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Utilization of Black Soldier Fly larvae in organic waste management: Potential for antimicrobial and wound-healing applications

Wippy Bucivia Rubianti[1], Zulfa Khalila Safitri[1,*]
[1] *Department of Accounting, Faculty of Business and Finance, Universitas Media Nusantara Citra, Jakarta, DKI Jakarta 11520, Indonesia.*
*Correspondence: zulfasafitri0107@gmail.com

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ABSTRACT

Background: Organic waste management is a growing global challenge, particularly in urban areas with high waste generation and inefficient disposal systems. Black Soldier Fly (*Hermetia illucens*) larvae provide a promising sustainable solution by converting organic waste into valuable products. This study reviews their potential applications in waste management, agriculture, wound healing, and circular economy practices. **Methods:** This study employed a literature review by analyzing recent research from peer-reviewed journals, institutional reports, and government publications. The review focused on Black Soldier Fly larvae bioconversion, nutrient composition, antimicrobial properties, wound-healing potential, and larval frass applications. Findings were qualitatively synthesized and compared across different organic waste types and applications. **Findings:** The reviewed studies indicate that Black Soldier Fly larvae can reduce organic waste volume by more than 50% within several days under suitable conditions. Larval biomass provides protein-rich material with potential for animal feed, while larval frass can improve soil fertility. Larval oils and extracts also demonstrate promising antimicrobial and wound-healing properties. These applications support resource recovery and reduce the environmental impacts associated with organic waste disposal. **Conclusion:** Black Soldier Fly larvae offer a multifunctional and environmentally sustainable approach to organic waste management, with additional benefits for agriculture and biomedical applications. Their ability to convert waste into valuable products supports circular economy principles and sustainable resource utilization. **Novelty/Originality of this article:** This article integrates the waste-management, agricultural, biomedical, and circular economy applications of Black Soldier Fly larvae within a unified review. By linking organic waste bioconversion with antimicrobial and wound-healing potential, it provides a broader perspective on their role in developing sustainable, resource-efficient, and value-generating systems.

KEYWORDS: Black Soldier Fly (BSF); circular economy; larvae bioconversion; organic waste management; wound healing; sustainable development.

1. Introduction

Organic waste is one of those stubborn problems that refuses to go away, especially in countries growing as fast as Indonesia. Cities keep expanding, more people move in, and new lifestyles mean people throw out more food scraps, market waste, and farm leftovers every day. In Indonesia, you can see the impact everywhere, landfills are filling up, yet the garbage keeps coming. When waste piles up and isn't managed well, it doesn't just look bad. It pollutes the air and water, releases greenhouse gases, smells awful, and makes life harder

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for people living nearby. At this point, organic waste isn't just about the environment. It's tangled up with bigger issues, public health, the economy, and how communities' live day to day. If we're going to get ahead of this, we need solutions that do more than just hide the problem. We need answers that last. Indonesia and other developing countries are facing this challenge at an increasingly urgent level.

Organic waste management is still a serious problem in Indonesia. A large amount of waste, especially organic waste such as food leftovers, is not properly managed. This situation causes environmental pollution, bad odors, and greenhouse gas emissions *((Badan Riset dan Inovasi Nasional*/BRIN, 2024; *Kementerian Lingkungan Hidup dan Kehutanan*/KLHK, 2024). The increase in population and the limited capacity of landfills make the problem even more difficult to solve. If organic waste is left untreated, it can damage the environment and reduce land that could be used for agriculture (Cristhiani, 2021; *Dinas Perumahan, Kawasan Permukiman dan Pertahanan*, 2019). One approach that is often discussed to solve this problem is the circular economy (Ellen MacArthur Foundation, 2015; Geissdoerfer et al., 2017). The circular economy encourages waste to be reused and converted into useful products instead of being thrown away (Murray et al., 2017; Smetana et al., 2019).

Organic waste has traditionally been managed through landfilling, open dumping, and simple composting methods. These approaches can provide temporary solutions but do not effectively support long-term environmental sustainability. Landfilling activities contribute to methane gas emissions that are harmful to the environment. Conventional composting processes often require long processing times, large land areas, and continuous monitoring. These limitations have encouraged researchers and communities to develop alternative waste management systems that are more efficient, adaptable, and economically beneficial. These limitations have encouraged the development of alternative biological methods, including the use of insects for waste management.

