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Systematic Literature Review on the Design and Prototype Testing of a Compact, Low-Cost, and Tropical Climate-Resilient Household Black Soldier Fly Larvae Cultivation System for Organic Waste Reduction at Source

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ABSTRACT

The increasing volume of household organic waste in urban areas is a major challenge for sustainable environmental management, particularly in tropical regions with high temperatures and humidity. Black soldier fly larvae (BSFL) bioconversion offers an effective and sustainable solution by reducing organic waste while producing high-protein biomass. However, household adoption remains limited due to the lack of compact, affordable, and climate-appropriate cultivation systems. This study aims to identify and synthesize key design principles for a household-scale BSFL cultivation prototype optimized for humid and high-temperature tropical environments. A Systematic Literature Review was conducted to examine studies on bioconversion efficiency, environmental parameters, and system design characteristics. The findings highlight three main priorities: (1) the use of locally available low-cost materials to improve affordability and scalability; (2) an effective passive aeration system to control humidity and prevent mold growth; and (3) adequate thermal insulation to maintain stable internal temperatures. Based on the synthesized evidence, the proposed prototype is expected to achieve at least 50% organic waste reduction within 7–10 days, with a daily processing capacity of 1–3 kg. These findings provide practical guidance for accessible and sustainable BSFL-based waste management solutions in tropical urban settings.

Keywords: BSFL; Household Organic Waste; Maggot Cultivation System; Organic Waste Bioconversion; Sustainable Waste Management; Tropical Climate

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INTRODUCTION

In this modern era, energy needs continue to increase exponentially along with population growth, industrialization, and urbanization. Many countries are still heavily reliant on fossil fuels, which are not only non-renewable resources but also the main cause of carbon emissions that exacerbate climate change. On the other hand, urban organic waste management is a significant environmental burden, as organic waste in landfills produces greenhouse gases (methane), odors, water pollution, and public health risks. To overcome this crisis, renewable energy is an important choice. Bioenergy, energy obtained from biomass, is a promising alternative. Biofuels such as biodiesel, biogas, and non-food vegetable oils have the potential to reduce dependence on diesel and other fossil fuels and substantially reduce carbon emissions. Municipal organic waste, food waste, market waste, and kitchen waste are often disposed of without utilization, or by methods such as landfill and incineration that damage the environment. Organic waste has carbon content and stored energy that can be converted into value-added products such as biofertilizer, biofuel, or compost. One of the approaches that is increasingly being researched is the bioconversion of organic waste using maggot larvae (Hermetia illucens, Black Soldier Fly larvae/BSFL) (Leong et al., 2021).

BSFL have a high ability to decompose organic matter because they can consume large amounts of organic waste, accelerate degradation, reduce waste volume, and produce biomass rich in lipids and proteins. This biomass can be further processed for various products, one of which is maggot oil, which has the potential to be used as biodiesel or green diesel. In addition, non-lipid residues or fractions can be used as organic fertilizers or animal feed. Research showed that pre-pupae BSF fed with food waste and fruit waste can produce biodiesel with a FAME yield of up to ~94-96% under optimal conditions (Leong et al., 2021). In another study, Mohan et al. (2023) reviewed the factors that affect biodiesel production from BSF, such as feed type, lipid extraction method, and transesterification conditions.

At the local level, the study by Warmadewa (2025) examines how maggot cultivation (BSF) can effectively manage organic waste in Bali, reducing waste volume and providing economic value. In addition, Sukowati et al. (2021) provide an idea that BSFL can be used not only as a source of biodiesel, but also as a by-product, such as chitosan. The key to success in the production of maggot oil as a renewable energy source lies in the efficiency of lipid extraction methods and optimization of cultivation conditions. For example, the study by Rohmanna et al. (2023) shows that using the microwave extraction method can obtain a fairly high percentage of lipids (around 20-29%) from BSFL. It is not enough to simply obtain oil; the conversion stage (such as esterification/transesterification, or hydro-oxygenation) must be considered in order for the final product to meet biodiesel or green diesel standards. The study by Lee et al. (2024b) explored the use of BSFL lipids to produce green diesel through the hydrodeoxygenation process, and concluded that the carbon distribution of its HDO products is close to conventional diesel fuel.

