

**How to Cite:**

Susilawati, N. K. S., Susrusa, K. B., & Sudarma, I. M. (2025). Sustainability analysis of black rice farming in Penebel District, Tabanan Regency, Bali Province. *International Journal of Economic Perspectives*, 19(7), 95–209. Retrieved from <https://ijeponline.org/index.php/journal/article/view/1116>

## **Sustainability analysis of black rice farming in Penebel District, Tabanan Regency, Bali Province**

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**Abstract**---Black rice (*Oryza sativa* L.) is a high-value functional food commodity that has the potential to support diversification and national food security. However, low productivity and limited market access are obstacles to the sustainability of its cultivation. This study aims to analyze the sustainability of black rice farming in Penebel District, Tabanan Regency, Bali, based on five dimensions: ecological, economic, social, technological, and institutional. The methods used included a Multidimensional Scaling (MDS) approach with RapFarm technique to assess status and sensitive attributes, and Interpretative Structural Modeling (ISM) to formulate priority strategies. Results show that black rice cultivation is at a moderately sustainable status with a score of 62.92. Sensitive attributes include: ecological (level of fertilizer use), economic (market access), social (frequency of extension and training), technological (application of resistant varieties), and institutional (financial institutions). Priority strategies are divided into: shortterm (focused on proper extension and fertilization), medium-term (directed at the use of resistant varieties according to local conditions), and long-term (strengthening farmers' access to financial institutions and markets). The findings are expected to be the basis

for policy formulation in supporting sustainable agriculture, especially in black rice cultivation.

**Keywords**---Black Rice, ISM, MDS, Prioritization Strategy, Sustainability.

## **Introduction**

The food crop sector plays an important role in Indonesia's agricultural development. Rice, as the main commodity, is not only the staple food for most people, but also a source of income for farmers. The high dependence on rice means that its availability must always be maintained in sufficient and sustainable quantities (Suryana et al., 2018). In the midst of global challenges such as environmental degradation, the need for nutritious food, and increasing public awareness of health, innovation in food production systems is important, including through the development of alternative rice varieties that not only meet consumption needs, but also provide added value in terms of health and economy. One rice variety that has high potential to be developed in this context is black rice (*Oryza sativa* L. indica).

Black rice is known to contain bioactive compounds such as anthocyanins and phenols, which function as antioxidants and anti-inflammatories and have the potential to help prevent chronic diseases such as cancer and diabetes (Panda et al., 2022). These advantages encourage increased consumer interest in black rice, especially among people who are increasingly concerned about a healthy diet. Palupi et al. (2023) added that the anthocyanin content in black rice is concentrated in the outer layer of the grain which gives it its characteristic dark color, while the high amylose content makes it slower to digest and helps control blood sugar levels. These advantages, coupled with the increasing awareness of organic food, make black rice more relevant to today's healthy lifestyle trends. In addition, organic black rice is considered safer because it is free from synthetic chemical residues (Sudarwati, 2020), thus opening up wider market opportunities for farmers and agribusiness actors.

Although demand for black rice continues to increase, the development of this commodity at the cultivation level still faces various obstacles. The main challenges faced include a longer planting period compared to white rice, relatively low productivity levels, and limited access of farmers to markets and technical cultivation information (Istanti & Triasih, 2021). This condition causes small profit margins and the sustainability of the farm is vulnerable to disruption. In addition, farmers' low knowledge of efficient organic cultivation techniques and lack of information related to market opportunities also worsen the situation, making it difficult for farmers to optimize yields and reach profitable distribution channels.

One of the areas that has started to develop black rice cultivation is Penebel District, Tabanan Regency, Bali. Since 2017, this region has been recognized as a black rice production center with an increasing planting area (Tabelak, 2020). Penebel has advantages in terms of agroecology and the support of local farmers'

enthusiasm as important capital in the development of this farming. However, this potential has not been fully maximized because there are still structural and technical barriers that limit further development. Without appropriate and integrated interventions, it is feared that the strategic potential of black rice as part of national food diversification and local economic strengthening will not be optimally developed.

