliferation (Chantigny, 2003) [4].

Liu *et al*. (2019) [10] reported the increasing number of livestock farms has led to a great deal of manure generation, and its improper treatment results in threats to the environment. Black soldier fly larvae (BSFL) have the potential to effectively convert manure into high-quality fertilizer.

To address these challenges, alternative methods of manure management are being explored. One promising approach is the use of *Hermetia illucens* larvae, commonly known as Black Soldier Fly Larvae (BSFL). These larvae are highly efficient at decomposing organic waste, including swine manure, and can convert it into valuable by-products such as protein-rich biomass and nutrient-dense frass. The potential of BSFL to enhance the sustainability of manure management systems has garnered increasing attention from researchers and practitioners (Diener *et al*., 2011; Lalander *et al*., 2013) [5, 8].

Hermetia illucens is recognized for its ability to reduce waste volume significantly while simultaneously producing biomass that can be used as animal feed, contributing to a circular economy in agriculture (Surendra *et al*., 2016) [13].

Source: Unsplash/oktavianus mulyadi

Fig 1: Hermetia illucens (Black Soldier Fly)

This review provides a comprehensive analysis of the use of BSFL in composting swine manure. It explores the biological characteristics of *Hermetia illucens* that make it suitable for waste management, evaluates the efficiency and environmental impact of BSFL composting, and discusses the economic benefits of this approach. Additionally, BSFL composting has been shown to have a lower environmental impact compared to traditional methods, particularly in terms of reduced greenhouse gas emissions and pathogen load (Lalander *et al*., 2013) [8].

Source: Unsplash/James Tiono

Fig 2: Black Soldier Fly larvae composting swine manure

Managing waste for a global population of over 8.17 billion people is an ongoing challenge that requires international cooperation, technological innovation, and public engagement. As the population grows, so too does the urgency of developing sustainable waste management solutions that protect both the environment and public health.

Furthermore, the review addresses the challenges associated with BSFL composting and outlines future research directions needed to optimize this innovative method for broader agricultural applications.

2. Materials and Methods

Search Strategy

A comprehensive literature search was conducted across databases such as ResearchGate, PubMed, ScienceDirect, and Google Scholar for articles published between 2002 and 2022. Search terms included "black soldier fly", "composting", "swine manure", "frass" and "organic fertilizer." Boolean operators "AND" and "OR" were used to refine the search.

Inclusion and Exclusion Criteria

We included peer-reviewed studies that examine the physicochemical properties of black soldier fly frass generated from the bioconversion of swine manure. Additionally, studies discussing pathogen reduction and the environmental impacts of BSFL composting were considered (Awasthi *et al*., 2020) [2].

We excluded studies published in languages that the reviewers could not access or for which no reliable translation was available.

Selection Process

From an initial pool of 84 articles, titles and abstracts were screened by two independent reviewers. After exclusion, 14 full-text articles were selected for in-depth review. Discrepancies were resolved by consulting a third reviewer. This rigorous selection process mirrors methodologies used in systematic reviews, ensuring only high-quality research is included (Amrul *et al*., 2022) [1].

Collection and Preparation of Swine Manure

Fresh swine manure was collected from local pig farms. To ensure consistency and quality, contaminants such as plastics and large debris were removed. Depending on the initial moisture content, water or dry organic material was added to adjust the moisture content to an optimal range of 60-70% (Diener *et al*., 2011) [5].

Source: Unsplash/wirestock

Fig 3: Swine manure

Consistent with findings by Banks *et al*. (2021), proper preparation of manure is crucial for the efficiency of the composting process.

Table 1: Optimal Conditions for BSFL Composting

Optimal Conditions for BSFL Composting	
Parameter	**Optimal range**
Temperature	25-35°C
Moisture Content	60-70%
Larval Density	5,000 - 10,000 larvae/m²
Manure Thickness	2-3 cm per layer

Selection and Preparation of the Composting Site

A well-ventilated area is needed, ideally shaded to avoid direct sunlight, which can raise temperatures to levels harmful to the larvae. Setting up adequate containers or bins for the composting process is essential. These should have a mesh bottom to allow drainage and prevent the accumulation of excess liquid. The bins should also be designed to prevent the larvae from escaping while allowing sufficient airflow. According to Nguyen *et al*. (2020) [9], maintaining proper ventilation is essential to prevent anaerobic conditions and ensure optimal larval activity.

Introduction of Black Soldier Fly Larvae

The black soldier fly, *Hermetia illucens*, a non-pest insect native to tropical and warm-temperate regions, valuable for its ability to manage large amounts of animal manure and other biosolids. Adult BSFs are approximately 15-20 mm in length, with a black body and metallic blue-green sheen on the thorax. Their wings are membranous and usually held flat over the abdomen when at rest, giving the adult a wasp-like appearance, which deters predators (Sheppard *et al*., 2002) [12]. Studies by Gold *et al*. (2021) suggest that maintaining appropriate larval density is key to maximizing bioconversion efficiency.