Management models that combine waste management and energy production produce synergies: organic waste that becomes an environmental burden can be treated immediately, while output in the form of oil or biodiesel contributes to renewable energy. In addition, maggot residues and fractions that do not become oil can be used as fertilizer or feed, so that the resource cycle becomes more closed (circular economy). Housing like Grand Mekarsari Residence is likely to generate large amounts of household organic waste: food scraps, rotten vegetables, and other kitchen waste. Factors such as waste sorting culture, frequency of waste collection, and access to waste management technology will affect the potential use of maggots. Local studies are needed to see how this model can be applied in medium-scale residential environments. In addition to technical potential, there are challenges such as infrastructure (space constraints, cultivation facilities, extraction equipment), economic aspects (initial costs, operational costs), and socio-cultural (public acceptance of larval cultivation, odors, public opinion). In addition, local regulations on waste and renewable energy can also be a limiting or supporting factor.

Based on the description above, this study aims to (i) measure the effectiveness of BSF maggot in reducing organic waste in Grand Mekarsari Residence Housing; (ii) determine the lipid and oil content produced from maggot larvae/prepupae; (iii) test the quality of the maggot oil if it is used as biodiesel or other energy sources; and (iv) evaluate the economic and environmental aspects of the implementation of this maggot-based Waste-to-Energy cycle. Some of the questions that will be answered include: What is the percentage of organic waste reduction through maggot cultivation in the housing? What is the yield of oil obtained from maggot biomass? How is the quality of biodiesel/oil (parameters such as viscosity, calorific value, density) produced? How economically and environmentally feasible is this implementation on a local scale?

This research is significant because it can be an integrated model for the use of household organic waste into renewable energy, while reducing the environmental burden. The results can be a reference for local policy makers (housing governments, environmental agencies), as well as communities to adopt environmentally friendly and circular economy solutions. This research will be limited to household organic waste in Grand Mekarsari Residence Housing; focus on BSF larval cultivation, oil extraction, physical-chemical analysis of oil and biodiesel; as well as a simple evaluation of economic and environmental aspects. The research time will be limited (e.g., a few months of cultivation cycles) and does not include mass production or energy distribution to the public grid.

LITERATURE REVIEW

Maggot (Hermetia illucens) in Bioconversion

Maggots or BSFL (Hermetia illucens) are natural decomposer organisms that are very effective in decomposing various types of organic waste. These larvae are able to consume food waste, market waste, and household organic residues in large quantities in a relatively short time. The result of maggot decomposition is in the form of larval body biomass rich in protein and fat, as well as organic residues called frass fertilizer, which can be used as organic fertilizer.

According to research by Supriyatna et al. (2021), BSFL are able to reduce organic waste by up to 50–60% of their initial weight in just 12–14 days. The effectiveness of this bioconversion makes BSF one of the innovative solutions to overcome the problem of urban organic waste deposits. In addition to reducing the volume of waste, BSF also produces by-products with economic value, such as animal feed and organic fertilizers. Another study by Leong et al. (2021) confirms that the use of BSFL in sewage treatment systems supports the concept of upcycling, which is to convert waste into higher-value products. The biomass produced can be directed to various sectors, ranging from food, feed, to energy. This confirms the role of maggots not only as decomposers, but also as a link between waste management and renewable energy production.

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Household Organic Waste Processing with Magot Utilization

This technology regarding the processing of organic waste and maggot (BSFL) is an effective, environmentally friendly, and economically valuable alternative. Diener et al. (2011) showed that BSFL is able to degrade household organic waste quickly, while producing larval biomass that has the potential to be a high-protein feed. Another study by Čičková et al. (2015) confirmed that the use of BSFL is more efficient than conventional methods, as it not only significantly reduces the volume of waste but also breaks the chain of transmission of diseases due to waste. In addition, Lalander et al. (2019) highlight the importance of the type of raw materials used, as the variety of organic waste affects the larval growth rate, process efficiency, and the quality of the residues produced.