Given the complexity of these challenges, a research effort is needed to assess the sustainability status of black rice farming comprehensively through the Multidimensional Scaling (MDS) and Interpretative Structural Modeling (ISM) approaches, with the aim to 1) analyze the sustainability status based on five main dimensions (ecological, economic, social, technological, and institutional), 2) identify sensitive attributes that influence it, and 3) formulate sustainability priority strategies based on the influence structure between elements. Through this approach, the research is expected to make a real contribution in maintaining the sustainability of black rice farming in Penebel District, as well as being a basis for consideration for relevant parties in designing initiatives or policies that support the development of this commodity in the future.

### **Research Methods**

This study used a descriptive quantitative approach supported by qualitative data, with the aim of analyzing the sustainability status of black rice farming in Penebel District, Tabanan Regency, Bali Province. The focus of the analysis was directed at five dimensions of sustainability, namely: ecological, economic, social, technological, and institutional. The research location was determined purposively based on the results of the preliminary study, taking into account the three main black rice producing villages in Penebel District, namely Mangesta Village, Tajen Village, and Senganan Village. The research was conducted during the period January to March 2025. The types of data used in this study include primary data and secondary data. Primary data was obtained through structured interviews using questionnaires and direct documentation from 40 black rice farmers as respondents (using the census method). Secondary data were collected from various sources, including scientific literature, relevant agency reports, and statistical data from government agencies. The variables used included 30 attributes representing the five dimensions of sustainability. These attributes were determined through literature review and consultation with local experts and stakeholders, to ensure validity and relevance in the local context.

Data analysis was conducted in two stages. The first stage used a Multidimensional Scaling (MDS) approach through the Rap-Farm method, which is a modification of RAPFISH. The analysis procedure included rating each attribute on an ordinal scale (0-3), calculating the sustainability index for each dimension, identifying sensitive attributes through leverage analysis (Root Mean Square/RMS), and testing uncertainty using Monte Carlo analysis. The sustainability index results were then classified into four categories, as presented in Table 1.

Table 1  
Index Categories and Sustainability Status

Index Value (%)	Sustainability Status
0,00 - 25,00	Unsustainable
25,01-50,00	Less Sustainable
50,01-75,00	Moderately Sustainable
75,01 -100,00	Sustainable

The second stage uses the Interpretative Structural Modeling (ISM) method to further analyze the sensitive attributes identified in the previous stage. ISM is used to map the relationship between elements in the form of a hierarchical structure through the stages of: element identification, Structural Self-Interaction Matrix (SSIM) preparation, conversion to Reachability Matrix, transitive analysis, determination of hierarchy levels through conical matrix, to diagraph preparation and ISM model building. This approach allows for the gradual and contextual formulation of prioritized strategies based on key elements that have a dominant influence on improving farm sustainability.

## Results and Discussion

### 1. Index and Status of Black Rice Farm Sustainability

The analysis of the sustainability of black rice farming in Penebel District was conducted using the Multidimensional Scaling (MDS) approach based on five main dimensions, namely: ecological, economic, social, technological, and institutional. The results of the analysis show that the overall sustainability index value is 62.92, which is in the "moderately sustainable" category. Details of the sustainability index and status of each dimension are presented in Table 2.

Table 2. Index and Sustainability Status of Black Rice Farming in Penebel District, Tabanan Regency, Bali Province

No.	Dimension	Index	Sustainability Status
1.	Ecology	64,24	Moderately Sustainable
2.	Economy	47,35	Less Sustainable
3.	Social	65,67	Moderately Sustainable
4.	Technology	69,64	Moderately Sustainable
5.	Institutional	67,69	Moderately Sustainable
	Total	<b>62,92</b>	Moderately Sustainable

Source: Primary data processed, 2025.

