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Research Paper

Multidimensional Scaling Analysis of Certified Extension Rice Seed Production within the Framework of Sustainable Agriculture

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Abstract

The production of certified extension rice seed is vital for ensuring the availability of superior and adaptive varieties, yet its sustainability faces multidimensional pressures. This study assesses the sustainability status of the extension seed production system in West Lombok Regency using data from rice seed producers, analyzed through Multidimensional Scaling (MDS) with the RAPHYTON approach. Model validity was confirmed by Monte Carlo simulation, low stress (<0.11), and high R-squared (>0.98). The results show a multidimensional sustainability index of 68.47, classified as moderately sustainable, with social and technological dimensions scoring highest, while economic and ecological dimensions lag behind. The findings reveal a fragile transitional system and suggest policy strategies emphasizing market diversification, capacity strengthening of seed growers, certification reforms, and digital marketing adoption to improve system resilience and adaptability.

Keywords: Agriculture; Extension Seed; Multidimensional Scaling; Seed System; Sustainability.

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1. Introduction

The world is currently facing significant challenges in ensuring food security. Rapid population growth has intensified food demand, while natural resource degradation, climate change, and global conflicts have simultaneously reduced production capacity (Mahor, 2025). This situation has turned the food crisis into a tangible threat rather than a mere future discourse. To address this challenge, a transformation toward a more resilient, equitable, and sustainable food system is urgently required. Accordingly, sustainable agriculture has emerged as the most relevant strategy to confront the global food crisis, emphasizing a balance between agricultural productivity, ecosystem preservation, and socio-economic well-being of farming communities (Umesha et al., 2017).

The urgency of food security in Indonesia has gained legal legitimacy through Law No. 18 of 2012 on Food, which affirms that access to adequate food is a fundamental right of every citizen as well as a responsibility of the state. This regulation underscores the importance of ensuring the availability, affordability, and consumption of food that is safe, nutritious, and sustainable. In line with this, the direction of agricultural policy is further reinforced by Law No. 22 of 2019 on the Sustainable Agricultural Cultivation System, which mandates that all agricultural activities must be grounded in ecological, economic, and social dimensions (Republic of Indonesia, 2019).

Within the framework of sustainable agriculture, seed serves as a critical pillar, as it determines agricultural productivity, resource-use efficiency, and crop adaptability to environmental dynamics. The importance of the seed system is further regulated under Law No. 12 of 1992 on Plant Seed Systems, which emphasizes the availability, quality, and accessibility of high-quality seeds for farmers. This provision is reinforced by the Minister of Agriculture Regulation No. 12 of 2018 concerning the production, certification, and distribution of registered food crop seeds, which provides technical guidelines for certification and seed circulation to ensure quality assurance from production to end-users. According to the regulation, seeds are classified into four categories: Breeder Seed (BS), Foundation Seed (FS or BD), Stock Seed (SS or BP), and Extension Seed (ES or BR). The latter is produced from stock seed and intended for widespread distribution to farmers as planting material for commercial production (Republic of Indonesia, 2018).

As a strategic national commodity, rice holds a central position in supporting food security. Enhancing its productivity and production efficiency remains a top priority to ensure stable food availability. Within this framework, extension seed (BR) plays a crucial role, as it is produced in large quantities to guarantee farmers' access to high-quality planting material. However, preliminary field findings indicate that the presence of extension rice seed still faces several challenges, particularly concerning farmers' perceptions and preferences, which do not always favor its use. Many farmers tend to prefer stock seed (BP) based on the perception that higher-class seeds yield better productivity, although empirical studies have shown no significant guarantee that BP seeds produce higher grain yields compared to BR seeds (Qadir et al., 2024).