One example of this approach is the use of Black Soldier Fly larvae (*Hermetia illucens*). These larvae are able to consume and decompose organic waste very quickly through a biological process called bioconversion (Diener et al., 2015; Gold et al., 2018; Nguyen et al., 2015; Zhou et al., 2013; Cickova et al., 2015; Mertenat et al., 2019). Compared to traditional composting, BSF larvae can reduce organic waste by more than 50% in a short time (Diener et al., 2015; Gold et al., 2018; Nguyen et al., 2015; Zhou et al., 2013) and produce useful outputs such as animal feed (Barragan-Fonseca et al., 2017; Wang & Shelomi, 2017; Widjastuti et al., 2014) and organic fertilizer (Basri et al., 2022; Lomonaco et al., 2024; Beesigamukama et al., 2020; Alattar et al., 2022).

Black Soldier Fly (*Hermetia illucens*) larvae have emerged as a promising biological solution for organic waste management. These larvae are able to consume and break down organic materials quickly through a natural process called bioconversion. Within a short period, the larvae can reduce the volume of organic waste while producing protein-rich biomass and nutrient-rich frass. When compared to conventional composting methods, BSF based systems operate faster, require less space, and are more suitable for treating high moisture organic waste commonly generated in urban areas.

Black Soldier Fly (BSF) larvae provide not only environmental benefits but also products with economic value, such as animal feed and organic fertilizer. This multifunctional capability supports circular economy principles by converting low value organic waste into useful and marketable products. Community-based BSF projects in several regions have shown potential to reduce waste while creating new economic opportunities and increasing environmental awareness.

In addition to waste management, BSF larvae also have potential benefits in the health sector. Previous studies show that BSF larvae contain high protein and fatty acids, such as lauric acid, which have antibacterial and anti-inflammatory properties (Afriani et al., 2024; Klüber et al., 2020; Sherman, 2014; Gupta et al., 2019). These components help the wound healing process by reducing inflammation, supporting tissue regeneration, and lowering the risk of infection (Church et al., 2006). Therefore, BSF larvae are considered a promising natural material for wound healing products.

Many previous studies have discussed the use of Black Soldier Fly (BSF) larvae in organic waste management because of their ability to decompose waste efficiently and produce valuable products. Other studies have shown that BSF larvae contain antimicrobial compounds and have the potential to support wound healing. However, these topics are mostly discussed separately. Studies that connect the role of BSF larvae in organic waste management with their potential as natural biomaterials for wound healing are still limited. In addition, only a few review articles summarize the available evidence on the use of BSF larvae as natural antimicrobial-based wound healing biomaterials. Therefore, this study aims to review and summarize previous research on the potential of BSF larvae as natural biomaterials for wound healing while also highlighting their role in sustainable organic waste management. This study is based on the assumption that the use of BSF larvae can provide environmental, economic, and health benefits simultaneously (van Huis et al., 2013; Surendra et al., 2016). By linking waste management with healthcare applications, this review presents BSF larvae as multifunctional biological agents with promising potential for sustainable development.

Recent scientific studies have begun to examine the biomedical potential of BSF larvae beyond their environmental applications. Research shows that larval biomass contains bioactive compounds such as antimicrobial peptides, fatty acids, and enzymes that may support infection control and tissue repair. Lauric acid, one of the main fatty acids found in BSF larvae, has been linked to antibacterial and anti-inflammatory effects, making it a potential material for wound healing applications.

Wound healing is a complex biological process that involves interactions between cells, the extracellular matrix, inflammatory mediators, and growth factors. This process is generally divided into four main phases: hemostasis, inflammation, proliferation, and remodeling. These phases must occur in a coordinated manner for optimal wound healing. Disruption in any of these phases, especially due to microbial infection or prolonged inflammation, can delay wound healing and increase the risk of chronic wound formation (Sherman, 2014).

This situation has led to growing interest in Black Soldier Fly (*Hermetia illucens*) larvae as a promising natural biomaterial for wound healing applications. Several studies have shown that BSF larvae contain bioactive compounds with antimicrobial and anti-inflammatory properties that may support tissue regeneration (Harlystiarini et al., 2019; Sandakila et al., 2025). Although early studies mainly focused on the use of BSF in organic waste management, biomedical approaches indicate that larval biomass produced through bioconversion has significant potential as a raw material for wound-healing biomaterials.