Of the five dimensions analyzed, four are classified as moderately sustainable, namely: ecological, social, technological, and institutional. This condition reflects that in general, black rice farming in the study area has been supported by farmers' ecological awareness, maintained social cohesion, adoption of relevant simple technology, and support from local institutions such as farmer groups and the Subak system. This is consistent with the findings of Linda et al. (2018) who

stated that the Subak system plays an important role in maintaining social and ecological balance in traditional farming systems in Bali.

However, the economic dimension scored the lowest (47.35) and was categorized as "less sustainable". The low economic sustainability is due to a number of constraints such as low productivity, small profit margins, and limited market access. This situation is in line with Nuraina's (2021) findings, which show that weak access to marketing and high production costs are the main obstacles to the economic sustainability of rice farmers in West Sebatik. Similarly, Dzikrillah et al. (2017) emphasized that the imbalance between crop yields and production inputs leads to low farming efficiency. Research by Wulandari and Nugroho (2020) also emphasized that without integration into value-added markets, farmers' bargaining position in the supply chain will remain weak.

The different levels of sustainability between these dimensions are visualized through a kite diagram (Figure 1), which shows the imbalance of the sustainability dimensions and highlights the need for special attention to the economic dimension as a critical point in strengthening sustainable farming systems.

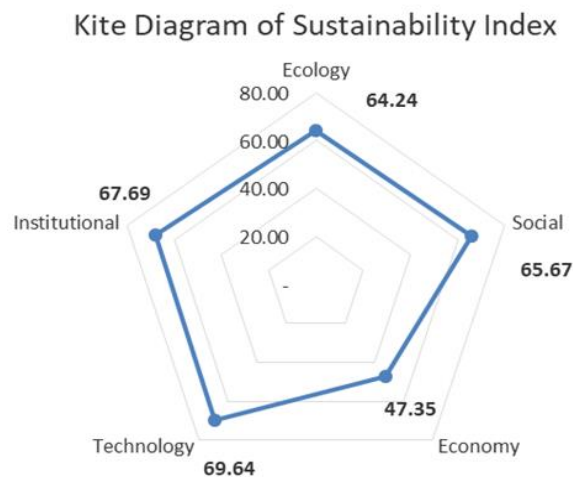


Figure 1. Kite Diagram of the Sustainability Status of Black Rice Farming in Penebel District, Tabanan Regency, Bali Province

Source: Primary data processed, 2025

In general, the sustainability of black rice farming in Penebel is in a relatively stable position. However, strategic interventions are still needed, especially to strengthen the economic dimension through increased market access, provision of affordable production facilities, and farmer training to improve business efficiency. On the other hand, the dimension that has been classified as quite sustainable still needs to be maintained and improved, especially through the integration of local cultural values and appropriate technological innovations. Mahardika and Santosa (2019) stated that the combination of local wisdom and adaptive technology is an important foundation for the development of inclusive sustainable agriculture in Bali.

## 2. Sensitive Attributes of Black Rice Farming Sustainability

The leverage analysis identified the most sensitive attributes in each sustainability dimension, i.e. the key factors that most influence changes in the sustainability index. These attributes are top priorities for strategic interventions to effectively improve farm sustainability.