This condition is also evident in West Nusa Tenggara Province, particularly in West Lombok Regency, which is recognized as one of the major centers for high-quality rice seed production in the region. Data from the Provincial Office of Agriculture and Plantation of West Nusa Tenggara indicate that the production of certified quality rice seed during the 2024/2025 planting season reached 381.080 tons, consisting of foundation seed (BD) 4.800 tons, stock seed (BP) 199.620 tons, and extension seed (BR) 176.660 tons. This means that the production of stock seed (52%) was higher than that of extension seed (46.3%), with a difference of 22.960 tons. Such disparity reflects a distortion in the seed system, wherein the production of stock seed has become more dominant than extension seed, which is actually recommended for large-scale cultivation and farmer use.

Based on these conditions, it is important to note that the discontinuation of extension seed production would create a gap in the seed system and potentially disrupt the entire seed supply chain. This occurs because the demand for higher seed classes, namely stock seed and foundation seed, would increase, while the availability of these classes remains nationally limited. As stated by Hamad et al. (2017), the purity and performance of rice tend to decline along with the decrease in seed class, emphasizing the necessity of maintaining continuous seed multiplication from breeder seed to certified seed. Furthermore, Hour *et al.* (2020) highlighted that the genetic base of modern rice varieties has become increasingly narrow due to the repeated use of a limited number of parental lines in breeding programs, which consequently restricts the availability of breeder and foundation seeds at the national level. Therefore, if the production of extension seed ceases at the grower level, the pressure on the breeder and foundation seed supply will intensify, ultimately threatening the stability and sustainability of the national seed system.

In their study, Westengen, Dalle, and Mulesa (2023) highlighted the critical role of seed systems in supporting food security. However, their analysis remains limited in addressing the practical dynamics of priority commercial seed use, which plays a vital role in sustainability, particularly as a key component bridging policy and field-level implementation. Similarly, Qadir *et al.* (2024) made an important contribution by mapping the production and distribution systems of commercial rice seed in Indonesia, including the identification of the dominance of stock seed (BP) over extension seed (BR) and the phenomenon of using higher-class seeds for consumption purposes. Nevertheless, their study primarily focuses on producer capacity and seed distribution within a commercialization framework, without providing an in-depth examination of the sustainability of extension seed systems as the main instrument for supplying superior seed at the farmer level. Conversely, the production disparity between BP and BR, coupled with the low farmer acceptance of extension seed, calls for a more comprehensive analytical approach.

To address this research gap, the present study employs the Multidimensional Scaling (MDS) approach, which enables a comprehensive assessment of sustainability status across multiple dimensions. This method not only facilitates the identification of key determinants of sustainability but also provides a framework for prioritizing improvement strategies to strengthen the role of extension seed within a sustainable seed system. Accordingly, the main objective of this study is to assess the sustainability level of the extension rice seed production system in West Lombok Regency within the broader framework of sustainable agriculture. In addition, this study contributes both empirically and conceptually by offering a replicable analytical framework for evaluating seed system sustainability in other regions, while also providing scientific evidence to support the formulation of adaptive, inclusive, and evidence-based agricultural policies.

