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Multidimensional Sustainability Assessment of Inpari Nutri Zinc Rice Farming in Bantul, Indonesia, Using the RAP–MDS Approach

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Abstract: Inpari Nutri Zinc rice, a biofortified variety enriched with zinc (Zn), has been developed to enhance the nutritional quality of staple crops and address widespread micronutrient deficiencies. Zinc plays a critical role in human health, particularly for children, pregnant women, and lactating mothers, and its deficiency has been linked to stunting. To evaluate the long-term viability of Inpari Nutri Zinc rice cultivation, a multidimensional sustainability assessment was conducted in Bantul Regency, Indonesia, with data collected from 125 farmers in Selopamiro, Wukirsari, and Kebonagung Villages. The Rapid Appraisal (RAP) approach, based on a multi-dimensional scaling (MDS)-based method, was applied to assess sustainability across economic, social, and ecological dimensions. The overall sustainability index was estimated at 62.86%, categorizing the farming system as moderately sustainable. Dimension-specific results indicated that the economic dimension scored 48.79% (unsustainable), the social dimension 66.15% (moderately sustainable), and the ecological dimension 73.65% (moderately sustainable), with a 24.86% disparity between the highest and lowest scores. Model robustness was confirmed by a Standardized Residual Sum of Squares (STRESS) value of 0.16 and a Coefficient of Determination (R^2) value of 0.94, demonstrating high reliability and explanatory strength. The economic dimension emerged as the weakest component, underscoring the need for targeted interventions such as guaranteed government procurement of harvests and the integration of biofortified rice into community health programs in areas vulnerable to stunting. Leveraging factors were identified as market access availability for the economic dimension, farmer–extension worker relations for the social dimension, and water quality management for the ecological dimension. These attributes represent critical entry points for enhancing the sustainability of Inpari Nutri Zinc rice farming. The findings provide evidence-based insights for policymakers, extension services, and development agencies to strengthen economic resilience while maintaining social and ecological sustainability in biofortified rice farming systems.

Keywords: Sustainability; RAP; Inpari Nutri Zinc rice; Stunting; Indonesia

1. Introduction

In low- and middle-income countries (LMICs), low dietary diversity coupled with a reliance on low-zinc and high-phytate foods are major contributors to zinc deficiency. Based on inadequate zinc in the diet, the World Health Organization (WHO) estimates that zinc deficiency affects 31% of the global population, with prevalence rates varying from 4% to 73% across regions. Specifically, prevalence is low (4–7%) in North America and Europe, while prevalence is high in North Africa and the Eastern Mediterranean (25–52%), South and Central America (68%), and South and Southeast Asia (34–73%). Regardless of the method used to assess zinc status, the zinc deficiency situation in low-income countries is a cause for concern (White et al., 2023). The stunting rate in Indonesia remains quite high, at 21.6%, according to the 2022 Indonesian Nutritional Status Survey (SSGI). Although this figure has decreased from 24.4% in 2021, significant efforts are still needed to achieve the 14% target for stunting reduction by 2024. Stunting can occur before birth, as evidenced by the prevalence of stunting by age group (Badan Pusat Statistik & Kementerian Kesehatan RI, 2024), where 18.5% of infants were born with a height of less than 48 cm. This data demonstrates the importance of ensuring adequate maternal nutrition during

pregnancy. A concerning finding from the same survey is that the risk of stunting increases 1.6-fold between the 6–11-month and 12–23-month age groups (from 13.7% to 22.4%).

Rice no longer only functions as a staple food for the community. It currently also functions to fulfill additional nutritional needs required by humans (Latruffe et al., 2016). Rice has mineral content that functions for the growth and development of several vital human organs. One of the micro mineral contents in rice is zinc (Majumder et al., 2019). Inpari Nutri Zinc rice is a superior rice variety developed to provide food crops that are rich in nutritional content (Nafiatunnisa, 2021). One of the nutritional contents of Inpari Nutri Zinc rice is zinc (Endriani et al., 2024). Zinc is useful for maintaining body resistance and health (Zhang et al., 2021). Zinc deficiency in children can cause stunted growth, diarrhea and decreased immune function (Arulappan & Vincent, 2024). Zinc consumption in children can stimulate appetite and increase energy intake for the body. In addition, zinc deficiency in the body can cause stunting disease (Fahri et al., 2024).

Stunting is a condition in which a child's growth is disrupted, resulting in a shorter height (dwarfism) than the standard for his age (Tondok et al., 2023). Stunting is said to be growth failure due to malnutrition (Arulappan & Vincent, 2024). Inpari Nutri Zinc rice is expected to be a useful solution to overcome zinc deficiency, especially for children, pregnant women, and breastfeeding mothers (Damayanthi et al., 2023). Inpari Nutri Zinc rice is characterized by an upright plant shape, an early maturity period (±115 days), a plant height of around 95 cm, slender grains with a straw-yellow color, and a moderate resistance to shedding and lodging (Damayanthi et al., 2023). Its development remains relatively limited; therefore, support is needed from various parties to promote and expand the adoption of this variety (Ali et al., 2023). In an effort to increase the production of Inpari Nutri Zinc rice, the government has issued a policy providing subsidies for production inputs, including seeds, fertilizers, and pesticides, to farmer groups (Zainuddin et al., 2022). Table 1 shows the details of government assistance for Inpari Nutri Zinc rice.

Table 1. Recipients of government assistance for Inpari Nutri Zinc rice in the special region of Yogyakarta

No.	Regency	Number of Farmer Groups	Land Area (Ha)	Seeds (Kg)
1	Bantul	1,504	100	2,500
2	Kulonprogo	1,105	67	1,675
3	South Mountain	465	33	825
	Total	3,074	200	5,000

Inpari Nutri Zinc rice farming contributes to overcoming the problem of stunting and zinc deficiency in the human body (Endriani et al., 2024). However, in terms of its implementation, this farming business has several challenges. Harvest results are less than optimal because the grain size of Inpari Nutri Zinc rice is smaller than that of other rice varieties, its color is dull, and its taste is relatively less palatable (Nurhayati et al., 2024). In addition, the lack of a special market to sell Inpari Nutri Zinc rice has caused some farmers to consume their harvest. It is difficult to sell Inpari Nutri Zinc rice because many people are still unfamiliar with this rice variety (Abdillah et al., 2024). Even many of the traders engaged in the sales of Inpari Nutri Zinc rice cannot differentiate between it and other rice varieties, which results in no price differentiation between Inpari Nutri Zinc rice and other varieties (Kartinaty et al., 2021).