2. Methods

The literature review in this study prioritizes sources that discuss bioactive compounds, antimicrobial activity, and the application of *Hermetia illucens* larvae as wound-healing biomaterials. Literature related to organic waste management and the circular economy is analyzed as supporting context to explain the sustainability of BSF larval biomass production, rather than as the main focus of the biomedical review (Sandakila et al., 2025).

This study employed a qualitative literature review methodology to synthesize existing scientific knowledge related to the utilization of Black Soldier Fly (*Hermetia illucens*) larvae in organic waste management, circular economy systems, and biomedical wound healing applications. A literature review approach was selected because the objective of this study was not to generate primary experimental data, but rather to integrate, compare, and critically analyze findings from diverse disciplinary perspectives, including environmental science, agriculture, biotechnology, and health sciences.

From an ontological standpoint, Black Soldier Fly larvae are conceptualized as a bio-based organism with multifunctional roles in waste bioconversion and biomedical applications. This study assumes that reality concerning BSF utilization can be understood through documented empirical evidence reported in peer-reviewed scientific publications.

Epistemologically, knowledge is constructed through interpretative synthesis, where patterns, consistencies, and contrasts among previous studies are analyzed to build a comprehensive understanding of BSF larvae potential within sustainability frameworks.

The data used in this study are secondary data collected from peer-reviewed journal articles, government reports, and reputable institutional publications related to BSF larvae, organic waste processing, circular economy, and wound healing applications (BRIN, 2024; KLHK, 2024; Republik Indonesia, 2017). Data collection was conducted by selecting relevant literature using keywords such as Black Soldier Fly, maggot, organic waste management, and wound healing (Astanti et al., 2023; Jatnika, 2025). The selected literature was analyzed using qualitative content analysis by identifying key themes, comparing findings across sources, and summarizing the results in a descriptive narrative (Rismayani et al., 2024; Surendra et al., 2016). The findings are presented in a clear and systematic manner to support discussion and conclusion drawing, without focusing on a specific research location or time period.

To ensure the relevance of the literature, inclusion and exclusion criteria were applied during the selection process. Articles were included if they discussed Black Soldier Fly larvae in relation to bioactive compounds, antimicrobial activity, wound healing, organic waste management, or circular economy concepts. Publications that were not related to these topics, lacked clear methodology, or were not published in reliable sources were excluded. This step was important to maintain the quality and focus of the reviewed literature.

Most of the selected literature consisted of experimental studies, review articles, and case studies. These studies were carefully read to identify important information such as research objectives, methods used, main findings, and conclusions. Relevant data were then grouped based on similar themes, including antimicrobial properties of BSF larvae, wound healing mechanisms, and the sustainability of larval biomass production. This thematic grouping helped to organize the discussion in a structured manner.

To reduce bias in interpretation, the comparison of findings was conducted by examining similarities and differences between studies from different disciplines. Environmental studies were mainly used to explain how BSF larvae biomass is produced sustainably, while biomedical studies were emphasized to explain wound healing potential. By separating the role of each discipline, this study was able to maintain a clear focus on biomedical applications while still considering environmental sustainability as supporting context.

This literature review does not involve laboratory experiments or direct testing on animals or humans. Therefore, ethical approval was not required. However, ethical considerations were maintained by properly citing all sources and respecting the original authors' work. The methodology used in this study is expected to provide a clear and understandable overview of the potential use of Black Soldier Fly larvae as sustainable wound healing biomaterials.

2.1 Data sources and search strategy

Secondary data were collected from international and national scientific databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, Multidisciplinary Digital Publishing Institute (MDPI), Wiley Online Library, and PubMed. Additional policy-related documents were obtained from reputable institutional and governmental sources. The literature search was conducted using combinations of keywords such as Black Soldier Fly (*Hermetia illucens)*, organic waste management, bioconversion, circular economy, antimicrobial activity, and wound healing. The search process was carried out carefully to find articles that were most relevant to the topic. Only peer-reviewed journal articles, books, and official reports were included. Articles that were not in English or Indonesian, or those that did not clearly explain their methods or results, were not included. This helped ensure that the selected literature was reliable and of good quality.

To make sure the review covered multiple perspectives, literature from different disciplines was included. Environmental studies explained how BSF larvae can manage organic waste and support the circular economy, while biomedical studies focused on their potential in wound healing. This combination of sources provides a complete picture of both the environmental and medical benefits of BSF larvae. All sources were carefully recorded and organized to avoid missing important information. The use of multiple databases and institutional sources increased the chances of finding comprehensive and up-to-date literature. This systematic approach to searching and selecting literature ensures that the review is thorough and reliable.