2. Methods

2.1 Study Area and Period

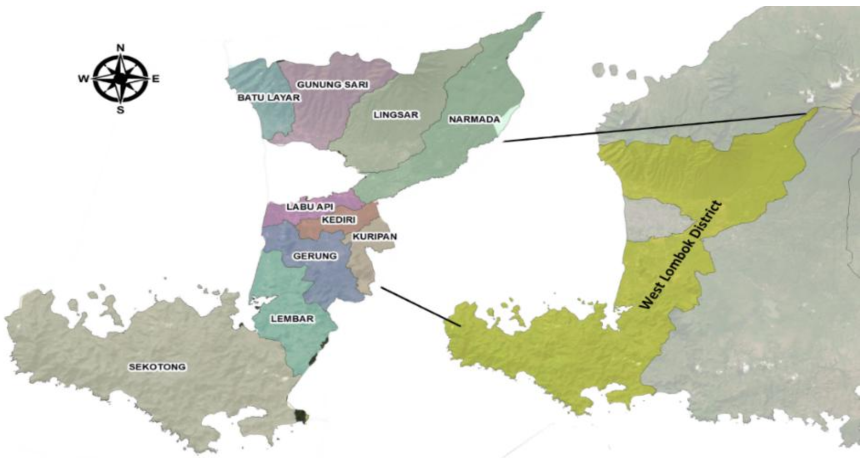


Figure 1. The sites of the studies

This study was conducted in West Lombok Regency, located in the Province of West Nusa Tenggara (Figure 1), Indonesia, which serves as one of the major centers for superior rice seed production in the region. The selection of this site was based on its strategic role as a supplier of certified seed, as well as its unique challenges in the distribution and utilization of extension seed. The research was carried out from March to May 2025.

2.2 Respondents and Sampling Technique

The primary respondents in this study were certified rice seed growers in West Lombok Regency, as this group represents the key actors in the production and supply of extension seed. Although the total population of certified seed growers in West Lombok is relatively small (45 individuals), the study did not include the entire population due to several methodological and practical considerations. The number of respondents was determined using the Slovin formula with a 5% margin of error, resulting in a sample size considered sufficient to represent the diversity of grower characteristics proportionally. The Slovin formula is expressed as follows:

$$n = \frac{N}{1 + N(e)^2}$$

where:

n = number of samples (respondents)

N = total population

e = tolerated error level (5% or 0.05)

The result was rounded down to 39 respondents, as several seed growers were found to be inactive during the study period. This number is considered adequate for Multidimensional Scaling (MDS) analysis, while also taking into account research efficiency, respondent availability, and data reliability in the field. Furthermore, the sample size of 39 respondents meets the minimum requirement for MDS analysis. According to Hout et al. (2018), MDS can be effectively applied to small-to-moderate sample sizes (approximately 10–30 units), and larger sets tend to improve the model's determinacy and stability when dimensional estimation is properly conducted. Therefore, the inclusion of 39 certified seed growers is deemed sufficient to ensure the robustness, representativeness, and reliability of the MDS results in this study.

2.3 Data Collection

Primary data were collected through a structured questionnaire employing an ordinal rating scale (0–2) to assess sustainability attributes. The development of these attributes was based on a comprehensive literature review and subsequently adjusted to reflect empirical field conditions (Table 1). Secondary data were obtained from official documents issued by the Seed Control and Certification Agency (BPSB) of West Nusa Tenggara, the Provincial Department of Agriculture, and relevant national regulations governing the seed system.

2.4 Questionnaire Testing, Data Validity, and Reliability

Before the questionnaire was distributed widely, a pilot test (pre-test) was conducted involving two certified rice seed growers and two expert informants to ensure the clarity of questions and their relevance to the research context. The feedback obtained from the pre-test was used to refine the wording and adjust the attributes to match the empirical conditions in West Lombok Regency. Subsequently, validity and reliability tests were conducted on the questionnaire instrument to ensure that each attribute was appropriate for further analysis.

The validity test was performed using the Pearson correlation (r test) to assess the extent to which each item correlated with the total score within its respective dimension. An item was considered valid if the calculated correlation coefficient (r-count) exceeded the critical value of r-table at a 0.05 significance level. Meanwhile, the reliability test was conducted using Cronbach's Alpha, which measures the internal consistency among items within each dimension. The instrument was deemed reliable if the Cronbach's Alpha value was ≥ 0.70, indicating that the questionnaire demonstrated satisfactory stability and reliability for subsequent analysis.