Siddiqui et al. (2022) broaden the perspective by stating that BSFL has a high affinity for processing different types of organic waste, thus contributing to a sustainable urban waste management system. Liu et al. (2021) also showed that the combination of organic waste with additives such as sawdust can improve the quality of the final compost produced through the larval bioconversion process. Thus, the use of BSFL in household organic waste processing not only solves the waste problem but also provides additional benefits in the form of the production of feed, fertilizers, and even energy raw materials, thus making it a solution that supports the principles of the circular economy.

Maggot Oil as an Alternative Source of Biofuel

Biodiesel production from insect biomass has gained increasing attention due to its potential to simultaneously address organic waste management and renewable energy generation. Black soldier fly larvae (BSFL) are particularly promising feedstocks because of their high lipid content and ability to efficiently convert food waste into valuable triglycerides suitable for transesterification. demonstrated that biodiesel derived from BSFL grown on food waste achieved a high yield (up to 86.51%) and met most fuel quality standards, highlighting BSFL-based biodiesel as a feasible alternative transportation fuel when appropriate purification and stabilization steps are applied (Park et al., 2022).

The fatty acid composition in maggot oil is dominated by lauric acid (C12:0), making it particularly suitable for the production of biodiesel through transesterification reactions (Li et al., 2011). According to Sukowati et al. (2021), maggot oil extracted from BSFL fed organic waste has a high saturated fatty acid profile, so the resulting biodiesel has good oxidative stability. This makes biodiesel from BSF able to compete with conventional vegetable oil-based biodiesel, such as palm oil or soybeans. The lipid content in BSFL generally ranges from 20–40% of dry weight, depending on the type of feed and cultivation conditions (Surendra et al., 2016). A study by Zheng et al. (2012) showed that by utilizing restaurant waste, the biodiesel yield can be multiplied because the fat residue in the feed also contributes to the larval oil content. Thus, maggot oil not only reduces dependence on conventional vegetable oils but also utilizes organic waste as part of the sustainable energy production cycle.

In the study, Nguyen et al. (2018) proved that the direct transesterification technique of BSFL can produce biodiesel that meets international standards without requiring separate oil extraction stages, making it more technically and economically efficient. Jung et al. (2022) added that with the non-catalytic transesterification method, biodiesel from maggot oil showed a combustion performance and calorific value that was competitive with plant oil-based biodiesel. Therefore, the use of maggot oil as a biofuel source offers promising prospects, both in terms of production efficiency and energy sustainability, making it one of the strategic innovations in the development of renewable energy. A study by Novianti et al. (2024) adds that with modern extraction methods such as Microwave Assisted Extraction (MAE), maggot oil yields can be significantly increased. The study showed that maggot oil not only meets the basic standards of biodiesel but also has a high enough calorific value that it has the potential to be an alternative energy source.

Concept of Circular Economy and Renewable Energy

The integration of maggots in organic waste treatment supports the application of the circular economy concept. Through the bioconversion process, nutrients from organic waste are not lost but are returned to the system in the form of energy, fertilizers, and biomass of economic value. Thus, the resource cycle becomes more closed, reducing reliance on primary resources. Leong et al. (2021) emphasize that the use of maggots within the framework of the circular economy can result in a waste-to-energy system that is not only sustainable but also environmentally friendly. This model has the potential to be applied at the household, community, and industrial scales to support the Sustainable Development Goals (SDGs), especially in the aspects of clean energy and waste management. In the context of renewable energy, maggot oil provides a great opportunity to reduce dependence on fossil fuels. In addition to generating energy, this system also supports the reduction of greenhouse gas emissions, especially methane from organic waste that usually ends up in landfills. This makes the maggot model a two-pronged solution: tackling waste and generating renewable energy.