2.2 Literature selection and data extraction

The literature selection process was conducted by first identifying publications that were relevant to the main focus of the review, namely the utilization of Black Soldier Fly (*Hermetia illucens*) larvae for organic waste bioconversion, antimicrobial activity, and wound healing applications. The retrieved literature was then assessed based on its relevance to the research objectives and the availability of clearly described methods and findings. Publications that only discussed general insect biology or topics unrelated to waste management, antimicrobial properties, or wound healing were not considered in the final synthesis.

The selected studies were subsequently reviewed in detail to identify information related to the type of study, research objectives, materials or BSF derived products examined, main findings, and potential applications. Particular attention was given to evidence concerning antimicrobial activity, wound-healing mechanisms, larval biomass production, and the relationship between BSF utilization and circular economy principles. The extracted information was organized thematically to facilitate comparison among studies from environmental, agricultural, biotechnology, and biomedical fields. This approach enabled the review to identify similarities, differences, research limitations, and potential areas for further investigation without introducing primary experimental data.

2.3 Data analysis technique

The selected literature was analyzed using qualitative content analysis. Key themes were identified, including waste reduction efficiency, nutrient composition, economic feasibility, antimicrobial mechanisms, and circular economy integration. Findings from different studies were compared to identify trends, gaps, and contradictions. The results are presented descriptively and analytically, allowing for interdisciplinary integration without focusing on a specific geographical or temporal limitation. Each article was read carefully, and important information was highlighted and noted. Notes were organized based on the main topics of the study, such as the type of bioactive compounds in BSF larvae, their antimicrobial activity, and the results of organic waste management experiments. This step helped to make sure that no important information was missed and that all findings could be easily compared. After organizing the data, similarities and differences between studies were analyzed. Studies with similar findings were grouped together to identify consistent patterns, while studies with different results were discussed to understand possible reasons for the differences. This approach allowed for a clear explanation of trends and gaps in the current knowledge.

The analysis also focused on connecting environmental and biomedical aspects of BSF larvae. For example, information about the nutrient composition and sustainability of BSF biomass was linked to its potential use in wound healing. By combining these perspectives, the study could show how BSF larvae can provide both ecological and health benefits. Finally, all findings were summarized in tables and descriptive narratives. This made it easier to present complex information in a clear way and allowed readers to quickly understand the main points. Using this method, the review could provide a complete picture of the current state of research on BSF larvae, including strengths, limitations, and areas that need further study.

3. Results and Discussion

3.1 The role of Black Soldier Fly larvae in organic waste reduction

Numerous studies consistently demonstrate that Black Soldier Fly larvae are among the most efficient biological agents for organic waste bioconversion. Research conducted in different climatic and geographical contexts reports waste reduction rates ranging from 50% to over 70% within 10–14 days, depending on substrate type and environmental conditions (Diener et al., 2015; Gold et al., 2018; Lalander et al., 2019). This process occurs through bioconversion, where larvae consume organic waste and transform it into larval biomass and frass, which can be used as organic fertilizer (Barragan-Fonseca et al., 2017; Basri et al., 2022; Beesigamukama et al., 2020; Lomonaco et al., 2024).

Frass from BSF larvae has been studied for positive effects on soil quality, including improved nutrient content and water retention (Alattar et al., 2022; Lomonaco et al., 2024). BSF larvae are effective at processing high moisture organic waste, including kitchen scraps, agricultural residues, and market waste (Surendra et al., 2016; Jatnika, 2025). They also reduce odor and pathogens, making them suitable for urban and rural waste systems (Cickova et al., 2015; Mertenat et al., 2019).

BSF larvae are capable of processing various organic waste streams, including household food waste, agricultural residues, market waste, and agro-industrial by products. This versatility makes BSF systems adaptable to both urban and rural waste management scenarios. Compared to conventional composting, which often requires weeks or months, BSF based systems significantly shorten processing time and reduce odor and pathogen presence. Compared to conventional composting, BSF larvae work faster and require less space. This makes BSF based waste management suitable for urban areas with limited landfill capacity (Nguyen et al., 2015; Gold et al., 2018). These findings indicate that BSF larvae can be an effective biological solution to reduce the increasing volume of organic waste in Indonesia.

