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Sustainability of Coffee Farming with the Application of Biopesticides of Angel's Trumpet White Flower (*Brugmansia Suaveolens Bercht. & J. Presl*) and Mahogany Leaves (*Swietenia macrophylla*)

Dedi Arta Putra[1*], Aminudin Afandhi[2], Rita Parmawati[2]

[1] Master's Program Environmental Resource Management and Development, Brawijaya University, Malang, Indonesia.
[2] Department of Postgraduate Programs, Brawijaya University, Indonesia.

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Corresponding Author:
Dedi Arta Putra
dediarta@student.ac.id

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Abstract: This study examines the sustainability of coffee farming in Ledug Village, Prigen, through the application of natural biopesticides derived from mountain brugmansia flowers (Brugmansia suaveolens) and mahogany leaves (Swietenia macrophylla). The research evaluates sustainability across five key dimensions: ecological, economic, social, technological, and institutional. Using Multi-Dimensional Scaling (MDS) Rapfish, SWOT, and QSPM methods, the findings reveal that the ecological dimension achieved a sustainability index of 76.41%, indicating a moderately sustainable status, with the use of chemical fertilizers identified as a critical sensitive factor. The economic dimension scored 65.48%, with market competitiveness and long-term profitability as main drivers. The social dimension reached 68.79%, influenced by farmer education, training, and overall well-being. Technological sustainability was measured at 62.74%, highlighting the importance of innovation and access to farming technology. Institutional sustainability was supported by mentoring programs with a high leverage score. Based on SWOT analysis, the WO strategy was prioritized to improve sustainability by enhancing partnerships, expanding market access, and fostering innovation. QSPM analysis emphasized two strategic actions: promoting eco-friendly coffee products using natural biopesticides and collaborating with NGOs to implement environmentally sustainable technologies. Recommendations include reducing chemical inputs, strengthening institutional support, and increasing farmer capacity through training.

Keywords: Biopesticides; Coffee farming; MDS-Rapfish; Strategic planning sustainability

Introduction

The use of conventional chemical pesticides in coffee farming has raised concerns about their impact on the environment, human health, and agricultural sustainability. Continuous exposure to chemical pesticides can lead to the development of resistant pest populations, making the pesticides ineffective over time (Hansen et al., 2001). Ledug is a village located in the Prigen subdistrict of Pasuruan Regency, East Java, with geographical coordinates of 7°53'46.884''S and 112°36'8.638''E, situated about 5.85 km southeast of the subdistrict center. The village borders Dayurejo to the south, Pecalukan to the north, Sukoreno to the east, and

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Sapen Forest to the west (Badan Pusat Statistik Pasuruan, 2021).

In Ledug, the main types of coffee grown are Arabica, Robusta, and Excelsa, with Arabica being the dominant variety, accounting for around 70% of the total production. Arabica coffee is known for its superior taste, characterized by a smoother and more aromatic flavor compared to other types of coffee. It thrives in Ledug's highland climate, which has cool temperatures and high humidity. However, coffee farmers in the region face several challenges that impact the sustainability of their farming practices. These challenges include climate change, which causes fluctuations in temperature and rainfall that can significantly affect coffee production. Pests such as coffee stem borers and aphids, as well as diseases like leaf rust, also pose serious threats. Additionally, soil erosion, especially in hilly areas, further depletes soil fertility despite efforts to implement terracing. The instability of coffee prices and the reliance on local markets create additional social and economic pressures for farmers. Therefore, it is crucial for coffee farmers in Ledug to adopt more environmentally friendly and sustainable farming practices to enhance resilience to these challenges (Aji et al., 2016).

Biopesticides provide a promising alternative to chemical pesticides, as they help maintain a natural balance between pests and their natural predators, supporting ecosystem sustainability. By using biopesticides, farmers can control pest populations effectively without harming the surrounding ecosystem. Moreover, biopesticides can improve the quality and safety of the coffee produced by reducing harmful pesticide residues, making the coffee safer for consumers (Anam et al., 2019). In Ledug, particularly on the slopes of Mount Arjuno around the Sapen Block III Forest, biopesticides have been applied by coffe farmers establisehd 2021. According to Ainiyah et al. (2023), plants such as *Brugmansia suaveolens* (White Trumpet Flower) and mahogany leaves (*Swietenia macrophylla*) have been identified as potential biopesticide ingredients due to their antioxidant properties. These plants contain flavonoids, including rotenone, which act as insecticides. This biopesticide effective in controlling the coffee berry borer (Hypothenemus hampei), a common pest in the region. The secondary metabolites in these plants act as toxins, accelerating the death of H. hampei. According to Rahmawati et al. (2024), the higher the concentration of plant-based insecticides, the greater the amount of secondary metabolites, which increases the toxicity and effectiveness of the biopesticide. If the coffee berry borer can be controlled, it is expected that coffee production in the Sapen Forest area by farmers in Ledug will increase, improving both the quantity and quality of the coffee.

This study aims to evaluate the sustainability of coffee farming in Ledug Village, Prigen, focusing on the ecological, economic, social, and institutional dimensions. Specifically, this research will examine how the use of biopesticides made from Brugmansia suaveolens and Swietenia macrophylla contributes to sustainable coffee farming practices, with the goal of identifying the sensitive attributes of each dimension. By evaluating these factors, the study will provide an overview of the sustainability index of coffee farming in the Ledug subdistrict, which can be enhanced by analyzing it using SWOT-QSPM. It is hoped that this research will be used as a basis for policy recommendations to support more sustainable coffee farming, both in Ledug Village and potentially for other coffee farming areas.

Method

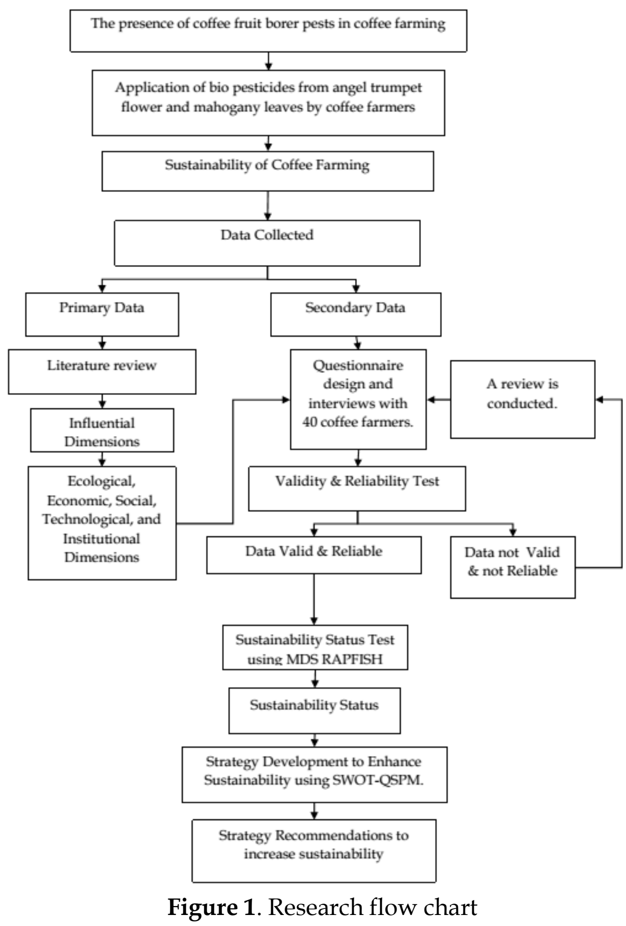

Figure 1. Research flow chart

This study employs a mixed-method approach, combining both descriptive quantitative and qualitative research designs as shown at figure 1. Primary data were collected through interviews with coffee farmers, surveys, and field observations, while secondary data were gathered from literature reviews and documentation. Data analysis was performed using several methods, including RAPFISH Multi-Dimensional Scaling (MDS) to calculate the sustainability index, SWOT analysis for internal and external factor evaluation, and the Quantitative Strategic Planning Matrix (QSPM) to develop sustainability strategies.