Table 1. Dimensions and Attributes for Assessing the Sustainability Index of Certified Extension Seed

Dimension	Attribute	Reference
Ecological	Fertilizer use	Rachman et al. (2022)
	Pesticide use	Rachman et al. (2022)
	Conversion of paddy fields	Rachman et al. (2022)
	Irrigation water	Rachman et al. (2022)
	Variety suitability with the agro-ecosystem	De Leon et al. (2016)
	Land use pressure	Rachman et al. (2022)
	Agricultural waste management	Rachman et al. (2022)
	Productivity	Rachman et al. (2022)
Economic	Efficiency of extension seed production	Rachman et al. (2022)
	Stability of extension seed production	Rachman et al. (2022)
	Income–cost ratio of seed enterprise	Rachman et al. (2022)
	Selling price of extension seed	Rachman et al. (2022)
	Price reference for contract farmers	Asrol et al. (2024)
	Payment mechanism for contract farmers	Salassa et al. (2025)
	Market competitiveness of extension seed	Rachman et al. (2022)
	Risk in the seed supply chain	Asrol et al. (2024)
Social	Activeness of seed grower groups	Salassa et al. (2025)
	Access to seed price information	Rachman et al. (2022)
	Labor criteria	Asrol et al. (2024)
	Absorption of local labor	Asrol et al. (2024)
	Motivation of seed growers	Rachman et al. (2022)
	Production conflicts	Rachman et al. (2022)
	Family participation	Salassa et al. (2025)
Institutional	Partnership arrangements	Salassa et al. (2025)
	Training and capacity building	Rachman et al. (2022)
	Business monitoring by related agencies	Rachman et al. (2022)
	Farm management practices	Fajar et al. (2023)
	Support from the local government	Rachman et al. (2022)
	Seed certification process	Gorda et al. (2022)
Technological	Planting system	Fajar et al. (2023)
	Harvesting technology	Fajar et al. (2023)
	Drying technique	Fajar et al. (2023)
	Transportation facilities	Fajar et al. (2023)
	Selection of source seed	Fajar et al. (2023)
	Marketing technology	Fajar et al. (2023)

The validity and reliability of the data used in the MDS RAPHYTON analysis were tested using the RAPHYTON software with three key indicators. First, a comparison between the ordination results and the Monte Carlo simulation was performed, with a maximum tolerance limit of 5 percent, to evaluate the stability of the model. Second, the stress value was used to indicate the degree of model fit, where values approaching zero reflect better model performance. Third, the coefficient of determination (R^2) measured the proportion of data variance explained by the model, with values close to 1 indicating a high-quality and well-fitted model. The details of sustainability attributes across each dimension used in the analysis are presented in Table 1.

2.5 Data Analysis

The collected data were processed using the RAP-Phyton software by applying the Multidimensional Scaling (MDS) approach to evaluate the sustainability index of certified extension seed production. The RAP-Phyton framework represents a rapid appraisal technique that facilitates a comprehensive evaluation of sustainability performance and functions as a decision-support tool for evidence-based policy formulation. The MDS method was selected over other analytical approaches due to its high measurement flexibility, enabling researchers to tailor dimensions, attributes, and scoring schemes to the regional characteristics and contextual conditions of the study area. In addition, the method offers several advantages, including computational efficiency, clarity of graphical visualization, and ease of application, which make it particularly suitable for multidimensional sustainability assessments in agricultural systems (Asrol et al., 2024; Rachman et al., 2022; Salassa et al., 2025).

This methodological framework has been widely adopted in sustainability assessments across multiple agricultural and agro-industrial sectors, including rice cultivation (Rachman et al., 2022; Salassa et al., 2025), coffee plantations (Fajar et al., 2023), sugarcane industries (Asrol et al., 2024), and soybean farming systems (Salsabila, 2024). These applications underscore the versatility and adaptability of the MDS method in analyzing complex, multidimensional production systems.