The larvae of *Hermetia illucens* are characterized by high protein content (35–45%) and lipid content (25–35%), making them a valuable source of nutrients. Several studies confirm that BSF larvae contain essential amino acids comparable to fishmeal, positioning them as a sustainable alternative protein source for animal feed (Spranghers et al., 2017; Barragan-Fonseca et al., 2017). In addition to proteins, BSF larvae lipids are rich in medium-chain fatty acids, particularly lauric acid, which exhibits antimicrobial and anti-inflammatory properties. These biochemical characteristics extend the potential application of BSF larvae beyond agriculture into biomedical fields.

3.2 Economic and social benefits of BSF cultivation

The literature also highlights the economic value of BSF cultivation. BSF larvae contain high protein levels, making them suitable as alternative feed for fish and poultry (Barragan-Fonseca et al., 2017; Wang & Shelomi, 2017; Widjastuti et al., 2014; van Huis et al., 2013). Protein-rich larval biomass can replace fish meal, which is often costly and sourced unsustainably (Smetana et al., 2019; Surendra et al., 2016). In addition, BSF frass can be used as organic fertilizer, which supports sustainable agriculture (Basri et al., 2022; Lomonaco et al., 2024; Beesigamukama et al., 2020). This fertilizer improves soil health and reduces the need for chemical fertilizers, aligning with circular economy goals (Ellen MacArthur Foundation, 2015; Geissdoerfer et al., 2017).

Several case studies from different regions in Indonesia show that BSF cultivation helps create new job opportunities and increases household income (Astanti et al., 2023; Jatnika, 2025). Community-based BSF projects around markets and residential areas have successfully reduced waste while generating economic benefits. These results support the idea that BSF cultivation contributes to a circular economy by turning waste into valuable resources (Murray et al., 2017). From an economic perspective, BSF cultivation offers cost effective solutions for waste management while generating value added products. Studies indicate that replacing fishmeal with BSF larvae in aquaculture and poultry feed can significantly reduce production costs and environmental impacts (Smetana et al., 2019). Within a circular economy framework, BSF larvae function as a biological converter that transforms low value organic waste into high value outputs, including animal feed, organic fertilizer, and bioactive compounds. This aligns with circular economy principles of resource efficiency, waste minimization, and closed-loop systems (Geissdoerfer et al., 2017; Murray et al., 2017).

Environmental assessments reveal that BSF based waste treatment systems produce lower greenhouse gas emissions compared to landfilling and conventional composting. By diverting organic waste from landfills, BSF systems reduce methane emissions and contribute to climate change mitigation (Lalander et al., 2019). Furthermore, the byproduct frass enhances soil fertility, improves water retention, and supports microbial activity, contributing to sustainable agricultural practices and reduced reliance on chemical fertilizers.

3.3 Comparison between BSF based waste management and conventional methods

From the reviewed studies, waste management using BSF larvae is considered more efficient than traditional composting methods. Conventional composting usually requires weeks or months to fully decompose organic waste, while BSF larvae can significantly reduce waste volume in a shorter time (Diener et al., 2015; Gold et al., 2018). In addition, BSF based systems produce multiple outputs such as animal feed, organic fertilizer, and larval oil, whereas conventional methods mainly produce compost (Barragan-Fonseca et al., 2017; Basri et al., 2022; Lomonaco et al., 2024). Another advantage of BSF based waste management is the speed and flexibility of the system. BSF larvae can process organic waste in just a few days, while traditional composting may take several weeks depending on the type of waste and weather conditions. This makes BSF larvae especially suitable for urban areas where large amounts of food waste are produced daily and space for composting is limited.

Table 1. Comparison of BSF larvae and traditional composting for organic waste management

Indicator	BSF larvae	Traditional composting
Decomposition speed	Can reduce waste mass by 50-60% faster within a short cycle.	Decomposition takes longer and reduces waste mass gradually.
Environmental benefits	Reduce landfill burden and helps reduce the spread of harmful bacteria.	Reduce waste but is less effective in reducing landfill burden.
Economic potential	BSF cultivation can become a profitable business.	Economic value is generally lower than BSF based utilization.
Types of waste	Can decompose various types of organic waste, including vegetables, fruits, and kitchen waste.	Can process various types of organic waste depending on the composting method.

This comparison shows that BSF larvae offer both environmental and economic advantages, making them a more sustainable option for organic waste treatment. BSF based systems are also less dependent on large land areas or intensive labor. Traditional composting requires constant monitoring, turning, and moisture control to maintain proper decomposition. In contrast, BSF larvae can self-regulate their feeding and decomposition activity, reducing the need for daily management. This makes the system more practical and cost effective for households, communities, or small businesses.