Table 1. Research Variables

Dimension	Attributes
Ecological Dimension	Availability of Local Organic Material Sources
	Biodiversity and Surrounding Ecosystems
	Use of Chemical Fertilizers and Pesticides
	Soil Characteristics
	Rainfall and Seasonal Patterns
Economic Dimension	Production Costs
	Farmers' Income
	Market Competitiveness
	Resource Efficiency
	Long-term Profit
	Market Access
Social Dimension	Social Awareness
	Community Involvement
	Farmers' Quality of Life
	Education and Training
	Social Relationships
	Influence on the Younger Generation
Technology Dimension	Ease of Technology Implementation
	Technology Access
	Technology Innovation
	Technology Support
	Ease of Accessing Technical Information
	Technology Effectiveness
Institutional Dimension	Government Policies
	Regulations and Legislation
	Support Programs
	Partnerships with Institutions
	Extension Services and Education
	Access to Financing

The main objective of this study is to assess and analyze the sustainability status of the ecological, social, economic, institutional, and technological dimensions associated with the use of biopesticides made from *Brugmansia suaveolens* (Angel's Trumpet White Flower) in the Sapen Forest area of Ledug District, located on the slopes of Mount Arjuna, using the MDS method. Each dimension consists of 5 to 6 attributes, resulting in a total of 29 attributes across all dimensions as shown at Tabel 1. The sustainability attributes in this study are based on direct field observations, which reflect the actual conditions in the study area.

The population in this study consists of coffee farmers in the Sapen Forest area of Ledug Village, Prigen District, Pasuruan Regency, East Java Province, who use biopesticides made from *Brugmansia suaveolens* and mahogany leaves. However, the study lacks clarity on the extent to which these biopesticides are used in the area. The sample for this study was selected using purposive sampling techniques, with 40 farmers chosen based on specific criteria that only farmers are using bio pesticide in Ledug Village.

Validity and reliability testing are crucial for evaluating the effectiveness of a research instrument, such as a questionnaire. Validity testing measures whether the instrument accurately measures what it is intended to measure. This study uses three types of validity: content validity, construct validity, and criterion validity. Content validity ensures the questionnaire covers all aspects of the concept being measured. Construct validity tests whether the instrument measures the intended theoretical construct, and criterion validity checks if the questionnaire results align with predefined external criteria. Statistical methods like exploratory and confirmatory factor analysis are used to test construct validity (Rifani et al., 2021).

After conducting validity and reliability testing, the next step is determining the sustainability status of using biopesticides made from angel's trumpet white flower and mahogany leaves using the Multidimensional Scaling (MDS) method. The process of determining the sustainability status of biopesticide use based on mahogany leaves and angel's trumpet white flower for coffee farming on the slopes of mount arjuna is carried out using RAPFISH in Microsoft Office Excel. The output generated from the MDS RAPFISH method includes sustainability status, leverage analysis to identify sensitive attributes affecting sustainability, and the calculation of uncertainty dimensions using Monte Carlo analysis (Susianah, 2018).

Table 2. Sustainability Index (Susianah, 2018)

Sustainability Index Scale	Sustainability Status
0% - 25.00%	Unsustainable
25.01% - 50.00%	Less Sustainable
50.01% - 75.00%	Fairly Sustainable
75.01% - 100.00%	Sustainable

Next, the sensitivity analysis output from the MDS RAPFISH is subjected to a SWOT analysis to assess the strengths, weaknesses, opportunities, and threats faced by a company. SWOT compares external factors such as opportunities and threats with internal factors like strengths and weaknesses. Internal factors are placed into a matrix called the Internal Strategic Factor Analysis Summary (IFAS). External factors are placed into a matrix called the External Strategic Factor Analysis Summary (EFAS). After the internal and external strategic factor matrices are compiled, the results are then incorporated into a quantitative model, which is the

SWOT matrix, to formulate the company's competitive strategy (Rangkuti, 2015).

Next, an assessment is conducted using the Quantitative Strategic Planning Matrix (QSPM). According to David (2017), QSPM is a tool that allows strategists to evaluate alternative strategies objectively, based on previously identified external and internal critical success factors. Like other strategy formulation tools, QSPM requires sound intuitive judgment. The QSPM evaluation results in all QSPM components, including key factors, weight alternatives, attractiveness scores (AS), total attractiveness scores (TAS), and the overall total attractiveness score. Thus, this method can provide a detailed overview of the sustainability status of coffee farming and produce an output in the form of strategies to improve the sustainability value in coffee farming in Ledug Village, Prigen.

Results and Discussion

Based on the RAPFISH analysis results, the sustainability value of coffee farming using biopesticides made from angel's trumpet white flower and mahogany leaves shows variation in each dimension analysed.

Table 3. Output RAPFISH

Dimension	Sustainability Index (%)	Stress	R2	Monte Carlo	Sustainability Status
Ecology	76.41	0.270846	0.909927	96.51	Sustainable
Economy	65.48	0.2796	0.910608	65.57	Fairly Sustainable
Social	68.79	0.270799	0.921226	72.23	Fairly Sustainable
Technology	62.74	0.279385	0.909931	60.91	Fairly Sustainable
Institutional	60.31	0.277851	0.902728	53.03	Fairly Sustainable

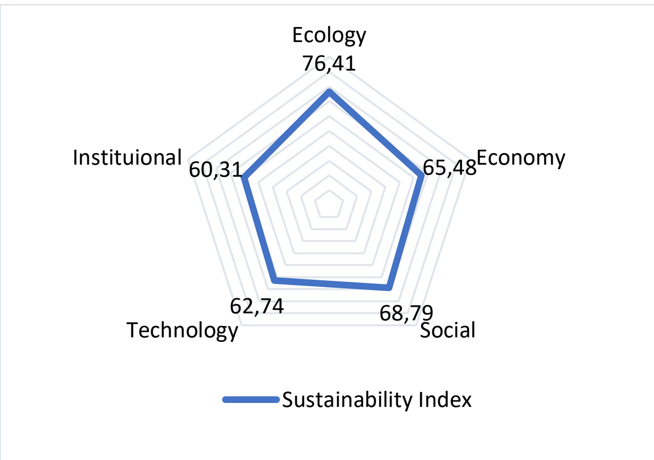

Figure 2. Kite Diagram of sustainability index

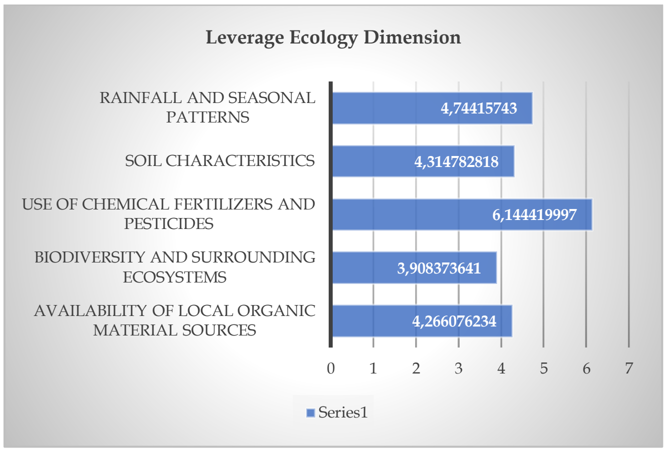

Figure 4. Sensitive atribute ecology dimension

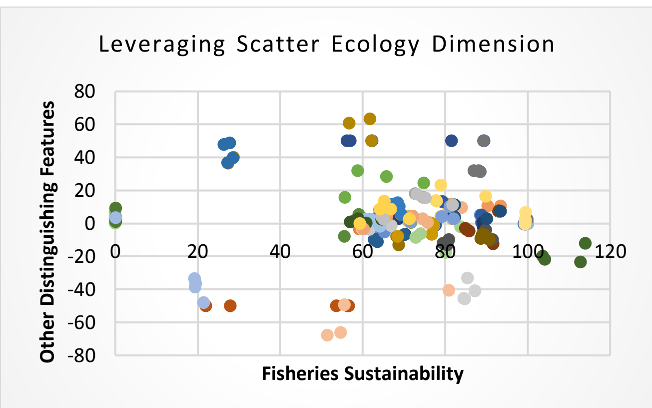

Figure 3. Leverage ecology dimension

Ecological Dimension: The ecological sustainability score is 76.41%, indicating that the application of biopesticides moderately supports environmental sustainability. However, dependence on chemicals is still a major challenge.

