Integrated model to support a sustainable farming system: utilization of Black Fly Soldier (BSF) as bioconversion agent

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Abstract. This study explores the use of Black Soldier Fly (BSF) larvae in integrated farming to support sustainable agriculture. Integrated farming systems, particularly the utilization of BSF larvae for organic waste management, animal feed production, and soil enhancement, are crucial in addressing challenges in regions like Bogor, West Java, which face issues such as organic waste management, soil degradation, and high animal feed costs. The objective is to study the integration process between BSF maggot production and the livestock sector, specifically quail layer production, and to develop and implement an integration model to support sustainable farming. The research design involved two steps: implementing an initial model from July 2023 until June 2024 through Focus Group Discussions (FGD) and in-depth interviews, followed by qualitative analysis. Results indicate the initial model was successfully applied, demonstrating the feasibility of integrating BSF larvae bioconversion into quail farming. The study found potential for developing a more comprehensive model applicable to the study location and adaptable to other regions. This research highlights the importance of innovative waste management solutions in agriculture to promote sustainability through integrated farming systems.

1 Introduction

Integrated farming systems are becoming increasingly critical in the global pursuit of sustainable agricultural practices, especially in regions with rapid population growth and environmental challenges. Livestock, as part of the agricultural, provide 25% of total dietary protein and contribute to a variety of critical global challenges, including greenhouse gas emissions as well as freshwater, fossil fuel, land consumption, and organic waste [17]. One

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such innovative approach is the utilization of the Black Soldier Fly (BSF) (*Hermetia illucens*) for integrated farming, which offers promising solutions for organic waste management, animal feed production, and soil enhancement. According to Novianti (2023), Black Soldier Fly larvae are highly suitable insects for managing organic waste. Additionally, according to previous research conducted by Hakim et al. (2017), BSF larvae are capable of reducing tuna waste by 77.09%, with a waste generation rate of 60 mg/larva/day.This case study in Bogor, West Java, exemplifies how BSF can be harnessed to support a sustainable economy through its multifaceted applications in farming systems, especially in the integration process with egg-laying quail production.

Bogor, a region known for its agricultural activities, faces typical challenges such as organic waste management, soil degradation, and the high cost of animal feed. The traditional farming methods often lead to inefficiencies and environmental degradation. To address these issues, the integration of BSF into farming practices presents a sustainable and economically viable alternative. BSF larvae are voracious feeders of organic waste, converting it into high-quality protein and fat, which can be used as feed for livestock and fish, thus reducing the reliance on conventional feed resources that are often expensive and environmentally taxing. Black soldier fly (BSF) larval bioconversion can recycle nutrients in organic wastes into larval biomass and frass. While the frass has been commonly marketed as a soil amendment, its usefulness in soilless cultivation remains largely unexplored [21]. The BSF larvae not only help in managing organic waste effectively but also produce frass (substrate residue), which is rich in nutrients and serves as an excellent organic fertilizer. This contributes to soil health and enhances crop productivity, creating a closed-loop system that minimizes waste and maximizes resource use. By incorporating BSF into integrated farming systems, farmers in Bogor can achieve significant cost savings and productivity gains, leading to a more sustainable and resilient agricultural practice.

Furthermore, the economic implications of BSF utilization extend beyond the immediate agricultural benefits. The production of BSF-based products opens new market opportunities and revenue streams. Farmers can diversify their income by selling BSF larvae, frass, and derived products such as animal feed and organic fertilizers. This diversification is particularly important in regions like Bogor, where smallholder farmers dominate the agricultural landscape and are often vulnerable to market and climate shocks. The environmental benefits of BSF integration are equally noteworthy.

By diverting organic waste from landfills, BSF farming reduces greenhouse gas emissions, mitigates pollution, and contributes to a cleaner environment. This aligns with global sustainability goals and local initiatives aimed at promoting environmental stewardship and sustainable resource management.