Thus, a literature review shows that the use of BSF maggot for waste bioconversion and biofuel production is in line with circular economy principles. In addition to reducing the environmental burden due to waste, this approach also produces alternative energy that can strengthen national energy security. Therefore, research on maggot oil as a biofuel source has academic and practical urgency in supporting the sustainable energy transition.

RESEARCH METHOD

Case Studies and Research Locations

This study uses a case study method carried out at the Integrated Waste Management Site (TPST) of Grand Mekarsari Residence, Mekarsari, Bogor. The selection of the location was carried out purposively because the housing produces a significant amount of household organic waste and has the potential to be integrated with maggot-based bioconversion systems. The focus of the research is directed at the utilization of household organic waste, such as food scraps, fruits, and vegetables, as a substrate for the cultivation of Black Soldier Fly (Hermetia illucens) larvae.

Maggot Cultivation and Bioconversion Process

The bioconversion process is carried out by preparing a substrate in the form of household organic waste that has been sorted and chopped. BSF instar-3 larvae were placed in a bioconversion tank with a ratio of larvae biomass to substrate of 1:5. Maintenance is carried out for 10 days with light stirring every two days to maintain the homogeneity of the substrate. The main parameters observed were Reduction Rate (RR) to determine the efficiency of waste reduction, Feed Conversion Ratio (FCR) to assess the efficiency of feed conversion to biomass, and the weight of maggot biomass produced at the end of the cycle.

Maggot Oil Extraction

The harvested larvae are then dried using an oven at 60 °C until the moisture content reaches <10%. The oil extraction process is carried out by the Soxhlet method using n-hexane solvent. This method was chosen because it is proven to be able to produce higher and purer oil yields than conventional pressing methods. The oil extract is then separated from the solvent using a rotary evaporator and stored in a dark container to prevent oxidation.

Characterization of Maggot Oil

Extracted oil is characterized based on biodiesel quality parameters. Laboratory tests include acid values, saponification values, iodine values, and fatty acid composition analysis using Gas Chromatography-Mass Spectrometry (GC-MS). This analysis aims to assess the feasibility of maggot oil as a raw material for biodiesel. The composition of fatty acids, especially the level of lauric acid (C12:0), is an important indicator to determine the suitability of oil as a biodiesel feedstock.

Data Analysis

Data on the results of substrate reduction, biomass conversion, and oil parameters were analyzed quantitatively. The measurement results were compared with biodiesel quality standards (SNI and ASTM) to evaluate the feasibility of maggot oil as a renewable energy source. In addition, the efficiency of waste bioconversion is also compared with similar research results as validation. This methodology refers to a similar approach in the research of Novianti et al. (2024) and Sukowati et al. (2021), which proved the effectiveness of BSF in the treatment of organic waste as well as the potential of maggot oil as a biodiesel.

RESULTS

Waste Treatment Efficiency

The results showed that BSF maggots were able to reduce the mass of organic waste by an average of 68.5% within 10 days. From the observation data, it can be seen that there has been a significant decrease since day 2 (15%), day 5 (45%), to reach 70% on day 10. This figure shows the great potential of BSFL in accelerating the degradation of household organic waste.

The efficiency of the reduction depends not only on the number of larvae and the quality of the substrate, but also on the humidity and aeration in the bioconversion medium. According to research by Leong et al. (2021), the condition of the substrate that is maintained with moisture between 60–70% is a key factor in the success of bioconversion. In this study, humidity adjustment was carried out through shredding of garbage and periodic addition of water to maintain the ideal environment.

Frass fertilizer or residues resulting from bioconversion have the potential to be organic fertilizers. The nutrient content in frass fertilizer is mainly nitrogen, phosphorus, and potassium, making it suitable for application as plant fertilizer.