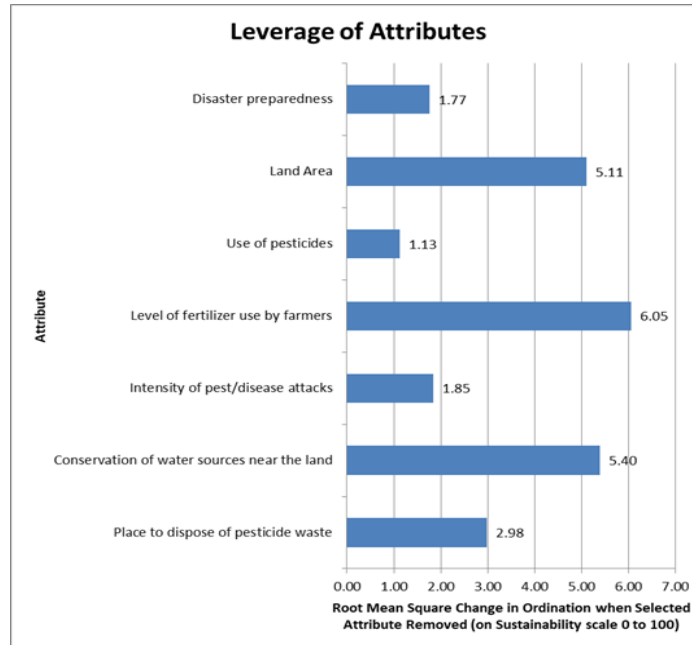


Figure 2 Sensitivity Distribution Analysis of Attributes on the Ecological Dimension

Source: Primary data processed, 2025

The most sensitive attribute in the ecological dimension is the level of fertilizer use by farmers, with a sensitivity value of 6.05. Intensive use of chemical fertilizers such as urea and NPK is still a common practice in Penebel district. Although aimed at increasing yields, over-reliance on inorganic fertilizers can reduce soil fertility, pollute irrigation water, and disrupt the balance of soil microorganisms. The collective irrigation system (Subak) used in this region magnifies the ecological impact, as fertilizer residues can spread between rice fields in one network. In contrast, the use of organic fertilizers or in combination with biofertilizers can improve soil structure, balance pH, and increase water and nutrient absorption. In the context of sustainable agriculture, this is important to preserve soil and water resources as long-term productivity capital. However, efforts to transition to organic fertilizer need to be complemented by technical training, access to local raw materials, and policy incentives. This finding is consistent with Prasetyo and Sari (2018) and Subiksa et al. (2017) which show that wise and locally-based fertilizer management supports the sustainability of the ecosystem of rice paddy farming. Thus, the wise use of fertilizers in terms of type, dose, and method is key to the ecological sustainability of black rice cultivation. Farmer education, easy access to organic fertilizers, and incentives for environmentally friendly practices

need to be strengthened. If managed properly, this will not only protect the ecosystem, but also strengthen the competitiveness of farming based on Subak local wisdom.

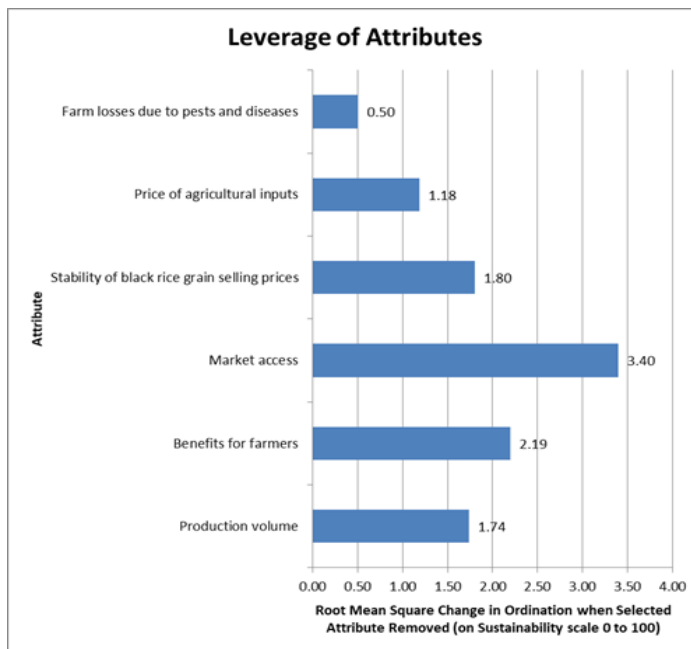


Figure 3. Sensitivity Distribution Analysis of Attributes in the Economic Dimension

