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Quail-Black Soldier Fly Larvae (BSFL) Integrated Farming: Bioconversion Efficiency, Economic Viability, and Farmers' Perception Toward Circular Agriculture

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Abstract

Integration farming of quail with Black Soldier Fly Larvae (BSFL) has the potential to support a circular economy and offer various benefits for future sustainability. To promote sustainable farming systems, it is essential to examine farmers' perceptions and the factors influencing their adoption of such systems. This study aimed to understand the bioconversion of BSFL using quail excreta as a substrate, the potential of integrated farming models, and farmers' perceptions of BSFL. This research was conducted from July 2023 to March 2024. The BSFL bioconversion data were collected through observational studies and measurement techniques. Production and economic performance data, along with farmers' perceptions, were obtained through a combination of observation, surveys, and in-depth interviews with 11 quail farmers. The collected data were analyzed using both descriptive and comparative methods, employing Microsoft Excel, SPSS 22, and Minitab 20. The findings indicated that the combination of organic phenolics added to quail feed and fermented excreta used as a substrate for BSFL yielded the optimal bioconversion value. Another notable finding is that integrated quail farming yields enhanced economic performance due to its ability to generate added value. However, it is essential to note that farmers exhibited varying degrees of knowledge and perceptions regarding BSFL. In conclusion, this study highlights the importance of enhancing production, economic, social, and environmental sustainability by fostering a circular economy through an integrated approach of integrating quail farming with BSFL. However, educational and training programs, mentorship related to the technical aspects of quail-BSFL production, and financial assistance, are crucial to augment the adoption rate of this integrated approach.

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1. Introduction

In Indonesia, the quail farming sector plays a significant role in enhancing community nutrition, generating employment opportunities, and contributing to regional income (Winanti *et al.*, 2022; Andaruisworo *et al.*, 2024). However, the sector faces numerous challenges, including economic, social, and environmental issues that hinder its ability to achieve long-term sustainability. Small-scale farms, predominantly operated by small-scale farmers, are particularly vulnerable due to their limited productivity, often attributable to insufficient capital (Fathurohman *et al.*, 2014). Furthermore, social challenges have been identified, including the potential for social conflicts and the impact on the quality of life of residents near quail farms due to odor and air quality complaints (Akanni and Benson, 2014). Moreover, concerns have been raised the environmental impact of quail farms, particularly ammonia emissions, comparable to those associated with other poultry production (Malovanyy *et al.*, 2021).

In response to these challenges, the utilization of Black Soldier Fly Larvae (BSFL) has emerged as a promising solution in poultry farming. The utilization of BSFL has been demonstrated to enhance economic viability while mitigating deleterious environmental effects (Mawaddah *et al.*, 2018; Sembada *et al.*, 2022). However, BSFL adoption faces various challenges, including land unavailability for cultivation, initial capital requirements, and high production costs (Olutegbe and Ojuoluwa, 2022).

In general, quail farming is conventional, focusing on a single business activity (not integrated) (Ta'wim *et al.*, 2024). However, integrated quail-BSFL farming has the potential to support the circular economy and offer various benefits (Sinaga *et al.*, 2024). However, research on this subject is limited, particularly regarding BSFL growth using organic phenolics in feed and fermented excreta as substrates. This utilization has the potential to increase BSFL bioconversion (Ayuningtias *et al.*, 2024). In the pursuit of a sustainable farming system, it is essential to examine farmers' perceptions and the factors influencing their adoption of BSFL on quail farms.

The present study had several objectives. The primary objective was to investigate the quail-BSFL integrated farming model and the difference in the bioconversion value of BSFL resulting from the incorporation of organic phenol in the feed and the fermentation of excreta used as the substrate. The subsequent objective was to identify and comparing the technical performance and economic potential of the quail-BSFL integrated farming model with that of the non-integrated one. Finally, the study sought to enhance comprehension of farmers' perceptions, knowledge, and factors influencing the adoption of BSFL.

The implications of this research for farmers are twofold: first, they can utilize the potential of BSFL to improve their farm performance; and second, they can use this knowledge to advocate for the adoption of BSFL at the policy level. For stakeholders, the implications are that they can promote integrated farming models to improve the sustainability of quail farming.