Inpari Nutri Zinc, released by the Indonesian Ministry of Agriculture in 2019, has a yield potential of 6.2 tons/ha of milled dry grain, a growth duration of approximately 110–115 days, and good adaptability to irrigated lowland conditions. This variety also exhibits moderate resistance to brown planthopper (*Nilaparvata lugens*) and bacterial leaf blight (*Xanthomonas oryzae* pv. oryzae) (Kementerian Pertanian Republik Indonesia, 2022). Challenges such as climate change and declining soil quality threaten the sustainability of Inpari Nutri Zinc rice farming. Therefore, some farmers use plant-based pesticides made from fermented tobacco leaves with the aim of preserving the soil and environment (Gusti et al., 2022). The lack of extension services regarding the additional benefits of this variety has led farmers to plant it only because of subsidies (Mbatha, 2024). Support from stakeholders, including the agricultural service and Agricultural Extension Center (BPP) extension workers, is needed to make the stunting eradication program a success through Inpari Nutri Zinc rice farming (Nafiatunnisa, 2021). The concept of sustainable development, including sustainable agriculture, is usually based on three pillars, namely economic, social and ecological/environmental sustainability (Ismail et al., 2024). Therefore, the concept of sustainable agriculture must be oriented towards three dimensions of sustainability, namely a profit-oriented economy, sustainability of human social life, and sustainability of the natural environment, all of which are integrated in a balanced manner (Beşen & Olhan, 2021).

Viewed from the three aspects of sustainable farming, it can be analyzed to what extent the level of sustainability of Inpari Nutri Zinc rice farming has an impact on farmers' welfare, environmental sustainability, and the social dynamics of the community (Khairunnisa et al., 2025) and what factors dominate as leverage factors for Inpari Nutri Zinc rice farming from three dimensions, namely economic, social and ecological dimensions, with each

dimension consisting of eight attributes (Gusti et al., 2022). The sustainability index (62.85%) of the Inpari Nutri Zinc rice farming exceeds the range of peatland rice farming in Indonesia (47.7–56.7%). This success is largely attributed to the social aspect, as a specific stunting management program enables farmer groups to collaborate better. Conversely, the economic dimension score (48.79%) is lower than the value in the study by Ismail et al. (2024) for rice farming systems in general in a national assessment. This condition occurs because the Inpari Nutri Zinc marketing system does not yet have established distribution channels and price premiums. Compared with the global rice sustainability assessment conducted by Edwards et al. (2024) and Latruffe et al. (2016), this study focuses on biofortified varieties, integrates agricultural sustainability metrics with public health objectives, and addresses the dual objectives of improving food security and nutritional adequacy.

2. Methodology

2.1 Research Location

The research was conducted in Imogiri District, Bantul Regency, in Kebon Agung Village (West Zone), Wukirsari (North Zone), and Selopamioro (South Zone). The research location was determined purposively. Two types of data, namely secondary and primary data, were used in the sustainability research of the Inpari Nutri Zinc rice farming business. Primary data refer to data obtained directly from the object/source being investigated. Primary data in the study were obtained through a research questionnaire. Secondary data refer to data obtained indirectly from the research object. Rainfall data were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) Imogiri Station for the period 2021–2023 (https://iklim.bmkg.go.id/en/). Rice production and farmer population statistics were also collected from BPS-Statistics of Bantul Regency (2023). The secondary data supported the assessment of sustainability indicators in the ecological, social, and economic dimensions.

2.2 Sampling Procedure and Data Collection

Data were collected through a census covering all 125 farmers in Bantul Regency, which is divided into three villages, namely Selopamioro Village, Wukirsari Village, and Kebonagung Village, as shown in Figure 1. Those farmers received assistance in the form of Inpari Nutri Zinc rice seeds, which they subsequently cultivated. The census approach was chosen because the population size was relatively small and accessible, allowing for collecting data from all members of the population. This approach improves the accuracy of the results and reduces potential sampling bias, as supported by methodological literature (Etikan & Bala, 2017).

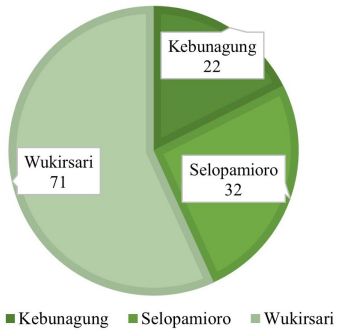

Figure 1. Number of respondents of Inpari Nutri Zinc rice farmers in Bantul Regency

The level of sustainability of the Inpari Nutri Zinc rice farming business was analyzed based on three aspects, namely economic, social and ecological/environmental aspects (Diazabakana et al., 2014). As shown in Table 2, the three aspects of sustainability consist of 24 attributes, with each aspect comprising eight-dimension attributes. Each attribute was assessed with a rating range of 1–4, with 1 representing poor, 2 representing less, 3 representing sufficient, and 4 representing good or excellent. Economic attributes assess how Inpari Nutri Zinc rice farming impacts the economy and welfare of farmers, including input and output prices associated with Inpari Nutri Zinc rice farming. Social attributes evaluate its impact on the social relations between farmers and the dynamics of farmer groups (Rozaki et al., 2024). Ecological attributes examine its impact on the environment and the maintenance of environmental sustainability.

The questionnaire's reliability was evaluated using Cronbach's α based on the collected data. The five sustainability dimensions demonstrated good internal consistency, with α values of 0.81 (social), 0.76 (economic), 0.79 (ecological), 0.74 (technological), and 0.83 (institutional), respectively. These values exceed the minimum threshold of 0.70 (Taber, 2018).

Table 2. Sustainability attributes of Inpari Nutri Zinc rice farming

Economic Aspects	Social Aspects	Ecological Aspects
1. Selling price of Inpari Nutri Zinc rice	1. Safety and health of farmers in implementing Inpari Nutri Zinc rice	1. Natural/organic farming
2. Increasing Inpari Nutri Zinc farmers' income	2. Farmers' insights and knowledge regarding the Inpari Nutri Zinc rice program	2. Availability of water for irrigation on land for Inpari Nutri Zinc rice farming (throughout the season)
3. Price of Inpari Nutri Zinc rice production facilities	3. Relationship between stakeholders (government)	3. Water quality management
4. Adequacy of subsidies for Inpari Nutri Zinc rice production facilities	4. Dynamics of farmer groups	4. Soil quality or fertility for Inpari Nutri Zinc rice farming
5. Increasing the production of Inpari Nutri Zinc rice	5. Relationship between farmers and partners	5. Rice resistance to pest and disease attacks
6. Market availability and access	6. Relationship between farmers and marketing actors	6. Waste management through conversion into fertilizers
7. Poverty alleviation efforts	7. Agricultural extension related to Inpari Nutri Zinc rice	7. The effect of fertilizers on soil quality
8. Long-term economic benefits of Inpari Nutri Zinc rice farming	8. Access to subsidies for Inpari Nutri Zinc production facilities	

2.3 Analytical Technique

In this study, the Rapid Appraisal (RAP) method, a multi-dimensional sustainability (MDS)-based approach, was selected because of its ability to comprehensively analyze and evaluate the sustainability of the Inpari Nutri Zinc rice farming system across multiple dimensions, including social, economic, ecological, technological, and institutional aspects. This method uses a scoring-based analysis of farmers' perceptions (Chrispin et al., 2022). The advantage of the RAP–MDS approach is its ability to integrate local indicators into a multidimensional framework, which is relevant for evaluating sustainability at the farming community level (Bakrie et al., 2023; Fahly et al., 2024; Istiyanti et al., 2024).