The utilization of BSF in integrated farming systems in Bogor, West Java, represents a transformative approach to sustainable agriculture. It addresses critical challenges in waste management, soil fertility, and animal feed production while offering economic benefits and environmental advantages.

As this case study demonstrates, BSF farming can play a pivotal role in supporting a sustainable economy by fostering resilient agricultural practices and creating new economic opportunities for farmers. The successful implementation of BSF in Bogor can serve as a model for other regions seeking to enhance their agricultural sustainability and economic resilience. The objective of this research is to study the integration process between BSF maggot production and the livestock sector, production of quail layer, as well as creating an integration model, developing and implementing the integration model to support a sustainable farming system.

2 Materials and Methods

The research activities were carried out in two stages. Stage 1, which took place in July - October 2023, an initial identification was carried out first on quail farmers. Then in stage 2, which was carried out in November 2023 - February 2024, data analysis was carried out to obtain the results of the first stage model (the existing model at the farmer level), a development model that can be used as a reference. Primary data obtained through observation, weighing, survey questionnaires, and in-depth interviews located in Bogor and Sukabumi, West Java (Figure 1). A total of 10 conventional and 1 integrated quail farmer respondents were used as one of the references to then be tested on the applied model. In addition, Focus Group Discussions (FGD) and in-depth interviews were also conducted by applying qualitative analysis from March to June 2024. The research design includes qualitative data and descriptive analysis and answers research questions. In data collection, the research methods and designs were also considered, which depend on other factors such as the availability of resources, time constraints, and the feasibility of conducting interviews and surveys in the poultry industry in Indonesia.

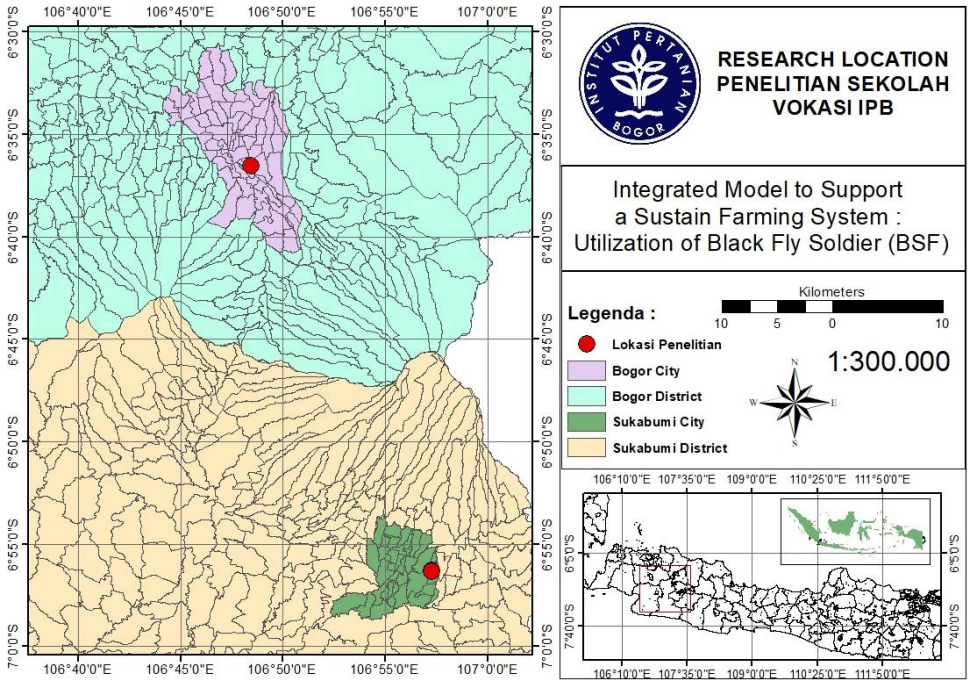

Fig. 1 Research location.