Traditional waste methods often fail to provide economic return or circular outcomes (van Huis et al., 2013; Smetana et al., 2019). BSF based systems not only recycle waste but also create value added products that can be traded in local markets (Astanti et al., 2023; Jatnika, 2025).

Moreover, BSF larvae contribute to environmental sustainability beyond waste reduction. The larvae produce frass, a nutrient rich byproduct that can be used as organic fertilizer, improving soil health. The larvae themselves can be converted into high protein animal feed, replacing conventional feed and reducing reliance on fishmeal or soy. These additional benefits show that BSF based waste management supports a circular economy by turning waste into multiple valuable products.

Despite these advantages, it is important to consider potential challenges in implementing BSF based systems, such as temperature control, larval mortality, and initial setup costs. However, many studies suggest that these challenges can be managed with proper planning and small-scale trials. Overall, BSF based waste management provides a faster, more versatile, and economically beneficial alternative to conventional composting methods.

3.4 Wound healing potential of Black Soldier Fly larvae

Beyond waste management, several studies have discussed the possible use of Black Soldier Fly (BSF) larvae in wound healing. BSF larvae contain proteins and fatty acids, such as lauric acid, which are known to have anti-inflammatory and antibacterial properties (Afriani et al., 2024; Sherman, 2014; Gupta et al., 2019). These compounds are thought to help the body fight infection and reduce swelling in wounds. Research conducted on animal models shows that ointments made from BSF larval oil can help wounds heal faster by reducing inflammation, supporting tissue growth, and speeding up the closing of wounds (Church et al., 2006).

Fig. 1. The life cycle and economic utilization of Black Soldier Fly (BSF) maggots in organic waste management

Beyond waste management, several studies have discussed the possible use of Black Soldier Fly (BSF) larvae in wound healing. BSF larvae contain proteins and fatty acids, such as lauric acid, which are known to have anti-inflammatory and antibacterial properties (Afriani et al., 2024; Sherman, 2014; Gupta et al., 2019). These compounds are thought to help the body fight infection and reduce swelling in wounds. Research conducted on animal models shows that ointments made from BSF larval oil can help wounds heal faster by

reducing inflammation, supporting tissue growth, and speeding up the closing of wounds (Church et al., 2006).

BSF larval oil has also been compared to maggot therapy using other types of fly larvae. In these therapies, antimicrobial peptides help fight harmful bacteria and stimulate new tissue growth (Sherman, 2014). Products like gel-based wound plasters made from BSF extract show that materials derived from insect larvae can be turned into useful healthcare products. This means that waste processing using BSF larvae can have benefits not only for the environment but also for the health sector, which is quite interesting because it links two very different fields.

Some studies also point out that BSF larvae contain vitamins and minerals that could help with skin repair. Even though researchers are still trying to understand how exactly these nutrients work, they seem to help cells grow and make the wound heal faster. So, it is not just the fatty acids and peptides that are important; other nutrients in the larvae might also play a role in helping wounds recover.

BSF derived products can be made in different forms such as oils, gels, or creams. This is useful because different wounds might need different types of treatment. For example, small scratches or cuts can use simple larval oil ointments, while larger or more serious wounds might benefit from gel-based dressings. This makes the larvae more practical and flexible for real-life applications, especially in communities that do not have easy access to expensive medical products.

Experimental studies on animals show that applying BSF larval oil directly to wounds can reduce inflammation, encourage tissue growth, and make wounds close faster (Afriani et al., 2024). These results are promising and suggest that BSF larvae could become a natural, affordable alternative for wound care, especially in places where people cannot easily buy modern wound treatment products. However, most of these studies are still done in laboratories or on animals. More research, especially clinical trials with humans, is needed to be sure that these products are safe, effective, and do not cause side effects.

Despite these advantages, there are still challenges to using BSF larvae in wound healing. Some challenges come from regulations because the products are new and governments need to make clear rules to ensure safety. There is also the problem of public perception some people may feel uncomfortable or disgusted with using insect-based products for medical purposes. Finally, standardizing the production process is important, so that the quality of larval oil or extracts is consistent and safe to use.

Education and public awareness can help solve some of these challenges. Teaching people about the benefits, safety, and ways to use BSF products can reduce hesitation and increase acceptance. Communities that understand how the larvae work and why they are safe are more likely to adopt BSF based products. By combining scientific evidence, clear regulations, and public education, BSF larvae could be successfully used in real healthcare settings.