2. Research Method

2.1. Time and Location of Study

The research was conducted from July 2023 to March 2024. The initial two phases of the study were conducted at the quail cage, Vocational College, IPB University. Phase 2 and 3 research took place on quail farms located in Bogor City and Regency.

2.2. Research Design

The study had three primary objectives, each employing distinct data collection techniques, variables, and analyses, as outlined below:

Phase 1 aimed to investigate the quail-BSFL integrated farming model and the difference in bioconversion value of BSFL resulting from the treatment of adding organic phenol to the feed and the fermentation of excreta in the substrate.

In this phase, we used a randomized block design and compared four different treatments using BSFL substrate, based on the incorporation of organic phenolics in feed and excreta fermentation. Each treatment consisted of 3 replicates. The organic phenolics were incorporated into the feed by spraying the feed with a solution five times. Concurrently, the excreta fermentation treatment involved collecting excreta and subjecting it to a two-day fermentation process. This fermentation process involved adding a mixture of 500 milliliters of water, 10 milliliters of EM4, and 10 grams of brown sugar per 2 kilograms of excreta. The following treatments were employed:

P1 = Organic phenol in feed, without excreta fermentation;
P2 = Organic phenol in feed, with excreta fermentation;
P3 = Without organic phenol in feed, without excreta fermentation; and
P4 = Without organic phenol in feed, with excreta fermentation.

The observed variables included: quantity of substrate, fresh BSFL harvest weight, percentage of fresh BSFL to substrate, dry BSFL weight, frass weight, BSFL flour yield, percentage of fresh to dry BSFL shrinkage, and frass conversion percentage. Fresh maggots were obtained from the results of bioconversion after 18 days, during the pre-puppa phase, by separating BSF maggots from the frass. Furthermore, fresh maggot was weighed, and then dried using a microwave (drying method) at 75 °C for 30 minutes (Ayuningtias *et al.*, 2024). The moisture content of fresh maggot ranged from 73.5% to 79.1%, while the moisture content of dried maggot ranged from 6.63 to 6.89 percent. The following formulae were used to calculate the observed variables (Ayuningtias *et al.*, 2024).

Fresh BSFL to substrate (%) = $\frac{Fresh\ BSFL\ harvest\ weight}{Quantity\ of\ substrate} \times 100\%$ ....(1)

Fresh to dry BSFL shrinkage percentage (%) = $\frac{(Fresh\ BSFL\ harvest\ weight - dry\ BSFL\ weight)}{Fresh\ BSFL\ harvest\ weight} \times 100\%$.......(2)

Frass conversion (%) = $\frac{Frass\ weight}{Quantity\ of\ substrate} \times 100\%$ ....(3)

Phase 2 aimed to identify and compare the technical performance and economic potential of the quail-BSFL integrated farming model with the non-integrated one. The observed integration model is as follows:

T1 = Integrated farm and has BSFL flour production activities;
T2 = Integrated farm and without BSFL flour production activities;
T3 = Conventional quail farm in one of the smallholder farms.

In this phase, primary data were collected through direct observation during the research and surveys of non-integrated quail farms, as well as surveys of the market prices of fresh BSFL, BSFL flour, and frass. To corroborate the primary data, secondary data were collected from the financial reports of the BSFL cultivation business and other documents obtained from the Central Bureau of Statistics (BPS), journals, related agencies, and previous research.

The observed and calculated variables included: egg production, quail-days, egg revenue, fresh BSFL revenue, BSFL flour revenue, frass fertilizer revenue, feed costs, total

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revenue, and Income Over Feed Cost (IOFC). The following formula was used to calculate revenue and IOFC:

TR = P × Q……………………………………………………………………………………..(4)

Description:
P = Selling price per unit
Q = Quantity of goods sold (fresh BSFL or BSFL flour or frass fertilizer)
IOFC = Total Revenue – Feed Cost (5)

For the additional revenue from the integrated farming business (fresh BSFL, BSFL flour, or frass fertilizer), we simulated the potential revenue based on the prevailing market price. This approach was adopted due to the absence of sales during the research activities.

Phase 3 aimed to gain a deeper understanding of farmers' perceptions, knowledge, and factors influencing their adoption of BSFL. Data for this phase were collected through a formal survey and in-depth interviews with 11 quail farmers.