Ecological Dimension: The ecological dimension is a fundamental aspect considered in maintaining the balance of natural resources and the environment to ensure greater sustainability. In this study, the ecological dimension consists of five attributes: seasonal patterns, soil characteristics, chemical fertilizer and pesticide use, biodiversity and surrounding ecosystem, and the availability of local organic materials.

Based on Figure 3, the sustainability index for the ecological dimension related to the use of biopesticides made from mountain brugmansia flowers and mahogany leaves in the coffee farming area of the Sapen forest block, Ledug Village, Prigen District, was 76.41%, indicating a moderately sustainable category. Figure 4 presents the leverage values that indicate the sensitive attributes affecting the ecological dimension. Parmawati et al. (2024) state that sensitive attributes in leverage analysis have the highest Root Mean Square (RMS) values. The use of chemical fertilizers and pesticides is the most sensitive attribute for sustainability in this study (RMS: 6.14). This is supported by field observations and interviews showing that some farmers in the Sapen coffee block still use chemical pesticides, though in relatively small amounts, and are now gradually transitioning to biopesticides.

The application of biopesticides derived from mountain brugmansia flowers and mahogany leaves in the Sapen Forest Block serves as an effective strategy to reduce dependence on chemical pesticides, which are known to cause soil and water pollution as well as disrupt ecosystem balance (Sinambela, 2024). By using natural, forest-based biopesticides, the risk of harmful residue accumulation in the soil can be minimized (Aulya et al., 2024), while also preserving soil microorganisms that play a vital role in decomposition and nutrient release for coffee plants.

Seasonal patterns (RMS: 4.74) were identified as the second most sensitive attribute after chemical fertilizer and pesticide use. Increasing climate variability poses a potential threat to the effectiveness of biopesticide use, especially in terms of application timing and the resilience of active compounds to extreme environmental conditions. Field observations revealed that the application of biopesticides does not follow a fixed schedule, typically occurring 2–3 times every 6–8 months or depending on pest attacks. Indonesia's unpredictable seasonal patterns may reduce the effectiveness of biopesticides, necessitating well-timed application intervals during both the rainy and dry seasons to achieve optimal results.

The availability of local organic materials (RMS: 4.26), such as mountain brugmansia flowers and mahogany leaves—the main ingredients for the biopesticide—must be managed sustainably to avoid disrupting the surrounding ecosystem balance. Although the mountain brugmansia is endemic to the Sapen Forest area (Ainiyah et al., 2023), coffee farmers and local communities are making efforts to cultivate biopesticide-producing plants. Farmers independently propagate the plants by seedling cultivation to ensure the availability of raw materials without threatening the sustainability of local natural resources.

Biodiversity and the surrounding ecosystem (RMS: 3.90) are key aspects influencing ecological sustainability. The use of brugmansia-based biopesticides helps maintain the ecological balance in the Sapen Block by not harming non-target organisms such as bees, natural pest predators, and other plant and animal species involved in sustainable agricultural systems (Aulya et al., 2024). According to observations and interviews, coffee farmers in the Sapen area practice intercropping with vegetables and fruits between coffee trees. Field observations also revealed that many shrubs and native plants still grow in the coffee plantations, indicating that flora in the Sapen coffee farming area remains in good condition and is not negatively impacted by biopesticide use.

Overall, the use of biopesticides based on mountain brugmansia and mahogany leaves has a significant positive impact on maintaining ecological sustainability in coffee farming within the Sapen Forest Block. By reducing reliance on chemical pesticides, adjusting biopesticide application schedules in accordance with seasonal changes, and ensuring sustainable access to local organic materials, agricultural ecosystems can be preserved without sacrificing productivity. Therefore, ecological sustainability in coffee farming should be supported by an integrated approach, including farmer training on biopesticide use, the implementation of agroforestry practices, and the strengthening of sustainable agricultural policies to ensure long-term ecological benefits.

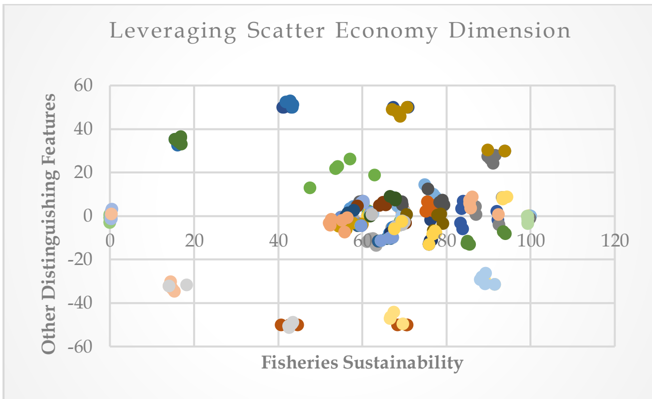

Figure 5. Leverage economy dimension

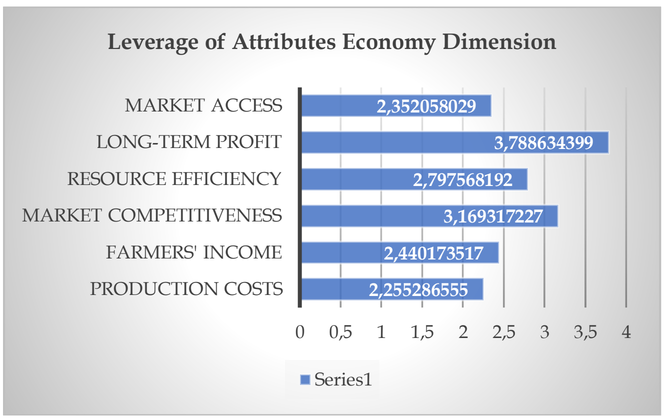

Figure 6. Sensitive atribute economy dimension

The economic dimension consists of six attributes: market access, long-term profit, resource efficiency, market competitiveness, farmer income, and production costs. Based on the results of sensitivity analysis (Leverage Analysis), the attribute with the highest RMS value is long-term profit, as shown in Figure 6.

Leverage analysis based on Figure 6 indicates that the values of influential factors within the economic dimension fall within the range of 2% to 4%. According to Pitcher et al. (2001), when the influence factors are evenly distributed between 2% and 6%, and no factor exceeds 8%, there is no dominant attribute in the dimension. This indicates that each attribute contributes to the economic sustainability of the coffee plantation.

As shown in Figure 5, the economic sustainability value of coffee farming in the Sapen Forest Block is 65.48%, which falls into the moderately sustainable category. Based on Leverage Analysis (Figure 6), the most sensitive attribute in the Economic Dimension is long-term profit (RMS: 3.79).

The use of natural biopesticides has the potential to reduce production costs compared to chemical pesticides, which are often expensive and dependent on imports (Daraban et al., 2023). This aligns with field findings, where farmers experienced profitability over two years of biopesticide use. However, with consistent application, economic analysis is needed to determine the profit difference achieved. By utilizing locally available natural materials, farmers are expected to save on input costs, allowing profit margins to remain stable over the long term. Moreover, biopesticide use can reduce the risk of dependence on chemical products whose prices fluctuate in the market (Rufo et al., 2024). Economic sustainability can be improved through this cost-efficiency, enabling farmers to maintain their income over longer periods.

Coffee competitiveness is the second most sensitive attribute in determining economic sustainability (Kusuma et al., 2025). The use of natural biopesticides enables the coffee produced to potentially meet organic or eco-friendly standards, which have a higher market value in premium segments. However, according to field findings, coffee cultivated with biopesticides has not yet gained significant consumer attention, and prices remain comparable to conventionally grown coffee. It is expected that the use of biopesticides will enhance the competitiveness of coffee from the Sapen Forest Block in both local and international markets through campaigns supported by government, academic institutions, and NGOs. These campaigns would raise consumer awareness of sustainability and health, giving pesticide-free coffee a better chance to achieve premium pricing. With the right marketing strategy, biopesticide use can become a value-added feature for product differentiation, increase farmers' bargaining power, and expand access to more profitable market segments.