Maggot Oil Yield and Characteristics

The following are the results of the table of Yield and Characteristics of Maggot Oil:

Table 1. Yield and Characteristics of Maggot Oil

Parameters	Unit	Value Results	Biodiesel Standard (SNI 7182:2015)
Oil Yield	% dry weight	28,5	-

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Acid Numbers	mg KOH/g	3,5	Max. 0.5 (for biodiesel)
Fatty Acid Composition	%	Lauric Acid (C12:0): 45.2%	-

The results in Table 1 showed that the maggot oil yield reached 28.5% of the dry weight of the larvae. GC-MS analysis revealed that maggot oil was dominated by lauric acid (C12:0) by 45.2%, followed by myristic acid (C14:0) and palmitic acid (C16:0). This content shows a high profile of saturated fatty acids, which is a positive characteristic for the production of biodiesel with good oxidative stability.

Maggot oil generally shows that: (1) Lauric acid (C12:0) is the most dominant fatty acid, often exceeding 40%; and (2) Myristic acid (C14:0) and Palmitic acid (C16:0) are the next two most abundant saturated fatty acids.

Some examples of the content ranges reported in maggot oil studies are presented in Table 2:

Table 2. Content Ranges Reported in Maggot Oil Studies

Fatty Acid	Percentage Range (of total fatty acids)
Myristic Acid (C14:0)	5%–17%
Palmitic Acid (C16:0)	5%–15%

Specific Examples

One study reported a myristic acid percentage of 16.7% and lauric acid (the dominant one) of 52.1% in maggots fed palm kernel cake. Another study found that lauric acid was the most abundant (28%–37%), followed by palmitic acid, myristic acid, oleic acid, and linoleic acid. Therefore, for a specific answer, you must refer to the GC-MS (Gas Chromatography–Mass Spectrometry) data results of the maggot oil you are studying, as its fatty acid composition is highly dependent on the feeding medium used.

However, the acid level of maggot oil was recorded at 3.5 mg KOH/g, far above the maximum limit of biodiesel standards according to SNI 7182:2015 (0.5 mg KOH/g). This indicates the need for an initial esterification stage before the transesterification process to lower the level of free fatty acids (FFA).

Characteristics of BSFL Lipid FAMEs, biodiesel components, were produced from the conversion of lipids, in particular, the transesterification of triglycerides and esterification of FFA. Because the (trans)esterification reactions are susceptible to the presence of organic and inorganic impurities that can be present in biomass feedstocks (Jung et al., 2020), lipid content was extracted from BSFL before its conversion to biodiesel. The lipid was extracted using the liquid/liquid extraction method. In Table 3, major chemical constituents of lipid extracted from BSFL and leftover cake (pressed cake) are shown. Lipid extracted had 85.49% of purity, having 9.91% protein, 2.65%.

Waste Treatment Efficiency (Mass Reduction)

The following are the results of the waste treatment efficiency (mass reduction) table:

Table 3. Waste Treatment Efficiency (Mass Reduction)

No	Experiment Day	Initial Waste Mass (kg)	Remaining Waste Mass (kg)	Cumulative Reduction Rate (%)
1	0	10	10	0%
2	2	10	8.5	15%

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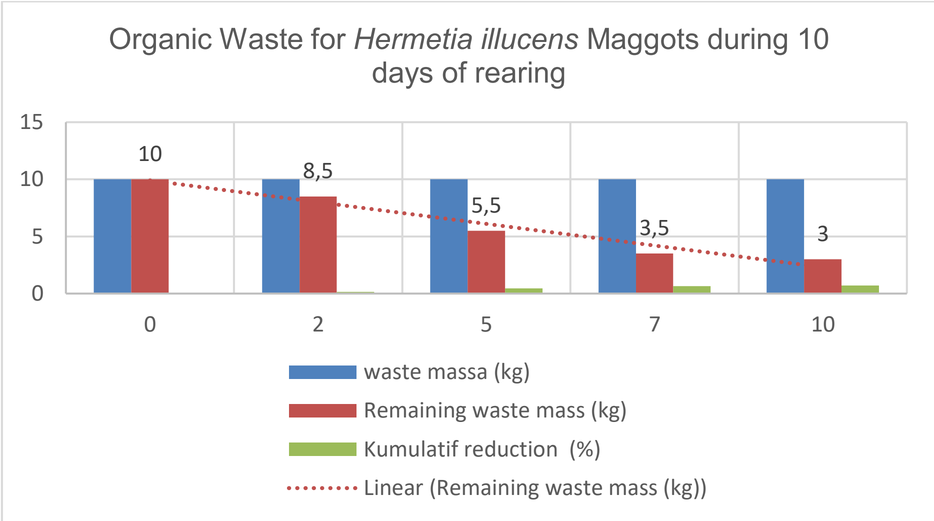
3	5	10	5.5	45%
4	7	10	3.5	65%
5	10	10	3	70%