The quail farmers were selected using purposive sampling, based on the number of laying quail populations, according the classification by Santi *et al.* (2022): type 1 (350-1000 quail), type 2 (1200-2000 quail), and type 3 (> 2000 quail). The observed variables included the farmers' level of knowledge and perception of BSFL, the importance of feed quality attributes, and the importance of using BSFL-based rations. The data were collected using a questionnaire in the survey, employing a 1-5 Likert scale (Martin-Collado *et al.*, 2021; Shafa *et al.*, 2024).

2.3. Data Analysis

Data from phases 1 were analyzed using analysis of variance, while data from phases 2 were analyzed using descriptive and comparative analysis between farm types. Data in Phase 3 collected through questionnaires and in-depth interviews, were analyzed using descriptive statistics, presenting the percentages of farmers (Likert scale response: 1-5). In this study, we used descriptive analysis with Likert scales to identify patterns and trends in farmers' knowledge and perceptions, as a preliminary step to understand the subject matter. The data obtained were tabulated using Microsoft Excel and analyzed using Minitab 20 and SPSS 22.

3. Results and Discussion

3.1. Circular Economy Model on Quail and BSFL Integration

The results indicate that the quail production system integrated with BSFL has the potential to support a circular economy (Figure 1). Quail farms produce eggs and culled quail as primary products for food. Excreta (waste) is another byproduct. The excreta is used as a substrate for BSFL. BSFL cultivation is carried out for 18 days, starting from the mini-larvae phase (third day after the egg is laid). BSFL is harvested and potentially used as feed for quail in the form of flour and mixed with other feed ingredients to form a ration. The remaining growth media or frass from BSFL cultivation can be used as fertilizer for agricultural activities. This model aligns with previous research, which reported that integrating quail and BSFL farming can support a circular economy with significant benefits (Aziz *et al.*, 2023; Bahtiar and Kamelia, 2023). Quail excreta can be used as a growing medium (substrate) and create a closed-loop system to improve resource optimization (Aziz *et al.*, 2023).

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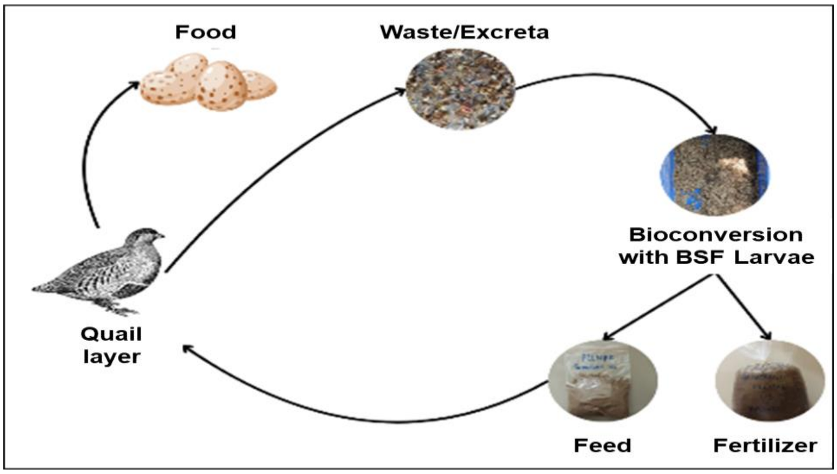

Figure 1. Integrated quail farming model with BSFL cultivation

3.2. Bioconversion Value of BSFL

This study utilized quail excreta from four distinct treatments for bioconversion using BSFL. The analysis of variance showed that each treatment did not significantly affect all observed bioconversion variables (Table 1). However, a total of 81.03 kilograms of excreta was used as substrate, with treatment P4 (32.28 kilograms) demonstrating the highest quantity compared to the other treatments. Consequently, quail reared without exposure to organic phenol produced a greater volume of excreta. This finding aligns with the previous research, indicating that incorporating of phenolic compounds into feed can enhance feed conversion and growth performance by optimizing nutrient utilization, thus reducing excreta production (Abdel-Wahab and Mosad, 2018). However, other research suggests that not all phenolic compounds present in quail feed have a direct effect on excreta quantity, short-term feed conversion ratio, and growth performance (Bayram *et al.*, 2007).