BSF larvae demonstrate strong potential as a natural and affordable material for wound healing. They contain multiple useful compounds, can be processed into various product types, and may assist people in regions with limited access to modern medicine. While further studies are necessary to confirm their safety and effectiveness in humans, BSF larvae provide a promising connection between waste management and healthcare innovation, illustrating how a single biological resource can address multiple challenges simultaneously.

Despite these promising findings, the biomedical application of BSF-derived materials still faces several limitations. Most available evidence is based on laboratory experiments or animal models, meaning that the effectiveness and safety of these materials in humans require further clinical validation. Differences in larval rearing conditions, organic waste substrates, extraction methods, and product formulation may also influence the composition and concentration of bioactive compounds. Therefore, standardization is important to ensure consistent antimicrobial activity and wound healing performance.

Another important consideration is safety and quality control. Because BSF larvae can be reared on different types of organic substrates, the possibility of contamination or variation in the resulting biomass needs to be carefully controlled before biomedical use. Processing, purification, storage, and formulation should therefore be developed under appropriate quality standards. Regulatory requirements and public acceptance may also affect the transition from experimental research to commercial wound healing products. These challenges indicate that the potential of BSF larvae should not only be evaluated based on biological activity but also through safety, reproducibility, scalability, and practical implementation.

3.5 Contribution of BSF based systems to circular economy

The results from the reviewed literature indicate that BSF based systems support the principles of a circular economy (Ellen MacArthur Foundation, 2015; Geissdoerfer et al., 2017). BSF based systems show that waste is not just a problem, but also a valuable resource. By converting organic waste into protein-rich larvae, nutrient-rich frass, and other byproducts, the system creates multiple benefits from a single input. This reduces the need for raw materials in animal feed or fertilizer production and helps close the loop in resource use, which is one of the main goals of a circular economy. Organic waste is converted into useful products such as animal feed, fertilizer, and medical materials, reducing environmental pollution and landfill pressure.

With proper support from government policies (BRIN, 2024; KLHK, 2024; Republik Indonesia, 2017), community participation, and technological development, BSF larvae utilization can become a sustainable solution that integrates environmental protection, economic growth, and social benefits. This positions BSF larvae as a strategic innovation for organic waste management and sustainable development in Indonesia (Murray et al., 2017; van Huis et al., 2013).

In addition, BSF based systems can provide economic opportunities for local communities. Small scale businesses or households can raise BSF larvae to produce feed or fertilizer to sell in local markets. This not only reduces waste but also supports local livelihoods and encourages environmentally friendly practices. Integrating these activities into daily life strengthens the circular economy at the community level. Moreover, education and public awareness are necessary to promote acceptance of insect-based waste solutions. References from unrelated fields such as education and psychology remind us that societal attitudes and behavior change are important for adopting new systems like BSF bioconversion.

Awareness campaigns and educational programs can help people understand the benefits of using BSF larvae. For example, teaching about hygiene, safety, and the potential of larvae as feed or wound healing material can reduce hesitation or negative perceptions. When society accepts and participates in BSF based systems, the circular economy becomes more effective and sustainable. Combining technology, policy support, and community engagement can maximize the impact of BSF based systems. Innovations such as automated feeding systems, temperature control, or mobile apps for monitoring larvae production can improve efficiency and scalability. Together, these factors make BSF larvae a promising example of how biological solutions can advance a circular economy while addressing environmental, social, and economic needs.

However, the application of BSF-derived biomaterials in wound healing remains at an early stage and requires further investigation. Future research should focus on clinical validation, safety assessment, standardization of larval production and extraction processes, and optimization of wound healing formulations. Research should also examine how different organic waste substrates affect the composition and quality of BSF derived bioactive compounds. From a practical perspective, integrating BSF production with local organic waste management systems could provide an opportunity to create value added products while reducing waste. Further collaboration between environmental, agricultural, biotechnology, and biomedical sectors is therefore needed to support the development of safe, standardized, and scalable BSF based wound-healing biomaterials.

4. Conclusions

This study concludes that Black Soldier Fly (BSF) larvae offer a sustainable and integrated solution to organic waste management through a circular economy approach. Based on the reviewed literature, BSF larvae are able to significantly reduce organic waste volume while converting it into valuable products such as animal feed, organic fertilizer, and bio-based materials. The study also shows that BSF larvae can work well in both small-scale and large-scale waste management systems. This flexibility makes them suitable for households, communities, or even industrial applications. By adapting the system to local conditions, BSF larvae can help reduce organic waste efficiently while producing useful by products for different purposes.