Data collection was conducted by conducting semi-structured interviews with key stakeholders in the Indonesian poultry industry including academics, business and government. These included representatives from farms, poultry, processing plants, regulatory agencies, environmental organizations, and consumers. The interviews explored their perspectives on circular supply chains, sustainability challenges, barriers, and opportunities. Data analysis was then conducted using thematic analysis of interview transcripts to identify recurring themes related to sustainability challenges, transition complexities, barriers, and potential strategies for a circular economy. Then, descriptive analysis was conducted to explain the potential of a circular economy in developing BSF Utilization for Integrated Farming

Criteria for improvement:
1. Different processin
2. Broader utilization
3. Involved stakeholders

3 Results

3.1 BSF Supply Chain - Before improvement model

The figure 2 illustrates a circular economy involving the management and conversion of organic waste, specifically quail excreta. Here's a breakdown of the process:
1. Excreta Waste: Quails produce excreta, depicted by a pile of waste, where quail excreta are collected.
2. Bioconversion (BSF Maggot): The waste is then subjected to bioconversion using Black Soldier Fly (BSF) larvae, also known as maggots. These larvae help break down the organic matter.
3. Fertilizer (Frass/ Residue): The bioconversion process produces fertilizer, which is derived from the larvae casting. Larvae castings, often referred to as frass, are the waste products produced by insect larvae, such as Black Soldier Fly (BSF) larvae, during the digestion of organic material. These frasses are rich in nutrients and beneficial microorganisms, making them an excellent natural fertilizer for plants [22][23]. They help improve soil structure, enhance water retention, and provide essential nutrients that promote healthy plant growth.
4. Feed: BSF Maggot bioconversion process produces alternative animal feed protein sources substitute, which can be used for poultry such as quails. This completes the cycle, as the feed eventually leads back to waste excreta.
5. Quail: Represented by an icon of a quail, Quails consume alternative animal feed protein sources, along with other feed ingredients such as energy sources, vitamins, and so on. The feed consumed is digested and absorbed by the quails to meet their nutritional needs. The waste products from this digestion process and any undigested feed become excreta.

This cycle demonstrates an eco-friendly approach to waste management, turning waste into valuable resources like fertilizer and animal feed.

Fig. 2. BSF Supply Chain - Before improvement model.

In-depth interviews with expertise showed that the initial model had already utilised BSF maggots in the bioconversion process of organic waste, especially quail excreta. Quail excreta is quail farm waste which has a relatively high content of organic matter, especially the element Nitrogen (N).

Frass or substrate residue resulted from waste bioconversion using maggot can potentially become fertilizer. This is in line with the results of research conducted by [9]. Economically, this model can potentially increase farm efficiency and profit, as reported by [6] and [16]. According to expertise, from an environmental aspect, this model has the potential to reduce the level of carbon emissions and odor pollution from quail farms. From a social perspective, this initial model is the first step to increase the acceptance rate of quail farming from the surrounding community. The disadvantage of this initial model is that the utilization of frass/substrate residues were not optimal, so it has the potential to become a new problem because it accumulates at the farm site.

3.2 BSF Supply Chain - The Development of the Integration Model.

Based on discussions with the experts, the integration model between quail laying and maggot BSF production has the potential to be developed into a more comprehensive model. The development of the integration model can be seen in the Figure 3.

Based on the results of the study, the bioconversion process of quail excreta organic waste by BSF maggots can produce new, more valuable biomass, namely BSF maggots themselves and also frass or leftover fertilizer from maggot growth media that has been well decomposed. The results of in-depth discussions with experts stated that BSF maggot has the potential to act as an alternative protein source feed ingredient, which is quite competitive with meat meal or fish meal from a nutritional aspect, especially its crude protein and crude fat content. Several research results report that the crude protein content of BSF maggots in different manure media shows the potential for relatively high crude protein content. [8] The reported crude protein content of maggot BSF was 24.05% (chicken manure), 18.74% (a mixture of chicken manure and buffalo manure), and 17.34% (buffalo manure). This is also supported by the research results of [18], which reported that the crude protein content of BSF pre puppa was 41.7% while the crude fat was 36.3%.