Figure 1. Efficiency of Mass Reduction of Organic Waste by Maggot Hermetia illucens During 10 Days of Bioconversion



Based on Table 3 and Figure 1, the efficiency of organic waste treatment through bioconversion with maggot Hermetia illucens shows a consistent trend of decreasing waste mass over a period of 10 days. On the second day, the waste mass was reduced from 10 kg to 8.5 kg, or about 15% reduction. The decrease was even more significant on the 5th day, with 5.5 kg of waste remaining (45% reduction). On the 10th day, only 3 kg of waste remained, with a cumulative reduction rate of 70%. This data shows that the activity of maggots in degrading waste is intensive, especially in the active growth phase.

The pattern of decreasing waste mass seen on the graph is in a descending shape with a linear inclination. This confirms that the process of waste consumption by maggots is stable throughout the bioconversion period. The greatest decrease occurs between day 2 and day 5, which signifies the peak phase of larval metabolism in decomposing organic substrates.

The Role of Maggots in the Renewable Energy Cycle

The results of the study prove that BSF maggots play a role as a transition agent in the renewable energy cycle by connecting the waste management sector and the energy sector. Organic waste, which has been considered an environmental burden, has been successfully converted into energy-valuable products in the form of maggot oil. Thus, there is a transformation of negative inputs into positive outputs in a waste-to-energy framework.

Housing such as Grand Mekarsari Residence can be used as a real laboratory to apply the concept of community-based circular energy. The application of local-scale maggot cultivation is able to create a community-based micro-energy system.

DISCUSSION

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Waste Treatment Efficiency
This reduction rate is in line with the results of Supriyatna et al. (2021), which found that BSFL can reduce the volume of organic waste by more than 60% within 12 days. This effectiveness shows that bioconversion with maggots is a real alternative to urban organic waste management systems, which have been dependent on landfills or open incineration.

Research by Sukowati et al. (2021) also proves that BSF residue can increase soil fertility while improving the physical structure of the soil. Thus, the benefits of bioconversion are not only in waste reduction, but also in the creation of valuable by-products.

The efficiency rate of reduction of up to 70% in 10 days confirms that the BSF maggot is a fast and effective decomposing agent. This is much more efficient than traditional composting methods that take weeks to months to produce similar reductions. Therefore, the application of BSF on a residential scale has the potential to reduce dependence on landfills while reducing methane emissions from waste decay. From a sustainability perspective, BSF-based bioconversion offers two dual advantages: addressing the problem of organic waste heaps while producing products of economic value. These findings reinforce the idea that biology-based solutions could be the answer to waste management challenges in urban areas.

Maggot Oil Yield and Characteristics
The research of Novianti et al. (2024) also emphasizes the importance of the pretreatment process to improve the quality of maggot oil to meet biodiesel standards.

The dominant uric acid content in maggot oil is a potential indicator for producing biodiesel with good cold flow properties. Biodiesel based on lauric acid has a low flash point and better oxidative stability than biodiesel from other vegetable oils. This is supported by a study by Mohan et al. (2023), which states that lauric acid is one of the ideal fatty acid components for biodiesel.

In terms of yield, the figure of 28.5% is in line with the research of Sukowati et al. (2021), which found that BSFL can produce oil yields of between 25–30% depending on the type of substrate and extraction method. This figure shows the consistency of the results that maggot can be used as an alternative feedstock in biofuel production.