BSFL are introduced into the prepared pig manure. The recommended density of larvae varies but typically ranges from 5000 to 10000. At this density they can process approximately 2 to 4 kilograms of fresh pig manure per square meter per day (Diener *et al*., 2011) [5].

Source: IStock/Jaka Suryanta

Fig 4: Larvae of Hermetia illucens

The manure should be spread in thin layers to allow the larvae to feed effectively. The larvae will begin feeding on the manure, breaking it down and converting it into biomass and frass.

Monitoring and Maintaining Optimal Conditions Is important to maintain the composting environment at an optimal temperature range of 25-35°C. Lower temperatures may slow down the process, while excessively high temperatures can harm the larvae (Lalander *et al*., 2019). The optimal moisture level is at around 60-70%. If the manure becomes too dry, water or a moisture source should be added. Conversely, if it is too wet, mixed dry material and drainage should be increased. The manure should be regularly turn or aerate to ensure even distribution of larvae and prevent anaerobic conditions, which can slow down the composting process and produce unpleasant odours. Regular monitoring ensures that conditions remain within the optimal range, as highlighted by Diener *et al*. (2011) [5].

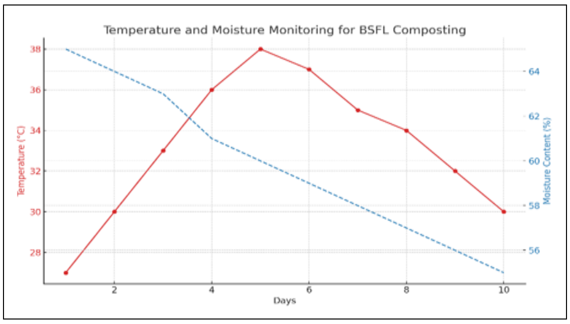

Fig 5: Temperature and Moisture Monitoring for BSFL Composting

Harvesting of Larvae

The larvae are usually ready for harvesting 14-28 days after introduction, depending on environmental conditions and manure composition. Harvesting is typically done when the larvae reach the prepupal stage, indicated by a change in colour from white to dark brown (Sheppard *et al*., 2002) [12]. A sieve or a mechanical separator should be used to separate the larvae from the residual frass. The larvae can then be processed into animal feed or other products, while the frass can be used as a fertilizer.

Processing of By-products

The harvested larvae can be dried, ground, or otherwise processed into high-protein animal feed. Alternatively, they can be used in aquaculture or as feed for poultry and livestock (Barragán-Fonseca *et al*., 2017) [3].

Source: Freepik

Fig 6: Frass

The frass, which is rich in nutrients, can be used as an organic fertilizer for crops. The physiochemical characteristics of BSFL frass can vary depending on the substrate used for rearing the larvae, but it generally exhibits certain consistent properties. It can also be further composted or processed depending on the specific requirements of the end use.

Monitoring and Quality Control

Cleaning the containers or bins after each composting cycle is essential to prevent the build-up of residues and to reduce the risk of disease. Any uneaten manure or larval residues can be mixed with new manure for the next composting cycle, ensuring efficient resource utilization. Depending on the intended use of the frass and larvae, it may be necessary to test for pathogens to ensure safety, particularly if the products are used in food production or agriculture (Lalander *et al*., 2013) [8]. Regularly checks in quality of the larvae and frass production lead to consistency in nutrient content and safety standards.

Pathogens in Manure

Swine manure can contain a variety of pathogens, including bacteria (such as E. coli and Salmonella), parasites and viruses. The presence of these pathogens poses a risk to human health if the manure is applied to crops consumed by humans or if it contaminates water sources (Hutchison *et al*., 2005) [7]. Ensuring that the manure is adequately treated before application is essential to mitigate these risks.

Biosecurity Issues

The use of pig manure in agriculture can also raise biosecurity concerns, especially if the manure is moved between different farms or regions. This movement can facilitate the spread of diseases among pig populations, with potentially devastating effects on pig farming operations (Goss *et al*., 2013) [6].

BSF larva addition was significantly reduce *Bacillus* and *Enterococus* genus. Black soldier fly amendment reduces 86–88% of PB abundance in pig manure and sewage sludge (Awasthi *et al*. 2020) [2].

Scaling and Optimization

If the process is to be applied at a larger scale, additional infrastructure, such as automated feeding systems and environmental control systems, may be required to maintain optimal conditions. Continues optimization of the process by experimenting with different feeding rates, larval densities, and environmental conditions led to maximize efficiency and product quality (Diener *et al*., 2011) [5].