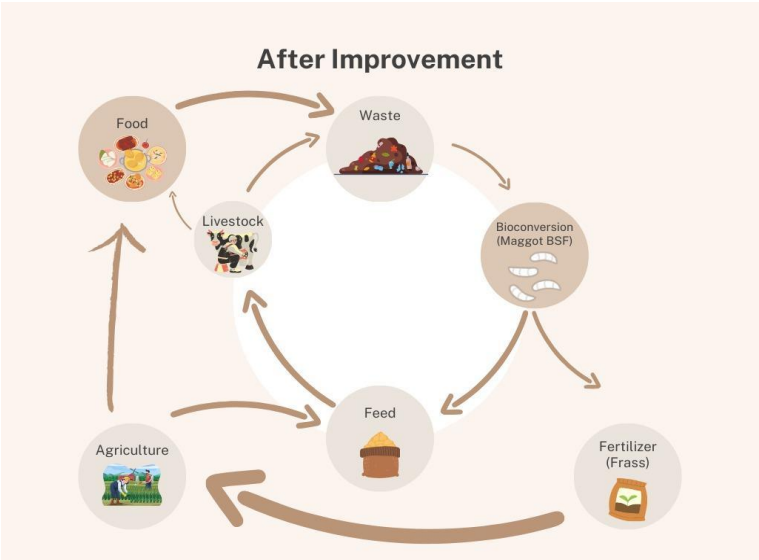

Fig 3. BSF Supply Chain - The development of the integration model.

The research results also show that frass has potential as an organic fertilizer that can be implemented in the production process in the agricultural sector. As is known, the agricultural production sector is an important pillar for providing food through its main products and providing feed through its by-products. Frass is residual biomass after larval bioconversion, can add up to >57% of the initial input biomass, depending on the STANDARoptimization of feeding rates [4]. Frass of undigested substrate wastes, excretions, shed larval skins, and to a defined degree also dead insects. While a standardization for insect frass has not been established yet, recent industrial and scientific efforts promote its use as an alternative organic fertilizer, emphasizing its beneficial effects on soil and plant health. [5, 10, 14]. Manure, as a organic waste from livestock sector, has long been used for biogas production, thus, frass obtained from the BSFL-based bioconversion of swine, poultry, or dairy manure could offer promising features for this application and add value to this circular process [11]. Household or kitchen organic waste or other food waste will become a suitable growth medium for BSF maggots, so that the coverage of the sectors in the picture above reflects the implementation of sustainable production activities. The development of an integrated model for quail and maggot cultivation is in line with the model from the research results of [20] which can be seen in the image below.

The Quail – Black Soldier Fly (BSF) bioconversion model provides benefits to the livestock and agricultural sectors. This integration concept offers several impacts and benefits on the three pillars of sustainability, including the environmental impact and benefits, social impact and benefits, economic impact and benefits. For environmental impact and benefits reducing organic waste has a direct impact that is very beneficial, especially for quail farmers. By utilising organic waste for maggot bioconversion, the model reduces the environmental burden of waste disposal.