In the initial stage, answers or responses were collected from respondents and were used to prepare supporting data for the main analysis. As shown in Table 3, the category of each attribute was determined based on the average value (Kholil et al., 2015).

After the response data from the respondents were collected, the data were then analyzed using the RAP–MDS approach (Istiyanti et al., 2024). As shown in Table 4, sustainability attributes within each dimension were evaluated (Prasetyo et al., 2022).

Table 3. Sustainability value ranges and categories

Attribute Values	Category
1–1.75	Bad
1.76–2.50	Not enough
2.51–3.25	Enough
3.26–4.0	Good

Table 4. Sustainability index values and categories

Index Value (%)	Criteria	Description
0–25	Bad	Unsustainable
25.01–50	Not enough	Less sustainable
50.01–75	Enough	Moderately sustainable
75.01–100	Good	Sustainable

The normalization test is said to be feasible if the Standardized Residual Sum of Squares (STRESS) value is less than 0.20 and R^2 is close to 1. The smaller the STRESS value, the more accurate and consistent it is with the actual conditions. The STRESS score received is usually less than 20% according to the five STRESS feasibility level categories, as shown in Table 5. A smaller STRESS value indicates a better monotonic relationship between dissimilarity and disparity, as well as a more accurate configuration map. Conversely, a high STRESS value indicates a large mismatch, or in other words, a high error rate (Syamsuri et al., 2022). Acceptable STRESS values are usually less than 20%, according to the five STRESS feasibility categories.

STRESS is a metric used to evaluate the extent to which the configuration of objects as points in the *Q* dimension is considered good. In the Alternative Least Square Scaling (ALSCAL) application, STRESS is interpreted as a measure of error or mismatch, where the smaller the STRESS value, the smaller the difference between the distance and similarity values in the represented space (Rozaki et al., 2024). Leverage analysis of attributes was then

conducted to identify the most sensitive attributes in each sustainability dimension. The most sensitive attributes can be determined by determining the Root Mean Square (RMS) value. Monte Carlo analysis was employed to test the validity and stability of the ordination results, which are considered valid and stable if no significant differences are found compared with random values.

Table 5. STREES value categories

STRESS Value (%)	Criteria
0–2.5	Perfect
2.6–5.0	Very good
5.01–10.0	Good
10.01–20.0	Enough
>20.01	Not enough

3. Results

3.1 Identity of Inpari Nutri Zinc

The socioeconomic and demographic characteristics of farmers were examined to see if the Inpari Nutri Zinc rice farming system would be sustainable. Age, education level, farming experience, land ownership status, and access to agricultural extension services influence decision-making, innovation adoption, and farm performance. Socioeconomic factors determine farmers' capacity to respond to market changes, climate variability, and policy interventions. Previous studies have shown that farmer characteristics are closely correlated with technology adoption rates, productivity, and household welfare in rice-based farming systems (Dyanty et al., 2025). Gender is a difference in biological characteristics that distinguish between men and women. Male farmers usually have stronger physical strength compared to female farmers. Age is information about a person's date, month and year of birth. Age information contains a measure of a person's life expectancy in years. The older a farmer is, the more likely he or she is to have a physical condition and thinking ability that is less than when he or she was young (Tong et al., 2024).

Table 6. Identity of Inpari Nutri Zinc rice farmers

Respondent Identity		Selopamioro		Wukirsari		Kebonagung		Total	
		Σ	%	Σ	%	Σ	%	Σ	%
Gender	Male	30	93.75	66	92.96	20	90.91	116	92.80
	Female	2	6.25	5	7.04	2	9.09	9	7.20
Age	42–50	8	25.00	11	15.49	4	18.18	23	18.40
	51–59	3	9.38	15	21.13	5	22.73	23	18.40
	60–68	6	18.75	28	39.44	8	36.36	42	33.60
	69–77	13	40.63	15	21.13	5	22.73	33	26.40
	78–86	2	6.25	2	2.82	0	0.00	4	3.20
Level of education	No school	4	12.50	9	12.68	2	9.09	15	12.00
	Elementary school	15	46.88	35	49.30	4	18.18	54	43.20
	Junior high school	6	18.75	11	15.49	5	22.73	22	17.60
	Senior high school	6	18.75	14	19.72	10	45.45	30	24.00
	College	1	3.13	2	2.82	1	4.55	4	3.20
Farming experience	3–15	3	9.38	12	16.90	6	27.27	21	16.80
	16–28	6	18.75	8	11.27	2	9.09	16	12.80
	29–41	7	21.88	29	40.85	4	18.18	40	32.00
	42–54	11	34.38	16	22.54	7	31.82	34	27.20
	55–67	5	15.63	6	8.45	3	13.64	14	11.20
Land ownership status (ILC et al., 2021)	Owned	26	81.25	37	52.11	15	68.18	78	62.40
	Leased	5	15.63	16	22.54	0	0.00	21	16.80
	Sharecropping	1	3.13	18	25.35	7	31.82	26	20.80
Types of irrigation	Irrigation	5	15.63	16	22.54	22	100	43	34.40
	Rainwater tank	9	28.13	38	53.52	0	0	47	37.60
	Rain tank and pump	18	56.25	17	23.94	0	0	35	28.00

Education is an activity to increase and improve a person's knowledge, and it affects a person's mindset. Farmers with a high educational background tend to have more advanced thinking compared to farmers with low education (Sukayat et al., 2023). Farming experience is the length of time spent by farmers in carrying out a farming activity which is calculated in years. Land ownership status indicates who holds the rights to the land. Land type is the division of land based on its water sources and availability. The land in Bantul Regency is divided into two types, namely wetlands and dry land (Charitas et al., 2023).