Production costs, with the lowest leverage value (2.25), indicate that this attribute has the least influence on economic sustainability. This is supported by field interviews showing that farmers who have switched to using biopesticides made from mountain brugmansia flowers and mahogany leaves can reduce production costs by up to 100%. The cost of chemical pesticides was previously IDR 500,000 per hectare per harvest, while biopesticide use incurs zero cost.

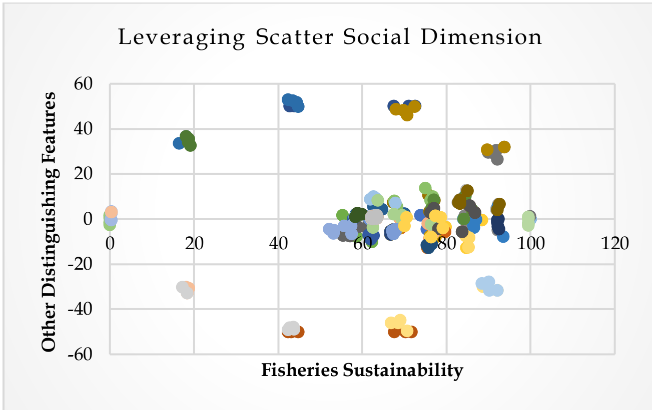

Figure 7. Leverage social dimension

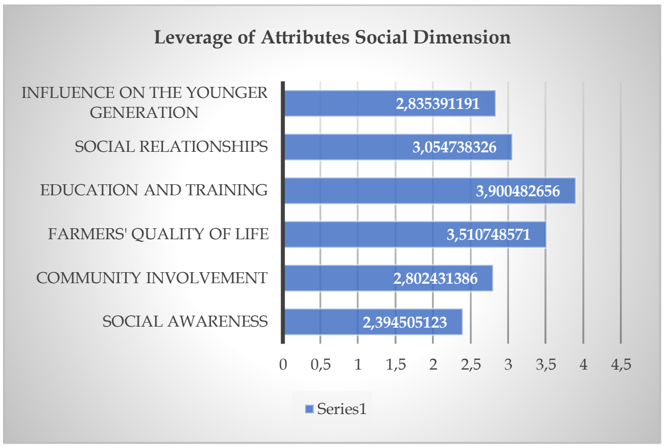

Figure 8. Sensitive atribute social dimension

Based on Figure 7, the social sustainability index of coffee farming in the Sapen Forest Block is 68.79%, placing it in the moderately sustainable category. According to the Leverage Analysis results (Figure 8), the most sensitive attribute within the Social Dimension is education and training (RMS: 3.90), followed by farmers' quality of life (RMS: 3.51).

The leverage analysis for the social dimension indicates that the most sensitive attribute in coffee farming in the Sapen Forest Block using biopesticides made from Brugmansia suaveolens and mahogany leaves is education and training. This attribute potentially impacts all three aspects—farmer skills, economic well-being, and community solidarity.

Questionnaire results showed that 52.5% of participants had completed junior high school, 30% high school, and 17.5% elementary school. Low levels of formal and informal education affect optimal coffee farm management, though this is often compensated by farmers' experience (Parmawati et al., 2022). Education and training play a crucial role in supporting social sustainability. In practice, applying biopesticides requires knowledge about dosage, application methods, and their effects on pests and the agricultural ecosystem. Thus, enhancing farmers' capacity through systematic education programs is essential to maximize the effectiveness of biopesticides. The involvement of academics, agricultural institutions, and farmer organizations in training and outreach can accelerate the widespread adoption of this technology. In addition, disseminating information through farmer forums, digital media, and field demonstrations can be an effective strategy to ensure equal knowledge access among all farmers.

Aside from education, the quality of life of farmers is another significant factor influencing the social sustainability of coffee farming. The use of natural biopesticides can contribute to improved farmer well-being through several mechanisms. First, in terms of health, biopesticides are safer compared to chemical pesticides, which pose toxic exposure risks (Sinambela, 2024)(. Second, economically, utilizing locally available natural materials can reduce production costs, allowing farmers to avoid the fluctuating prices of chemical pesticides (Aulya et al., 2024). Therefore, economic sustainability can also be improved through cost efficiency and long-term income stability. However, to fully realize these impacts, support from government and farmer cooperatives is needed, particularly in market access and the promotion of eco-friendly coffee.

Social relationships within farmer communities also play an important role in achieving social sustainability. The use of biopesticides can strengthen social bonds by encouraging knowledge-sharing practices and building solidarity among farmers. The need to share information and experiences in producing and applying biopesticides fosters greater social interaction (Hanim et al., 2024). Social sustainability can also be enhanced through the formation of farmer groups focused on sustainable agricultural practices. This aligns with observations in which farmers in Sapen are members of such groups, making it easier to disseminate information and education among them.

Social awareness is the most influential attribute in the social dimension. Field interviews and observations revealed that Sapen farmers demonstrate a strong willingness and self-awareness to use biopesticides as a means of preserving the ecosystem in the Sapen Forest. They also take the initiative to share their experiences in using locally sourced biopesticide materials with other farmers through farmer group forums.

Based on this analysis, it can be concluded that the social dimension plays a vital role in determining the sustainability of coffee farming through the application of Brugmansia suaveolens and mahogany-based biopesticides in the Sapen Forest Block. The success of enhancing social sustainability depends on farmers' access to education, improvements in economic well-being, and strengthened social relationships within the community. Therefore, an integrated strategy involving multiple stakeholders is necessary to ensure that the adoption of biopesticide innovations is sustainable—not only environmentally but also in supporting farmers' social and economic welfare.

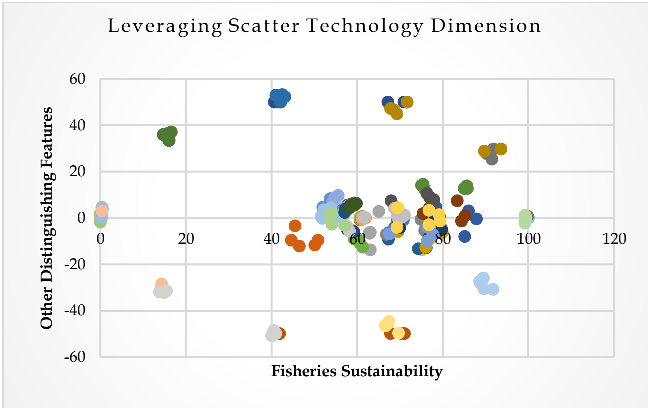

Figure 9. Leverage technology dimension

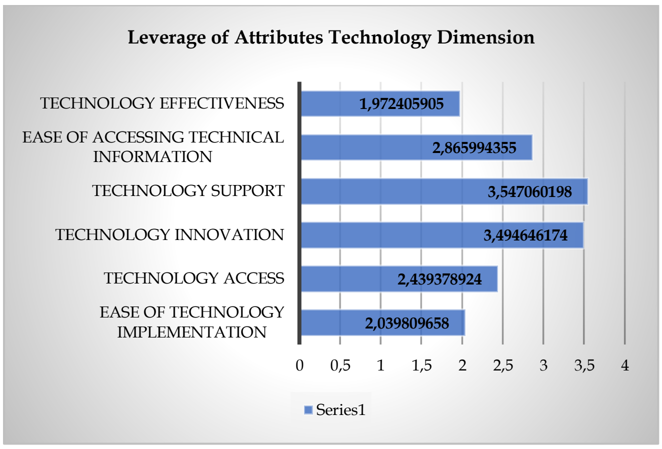

Figure 10. Sensitive atribute technology dimension

Based on Figure 9, the technological sustainability value of coffee farming in the Sapen Forest Block is 62.74%, which falls under the moderately sustainable category. According to the results of the Leverage Analysis (Figure 10), the most sensitive attribute within the Technological Dimension is technological support (RMS: 3.54), followed by technological innovation (RMS: 3.49).