Source: Primary data processed, 2025

In the economic dimension, market access is the most sensitive attribute with a sensitivity value of 3.40. Black rice actually has the potential for high economic value, but limited distribution networks, dependence on local markets or middlemen, and lack of connection to premium markets (such as organic markets and the tourism sector) hinder the achievement of economic sustainability. This condition is crucial in Penebel district because most farmers do not have strong farming institutions and are still oriented towards conventional sales without a targeted marketing strategy. As a result, product selling prices are low and unstable, making it difficult for farmers to earn a decent income. This is reinforced by Linda et al. (2018) and Wulandari and Nugroho (2020) who emphasized the importance of integration into value-added markets to strengthen farmers' bargaining position. Suggested solutions include utilizing digital platforms, strengthening marketing institutions, and developing business partnership networks.

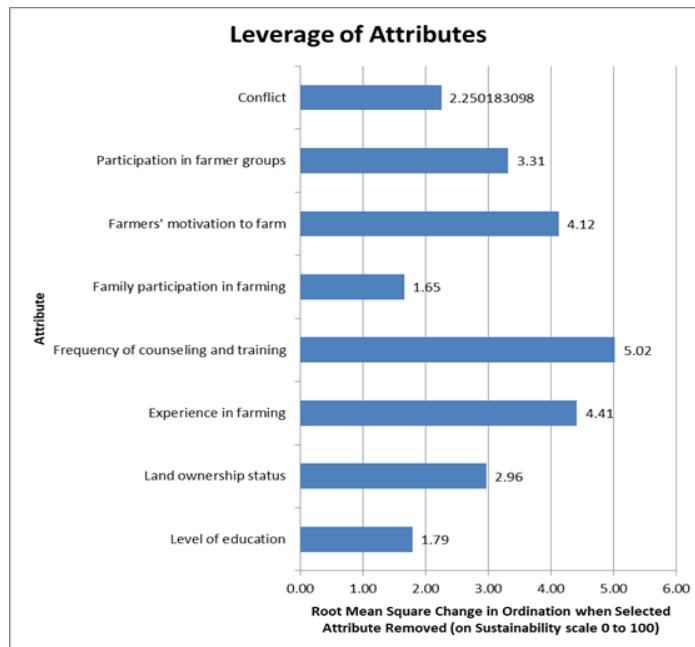


Figure 4. Sensitivity Distribution Analysis of Attributes in the Social Dimension  
Source: Primary data processed, 2025.

The most sensitive attribute in the social dimension is the frequency of counseling and training, with a sensitivity value of 5.02. The counseling conducted is still general in nature and has not focused on black rice commodities. The lack of specific technical information such as cultivation, pest control, and marketing strategies leads to slow adoption of innovations and weak social participation of farmers in sustainable farming management. A thematic and participatory approach, such as the Farmer Field School (SLP), is needed to bridge the knowledge gap. This finding is in line with Sulastrı et al. (2021) and Prasetyo and Anggraeni (2019) who state that increasing farmers' capacity through commodity-based extension is important in strengthening social sustainability and farmer regeneration. Therefore, routine, directed, and tailored extension services not only improve technical capacity, but also build a more adaptive and competitive social ecosystem. Institutional support and the active role of local governments are needed to encourage social transformation towards sustainable agriculture.