Based on Table 6 regarding farmer identity, it is known that the majority of respondents are male, totaling 116 people, and only nine people are female. Farmers who plant Inpari Nutri Zinc rice are members of a farmer group which is also predominantly composed of men. Therefore, most respondents are male. The majority of farmers in the study area were between 60 and 77 years old. This age structure influences how quickly people adopt new technologies because older people are less likely to take risks, have less access to information, and do not frequently consult agricultural extension workers. Rogers' Diffusion of Innovations Theory emphasizes that age is a key determinant in influencing the rate of innovation adoption. Younger farmers are more open to change and adapt to new technologies more quickly. On the other hand, older farmers require different types of mentoring to effectively use new technologies. To accelerate the spread of agricultural technologies, extension programs need to adapt their teaching and communication methods to suit the age of farmers (Rogers et al., 2014).

Based on Table 6, it can be seen that the majority of respondents (54 people) have an elementary school education out of a total of 125 respondents, indicating a generally low level of formal education of farmers. Farmers with the shortest and longest experience are in Wukirsari Village. The majority of respondents' farming experience ranges from 29 to 41 years and it can be said that farmers' experience is sufficient in running their farming businesses. The majority of land owned by farmers is their own or inherited from their parents. Selopamioro Village mostly uses rain-fed irrigation because the village is located higher, and the availability of water is lacking. Kebonagung Village uses irrigation because the Keboangung area is definitely flooded with water every year.

3.2 Descriptive Analysis of Sustainability of Inpari Nutri Zinc Rice Farming Business

The descriptive analysis of sustainability offers an extensive assessment of the present condition of Inpari Nutri Zinc rice farming from economic, social, and ecological viewpoints. This analysis is necessary to determine strengths, weaknesses, and key areas for intervention to improve long-term sustainability. Many things affect the sustainability of rice farming, such as how resources are managed, how skilled farmers are, the policy environment, and how the market works (Hou et al., 2020).

3.2.1 Economic aspects

Sustainability analysis from the economic aspect assesses how the Inpari Nutri Zinc rice farming business affects farmers' income and economy and community welfare. There are eight types of attributes used in the economic dimension to assess the sustainability of the farming business.

Table 7. Results of descriptive analysis of the economic dimension

Economic Dimension	Selopamioro		Wukirsari		Kebonagung		Total	
	Score	Category	Score	Category	Score	Category	Score	Category
Selling price aspect	2.91	Enough	2.55	Enough	2.77	Enough	2.68	Enough
Increasing farmers' income	2.63	Enough	2.42	Not enough	2.41	Not enough	2.47	Not enough
Price of means of production	2.91	Enough	2.86	Enough	2.91	Enough	2.88	Enough
Subsidy adequacy	2.75	Enough	2.56	Enough	1.91	Not enough	2.50	Not enough
Increasing production	2.75	Enough	2.51	Enough	2.45	Not enough	2.56	Enough
Market availability and access	2.00	Not enough	1.80	Not enough	2.73	Enough	2.02	Not enough
Poverty alleviation efforts	2.47	Not enough	2.30	Not enough	2.23	Not enough	2.33	Not enough
Long-term economic benefits	2.41	Not enough	2.28	Not enough	1.95	Not enough	2.26	Not enough
Amount	20.83		19.28		19.40		19.70	
Average	2.60	Enough	2.41	Not enough	2.42	Not enough	2.46	Not enough

Based on Table 7, the average value of the economic dimension was found to be 2.46, categorized as less

sustainable. This result indicates that the economic aspect is the weakest pillar in the sustainability of the Inpari Nutri Zinc rice farming business. After assessing eight attributes, the attribute of production input prices received the highest score (average = 2.88, category sufficient). This score reflects that the government's subsidies for fertilizers, seeds, and pesticides have succeeded in reducing farmers' production costs. Conversely, the attributes of availability and market access received the lowest score (average = 2.02, category less). This score indicates that the lack of a dedicated market for Inpari Nutri Zinc rice limits farmers' opportunities to obtain premium prices and expands marketing reach. This condition also lowers the scores of the attributes of long-term economic benefits (average = 2.26) and poverty alleviation efforts (average = 2.33) because farmers have not been able to maximize profit margins from their production.

Farmers face economic challenges due to high production costs, fluctuating grain prices, and limited market access. The government purchase price aims to protect farmers and make sure they have a minimum income, but it doesn't work well because there isn't enough oversight and middlemen dominate market transactions. According to research, the government purchase price policy will only work if market players follow the rules and Bulog (the Logistics Agency) is able to absorb farmers' grain (Shobur et al., 2025). Low scores on the economic dimension reflect low incomes due to price fluctuations and market policies. International studies show that price support policies significantly improve farmers' incomes and food security (Qian et al., 2020). Furthermore, input support is more effective in reducing income disparities than output subsidies (Tang et al., 2024), and price support has also been shown to increase smallholder farmers' productivity (Quist & Xiao, 2024).

3.2.2 Social aspects

Sustainability analysis examines how the Inpari Nutri Zinc rice farming business influences farmers' welfare, government support and dynamics between farmers from a social aspect (Istiyanti et al., 2024). There are eight types of attributes used in the social dimension to assess the sustainability of the Inpari Nutri Zinc rice farming business.

Based on Table 8, it can be seen that the descriptive analysis of the social dimension is in the sufficient category. There are three aspects included in the good category, including the dynamics of farmer groups and the relationship between farmers and farming partners. The attribute of the dynamics of farmer groups has the highest average (3.62). The attribute of the farmer insight and knowledge has the lowest average of 2.31, which is in the less category. Farmers who receive subsidies for production facilities do not understand the variety being cultivated and the benefits of Inpari Nutri Zinc rice. It is necessary to disseminate information about the stunting alleviation program through Inpari Nutri Zinc rice cultivation so that farmers understand the varieties and benefits of the rice they cultivate (Valera et al., 2025).

Table 8. Results of descriptive analysis of the social dimension

Social dimension	Selopamioro		Wukirsari		Kebonagung		Total	
	Score	Category	Score	Category	Score	Category	Score	Category
Farmer safety and health	3.22	Enough	2.92	Enough	3.09	Enough	3.02	Enough
Farmer insight and knowledge	2.56	Enough	2.31	Not enough	2.73	Enough	2.45	Not enough
Relationship between stakeholders	2.69	Enough	3.03	Enough	3.14	Enough	2.96	Enough
Dynamics of farmer groups	3.91	Good	3.56	Good	3.41	Good	3.62	Good
Relationship between farmers and farming partners	3.34	Good	3.28	Good	3.41	Good	3.32	Good
Relationship between farmers and marketing actors	2.59	Enough	2.32	Not enough	3.14	Enough	2.54	Enough
Agricultural extension	2.53	Enough	2.70	Enough	2.45	Not enough	2.62	Enough
Access to production facility subsidies	2.91	Enough	3.06	Enough	2.82	Enough	2.98	Enough
Amount	23.75		23.18		24.19		24.51	
Average	2.97	Enough	2.90	Enough	3.02	Enough	3.06	Enough