In the context of coffee farm sustainability in the Sapen Forest Block, the technological dimension plays a crucial role in the effective application of biopesticides derived from Brugmansia suaveolens and mahogany leaves. Based on the leverage analysis, the most sensitive attribute is technological support (RMS: 3.55), indicating that the availability of technological facilities and infrastructure is essential in sustaining the use of biopesticides. Without adequate technological support, the effectiveness of biopesticides in controlling coffee pests and diseases may face obstacles in terms of production, storage, and field application. Field observations and discussions with farmers confirm that the development of support facilities such as proper extraction equipment, appropriate sprayers, and farmer training need to be improved, as these are critical to ensuring the sustainability of this innovation.

In addition, technological innovation (RMS: 3.49) is another key factor in the implementation of biopesticides. Developing more stable and long-lasting biopesticide formulations, along with more efficient application methods, can enhance their effectiveness and competitiveness compared to conventional chemical pesticides. Innovations in extraction and fermentation technologies for active compounds from Brugmansia and mahogany leaves can improve biopesticide quality, allowing for more optimal application in coffee farming systems. Furthermore, ongoing research and development in this field must be encouraged to ensure biopesticides can adapt to diverse environmental conditions and farmer needs.

Ease of technology use (RMS: 2.87) and access to technology (RMS: 2.44) also influence how well farmers can sustainably adopt biopesticide technology. If the technologies used in the production and application processes are too complex or inaccessible, adoption rates will be low. Therefore, a more practical approach is needed—such as promoting biopesticide production methods rooted in local wisdom, which are easier for farmers to adopt using available resources in their environment.

Ease of application (RMS: 2.04) and technological effectiveness (RMS: 1.97) indicate that, although biopesticide innovations hold great potential for supporting sustainable coffee farming, successful implementation heavily depends on how easily the technology can be applied in the field and its tangible impact on coffee plant productivity and health. According to field observations and interviews, the use of biopesticides has proven effective in controlling coffee berry borer pests and has no negative effects on coffee yield. Therefore, the integration of technological innovations with farmers' practical needs must be continuously developed, including through training and extension programs, to improve farmers' understanding of the benefits and proper use of biopesticides.

Overall, the technological dimension in the sustainability of coffee farming using Brugmansia suaveolens and mahogany leaf-based biopesticides is strongly influenced by the availability of technological support, continuous innovation, and ease of access and application. Therefore, collaboration among farmers, researchers, and the government is essential to create a technological ecosystem that supports widespread and sustainable use of biopesticides. This can serve as an effective alternative solution for reducing dependence on chemical pesticides and maintaining ecological balance in coffee-growing areas.

Institutional Dimension: With a score of 60.31%, the institutional aspect needs improvement in terms of regulations and policies that support the widespread use of biopesticides.

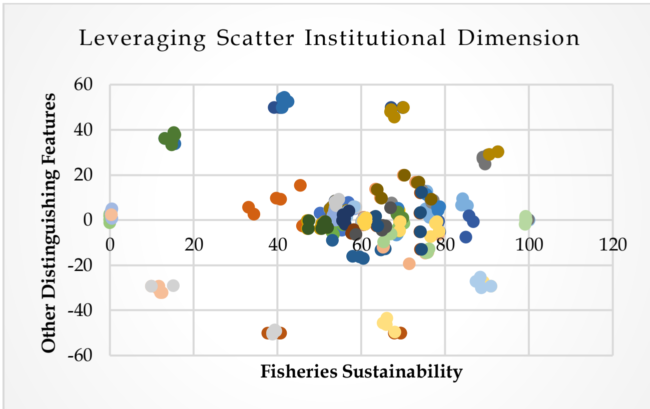

Figure 11. Leverage institutional dimension

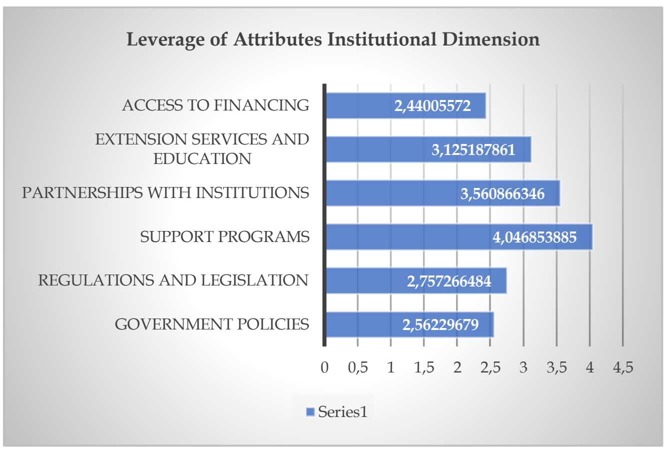

Figure 12. Sensitive atribute institutional dimension

Based on Figure 11, the institutional sustainability score of coffee farming in the Sapen Forest Block is 60.31%, which falls under the moderately sustainable category. According to the Leverage Analysis results (Figure 12), the most sensitive attribute within the Institutional Dimension is the mentoring program

(RMS: 4.05), followed by institutional partnership (RMS: 3.56).

The institutional dimension plays a key role in ensuring the sustainability of coffee farming with the application of biopesticides made from Brugmansia suaveolens flowers and mahogany leaves. Based on the leverage analysis, the most sensitive attribute is the mentoring program (RMS: 4.05), indicating that the involvement of support institutions—including government, academia, and agricultural organizations—is critical in ensuring the sustainable use of biopesticides. An effective mentoring program can help farmers understand how to prepare, store, and apply biopesticides optimally while also enhancing their skills in sustainable agricultural practices. Field conditions observed by the researchers revealed that government-led mentoring programs have not yet been implemented, while training activities have been conducted in collaboration with academics, NGOs, and private companies through CSR initiatives to introduce the use of natural resources, including biopesticides, in Sapen.

Moreover, partnerships with institutions (RMS: 3.56) are also crucial. Collaborations with research institutions, universities, and environmental organizations can support the development of biopesticide technologies and expand distribution networks and adoption among farmers. These partnerships facilitate the transfer of knowledge and innovations, enabling farmers to access the latest information on biopesticide effectiveness and best practices.

Extension services and education (RMS: 3.13) also play a significant role in raising awareness and understanding among farmers regarding the benefits of biopesticides as a more environmentally friendly alternative to chemical pesticides. Ongoing extension activities can help farmers overcome challenges in applying biopesticides, such as determining proper dosages, optimal application timing, and effective mixing methods to enhance their efficacy in controlling coffee pests and diseases.

On the other hand, regulatory and legal frameworks (RMS: 2.76) as well as government policies (RMS: 2.56) contribute to creating a supportive environment for biopesticide development and use. Clear regulations concerning biopesticide production standards and safety are essential to provide farmers with proper guidelines. Additionally, supportive government policies—such as incentives for farmers who adopt environmentally friendly practices—can encourage broader biopesticide adoption.

Access to financing (RMS: 2.44) scored the lowest among all attributes. While most farmers in the area independently finance their biopesticide production due to the low cost, access to credit or financial assistance could help them scale up production. Financial support could be used to acquire extraction equipment, provide training, and conduct further research to improve biopesticide effectiveness. Field observations show that although farmers in Sapen produce biopesticides independently and affordably, enhanced financial support is still needed to improve biopesticide effectiveness and enable broader outreach to other farmers facing similar challenges. Therefore, a dedicated funding scheme is necessary to support innovation and development in sustainable agriculture.

Overall, the institutional dimension holds a strategic role in ensuring the sustainability of coffee farming using biopesticides based on Brugmansia suaveolens and mahogany leaves. Support from various stakeholders, including the government, academia, and agricultural organizations, is essential to build an institutional ecosystem that facilitates broader adoption of biopesticide technologies. A combination of intensive mentoring, strong partnerships, continuous extension services, and supportive regulations will create a more stable environment for farmers to implement more environmentally friendly and sustainable agricultural systems. Monte Carlo testing is used to measure the stability of the analysis results by performing a recalculation simulation to test the impact of data variability on the sustainability index. The Monte Carlo results show that the highest value is found in the ecological dimension (96.51%), followed by social (72.23%), economic (65.57%), technological (60.91%), and the lowest in the institutional dimension (53.03%).