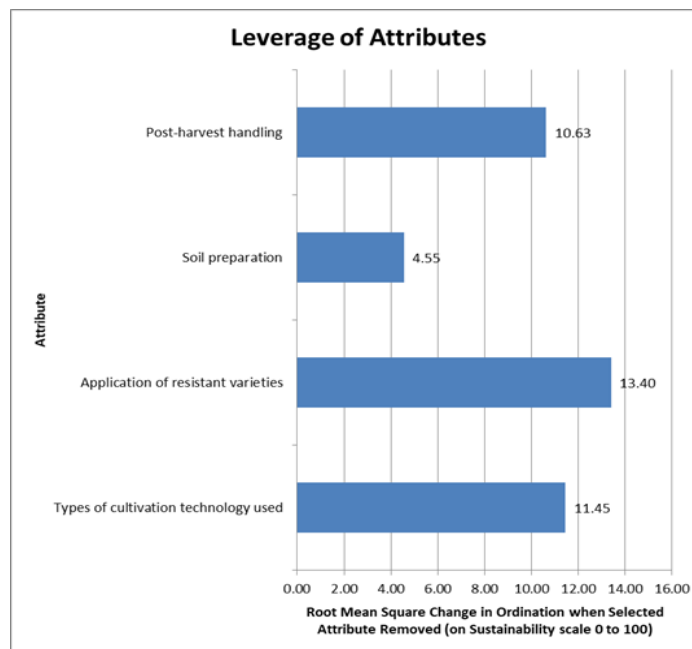


Figure 5. Sensitivity Distribution Analysis of Attributes in the Technology Dimension

Source: Primary data processed, 2025

In the technology dimension, the application of resistant varieties is the most sensitive attribute with the highest value among all dimensions, namely 13.40. Farmers in the Penebel region generally still rely on traditional local varieties that are superior in terms of color and nutritional content, but not optimal in productivity and resistance to pests and diseases. The use of varieties that are not resistant to pests, diseases or climate change leads to production losses and encourages reliance on chemical pesticides, which has a negative impact on the environment and farming costs. In addition, repeated use of the same seed without regeneration reduces color intensity, anthocyanin content, and market appeal. Conversely, resistant varieties that do not match local characteristics risk losing the distinctive features of Penebel black rice such as texture, flavor, and visual aesthetics. Therefore, the application of resistant varieties that are adaptive to the Penebel agroecosystem while maintaining the distinctive characteristics of black rice is very important. These varieties must be able to balance biotic and abiotic resistance with market preferences, thus supporting sustainability both in terms of technology and economics. Research by Saragih et al. (2020) and Mahardika & Santosa (2019) also emphasize the importance of adopting technology based on local needs to improve agricultural sustainability. Thus, the development and application of appropriate varieties is key to encouraging technical efficiency, reducing environmental impacts, and maintaining product competitiveness in the market in a sustainable manner.

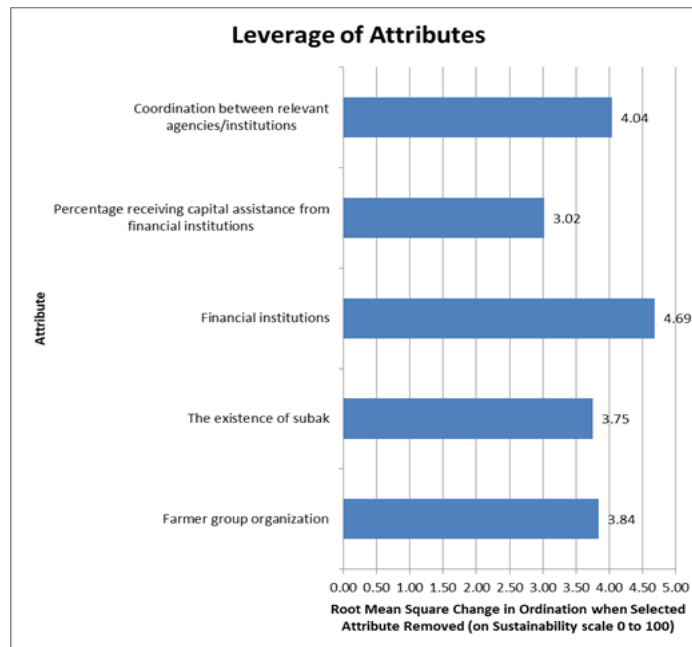


Figure 6. Sensitivity Distribution Analysis of Attributes in the Institutional Dimension