3.2.3 Ecological aspects

Sustainability analysis assesses how the Inpari Nutri Zinc rice farming business impacts ecology or the environment from the ecological aspect (de Miranda et al., 2015). Water availability, soil quality, pest and disease attacks affect the production and sustainability of Inpari Nutri Zinc rice farming. From an ecological perspective, several efforts need to be made to improve the farming sustainability such as soil and water management, and pest and disease control (Heong et al., 2021). Farmers can contribute to environmental sustainability by following the Intergovernmental Panel on Climate Change (IPCC) framework for water quality management. Farmers use rainwater harvesting systems to make sure they have enough water during dry times, cutting down on their

dependence on unreliable water sources and lowering the cost of irrigation. This method also keeps the soil fertile and makes it more resistant to weather changes. Akhtar et al. (2020) proposed that combining local water management practices with adaptation strategies like collecting rainwater, building sedimentation ponds, and planting vegetative buffer strips can greatly lower the risks that climate change poses to farming. Studies show that harvested rainwater is safe to use in farming and is widely accepted in rural areas (Vidal et al., 2024). In addition, evidence from around the world shows that collecting rainwater helps farming and lowers the risk of disasters (Zhang et al., 2024).

Based on Table 9, it can be seen that the average score of respondents from Bantul Regency is classified as sufficient. The attribute with the highest score is the resistance of rice to pest and disease attacks. The Inpari Nutri Zinc rice variety is classified as resistant to pest and disease attacks; therefore, farmers use little pesticides, reducing related costs. The attribute with the lowest score (2.25) is waste management through conversion into fertilizers. Only a small number of farmers process waste into fertilizers. The waste processed by farmers consists of straw, which is burned and spread on the land where seeds are sown (Huang et al., 2023).

Table 9. Results of descriptive analysis of the ecological dimension

Ecological Dimension	Selopamioro		Wukirsari		Kebonagung		Total	
	Score	Category	Score	Category	Score	Category	Score	Category
Natural/organic farming	2.91	Enough	2.17	Not enough	2.23	Not enough	2.37	Not enough
Availability of water for irrigation on land for Inpari Nutri Zinc rice farming (throughout the season)	2.97	Enough	2.61	Enough	3.36	Good	2.83	Enough
Water quality management	2.53	Enough	2.34	Not enough	3.32	Good	2.56	Enough
Soil quality or fertility for Inpari Nutri Zinc rice farming	3.25	Enough	3.03	Enough	3.41	Good	3.15	Enough
Rice resistance to pest and disease attacks	3.41	Good	3.11	Enough	3.45	Good	3.25	Enough
Waste management through conversion into fertilizers	2.38	Not enough	2.10	Not enough	2.55	Enough	2.25	Not enough
The effect of fertilizers on soil quality	3.34	Good	2.90	Enough	3.36	Good	3.10	Enough
The effect of pesticides on soil quality	2.81	Enough	2.69	Enough	2.68	Enough	2.72	Enough
Total	23.60		20.96		24.36		22.23	
Average	2.95	Enough	2.62	Enough	3.05	Enough	2.78	Enough

3.3 Index and Validation Status of the Inpari Nutri Zinc Rice Farming Sustainability Model

Sustainability analysis was conducted using the RAP–MDS approach. Economic sustainability can be seen in that farmers spend less to buy production inputs because they are subsidized by the government, but a special market is needed to accommodate farmers' harvests. Socially, farmers have good dynamics between them, sharing Inpari Nutri Zinc rice production facilities because these inputs are not traded in bulk. Ecologically, environmental management is carried out by not using excessive pesticides and chemical fertilizers, thereby reducing the impact of environmental pollution. It is expected that there will be better water management. Table 10 shows that Wukirsari Village is less economically sustainable. Several attributes in the economic category still have low scores, including increasing farmer income, adequacy of production input subsidies, market access, poverty alleviation efforts, and long-term economic benefits. This indicates that Wukirsari farmers have not yet achieved the maximum financial benefits from cultivating Inpari Nutri Zinc rice.

The results of the analysis show that the Inpari Nutri Zinc rice farming business in Bantul Regency has an average sustainability index of 62.85%, which indicates that the sustainability of the farming business can be categorized as moderately sustainable. This means that the farming business can operate and meet the needs of farmers in economic, social and ecological aspects, but improvements need to be made in the economic aspect in order to achieve better sustainability, especially in Wukirsari Village. The Analysis of Variance (ANOVA) test results showed that there were big differences in the ecological dimension between villages (F = 10.191; p = 0.0001), but not in the economic (F = 1.600; p = 0.206) and social dimensions (F = 1.371; p = 0.258). A further Least Significance Different (LSD) test on the ecological dimension showed that the sustainability index in Wukirsari Village was lower than that of Selopamioro and Kebonagung, while Selopamioro and Kebonagung were not significantly different. These findings indicate that environmental aspects are more susceptible to being influenced by local conditions, especially the availability of natural resources and environmental management

practices.

Table 10. Sustainability values and indexes of each dimension

Dimensions	Selopamioro		Wukirsari		Kebonagung	
	Mean Sustainability Index (%)	Status	Mean Sustainability Index (%)	Status	Mean Sustainability Index (%)	Status
Economy	62.18	Moderately sustainable	58.48	Moderately sustainable	57.57	Moderately sustainable
Social	72.40	Moderately sustainable	70.27	Moderately sustainable	71.44	Moderately sustainable
Ecology	70.74	Moderately sustainable	63.58	Moderately sustainable	71.78	Moderately sustainable

In terms of the economy, the index scores for the villages were pretty even. The lack of major differences means that farmers in all villages have similar income patterns, production costs, and access to markets. This indicates that economic factors are more affected by regional price fluctuations and market policies than by conditions specific to individual villages. There was also no significant change in the social dimension. The dynamics within farmer groups, relationships between farmers, and access to extension services were fairly similar in all three villages. This shows how similar social interactions and institutions are in supporting sustainability. Therefore, social stability can be a big help in making the economy and the environment more resilient in the future. In general, these results show that ecological factors are the primary factors that make villages more or less sustainable. Intervention strategies should focus on better environmental management, like fixing irrigation systems, using organic waste, and protecting soil. This is especially true for Wukirsari Village, which got a lower score.

Based on previous research on the sustainability of rice farming on peatland in Kapuas District (Barchia et al., 2021), the social and cultural dimension sustainability index was 56.70% in Bunga Raya District, 47.70% in Sungai Apit District (less sustainable, <50%), 51.10% in Mandau, and 50.80% in Sabak Auh, the latter two indicating that the status of this dimension was moderately sustainable (>50%). To optimize the sustainability of rice farming in Sungai Apit District, important social and cultural dimensions must be considered and improved.