Although the high FFA content is an obstacle, various studies suggest processing methods such as microwave-assisted extraction (Novianti et al., 2024) or hydrodeoxygenation (Lee et al., 2024a) to improve the quality of maggot oil. With technological optimization, maggot oil can be further processed into biodiesel or green diesel in accordance with international standards. Overall, although maggot oil has not fully met the standards of biodiesel without pretreatment, its fatty acid profile is very promising. This study confirms the importance of developing advanced processing technology so that maggot oil can function as a commercially viable renewable energy source.

Waste Treatment Efficiency (Mass Reduction)
According to research by Leong et al. (2021), this phase is the optimal period for maggots in utilizing energy sources for biomass growth.

The reduction efficiency of reaching 70% in a relatively short time proves the advantages of the bioconversion method with maggot compared to conventional composting methods, which usually take weeks. This is in accordance with the findings of Sukowati

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et al. (2021), who reported that BSFL were able to reduce the volume of organic waste by 65–75% within 10–14 days. Thus, maggots have proven to be effective as a rapid decomposing biological agent in the treatment of household organic waste.

In addition to the aspect of mass reduction, the results of bioconversion also produce residues in the form of frass fertilizer, which has the potential to be used as organic fertilizer. This provides added value in the context of a circular economy, where waste is not only reduced in volume but also converted into useful products. Thus, the efficiency of waste treatment through maggots is not only oriented towards reducing the burden of landfills, but also on the creation of by-products that support the sustainability of urban agriculture.

Overall, the results of the analysis of the tables and graphs show that the use of Hermetia illucens maggots in organic waste treatment is very efficient, with a reduction rate of 70% in 10 days. These findings confirm the great potential of maggot-based bioconversion as an alternative solution that is environmentally friendly, fast, and economically valuable. By optimizing cultivation systems and substrate management, this method has the potential to become an organic waste management strategy that can be widely applied in residential and urban environments.

The Role of Maggots in the Renewable Energy Cycle

This model is consistent with the principle of a circular economy, in which resources are repurposed through closed cycles. According to Leong et al. (2021), the integration of maggots in waste treatment supports the creation of a zero-waste system, as waste is not only reduced but also converted into energy and organic fertilizers. This creates double added value, namely ecological and economic benefits.

From a renewable energy perspective, maggot oil has the potential to be a substitute for non-food vegetable oils. Its use can reduce dependence on palm oil, which has been causing deforestation and environmental degradation issues. Lee et al. (2024a) study shows that maggot lipids can be processed into green diesel with quality equivalent to fossil diesel, thus contributing directly to the clean energy transition.

The role of maggots in the energy cycle also contributes to the reduction of carbon emissions. Organic waste managed with BSF does not produce excess methane as happens in landfills. In addition, the use of biodiesel from maggots can reduce CO_2 emissions from the transportation sector. Thus, this model supports the Net Zero Emission target.

This suggests that maggot-based energy solutions can be inclusive and community-based (Lainawa et al., 2024; Xufeng and Waworuntu, 2025).

Thus, the role of maggots in the renewable energy cycle is not only limited to technical aspects, but also includes social, economic, and environmental dimensions. This model shows that biological approaches can be an innovative strategy in achieving energy sustainability while addressing urban waste problems.

CONCLUSION

This study confirms that Hermetia illucens maggots are highly effective in reducing household organic waste, achieving up to 70% mass reduction within 10 days, which demonstrates their potential as a fast, efficient, and environmentally friendly alternative to conventional waste treatment methods. In addition to waste reduction, BSFL bioconversion generates value-added products, including frass fertilizer, protein-rich biomass, and maggot oil with lauric acid as the dominant fatty acid, indicating strong potential as a biodiesel feedstock. However, the relatively high acid value shows that pretreatment through esterification is still required to meet SNI 7182:2015 biodiesel standards. Overall, these findings highlight the important role of BSFL in supporting a circular economy by transforming organic waste into useful resources while contributing to sustainable waste management and renewable energy development at residential and urban levels.

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DECLARATION OF CONFLICTING INTERESTS
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