Table 1. BSFL bioconversion performance

Variables	Organic phenol in feed		Without Organic phenol in feed	
	P1	P2	P3	P4
Total quantity of substrate (kg)	11,13	27,24	10,38	32,28
Total of fresh BSFL harvest weight (kg)	1,76	3,89	1,16	3,79
Percentage of fresh BSFL to substrate (%)	15,81±2,08	14,28±1,73	11,15±6,74	11,75±1,97
Total of dry BSFL weight (kg)	0,37	1,03	0,30	0,84
Total of frass weight (kg)	7,89	20,62	6,61	15,22
Total of BSFL flour (kg)	0,37	1,03	0,30	0,84
Percentage of fresh to dry BSFL shrinkage (%)	79,1±2,11	73,5±3,79	74±14,36	77,9±1,88
Percentage of frass conversion (%)	70,83±0,33	75,70±0,32	63,65±7,76	47,15±11,85

*Notes: P1 = Organic phenol in feed, without excreta fermentation; P2 = organic phenol in feed, with excreta fermentation; P3 = without organic phenol in feed, without excreta fermentation; P4 = without organic phenol in feed, with excreta fermentation

This study also demonstrates that the treatment with organic phenol exhibits a higher bioconversion value. This is shown by the higher percentage of fresh BSFL weight produced relative to the substrate quantity in P1 and P2, compared to treatments without organic phenol (P3 and P4). Furthermore, as illustrated in Table 1, treatment with organic phenol (P1 and P2) exhibited a higher percentage of frass conversion compared to the treatment without organic phenol. The highest conversion rate was achieved in P2, reaching 75.7%.

Several key factors influence the capacity of bioconversion. As Naser El Deen *et al.* (2023) have demonstrated, the chemical composition of the substrate, particularly its crude protein and nitrogen content, has a significant impact on larval growth, the waste reduction index (WRI), and conversion efficiency. Additionally, Kusumah (2023) has demonstrated that bioconversion efficiency and the quality of the resulting products are significantly influenced by the presence of specific nutrients and the absence of harmful substances in the BSF maggot growth medium. Concurrently, the research by Widyaswara *et al.* (2022) underscores the pivotal role of substrate composition and moisture content in restraining larval growth, while emphasizing the facilitation of decomposition microorganisms in enhancing the efficacy of organic waste breakdown. The enhanced bioconversion value of BSFL in the treatment with organic phenol may be attributed to the substrate's moisture content.

The fermentation of quail excreta as a substrate for BSFL yielded disparate values, as presented in Table 1. The fermented excreta treatments (P2 and P4) yielded a greater quantity of fresh BSFL, dried BSFL, and frass in comparison to the treatments that did not undergo fermentation (P1 and P3). The weight of BSFL followed the trend of the substrate (excreta) weight in each treatment. Fermentation has been shown to impact the chemical composition and microbial content of excreta, thereby influencing the growth and performance of BSFL. According to Fitrihidajati *et al.* (2015), the fermentation process can enhance crude protein and reduce crude fiber, thereby facilitating the digestive process. Furthermore, research on fermentation in poultry excreta (Ayantola and Imole, 2022) has indicated that physico-chemical properties, including moisture content, ash content, pH, crude protein, and total volatile nitrogen, can undergo enhancement. Furthermore, fermentation has been shown to reduce the presence of potentially harmful bacteria and increase the population of lactic acid bacteria, thereby enhancing the overall quality of the product. The presence of lactic acid bacteria has been shown to positively impact the quality of fermented products by reducing mold growth and harmful mycotoxins (Guan *et al.*, 2023). As previously mentioned by Tang *et al.* (2022), fermentation enhanced the efficiency of organic matter decomposition and the generation of beneficial compounds. The utilization of fermentation products, such as fermented excreta, has been demonstrated to improve the health and performance of animals that consume them (Vinderola *et al.*, 2023). This performance improvement is evident in the increased weight of the animals.

Although not statistically across all treatments, this study highlights the potential of incorporating organic phenolics into quail feed and using fermented excreta as a substrate. The incorporation of these components yielded outcomes that diverged from those observed in the absence of these additions.