The Monte Carlo test is used to assess the stability of analysis results by simulating recalculations to evaluate the impact of data variability on the sustainability index. According to Pitcher et al. (2001), Monte Carlo simulations are applied to test the robustness of the RAPFISH sustainability index. A difference of more than 10 points from the initial RAPFISH value is considered indicative of index instability due to data variation. The Monte Carlo results show the highest value in the ecological dimension (96.51%), followed by social (72.23%), economic (65.57%), technological (60.91%), and the lowest in the institutional dimension (53.03%).

When compared with the sustainability index values, the greatest difference is found in the ecological dimension, with a deviation of 20.1%. This significant gap between the Monte Carlo simulation and the deterministic sustainability index indicates a high level of uncertainty in the coffee farming system, caused by various factors. Sensitive variables such as the use of chemical fertilizers are the main contributors to fluctuations in the Monte Carlo simulation results. When these factors are randomly simulated 25 times in the

Monte Carlo model, the results show a wide value range, reflecting the vulnerability of the sustainability system to environmental, social, and economic dynamics. Therefore, this high discrepancy emphasizes the need for strategic interventions at sensitive leverage points to enhance the stability and reliability of coffee farm sustainability in the Mount Arjuno slope region.

For future research, several key steps are needed to minimize the gap between the sustainability index and Monte Carlo results, such as validating and calibrating representative input data, using reliable survey instruments with Cronbach's Alpha ≥ 0.70 (Gliem et al., 2003), and increasing the number of simulations to at least 10,000 iterations for improved accuracy. In addition, the influence of fluctuating sensitive or leverage variables should be minimized through policy interventions, accompanied by the selection of probabilistic distributions that match the characteristics of the data. Lastly, adjusting the base value and comparing the mean or median Monte Carlo results with the sustainability index values are essential to ensure the simulations remain statistically valid and do not deviate from the actual system.

Based on the results of the RAPFISH analysis on the sustainability of coffee farming in Ledug Subdistrict, Prigen, five main dimensions were identified as influencing sustainability: ecological, economic, social, technological, and institutional. Each dimension contains strategic factors that contribute to sustainability, as outlined in the RAPFISH leverage factor table. These factors were further analyzed using the SWOT (Strengths, Weaknesses, Opportunities, Threats) method to identify potential strategies by selecting the most sensitive attributes as internal factors. Attributes with the highest leverage values were considered strengths, while those with the lowest were identified as weaknesses. Meanwhile, opportunities and threats were determined based on external factors.

This analysis was grounded in the qualitative data analysis process of Miles and Huberman, as cited in Sugiyono (2019), which includes data reduction by summarizing, selecting key points, focusing on important aspects, identifying themes and patterns, and eliminating irrelevant information. Reduced data provides a clearer picture and facilitates subsequent data collection and retrieval if necessary. Therefore, the data from field findings that have been reduced, particularly those attributes with the highest leverage values that most influence coffee farming sustainability in Ledug, are presented in Table 4.

Table 4. SWOT Analysis Results

Strengths – Internal Positive	Weaknesses – Internal Negative
(S1) Biodiversity and surrounding ecosystem (3.908)	(W1) Use of chemical fertilizers and pesticides (6.114)
(S2) Market access (2.352)	(W2) Long-term profitability (3.789)
(S3) Social awareness (2.395)	(W3) Education and training (3.900)
(S4) Technological effectiveness (1.972)	(W4) Technological support (3.547)
(S5) Access to financing (2.440)	(W5) Mentoring programs (4.047)
Opportunities (External Positive)	Threats (External Negative)
(O1) Government policy support	(T1) Climate change and extreme weather
(O2) Demand for organic products	(T2) Dependence on external inputs
(O3) Technology access from partners/NGOs	(T3) Fluctuations in global coffee prices
(O4) CSR programs/assistance from external institutions	(T4) Lack of chemical substance control

Based on the results of Table 4, the SWOT matrix was constructed and presented in Table 5. The resulting strategies for coffee farming can be categorized into several groups that focus on optimizing internal strengths and leveraging external opportunities. The implementation follows the SWOT analysis matrix, which consists of four quadrants: the first quadrant includes SO strategies, the second covers WO strategies, the third outlines ST strategies, and the fourth consists of WT strategies (Gultom et al., 2024).

SO strategies focus on utilizing the internal strengths of coffee farming in Ledug Village, Prigen, to capitalize on existing external opportunities, particularly those related to sustainability and market demand for environmentally friendly agricultural products. In this context, the use of biopesticides derived from mountain brugmansia flowers and mahogany leaves becomes a key strength that can be leveraged to take advantage of growing consumer awareness about the importance of sustainable and chemical-free agricultural products. The expanding market for organic coffee products, both for domestic consumption and export, allows farmers in Ledug Prigen to introduce their coffee as a flagship eco-friendly product. By utilizing agricultural technologies based on environmentally friendly principles, such as the use of natural biopesticides, coffee farming in this area can align with the trends of organic and green products and expand distribution networks to broader markets. Additionally, support from the government and environmental organizations can open new opportunities in the form of funding or subsidies to scale up the application of biopesticides.

WO strategies aim to address internal weaknesses in coffee farming in Ledug Village, Prigen, by taking advantage of external opportunities. One of the weaknesses that needs to be addressed is the limited knowledge and skills of farmers in effectively managing the use of biopesticides derived from mountain brugmansia and mahogany leaves. To tackle this, existing opportunities can be leveraged through training or outreach programs on the use of natural biopesticides, so that farmers better understand the proper and safe methods of applying these products. Furthermore, strengthening market access and distribution is necessary, as the market for eco-friendly and organic coffee is still limited and requires more intensive efforts in marketing and branding. Partnerships with NGOs or universities that specialize in sustainable agricultural research can help improve the application of organic farming techniques and biopesticides, while also expanding market access for coffee farmers in Ledug Prigen.

ST strategies focus on using internal strengths to overcome external threats that may hinder the sustainability of coffee farming. One of the main threats is competition from non-organic coffee products that use synthetic chemicals for pest and disease control, which are often cheaper and more easily available. In response to this threat, farmers in Ledug Prigen can leverage the use of biopesticides based on mountain brugmansia and mahogany leaves as a competitive advantage that differentiates their product in the market. Additionally, CSR programs that emphasize environmental sustainability can be used to increase market awareness of the benefits of coffee grown with eco-friendly methods. This also strengthens the brand image of Ledug Prigen's coffee as a premium sustainable product. To counter the threat of climate change and natural disasters that may affect coffee yields, farmers can utilize local biodiversity and natural resources to develop farming systems that are more resistant to extreme conditions and more resilient to environmental threats.

Table 5. SWOT Matrix

SO Strategies (Use strengths to seize opportunities)	WO Strategies (Overcome weaknesses using opportunities)
Use biodiversity (S1) to develop eco-friendly coffee for organic markets (O2)	Provide training on biopesticide use (W3) with NGO partners (O3)
Apply biopesticides with tech support (S4) to reach green coffee export markets (O5)	Partner with NGOs (O3) to improve eco-farming technologies (W4)
Partner with NGOs (O3) to boost biopesticide efficiency (S4)	Diversify organic coffee products (W1) to meet growing demand (O2)
Leverage social awareness (S3) and CSR (O4) to promote organic coffee	Use digital marketing (O4) and CSR to support farmers (W5)
Use market access (S2) to promote organic coffee globally (O5)	Conduct entrepreneurship mentoring programs for farmers (W5)
ST Strategies (Use strengths to tackle threats)	**WT Strategies (Minimize weaknesses to reduce threats)**
Promote sustainable coffee via social awareness (S3) to compete with non-organic (T5)	Reduce dependence on external funding (W5) by establishing coffee farmer cooperatives to support self-financing and enhance financial stability amid global coffee price fluctuations (T3).
Use biodiversity (S1) to improve climate-resilient farming (T1)	Develop risk management systems (W4) to address global coffee price fluctuations (T3) by utilizing more efficient coffee processing technologies.
Enhance biodiversity-based practices to adapt to climate (T1)	Conduct training for farmers on the use of natural biopesticides (W3) to mitigate threats from the lack of chemical supervision (T4) in conventional agriculture.
Use market access (S2) to reach eco-conscious global buyers (T3)	Promote income diversification (W5) by developing coffee-derived products and building partnerships with local suppliers to reduce reliance on external inputs (T2).
Invest in distribution tech (W4) to stay competitive against unsustainable coffee (T5)	Improve distribution infrastructure (W4) and use more efficient technologies to support the marketing of organic coffee and compete with non-sustainable coffee products (T5).