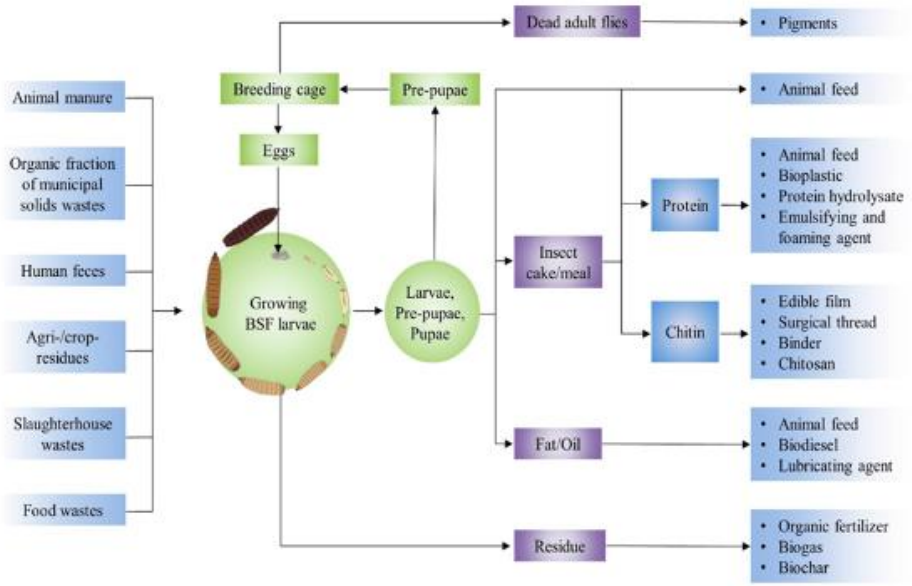

Fig 4. Schematic of a BSF-based biorefinery for producing value-added products with concurrent valorization of organic bioresources [20].

This contributes to the reduction of greenhouse gas emissions and minimizes the need for landfill space. Frass as the kind of fertilizer provides a sustainable alternative to chemical fertilizers. It promotes soil health and fertility without the negative environmental impacts

associated with synthetic fertilizers, such as soil degradation and water pollution. The improvement model enhances resource efficiency by converting organic waste into valuable products like fertilizer and protein-rich biomass, thus reducing the need for virgin resources and promoting circularity within the agricultural system.

In line with the impact on the environment, the development of this integration model also has a positive impact on social aspects. The production of fertilizer (kasgot) and protein-rich biomass creates economic opportunities for farmers and waste management facilities. It can generate additional revenue streams and contribute to local economic development. Utilizing protein-rich biomass from black soldier fly larvae as feed for quails or other livestock enhances food security by providing a sustainable source of protein. This is especially beneficial in regions where access to traditional protein sources is limited. Implementing sustainable practices like waste management and organic farming fosters community engagement and empowerment. It educates and involves local communities in environmental stewardship and sustainable agriculture.

Ultimately, the development of this circular integration model is expected to encourage opportunities to improve economic aspects for quail breeders and other actors involved in this integration model. The use of fertilizer (kasgot) produced from black soldier fly larvae waste can lead to cost savings for farmers compared to purchasing chemical fertilizers. Similarly, utilizing protein-rich biomass as animal feed reduces feed costs and improves farm profitability. Beyond fertilizer and animal feed, black soldier fly larvae and their byproducts can be processed into various value-added products such as biodiesel, pharmaceuticals, or cosmetic ingredients. This diversifies revenue streams and enhances the economic viability of the model. As awareness of sustainable agriculture and circular economy practices grows, there is increasing market potential for products derived from the Quail - Black Soldier Fly bioconversion model. This can open up new market opportunities and drive innovation in the agricultural sector. Overall, the Quail - Black Soldier Fly bioconversion model, with its focus on fertilizer production, farm benefits, and waste utilization, offers significant potential to promote sustainability across environmental, social, and economic dimensions.

4 Discussion

Expert interviews revealed that the initial model had already incorporated BSF maggots in the process of converting organic waste, particularly quail excreta. Quail excreta, a type of waste from quail farms, contains a high level of organic matter, especially nitrogen (N). Quail consumes feed that is high in crude protein content: 20% (starter and grower period) and 20-22% (layer period) [2]. One quail is capable of producing 25 grams of excreta per day [19]. This has the potential to increase the usefulness of quail excreta. Expertise argued that the problem of environmental pollution from quail excreta can be handled well through bioconversion. BSF maggot as a waste processing agent can be reused as a feed ingredient for quail because it has a high protein content [15].