3. Results and Discussion

Swine manure provides all 13 essential nutrients required by plants. This includes nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), manganese (Mn), copper (Cu), zinc (Zn), chlorine (Cl), boron (B), iron (Fe), and last but not least molybdenum (Mo). So is important to manage a compost operation to harness those nutrients and reintroduce them into agricultural practices.

3.1 Results

Volume and Weight Reduction

The use of *Hermetia illucens* larvae in composting swine manure has demonstrated significant reductions in both the volume and weight of the manure. Studies show a reduction of up to 50-60% in manure volume after larval treatment, largely due to the efficient conversion of organic matter into larval biomass (Amrul *et al*. 2022) [1]. This process not only reduces the waste but also minimizes the need for additional waste management practices. (Purkayastha *et al*. 2022) [11].

Table 2: Volume and Weight Reduction in BSFL Composting

Study	Volume Reduction	Weight Reduction
Amrul et al. (2022)	60%	55%
Purkayastha et al. (2022)	80%	70%

Larval Biomass Yield

The larvae converted approximately 15-20% of the dry weight of manure into biomass, which is rich in proteins and fats. This biomass can be utilized as high-quality animal feed, supporting the circular economy by recycling waste into valuable resources (Barragán-Fonseca *et al*., 2017) [3]. The protein content in BSFL biomass has been shown to be comparable to traditional feed sources, making it a viable alternative for livestock and aquaculture (Gold *et al*., 2021).

Nutrient Content

The residue left after larval composting is rich in essential nutrients like NPK, which are crucial for soil fertility. The nitrogen concentration tends to increase, although the total nitrogen content decreases due to the reduction in overall mass (Purkayastha *et al*. 2022) [11].

C:N Ratio Improvement

The carbon-to-nitrogen (C:N) ratio of the compost is significantly reduced, making the compost more suitable as a soil amendment. This is beneficial for enhancing soil health and promoting sustainable agricultural practices (Amrul *et al*. 2022) [1].

Pathogen Load Reduction

BSFL composting significantly reduced the pathogen load in swine manure. Studies reported reductions of 86-88% in harmful microorganisms like E. coli and Salmonella, enhancing the compost's safety for agricultural use (Awasthi *et al*., 2020) [2]. This pathogen reduction is crucial for preventing the spread of diseases in farming environments.

Environmental Benefits

Compared to traditional composting methods, BSFL composting reduced greenhouse gas emissions, particularly methane and ammonia. The process also minimized odour, making it suitable for areas close to human habitation (Amrul *et al*., 2022) [1]. These findings align with the work of Nguyen *et al*. (2020) [9], who reported similar environmental benefits, making BSFL composting an attractive option for sustainable waste management.

3.2 Discussions

Efficiency and Practical Application

The ability of *Hermetia illucens* larvae to rapidly decompose swine manure and reduce waste volume makes it an efficient alternative to traditional composting methods. The dual benefit of reducing waste while producing valuable by-products such as larvae biomass adds economic value, potentially making the process more attractive to large-scale swine producers.

Operational Considerations

Practical challenges, such as maintaining optimal environmental conditions (e.g., temperature, moisture) for larval growth, are crucial for maximizing composting efficiency. These factors need careful management to ensure the success of the composting process.

Environmental and Health Considerations

The reduction in pathogen load and greenhouse gas emissions underscores the environmental and health benefits of this composting method. By producing a nutrient-rich, pathogen-free compost, the process supports sustainable agriculture and reduces the potential environmental impact of swine manure disposal.

Future Prospects and Research Needs

Continued research is necessary to optimize the process for different types of organic waste, improve the economic feasibility of large-scale operations, and explore the full potential of *H. illucens* larvae in waste management. Investigating the larvae's interactions with different manure types and their long-term effects on soil health will be essential for advancing this technology.

4. Conclusions

The use of Hermetia illucens larvae for composting swine manure represents a promising and sustainable waste management approach. The larvae effectively reduce the volume and weight of swine manure by 50% to 80%, converting it into valuable by-products such as protein-rich biomass and nutrient-dense compost (frass). This method not only decreases waste but also enhances the environmental safety of the manure by significantly reducing pathogen loads and greenhouse gas emissions.

The process offers economic benefits through the production of larvae that can be used in animal feed and the generation of high-quality compost suitable for agricultural applications. However, successful implementation requires careful management of environmental conditions, such as temperature and moisture, to optimize larval growth and composting efficiency.

Overall, while challenges remain, particularly in scaling up the process, Black Soldier Fly Larvae offer a viable solution to the environmental and logistical issues associated with swine manure management, contributing to more sustainable agricultural practices.

These conclusions summarize the key findings and considerations for using black soldier fly larvae in swine manure composting, emphasizing its efficiency, safety, environmental benefits, and economic potential while also acknowledging areas for future research and development.

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