Source: Primary data processed, 2025

The most sensitive attribute in the institutional dimension is financial institutions, with a sensitivity value of 4.69. Although institutions such as BUMDes, cooperatives and banks are available in the Penebel region, farmers' access to financing is still limited due to complicated administrative procedures and the absence of specific financing programs for black rice commodities. In fact, the availability of financing is very important to support input needs, technology adoption, and farm development. This is in line with the findings of Rachmawati et al. (2019) and Ardiansyah and Maulana (2020) which state that profarmer financial institutions play a strategic role in strengthening institutions, increasing farmer group participation, and improving farmers' responses to farming risks. Therefore, strengthening local financial institutions is crucial through appropriate financing schemes, simpler procedures, and improving farmers' financial literacy. BUMDes and cooperatives need to be optimized as productive economic drivers. If managed in a targeted manner, this will strengthen institutional sustainability while supporting the economic, social and technological dimensions in an integrated manner.

To ensure the reliability of the analysis results, a validity test was conducted using a Monte Carlo simulation approach. The results of the comparison between the MDS and Monte Carlo index values show a very small difference (<1%), as presented in Table 3.

Table 3 Comparison of MDS and Monte Carlo Values for the Value of Rap-Farm Value of Black Rice Farming in Penebel District, Tabanan Regency, Bali Province

No.	Dimension	MDS (%)	Monte Carlo (%)	Difference (MDS-MC) (%)
1	Ecology	64,24	63,52	0,72
2	Economy	47,35	47,05	0,30
3	Social	65,67	64,84	0,83
4	Technology	69,64	69,09	0,55
5	Institutional	67,69	66,73	0,96

Note: 95% confidence level

Source: Primary data processed, 2025.

This small difference indicates that the error in determining the score for each attribute is low, and the variability of perceptions between raters is also limited. Thus, the results of the sustainability analysis through the RAP-Farm approach can be said to be reliable and feasible as a basis for formulating strategies for the sustainable development of black rice farming in Penebel District.

### 3. Sustainability Strategy for Black Rice Farming

The results of the Multidimensional Scaling (MDS) analysis identified the five most sensitive attributes that significantly influence the sustainability of black rice farming in Penebel District. These attributes include: the level of fertilizer use by farmers (ecological dimension), market access (economic dimension), frequency of extension and training (social dimension), application of resistant varieties (technological dimension), and financial institutions (institutional dimension). These five attributes became the main elements that were further analyzed using the Interpretive Structural Modeling (ISM) approach to develop a more targeted sustainability strategy. Details of the sensitive attributes used in the ISM analysis are presented in Table 3.

Table 3. Sensitive Attributes Used in ISM Analysis

Code	Dimension	Sensitive attributes
E1	Ecology	Fertilizer usage rate by farmers
E2	Economy	Market access
E3	Social	Frequency of counseling and training
E4	Technology	Application of resistant varieties
E5	Institutional	Financial institutions

Source: Primary data processed, 2025.

The five attributes were then further analyzed using the Interpretive Structural Modeling (ISM) approach to understand the interrelationships between strategic elements and to hierarchically order intervention priorities. The results of the ISM structural modeling are visualized in Figure 7.

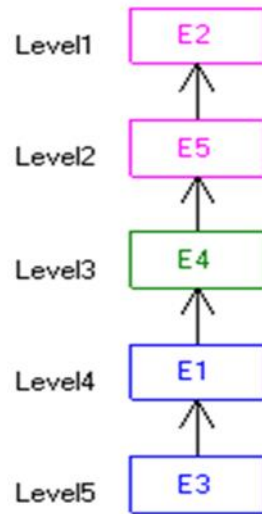


Figure 7. Diagram of ISM Structural Model for Strategic Sustainability of Black Rice Farming

Source: Primary data processed, 2025

The ISM structural model shows that the frequency of extension and training (E3) is at the bottom of the hierarchy as the driving element, while market access (E2) is at the top as the dependent element. This structure indicates that farmer capacity building through extension activities is an important foundation that must be built first to support systemic farm sustainability. Interventions on basic elements such as E3 will lead to cascading changes in other more external elements, such as institutions and market access. Based on this hierarchical structure, strategies are designed in three stages: short-term, medium-term and long-term, in the order of influence between elements.