3.3. Production Performance and Economic Performance Simulation

This study also analysed and compared the simulation production and economic performance between the quail-BSFL integrated farming model (T1 and T2) with conventional farming models off smallholder farmers (non-integration) (T3). The findings indicated that the production performance of non-integrated farmers surpassed that of their integrated counterparts. This discrepancy was evident in the egg production, quail day, and total revenue. The observed disparities in performance can be attributed to variations in the number of quail populations managed by each farming system. These outcomes align with earlier research that identified group size (population) in meat and egg quails (Santos *et al.*, 2011) and the presence of female quails (Rehman *et al.*, 2022) as key factors influencing production performance. The farmer's experience is also a significant factor. This finding aligns with the conclusions of Wahyuri *et al.* (2014), who posited that the experience of farmers significantly mitigates quail behaviour under stress, thereby enhancing production performance. Experienced farmers have been shown to exhibit superior management skills, particularly in the domains of hatchability, mortality rate, and egg production. The level of egg production is also strongly influenced by the age of the female quail. Female quail in models T1 and T2 were 9 months old, while those simulated in model T3 were 6-7 months old.

Table 2 Comparison of production and economic performance between integrated and non-integrated quail farms

Variables	Type of farm		
	Quail-BSFL integrated farming model (T1)	Quail-BSFL integrated farming model (T2)	Non-Integrated Model (T3)
Egg production (pcs)	3300	3300	9000
Quail Day (%)	32,07	32,07	75
Revenue from egg sales (IDR)	1.320.000	1.320.000	3.600.000
Revenue from fresh BSFL (IDR)	-	105.990	-
Revenue from BSFL flour (IDR)	164.645	-	-
Revenue from frass fertilizer (IDR)	251.660	251.660	-
Total revenue (IDR)	1.736.305	1.677.650	3.600.000
Feed cost (IDR)	1.130.117	1.130.117	2.232.000
IOFC (IDR/pc)	183,69	165,92	152

*Notes: T1 = Integrated farm and has BSFL flour production activities; T2 = Integrated farm and without BSFL flour production activities; T3 = Conventional quail farm in one of the smallholder farms

A key finding of this study is that integrated farms (T1 and T2) show superior economic performance. These findings were derived from calculations using prices at the time the study was conducted. As illustrated in Table 2, integrated farms generate additional revenue from by-products and exhibit reduced costs, thereby achieving higher IOFC. Furthermore, integrated farms have the potential to offer further advantages in terms of social and environmental aspects. For example, quail farm waste (excreta) can be used to mitigate environmental impacts and reduce community protests.

Using by-products as a component of a circular economy can significantly enhance the added value of farms, economically, socially, and environmentally. Research by Hanifah *et al.* (2019) indicated that the incorporation of BSFL can substitute for a portion of commercial feed, thereby enhancing production performance and profitability. Another study reported that the use of BSFL in quail farms has the potential to increase growth and production efficiency by providing alternative high-protein feed ingredients (Koly *et al.*, 2023). Furthermore, the utilization of BSFL has the potential to enhance ecological balance by converting organic waste into alternative protein sources for poultry. Furthermore, frass fertilizer has been shown to improve the economic viability and added value of poultry farming systems, as evidenced by research conducted by (Beesigamukama *et al.*, 2022).

3.4. Knowledge and perception of farmers towards the use of BSFL

To further understand the potential of the integration system, data were collected from quail farmers regarding their knowledge and perception about BSFL. The results indicated that the majority of farmers (over 60 percent) were knowledgeable about the use of BSFL as a feed ingredients (Figure 2). However, most farmers are unfamiliar with the nutritional content of BSFL flour and its benefits as a feed ingredient. Furthermore, a relatively small percentage of farmers (under 40%) expressed a willingness to substitute the animal protein ingredients in their quail rations with BSFL flour.