Based on Table 11, the model validation results show that all sustainability dimensions have a STRESS value below 0.20 and an R^2 value above 0.89, indicating a very good level of model suitability and reliability. The economic dimension recorded a STRESS value of 0.17 with an R^2 value of 0.93, indicating that the model is able to accurately represent field conditions in the economic aspect. The social dimension obtained the lowest STRESS value (0.15) and the highest R^2 value (0.94), indicating that the social indicators used in the RAP–MDS analysis have the highest representation power among the three dimensions. The ecological dimension recorded a STRESS value of 0.16 with an R^2 value of 0.94, indicating that the ecological attributes are well measured and have a high level of consistency with factual conditions. The low STRESS values and high R^2 values in all dimensions strengthen the belief that the instruments and indicators used are valid and the RAP–MDS methodology is appropriate for analyzing the sustainability of Inpari Nutri Zinc rice farming. Thus, the model results can be used as a strong basis for policy formulation because the resulting findings reflect field conditions with high accuracy and minimal risk of bias.

Table 11. Model validation values in each dimension

Validation Modes	Selopamioro		Wukirsari		Kebonagung		Total	
	STRESS	R^2	STRESS	R^2	STRESS	R^2	STRESS	R^2
Economic dimension	0.24	0.89	0.26	0.89	0.25	0.90	0.17	0.93
Social dimension	0.20	0.92	0.24	0.91	0.23	0.92	0.15	0.94
Ecological dimension	0.22	0.92	0.25	0.90	0.20	0.93	0.16	0.94
Total value of STRESS and R^2	0.66	2.73	0.75	2.70	0.68	2.48	0.48	2.81
Average value	0.22	0.91	0.25	0.90	0.23	0.92	0.16	0.94

4. Discussion

Many economic, social, and environmental factors influence the sustainability of the Inpari Nutri Zinc rice farming system. Each dimension has specific characteristics that can positively or negatively affect the sustainability of the farming system. An analysis was conducted to identify the most important factors within each dimension, allowing actions to be focused on increasing profits, strengthening social roles, and protecting the environment.

4.1 Economic Dimension

The economic dimension is a key determinant of the sustainability of the Inpari Nutri Zinc rice farming business because it directly impacts income, production costs, and market access. This aspect analysis focuses on eight attributes such as selling price, income generation, input subsidies, market availability, and long-term economic benefits. As shown in Figure 2, the RAP–MDS analysis on the economic dimension yielded a sustainability index of 48.79%, categorized as less sustainable. It was found that poor market access and the absence of a premium pricing mechanism were the main factors contributing to the declining score.

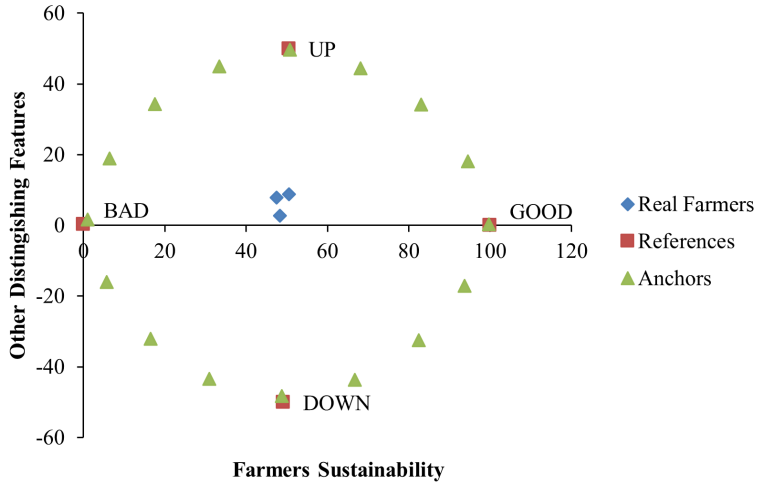

Figure 2. Results of the RAP–MDS of Inpari Nutri Zinc rice farming in the economic dimension in Bantul Regency

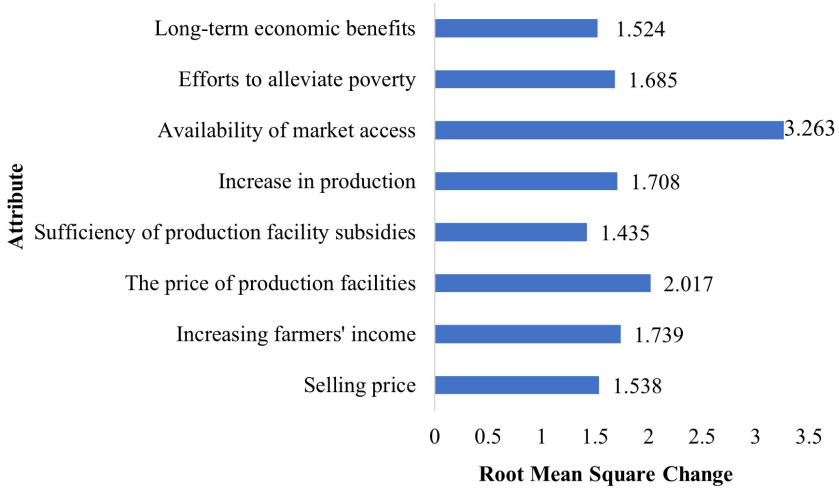

Figure 3. Leverage analysis of sustainability attributes in the economic dimension in Bantul Regency

Figure 3 shows that the attribute of market availability and access had the highest RMS value (3.26), making it the most significant leveraging factor. Improving market access through the public-private partnership (PPP) can strengthen value chain coordination, stabilize prices, and expand distribution. It was also noted that the price of production inputs and the adequacy of input subsidies scored high, but farmer income increases were not significant due to limited market absorption capacity. This situation indicates the need for a dual strategy: establishing a dedicated market for biofortified rice for stunting reduction programs and strengthening farmer institutions to increase bargaining power. Determination of the most influential leverage factor is based on the approach of the law of extreme values or extreme bars. This law identifies attributes with RMS values that differ markedly from those of other attributes. The sustainability index of the economic dimension is around 48.79 which is included in the less sustainable category. Farmers and other interested parties are making Inpari Nutri Zinc more competitive by using a PPP model to set it apart from other products. This plan brings together government agencies, private businesses, and farmer groups to help build stronger product brands, keep prices stable, and grow distribution networks. The PPP model has been shown to better coordinate the value chain, lower transaction costs,

and give farmers access to better markets (Rankin et al., 2016; Smyth et al., 2021).