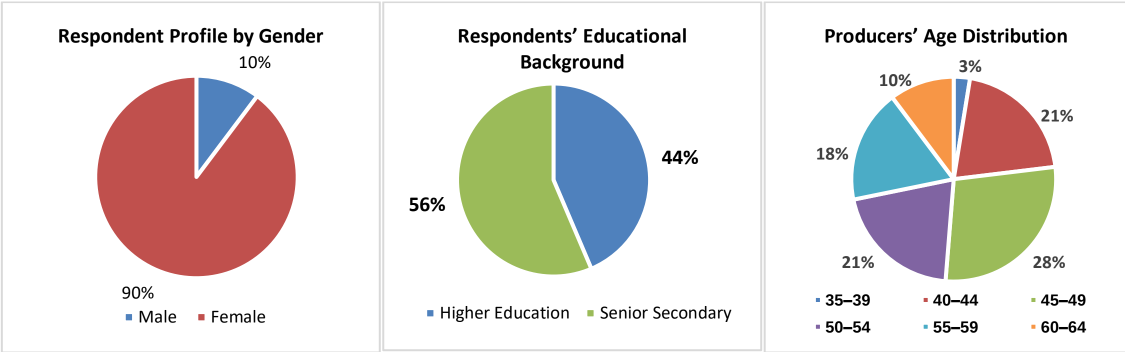
The MDS analysis was conducted through the following steps: (1) Defining the research focus and unit of analysis; (2) Establishing sustainability dimensions based on literature reviews and *in-depth interviews* with key respondents; (3) Identifying attributes within each dimension; (4) Developing an ordinal scoring scale (0–2) for each attribute; (5) Inputting attribute scores into the RAPHYTON software; (6) Constructing reference and anchor matrices; (7) Adjusting the software template to the unit of analysis; (8) Running the Raps analysis to obtain the sustainability index for each dimension (Table 2); (9) Conducting leverage analysis to identify dominant attributes that most strongly influence sustainability; (10) Performing Monte Carlo simulations with a 95% confidence interval to evaluate the effect of data uncertainty; (11) Validating the model using the coefficient of determination (R^2) and Stress value; and (12) Constructing a kite-shaped trade-off diagram to visualize the interaction among sustainability dimensions.

Table 2. Sustainability Index Categories and Status

Score	Category Index
0.00 – 24.99	Unsustainable
25.00 – 49.99	Less Sustainable
50.00 – 74.99	Moderately Sustainable
75.00 – 100.00	Highly Sustainable

2.6 Respondent Caracteristic

The socio-demographic characteristics of respondents are essential to understanding the capacity of actors within the extension seed (certified seed) production system. This study involved seed producers in West Lombok Regency, focusing on three main variables, namely gender, education level, and age group, which are visualized in Figure 2. Based on sociodemographic data, the majority of rice seed producers participating in this study were male (90%), while female respondents accounted for only 10%. The dominance of male respondents reflects prevailing administrative practices and social norms, as women are more actively involved in supporting activities such as post-harvest handling and seed packaging. Most respondents (56%) had completed upper secondary education (high school or equivalent), while the remaining 44% had attained tertiary level education. This educational profile supports their understanding of technical seed production procedures, access to innovation, and the application of sound farm management practices. The age distribution was dominated by individuals in the productive age group (30–59 years), representing 91% of respondents, with the 40–49 age range being the most prevalent (49%). This group typically demonstrates optimal technical and managerial capacity. Meanwhile, the elderly group (≥60 years) accounted for only 10%, yet they remain a valuable source of experiential knowledge in maintaining traditional cultivation practices.



(a) (b) (c)

Figure 2. Visualization of respondents' sociodemographic characteristics: (a) producers' profile by gender, (b) respondents' educational background, and (c) age distribution of producers. Source: Primary data analysis (2025).

3. Results and Discussions

3.1 Result

3.1.1 Validity and Reliability Result

Based on the validity test results using SPSS for the five sustainability dimensions, all questionnaire items related to the assessment attributes were found to be valid and reliable for evaluating sustainability status, as indicated by Sig. (2-tailed) values less than 0.05 and positive Pearson Correlation coefficients. This finding is further supported by the calculated *r* value, which exceeded the critical *r* table value of 0.316 (Table 3).