WT strategies aim to minimize internal weaknesses while avoiding external threats that may negatively impact the sustainability of coffee farming in Ledug Village, Prigen. One key weakness that needs improvement is the lack of adequate infrastructure to support efficient product distribution and market competitiveness. External threats such as global coffee price fluctuations and uncertainty in agricultural policies can negatively affect farmers' income stability. To address this weakness, farmers can optimize partnerships with government or private institutions to build better distribution infrastructure and enhance market access through digital marketing and proper branding. Furthermore, companies or farmers can reduce dependence on external funding, which is vulnerable to market uncertainty, by developing community-based financing systems such as coffee farmer cooperatives, which can provide financial support and security during difficult times. These strategies allow coffee farming in Ledug Prigen to become more self-reliant, reduce exposure to external threats, and enhance long-term sustainability.

Next, to determine the appropriate strategy, an IFE (Internal Factor Evaluation) and EFE (External Factor Evaluation) analysis was conducted by assigning weights and ratings to each internal and external factor shown at Table 6 and 7. The total values of each category—strengths, weaknesses, opportunities, and threats—were then used to calculate the internal analysis coordinate as the X-axis and the external analysis coordinate as the Y-axis, based on the following formula (Supriyadi et al., 2022):

Strengths value (S) = 1.46
Weaknesses value (W) = 2.04
Opportunities value (O) = 1.14
Threats value (T) = 1.05

$$\text{Coordinate } (X, Y) = ((S - W)/2; (O - T)/2) = ((1.46 - 2.04)/2 ; (1.14 - 1.05)/2) = (-0.288 ; 0.043) \quad (1)$$

Table 6. IFE Table

Category	Internal Factors	Weight	Rating	Weighted Score
Strengths	Biodiversity and surrounding ecosystem	0.07	4	0.28
	Market access	0.08	3	0.25
	Social awareness	0.10	4	0.39
	Technological effectiveness	0.10	2	0.20
	Access to financing	0.08	4	0.34
Total Strength Score				1.46
Weaknesses	Use of chemical fertilizers and pesticides	0.10	3	0.30
	Long-term profitability	0.11	4	0.45
	Education and training	0.11	3	0.34
	Technological support	0.13	4	0.51
	Mentoring programs	0.11	4	0.45
Total Weakness Score				2.04

Table 7. EFE Table

Category	External Factors	Weight	Rating	Weighted Score
Opportunities	Government policy support	0.10	4	0.10
	Demand for organic products	0.12	4	0.12
	Technology access from partners/NGOs	0.12	3	0.35
	CSR programs/assistance from external institutions	0.12	3	0.35
	Green coffee export trends	0.12	3	0.23
Total Opportunity Score				1.14
Threats	Climate change and extreme weather	0.09	2	0.17
	Dependency on external inputs	0.06	2	0.12
	Global coffee price fluctuations	0.10	2	0.30
	Lack of chemical supervision	0.10	2	0.20
	Competition from non-sustainable coffee	0.09	2	0.26
Total Threat Score				1.05

Based on the strategic quadrant analysis derived from the IFE (Internal Factor Evaluation) and EFE (External Factor Evaluation) tables, coffee farming with the application of biopesticides made from Brugmansia suaveolens and Swietenia mahagoni is positioned in Quadrant III, as shown in Figure 13. In analyzing the sustainability of coffee farming in Ledug Village, Prigen, the Cartesian diagram emphasizes the internal weaknesses that must be addressed—particularly the limited knowledge of farmers regarding the use of natural biopesticides. The lack of understanding about biopesticides derived from Brugmansia suaveolens flowers and Swietenia mahagoni leaves represents a key weakness that hinders the optimal application of this eco-friendly innovation. Without adequate understanding, the application of natural biopesticides may yield suboptimal results and negatively affect coffee productivity.

Additionally, the reliance on outdated farming technologies, such as traditional pest control methods, poses a serious challenge that limits farmers' ability to respond effectively to pest attacks and increases the risk of environmental degradation. This highlights the need for a transition toward more efficient and environmentally sustainable agricultural practices to enhance the long-term viability of coffee farming. On the other hand, several external opportunities can be utilized to address these internal weaknesses. Global demand for organic, pesticide-free agricultural products is steadily rising, creating opportunities to introduce organic coffee from Ledug Prigen to broader markets. If the farmers' knowledge gap can be addressed, local coffee farming can expand its market reach and align with growing consumer trends. Collaboration with external partners such as NGOs and research institutions also provides opportunities to introduce more environmentally sound farming technologies. These partnerships can help reduce dependence on outdated methods and facilitate the adoption of natural biopesticides and more sustainable farming systems.

In light of these internal weaknesses and external opportunities, several strategic actions are recommended. First, continuous training should be provided to farmers to enhance their skills in applying natural biopesticides efficiently and safely. Second, partnerships with NGOs and research institutions should be strengthened to support the introduction of modern, sustainable technologies. Third, farmers' market access should be improved through established distribution networks and by leveraging CSR programs that focus on sustainability. Lastly, marketing strategies should emphasize the environmental benefits of organic coffee to attract environmentally conscious consumers.

By implementing these strategies, coffee farmers in Ledug Village will be better equipped to overcome internal challenges, such as lack of biopesticide knowledge and technological limitations. This will position them to take advantage of the expanding organic market. Furthermore, collaboration between local governments, researchers, and NGOs will reinforce the adoption of environmentally friendly technologies and provide essential support to farmers, thereby promoting the long-term sustainability of coffee farming in the region.

To determine the strategy quantitatively, the QSPM (Quantitative Strategic Planning Matrix) method can be used. The selected factors correspond to the strengths, weaknesses, opportunities, and threats identified in the SWOT analysis. These factors are assigned weights based on their level of importance to the overall sustainability of coffee farming. The Attractive Score (AS) values are obtained based on the researcher's judgment. Then, the Total Attractive Score (TAS) is calculated by multiplying each factor's AS by its respective weight from the previously developed SWOT matrix. A comparison of the Sum of Total Attractive Scores (STAS) indicates the priority ranking of each strategic alternative (Sumiarsih et al., 2018).

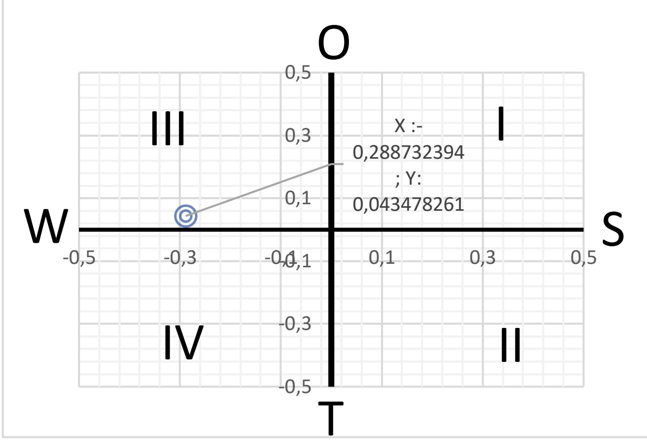

Figure 13. Grand SWOT strategy analysis (cartesius diagram)

Based on the TAS (Total Attractive Score) calculation results for each strategy from the QSPM Matrix analysis in Table 5.8, the highest TAS value was found in SO Strategy Alternative 2, which involves using natural biopesticides derived from *Brugmansia suaveolens* and *Swietenia mahagoni* (S1) to improve the quality of environmentally friendly coffee products, as well as utilizing modern technology (S4) in the production process. This strategy also includes introducing environmentally friendly coffee products to the green coffee export market (O5), with a score of 8.03. This result differs from the Cartesian diagram calculation, which indicated that the highest priority strategy lies in Quadrant II. This discrepancy may be attributed to respondent preferences when completing the questionnaire in response to the strategies offered. Nevertheless, this strategy remains highly relevant for coffee farming in Sapen District, as current consumer behavior and local market trends still show low awareness regarding the consumption of environmentally friendly and health-conscious coffee. Therefore, it is essential to expand the market share, especially targeting export markets with higher awareness of sustainable and health-oriented coffee products. Furthermore, field observations indicate that coffee farmers in Sapen also require technological support, both in the efficient application of biopesticides and in processing technology to increase the value of coffee produced using these biopesticides.