The drawback of this initial model is that the use of frass/substrate residues was not efficient, leading to potential issues due to accumulation at the farm site. This was also reported by previous research [11] and previous study dealt with excreta eaten by BSF larvae and poultry manure residues in the integration of BSF larvae in poultry farms. Some of the recommendations from the previous study were the need for the maintenance of suitable insect species, available technical capacity, and the economic feasibility of facilities and equipment to obtain more optimal substrate residues utilization results. In addition to the suboptimal utilization of kasgot, based on discussions with expertise, some quail farmers have implemented this initial model but need to pay attention to the limit of quail excreta that easily hardens so that the bioconversion process is not optimal.

Discussions with the expertise showed that the model developed has opportunities and challenges in the implementation stage. Some quail businesses have challenges in becoming sustainable, such as inefficient production, high production costs, poor waste management, lack of diverse sources of income (only from egg sales and culled quail), and social conflicts between farms and neighbouring communities. The implementation of the developed model can play a role in overcoming some of these problems. This is because farmers can increase production efficiency through the utilisation of maggot as a high-protein quail feed. In addition, farmers can also utilise unsold livestock products as feed for BSF maggots. From an economic perspective, the utilisation of BSF as feed can also save production costs because it does not rely solely on commercial feed but substitutes with BSF maggot and integrated agricultural waste. Other benefits include additional revenue from agricultural products fertilised using BSF maggot and sales of BSF maggot. From an environmental perspective, waste in quail farming can be bio-converted by utilising BSF maggot. This can reduce environmental pollution in the community. Thus, socially, the potential conflict with the community around the farm can be minimised. This result is in line with several previous studies that underline the importance of maggot BSF utilisation in integrated farming systems [3, 6, 9, 16].

However, the results show that there are several challenges in implementing the developed model. The first challenge is the selection of growth media for BSF maggots. Maggots generally cannot process fatty food waste. Therefore, to optimise the results of food waste processing and maggot yields, it is necessary to classify the types of food waste produced. The second challenge is the quality and quantity of maggot produced. Maggot that will be used as feed ingredients for quail must have good quality in terms of nutrition and the quality must be stable so that it does not affect the feed formulation prepared. This is also necessary to maintain the quality of the quail health. The utilisation of quail farm waste as a growing medium for BSF maggot and then using the BSF maggot as quail feed can be a critical point for the safety and health of the quail. Several studies have shown that the medium used for maggot growth greatly affects the nutritional quality of the maggot produced [1, 7, 13]. If these maggots are to be used as feed ingredients, it is necessary to ensure that the nutritional content of these maggots is stable. In terms of quantity, management of maggot and agricultural waste production to meet the quail feed needs to be done well so that it does not become a challenge for sustainable production. The next challenges are capital and human resources. To implement the model, farmers will need to invest more capital as more land is required, additional production equipment in the waste management (black soldier fly cultivation), agriculture and post-harvest sectors. This integrated business also requires human resources with multi-disciplinary skills in quail farming, maggot cultivation, agriculture and post-harvest. The fourth challenge is quail productivity. Quail productivity is currently still dependent on commercial feed, so if there is a substitution or even elimination of feed with BSF maggot or other waste, it is necessary to have a formulation that can maintain production.

5 Conclusions

Opportunities and difficulties arise throughout the implementation stage of the developed model. Inefficient production, high production costs, inadequate waste management, a lack of varied revenue streams, and social tensions between farms and nearby towns are some of the obstacles that some quail businesses face in their efforts to become sustainable. Education is also needed as an effort to introduce BSF's potential in supporting sustainable agriculture. Research found there are four challenges in implementing the development model of this research such as the selection of growth media for BSF maggots; the quality and quantity of maggot produced; capital and human resources; and quail productivity. Implementing

innovative waste management solutions is needed to promote sustainability through integrated farming using BSF larvae in bioconversion exemplifies. These circular economy principles can be implemented with the development of a model that can be applied to the study location and potentially adapted to other suitable locations. Implementing innovative waste management is needed as a solution in agriculture to promote sustainability. The use of BSF larvae in bioconversion exemplifies how circular economy principles can be applied to agriculture, mitigating environmental impacts and enhancing the economic sustainability of farming operations.

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