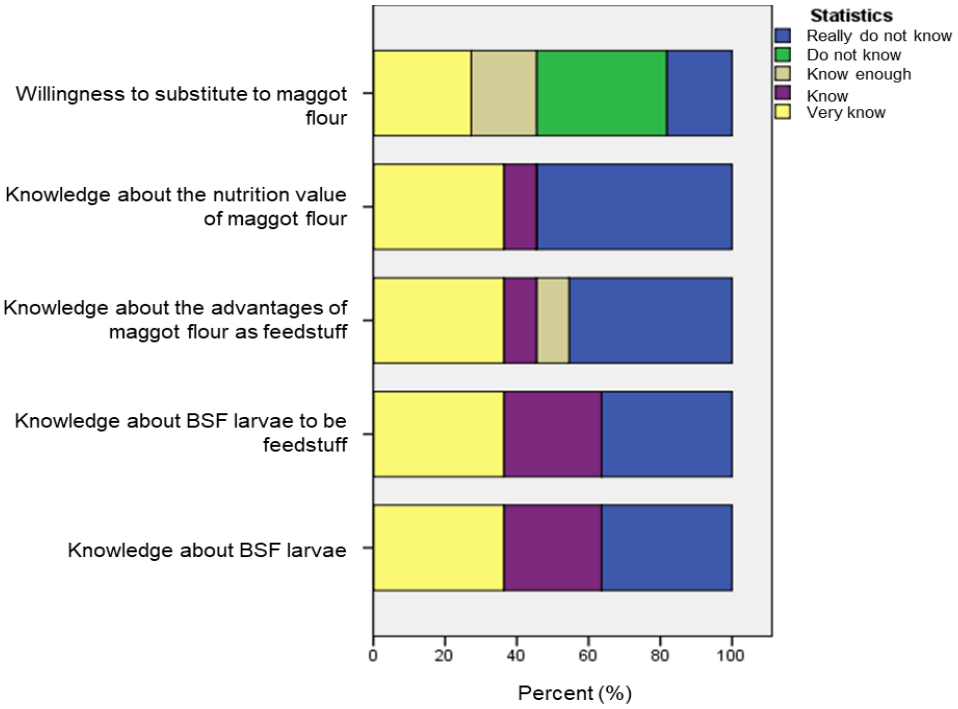

Figure 2. Knowledge and perception of farmers regarding BSFL

Feed quality, characterized by various attributes identified through research, plays a crucial role in the success of quail farming. However, farmers have varying perceptions of the relative importance of different animal feed attributes. The findings of the study indicated that all farmers acknowledged the significance of attributes such as durability, nutritional content, and palatability in terms of feed quality (Figure 3). In contrast, a smaller proportion of farmers (under 50%) considered packaging design and color to be significantly important.

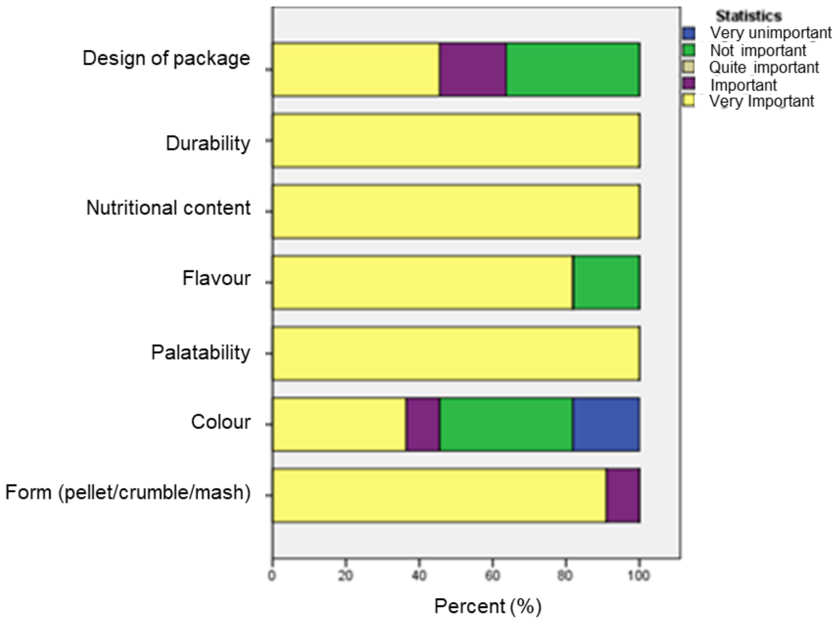

Figure 3. Level of importance of animal feed quality attributes

This study identified factors considered significant by quail farmers regarding the use of BSFL flour as an alternative feed ingredient. All farmers indicated that product quality, competitive pricing, accessibility, continuous availability, consumer satisfaction, and technical services were very important factors when considering the use of BSFL flour, both for personal use and for sale (Figure 4). However, not all farmers considered product information, product appearance, and product certificates as significant.