The second highest TAS value was found in WO Strategy Alternative 7, with a score of 5.70. This strategy involves establishing partnerships with NGOs (O3) to optimize the use of environmentally friendly agricultural technologies, thereby increasing production efficiency and reducing dependence on outdated technologies (W4). This approach is also important for facilitating promotion efforts that highlight the benefits of using more eco-friendly biopesticides.

The third highest TAS values were found in two WO strategies: Alternative 6 with a score of 5.56, which involves conducting continuous training for farmers on the use of natural biopesticides derived from *Brugmansia suaveolens* and *Swietenia mahagoni* (W3) by inviting experts or NGOs (O3) with expertise in sustainable agriculture; and Alternative 8, also with a score of 5.56, which involves increasing diversification of organic coffee products (W1) by introducing new chemical-free and environmentally friendly coffee varieties to meet the growing market demand (O2) for organic products.

Table 8. QSPM Analysis Results

Strategy Code	Strategy	TAS
Alternative 2	Use natural biopesticides derived from *Brugmansia suaveolens* and *Swietenia mahagoni* (S1) to improve the quality of environmentally friendly coffee products, and utilize modern technology (S4) in the production process. Introduce environmentally friendly coffee products to the green coffee export market (O5).	8.03
Alternative 7	Establish partnerships with NGOs (O3) to optimize the use of environmentally friendly agricultural technology to improve production efficiency and reduce dependence on outdated technologies (W4).	5.70
Alternative 6	Conduct continuous training for farmers on the use of natural biopesticides derived from *Brugmansia suaveolens* and *Swietenia mahagoni* (W3) by inviting NGOs (O3) with expertise in sustainable agriculture.	5.56
Alternative 8	Increase the diversification of organic coffee products (W1) by introducing new chemical-free and environmentally friendly coffee products to meet the growing market demand (O2) for organic products.	5.56
Alternative 9	Use digital marketing (O4) to expand the reach of organic coffee products to the global market and strengthen CSR programs to assist farmers with marketing.	5.35
Alternative 10	Conduct entrepreneurship mentoring programs for coffee farmers (W5) to help them become more independent in running sustainable coffee farming using natural biopesticides.	5.07
Alternative 12	Improve the quality of organic coffee (S1) by using natural biopesticides to face the threat of competition from cheaper and more accessible non-organic coffee.	4.44
Alternative 13	Use biodiversity (S1) to develop farming practices adaptive to climate change (T1), and reduce the threats posed by climate variability.	4.30
Alternative 11	Utilize social awareness (S3) to promote sustainable coffee and counter the competition from non-organic coffee (T5) through CSR programs focused on sustainability and the use of natural biopesticides.	4.23
Alternative 14	Use biodiversity to develop farming systems that are resilient to climate change (T1) and extreme weather, and reduce threats from natural disasters.	4.23
Alternative 4	Leverage increasing social awareness (S3) of sustainability and environmental issues to promote organic coffee from Ledug Prigen, and integrate CSR focused on sustainability (O4).	4.15
Alternative 20	Improve distribution infrastructure (W4) and use more efficient technology to support the marketing of organic coffee and compete with non-sustainable coffee products (T5).	4.08
Alternative 17	Develop a risk management system (W4) to deal with fluctuations in global coffee prices (T3) by using more efficient coffee processing technologies.	3.94
Alternative 3	Build partnerships with NGOs that have sustainable agricultural technology (O3) to improve the effectiveness of natural biopesticide use in coffee farming (S4).	3.80
Alternative 16	Reduce dependence on external funding (W5) by establishing coffee farmer cooperatives to support self-financing and improve financial stability amidst global coffee price fluctuations (T3).	3.80
Alternative 5	Optimize market access (S2) to introduce organic coffee to the international market, leveraging global trends toward eco-friendly products (O5).	3.66
Alternative 15	Optimize market access (S2) to introduce organic coffee to the international market, focusing on eco-friendly products to mitigate the impact of global coffee price fluctuations (T3).	3.59
Alternative 1	Utilize biodiversity and the surrounding ecosystem (S1) to develop coffee products based on natural biopesticides (*Brugmansia suaveolens* and *Swietenia mahagoni*) that are environmentally friendly, considering the growing demand for organic products (O2).	3.52
Alternative 18	Conduct farmer training on the use of natural biopesticides (W3) to reduce the threat posed by the lack of chemical monitoring (T4) in conventional agriculture.	3.52
Alternative 19	Encourage income source diversification (W5) by developing coffee derivative products and partnerships with local suppliers to reduce dependence on external inputs (T2).	3.45

Alternative 6 should be implemented immediately, as the RAPFISH sustainability analysis shows that the education attribute is relatively strong, indicating the need for training so that farmers can quickly understand and implement the use of biopesticides to enhance the sustainability of their farming practices. Alternative 8 serves as a form of promotion hoped for by farmers in Ledug District—not only to consistently maintain environmental sustainability in their coffee farming, but also to become pioneers for sustainable coffee farming in other regions. The TAS rankings of other alternatives are presented in Table 8.

Conclusion

Based on the research findings on the sustainability of coffee farming using biopesticides derived from *Brugmansia suaveolens* and *Swietenia mahagoni* in Ledug Village, Prigen, it can be concluded that the coffee farming system falls within the "moderately sustainable" category across five key dimensions: ecological, economic, social, technological, and institutional. Ecologically, the sustainability score of 76.41% reflects the potential of biopesticide application in promoting environmentally friendly farming practices, although the continued use of chemical inputs remains a sensitive issue. The economic dimension scored 65.48%, indicating that while biopesticides may help reduce production costs and support long-term profitability, market competitiveness still presents a challenge. The social dimension reached a sustainability level of 68.79%, emphasizing the need to enhance farmer education, training, and quality of life. Technological sustainability, with a score of 62.74%, highlights the importance of adopting and supporting modern agricultural technologies to improve biopesticide efficiency. Institutional support plays a crucial role, particularly through extension programs, government assistance, and collaborations with academic and agricultural institutions, which yielded the highest leverage value (RMS: 4.05). Furthermore, the integrated RAPFISH, SWOT, and QSPM analyses identified two most effective strategic options for implementation. The first, an SO strategy, promotes the use of biopesticides derived from *Brugmansia suaveolens* and *Swietenia mahagoni* to improve the quality of environmentally friendly coffee and to introduce it to the green coffee export market. The second, a WO strategy, involves building partnerships with NGOs to enhance the application of eco-friendly agricultural technologies, aiming to improve production efficiency and reduce dependence on outdated farming methods. To further enhance sustainability, especially in the institutional dimension—which scored the lowest at 60.31%—several recommendations are proposed. These include strengthening farmer mentoring programs focused on sustainable practices, expanding partnerships with external institutions for technology transfer and market access, and increasing educational outreach. Local governments are also encouraged to enact environmentally friendly agricultural regulations and facilitate access to green financing schemes. These efforts collectively aim to reinforce the institutional resilience of coffee farming in Ledug and support the broader goals of sustainable agricultural development.

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Author Contributions

Conceptualization, P.D and A.A.; methodology, R.P.; software, R.P.; validation, P.D, A.A. and R.P.; formal analysis, P.D.; investigation, P.D.; resources, A.A.; data curation, P.D.; writing—original draft preparation, P.D.; writing—review and editing, P.D.; visualization, P.D.; supervision, A.A.; project administration, R.P.; funding acquisition, R.P. All authors have read and agreed to the published version of the manuscript."

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Conflicts of Interest

The authors declare no conflict of interest.

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