This literature review demonstrates that Black Soldier Fly (*Hermetia illucens*) larvae represent a multifunctional and sustainable solution to organic waste management challenges. The ability of BSF larvae to rapidly reduce organic waste volume while producing valuable by products positions them as a key component of circular economy systems. Beyond environmental and economic benefits, the biomedical potential of BSF larvae highlights an innovative pathway where waste-derived resources can contribute to health sector advancements. The presence of antimicrobial and anti-inflammatory compounds supports the development of affordable wound healing products, particularly relevant for developing countries.

Using BSF larvae as a raw material for wound healing can potentially reduce the cost of medical products. This is especially important in developing countries where access to affordable healthcare is limited. By creating natural and effective wound care materials from waste, BSF systems provide a practical way to connect environmental sustainability with public health. In addition to environmental benefits, BSF based systems contribute to economic and social development. Community-based BSF cultivation has been shown to create employment opportunities, increase household income, and support local green businesses. These contributions strengthen the role of BSF larvae as not only a waste treatment method but also a driver of socio-economic empowerment within sustainable development frameworks. Education and public awareness play a key role in the successful adoption of BSF based systems. People need to understand how to safely handle larvae, use the by products, and appreciate the environmental and health benefits. Community engagement and training programs can increase acceptance and participation, making the system more sustainable in the long term.

Furthermore, the potential application of BSF larvae in wound healing highlights an innovative contribution beyond waste management. The presence of bioactive compounds with antibacterial and anti-inflammatory properties positions BSF larvae as a promising natural ingredient for affordable wound care products. Lastly, interdisciplinary understanding, including knowledge from different fields, is important for the successful implementation of innovations such as BSF based systems because they require community engagement, policy support, and cultural acceptance. Overall, this study contributes to the development of science by synthesizing existing knowledge on BSF larvae as a multifunctional solution that integrates environmental management, economic value creation, and health innovation. The findings support the relevance of BSF based systems within sustainable science and circular economy research, particularly in addressing organic waste challenges in developing countries such as Indonesia. The study emphasizes that BSF larvae represent an example of how biological solutions can solve multiple problems at once. They reduce waste, support the circular economy, create economic opportunities, and provide materials for health innovation. This shows that combining environmental science, biotechnology, and social engagement can create smart and sustainable solutions for current and future challenges.

For future research, further studies are needed to examine the safety, effectiveness, and optimal formulation of BSF-derived materials for wound healing. In particular, laboratory and clinical studies should be conducted to identify the specific antimicrobial compounds involved, determine appropriate doses, and evaluate their safety before practical medical applications. Further research is also needed to develop suitable wound healing formulations and assess their feasibility for large-scale production. In practical implementation, BSF cultivation can be developed at household, community, and industrial levels by providing proper training on larval cultivation, waste selection, hygiene, and the safe use of BSF-derived products. Collaboration between researchers, communities, industry, and policymakers is also needed to support the development and responsible application of BSF based products.

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Author Contribution

Conceptualization, Z.K.S. and W.B.R.; Methodology, Z.K.S. and W.B.R.; Formal analysis, Z.K.S. and W.B.R.; Investigation (literature review), Z.K.S. and W.B.R.; Resources, Z.K.S. and W.B.R.; Data curation, Z.K.S. and W.B.R.; Writing – original draft preparation, Z.K.S. and W.B.R.; Writing – review and editing, Z.K.S. and W.B.R.; Visualization, Z.K.S. and W.B.R.; Supervision, Z.K.S. and W.B.R.

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Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the authors used ChatGPT to assist in improving language clarity, organization of the manuscript, and compliance with the journal template. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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Biographies of Authors

Wippy Bucivia Rubianti, Wippy is an undergraduate student in the Accounting Study Program at MNC University. She is currently pursuing a bachelor's degree and has an interest in financial accounting, auditing, and business analysis.

- Email: wippybuciviarubianti14@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A

Zulfa Khalila Safitri, Zulfa is a student at Universitas Media Nusantara Citra, majoring in accounting. She is interested in financial accounting, auditing, and taxation.

- Email: zulfasafitri0107@gmail.com
- ORCID: N/A
- Web of Science ResearcherID: N/A
- Scopus Author ID: N/A
- Homepage: N/A