Based on the analysis results of the leveraging factors in the economic dimension, the most extreme value is the attribute of market access availability with an RMS value of 3.26. This shows that the attribute of market access availability is the most significant factor in influencing the sustainability of the Inpari Nutri Zinc rice farming business. The availability of market access is a special concern for the government in seeking the sustainability of the stunting alleviation program through this Inpari Nutri Zinc rice. Referring to Muntoro et al. (2024), the results of the study indicate that the leveraging factors in the economic aspect lie in the attributes of government support and financial institutions in providing capital. The results of the study have similarities, namely requiring support from the government regarding the availability of market access or capital to continue farming.

4.2 Social Dimension

The social dimension indicates a sustainability index in the moderately sustainable category. The attributes of farmer group dynamics, farmer-business partner relationships, and inter-farmer relationships scored highest because strong social interactions successfully supported information exchange, innovation adoption, and production efficiency (Bebbington & Foo, 2024). Leverage factor analysis placed relationships with extension workers as the most influential factor because those workers facilitate technology transfer, increase production capacity, and expand market access (Abd Halim et al., 2022; Olagunju et al., 2019). The role of extension workers is crucial for the Inpari Nutri Zinc rice variety, which requires technical knowledge and proper post-harvest management (Naik et al., 2022). Based on the results of the leverage of attributes on the social dimension, the most influential attribute is the attribute of relationship with extension workers with an average value of 3.74 compared to other attributes. This shows that the relationship between farmers and extension workers has a significant effect on the sustainability of Inpari Nutri Zinc rice farming in Bantul Regency. A harmonious relationship between farmers and extension workers has an impact on the level of sustainability of a farming business. Extension workers, or BPP, act as an extension of farmers to the government or agricultural service. Through knowledge transfer, technology facilitation, and market access support, agricultural extension workers help farmers improve their skills. Farmers' roles are more effective when they collaborate with Indonesian agricultural extension workers, such as BPP, which coordinates program implementation, trains farmers, and evaluates farmer performance. BPP helps local governments, extension workers, and farmer groups collaborate to develop extension plans to meet community needs. Studies show that integrating extension workers with extension institutions increases technology adoption, strengthens farmers' social networks, and enhances the sustainability of agricultural systems (Davis et al., 2021).

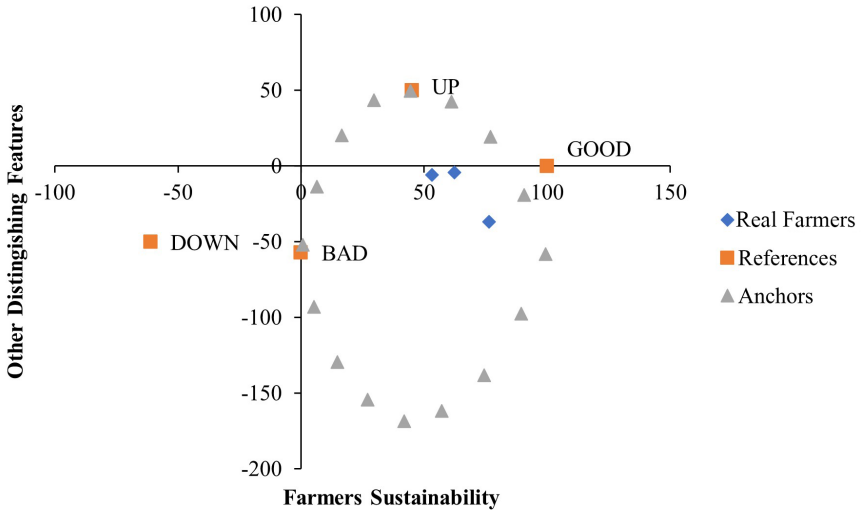

Figure 4. Results of the the RAP–MDS on the sustainability of Inpari Nutri Zinc rice farming in the social dimension

Figure 4 and Figure 5 show the results of the RAP–MDS on the sustainability of Inpari Nutri Zinc rice farming and the analysis of the average of sustainability attributes in the social dimension in Bantul Regency. A good relationship between the two can contribute to the success of the government's program to overcome stunting through Inpari Nutri Zinc rice. Based on the research by Mucharam et al. (2020), on the sustainability of the socio-cultural dimensions of rice farming in Siak Regency, Riau Province, the most influential leverage factor of the social dimension is the conflict between farmers, which is in line with the research on the sustainability of Inpari Nutri Zinc rice farming that relations between farmers and conflicts between farmers are influential leverage

factors.

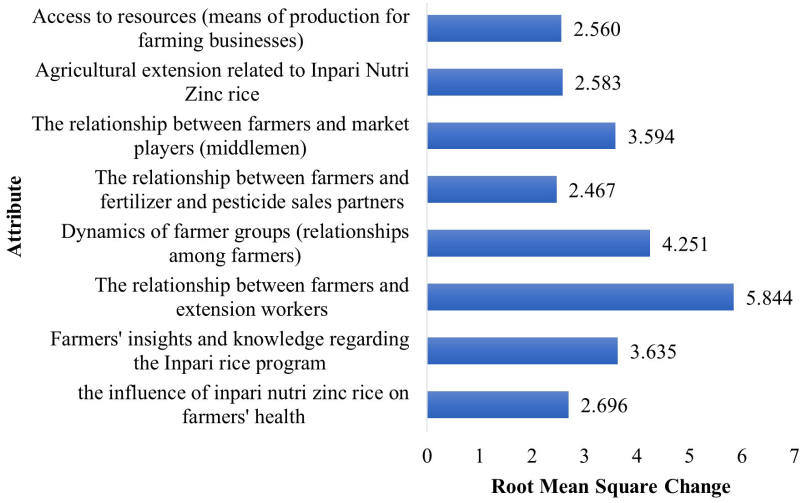

Figure 5. Results of the analysis of the average of sustainability attributes in the social dimension

4.3 Ecological Dimension

Sustainable agriculture's ecological dimension refers to a farming system's capacity to preserve natural resources, minimize adverse effects on ecosystems, and preserve environmental integrity while preserving long-term productivity (Latruffe et al., 2016). In rice cultivation, this dimension includes indicators such as soil fertility, water quality and availability, biodiversity conservation, pest and disease control, and organic waste utilization (Hou et al., 2020). All of these indicators determine the extent to which agricultural practices align with environmental sustainability goals and the climate adaptation framework recommended by IPCC (Hughes, 2024).