Table 3. Validity Result

Atribut	Pearson Correlation	R-Table	Status
Fertilizer use	0.580	0.316	Valid
Pesticide use	0.601	0.316	Valid
Conversion of paddy fields	0.508	0.316	Valid
Irrigation water	0.484	0.316	Valid
Variety suitability with the agro-ecosystem	0.587	0.316	Valid
Land use pressure	0.666	0.316	Valid
Agricultural waste management	0.657	0.316	Valid
Productivity	0.520	0.316	Valid
Efficiency of extension seed production	0.507	0.316	Valid
Stability of extension seed production	0.569	0.316	Valid
Income–cost ratio of seed enterprise	0.531	0.316	Valid
Selling price of extension seed	0.730	0.316	Valid
Price reference for contract farmers	0.573	0.316	Valid
Payment mechanism for contract farmers	0.500	0.316	Valid
Market competitiveness of extension seed	0.490	0.316	Valid
Risk in the seed supply chain	0.713	0.316	Valid
Activeness of seed grower groups	0.604	0.316	Valid
Access to seed price information	0.785	0.316	Valid
Labor criteria	0.842	0.316	Valid
Absorption of local labor	0.608	0.316	Valid
Motivation of seed growers	0.494	0.316	Valid
Production conflicts	0.363	0.316	Valid
Family participation	0.590	0.316	Valid
Partnership arrangements	0.657	0.316	Valid
Training and capacity building	0.536	0.316	Valid
Business monitoring by related agencies	0.531	0.316	Valid
Farm management practices	0.679	0.316	Valid
Support from the local government	0.643	0.316	Valid
Seed certification process	0.593	0.316	Valid
Planting system	0.555	0.316	Valid
Harvesting technology	0.848	0.316	Valid
Drying technique	0.445	0.316	Valid
Transportation facilities	0.700	0.316	Valid

Atribut	Pearson Correlation	R-Table	Status
Selection of source seed	0.442	0.316	Valid
Marketing technology	0.710	0.316	Valid

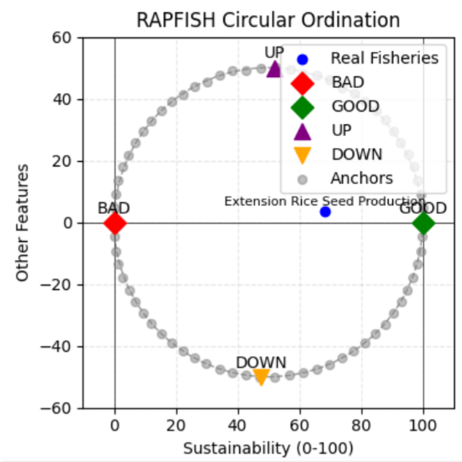
Table 4. Reliability Result

Dimension	Cronbach's Alpha Value	Reliability Level
Ecological	0.702	High Reliability
Economic	0.703	High Reliability
Social	0.702	High Reliability
Institutional	0.652	High Reliability
Technologi	0.647	Moderate Reliability

Meanwhile, the reliability test results using SPSS show that the Cronbach's Alpha values exceeded 0.5, indicating a high level of reliability for the ecological, economic, social, and institutional dimensions, and a moderate level of reliability for the technological dimension (Table 4). These results confirm that all dimensions are reliable and suitable for use in assessing sustainability status.

3.1.2 Sustainability Status

The sustainability index scores for each dimension indicate the extent to which the current extension rice seed production system can persist and develop over the long term, while also reflecting its strengths and weaknesses that should guide future policy priorities. The multidimensional analysis of the sustainability of extension seed production in West Lombok Regency produced a composite score of 68.47 (Figure 3), indicating a moderately sustainable status. The position of this score within the sustainability quadrant is close to the "good" category, representing a transitional yet relatively fragile phase. The system has the potential to progress toward a higher level of sustainability if consistent improvements are implemented. However, it also remains vulnerable to regression toward unsustainability if key constraining factors are not adequately addressed.