In the short-term stage, the strategy focuses on increasing the intensity and quality of extension and transforming fertilization practices. The lack of black rice-specific extension services hinders the adoption of sustainable cultivation technologies, including the selection of superior varieties and the use of organic fertilizers. Local governments through the Agriculture Office are expected to play an active role in providing thematic extension programs based on local needs. Field instructors and farmer groups need to be encouraged to apply participatory methods such as Farmer Field Schools (SLP). This finding is in line with Prasetyo and Anggraeni (2019) who stated that the low frequency of extension services is a major obstacle to increasing farmers' capacity. Participatory extension based on local needs, as stated by Sulastris et al. (2021), is very important to accelerate the transformation of agricultural practices.

In the medium-term stage, the strategy focuses on the development and adoption of high-yielding varieties that are resistant to pests, diseases and climate stress and are suitable for the characteristics of the Penebel agroecosystem. This step is

expected to increase productivity and crop competitiveness, by encouraging collaboration between farmers, farmer groups, and research institutions (such as the Agricultural Technology Assessment Center or universities) in testing and introducing suitable new varieties. A participatory approach is essential so that the varieties developed are not only technically superior, but also in line with local preferences. This is in line with Suamba (2021) who stated that the development of varieties based on local wisdom strengthens technology adoption and cultural preservation.

Meanwhile, the long-term strategy focuses on strengthening farmers' access to financial institutions and markets. Local governments and financial institutions such as BUMDes and cooperatives should provide special financing schemes for farmers, with procedures tailored to local conditions. Financial literacy assistance by agricultural extension workers and NGOs is also needed so that farmers can optimally manage their financing. On the other hand, market access needs to be strengthened through collective brand development, product certification (e.g. organic or geographical indication), and utilization of digital marketing. The role of farmer youth and millennial farmer groups is crucial in managing social media and digital platforms as a means of promotion and distribution. Lestari and Wibowo (2021) show that youth involvement in digital marketing can expand market access and improve the efficiency of agricultural product distribution.

Overall, the ISM approach allows for a phased, synergistic and contextualized strategy formulation. Each stage of intervention is mutually reinforcing, starting from increasing the capacity of farmers at the basic level to strengthening the economic support system at the top level. This strategy is expected to form a sustainable, resilient, and competitive black rice farming system, both in terms of production and market access.

## **Conclusion**

This study shows that black rice farming in Penebel District is quite sustainable with an index score of 62.92, where four of the five dimensions namely ecological, social, technological, and institutional are in the category of quite sustainable, while the economic dimension is still classified as less sustainable and is the main weak point. Sensitive attributes that affect sustainability include fertilizer use by farmers (ecological), market access (economic), frequency of extension and training (social), application of resistant varieties (technological), and financial institution support (institutional). The sustainability strategy is structured in stages based on the hierarchical structure of the ISM, starting with a short-term stage that focuses on increasing farmers' capacity through extension and improving fertilizer practices, followed by a medium-term stage that emphasizes the application of resistant varieties according to local conditions to increase productivity and competitiveness, and a long-term stage directed at strengthening access to financial institutions and markets as the main lever of economic and institutional sustainability.

## Recommendations

Based on the research results and field findings, it is recommended that local governments, especially the Department of Agriculture and Food Security, increase efforts to promote and educate the public about the benefits and nutritional value of black rice as a functional food. This education can be done through various media, including mass media, social media, and activities such as agricultural exhibitions and healthy food campaigns in schools, traditional markets and tourism areas. In addition, there needs to be concrete support in expanding market access through strengthening farmers' institutions, facilitating business partnerships, utilizing digital platforms (e-commerce), and integrating local black rice products into the supply chain of the tourism and export sectors. The government also needs to assist farmers in obtaining certifications such as organic and healthy food labeling, and encourage product quality standardization to increase the competitiveness of Penebel black rice in the market. These efforts are expected to increase consumer demand, farmers' income, and the sustainability of the black rice farming system as a whole.

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