Figure 6 shows that the Inpari Nutri Zinc rice farming in Bantul is only moderately sustainable. Selopamioro Village (70.74%) and Kebonagung Village (71.78%) scored higher because farmers are able to maintain water availability and effectively control pests. Wukirsari Village scored lowest (63.58%) because farmers still rely on rain-fed irrigation and have not optimally managed organic waste. Farmers received high marks for both the impact of fertilizers on soil fertility and plant resistance to pest and disease attacks. According to the studies by Hou et al. (2020) and Rozaki et al. (2025), farmers have effectively decreased their use of chemical pesticides, preserving soil biodiversity and lowering environmental pollution. Conversely, the lowest score was found on the attribute of waste management through conversion into fertilizers because most farmers still burn post-harvest straw (Hamzah et al., 2021). This practice releases carbon emissions and reduces soil organic matter content. Research by Syamsuri et al. (2022) confirms that composting straw can make soil better without the bad effects of open burning.

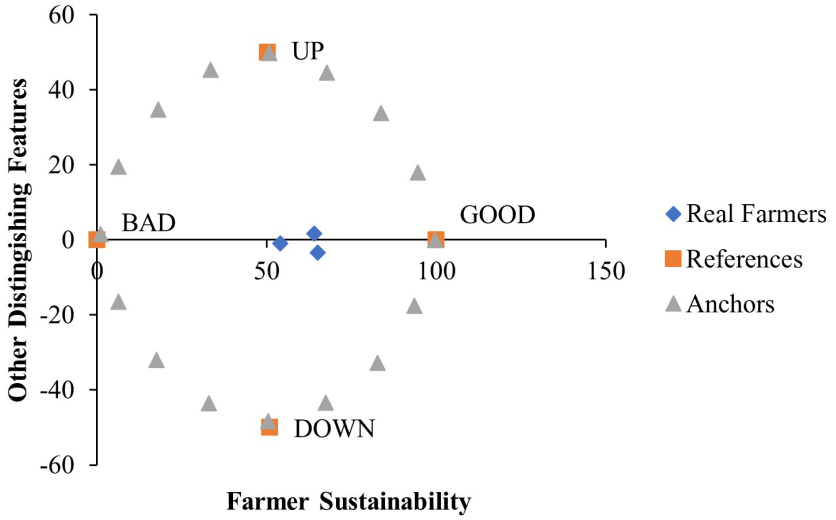

Figure 6. Results of the RAP–MDS on the sustainability of Inpari Nutri Zinc rice farming on the ecological dimension

Figure 7 shows that water quality management is the most influential leverage attribute with an RMS of 2.9 (Kasid et al., 2024). Farmers in Wukirsari and Selopamioro experience water constraints due to their reliance on rain-fed irrigation, especially during the dry season. Farmers can improve this situation by implementing rainwater harvesting technology, constructing sedimentation ponds, and planting vegetative buffer strips. These strategies have been shown to maintain water availability, improve soil quality, and mitigate the risks of climate change (Akhtar et al., 2020; Vidal et al., 2024; Zhang et al., 2024).

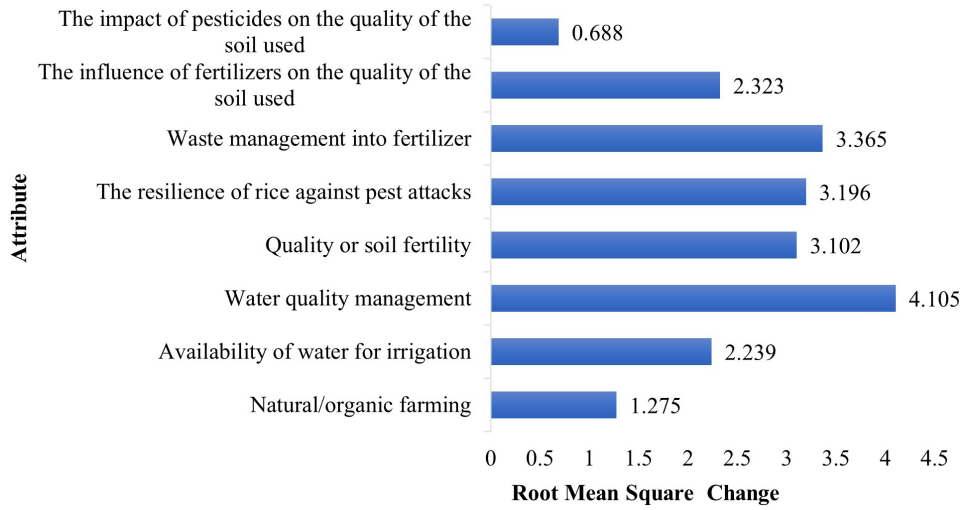

Figure 7. Analysis results of the leverage of sustainability attributes in the ecological dimension in Bantul Regency

Figure 6 and Figure 7 emphasize that strengthening water quality management and utilizing organic waste are key to improving the ecological sustainability of Inpari Nutri Zinc rice farming. Villages that employ adaptive water management and convert straw into compost generally achieve superior sustainability scores. The government must incentivize farmers by investing in water infrastructure, providing composting training programs, and offering environmental incentives to enhance ecological sustainability from moderate to good.

5. Conclusions

This study demonstrates that the sustainability of Inpari Nutri Zinc rice farming remains constrained by economic limitations. The economic aspect, which obtained a score of 48.79%, constitutes the primary barrier to achieving full sustainability due to limited market access, the absence of price premiums, and fluctuations in input costs. The overall sustainability index of 62.85% indicates a moderate level of sustainability. The social dimension obtained the best score because of strong farmer group dynamics and programs that focus on reducing stunting. The ecological aspect indicates that improvements could be achieved through water quality management strategies aligned with the IPCC framework, including rainwater harvesting and the establishment of vegetative buffer zones.

Additional insights from the analysis suggest the important institutional support from BPP, which strengthens farmers' capacities. However, coordination and resource allocation need to be improved. The limited adoption of technology, especially in the processing and sales of crops, makes it more difficult to improve the value chain. It is possible to combine the production of biofortified rice with nutrition programs to improve both food security and public health.

Based on these findings, several recommendations were proposed. First, special subsidies from the government for zinc-fortified rice should be introduced to reduce production costs and increase farmers' profitability. Second, the inclusion of Inpari Nutri Zinc into the National Stunting Reduction Program should be strengthened to increase its marketability and promote public health. Third, the operational capacity of the BPP should be enhanced to facilitate adoption and expand farmer group networks. Finally, incentives should be provided for farmers who adopt environmentally friendly methods, such as planting buffer zones and harvesting rainwater.

Author Contributions

Conceptualization, L.R.; methodology, L.R. and C.W.R.; formal analysis, L.R. and L.I.; investigation, L.R. and L.I.; data curation, L.I.; writing—original draft preparation, L.R. and L.I.; writing—review and editing, L.R., L.I., and C.W.R.; visualization, L.I.; supervision, C.W.R.; funding acquisition, L.R. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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