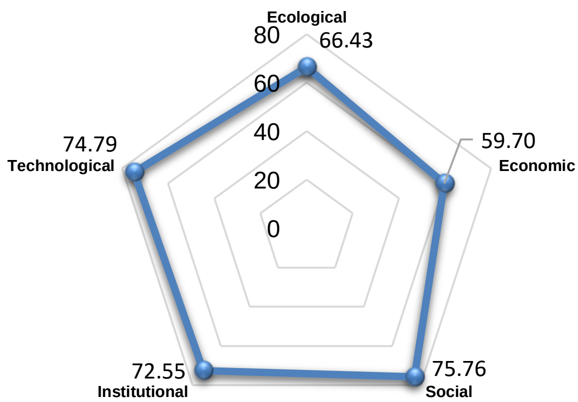


Figure 3. (a) Multidimensional Sustainability Index and (b) Sustainability Kite Diagram of Extension Rice Seed Production. Source: Processed primary data using RAPHYTON (2025).

The validity of the analysis was further supported by the Monte Carlo simulation at a 95 percent confidence level, which showed a very small analytical error. The low stress values (<0.11) and high R-squared values (>0.98) (Table 5) confirm that the Multidimensional Scaling (MDS) approach applied in this study is statistically sound and reliable. These findings indicate that the sustainability of extension rice seed production in West Lombok is shaped by complex interactions among ecological, economic, social, institutional, and technological dimensions, each demonstrating distinct strengths and vulnerabilities.

Table 5. Stress and R-squared Values of the Sustainability Analysis of Extension Rice Seed Production

Dimensi	MDS Index	Monte Carlo Index	Stress	R^2	Status
Ecological	66.43	69.08	0.1054	0.9889	Moderately Sustainable
Economic	59.70	59.91	0.1067	0.9886	Moderately Sustainable
Social	75.76	75.95	0.1036	0.9893	Highly Sustainable
Institutional	72.55	72.85	0.0999	0.9900	Moderately Sustainable
Technological	74.79	74.66	0.0988	0.9902	Moderately Sustainable

Source: Processed primary data using RAPHYTON (2025).