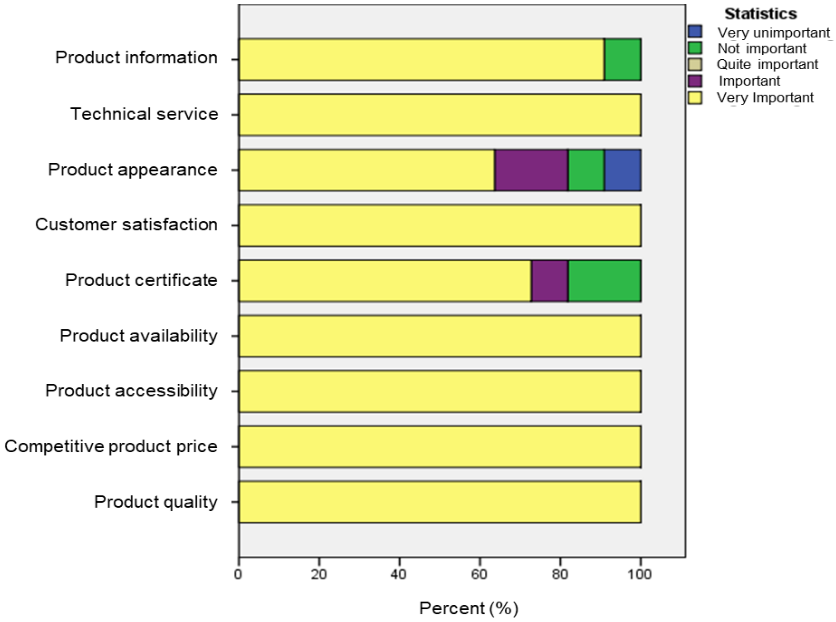

Figure 4. Important factors in using BSFL as an alternative feed ingredient

The use of BSFL offers several advantages, including enhanced economic performance (Mohapatra *et al.*, 2023), improved animal nutrition and health (Citra *et al.*, 2019; Hatab *et al.*, 2020), and enhanced environmental sustainability (Makinde, 2015). However, our study generally found that farmers' knowledge and perceptions of farmers still varied, particularly concerning the quality of feed from BSFL. This finding aligns with the conclusions of Shafa *et al.* (2024). Furthermore, Sajid *et al.* (2023) noted that a significant challenge for farmers in adopting BSFL is the perception of both farmers and the feed industry regarding the advantages and disadvantages of BSFL. Farmers need assurance regarding the quality and sustainability of production. Addressing this challenge is crucial for enhancing the prospects of successfully integrating of quail farming with BSFL cultivation. Nurdin *et al.* (2024) further emphasized the importance of educational initiatives to improve farmers' understanding of the benefits of BSFL, thus promoting its wider acceptance and adoption.

The findings of this study are particularly interesting because they suggest that farmers' knowledge and perception of BSFL can positively influence their decision to use it on their farms. Education, training, and mentorship in technical and economic aspects, along with facilitating access to capital, can enhance the appeal and effectiveness of integrated quail farming.

4. Conclusion

In conclusion, the utilization of BSFL has considerable potential to improve production performance, as well as economic, social, and environmental sustainability. However, to further promote adoption, it is essential to consider farmers' knowledge and perceptions. The integration of organic phenol in quail feed, along with fermented excreta as a substrate for BSFL, has been identified as a potential key element in achieving optimal bioconversion value. At the farm level, integrated quail farming has the potential to achieve better economic performance by generating added value from BSFL cultivation as feed and fertilizer. However, it is essential to recognize that farmers' knowledge and perceptions of the benefits of BSFL as feed, and the factors influencing their adoption of BSFL as an alternative feed, vary.

A notable limitation of this study is the small sample size in phase 1 and the limited number of participating farmers. To enhance the robustness of the research findings, future studies should use more rigorous designs with a larger sample size and more repetition. The study's findings highlight the need for educational initiatives, training programs, and mentorship to improve the effectiveness and success of integrating quail farming with BSFL.

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