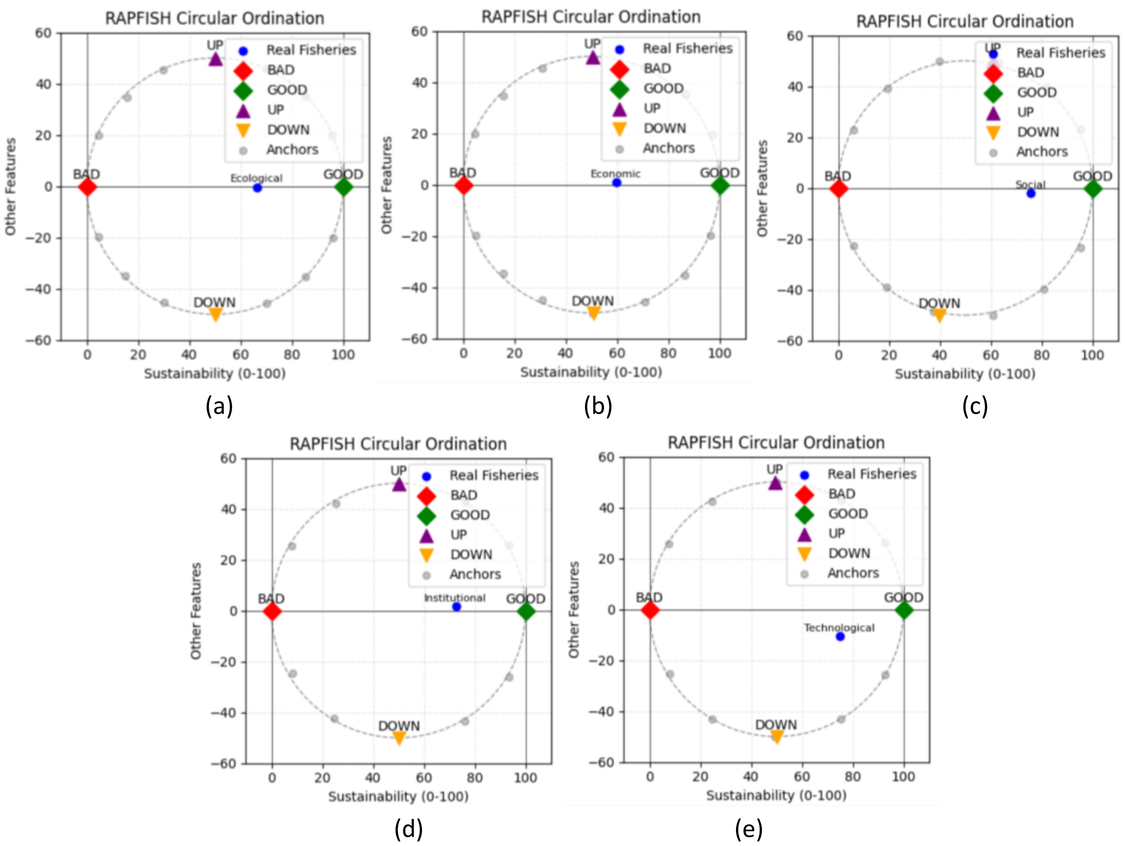


Figure 4. Visualization of the Sustainability Analysis Results for Extension Rice Seed Production: (a) Ecological Dimension; (b) Social Dimension; (c) Economic Dimension; (d) Institutional Dimension; (e) Technological Dimension. Source: Processed primary data using RAPHYTON (2025).

Furthermore, the MDS results reveal that the sustainability of the extension seed production and distribution system in West Lombok Regency forms an interconnected structure across dimensions (Table 5; Figure 4). Each dimension provides specific insights into the factors that either support or constrain the sustainability of the seed system, thereby offering a comprehensive understanding of the current state of the extension seed production in the region.

3.1.2 Laverance Analysis

The leverage analysis using the RAPHYTON approach revealed that the sustainability of extension rice seed production in West Lombok Regency is influenced by multiple attributes with varying degrees of sensitivity. The variation in leverage values indicates that the seed system is inherently multidimensional, where small changes in a specific attribute can generate wider impacts on the overall sustainability structure (Figure 5). The results show that each dimension has dominant attributes that serve as key drivers. In the ecological dimension, the attribute with the highest leverage value is varietal suitability to the agroecosystem (1.35), highlighting the importance of aligning varietal characteristics with local environmental conditions.

In the economic dimension, the selling price of extension seed (4.29) recorded the highest leverage value, followed by seed competitiveness (2.11) and production stability (1.66). These findings demonstrate that price dynamics and financial continuity are central to the economic sustainability of seed growers. Meanwhile, the relatively low value of supply chain risk (0.19) reflects the stabilizing role of government-supported market schemes in maintaining production continuity. In the social dimension, the motivation of seed growers (2.20) emerged as the most influential attribute, followed by access to seed price information (1.32) and labor quality (1.12). These results indicate that social factors such as farmer motivation, participation, and human resource capacity also contribute significantly to sustaining the seed production system.

The institutional and technological dimensions also play significant roles in maintaining system sustainability. In the institutional dimension, enterprise monitoring by supervisory institutions (4.13) represents the most influential factor, followed by farm management (1.85) and training programs (1.43), emphasizing the critical role of formal oversight and capacity building in ensuring quality assurance. The technological dimension contributes the most to overall sustainability, with marketing technology (6.58) being the most dominant attribute, followed by transportation infrastructure (2.43) and source seed selection (1.83). Overall, the leverage results confirm that the sustainability of extension rice seed production in West Lombok is not determined by a single factor but rather by the dynamic interaction among multiple attributes across dimensions, forming an interconnected and adaptive sustainability structure (Figure 5).

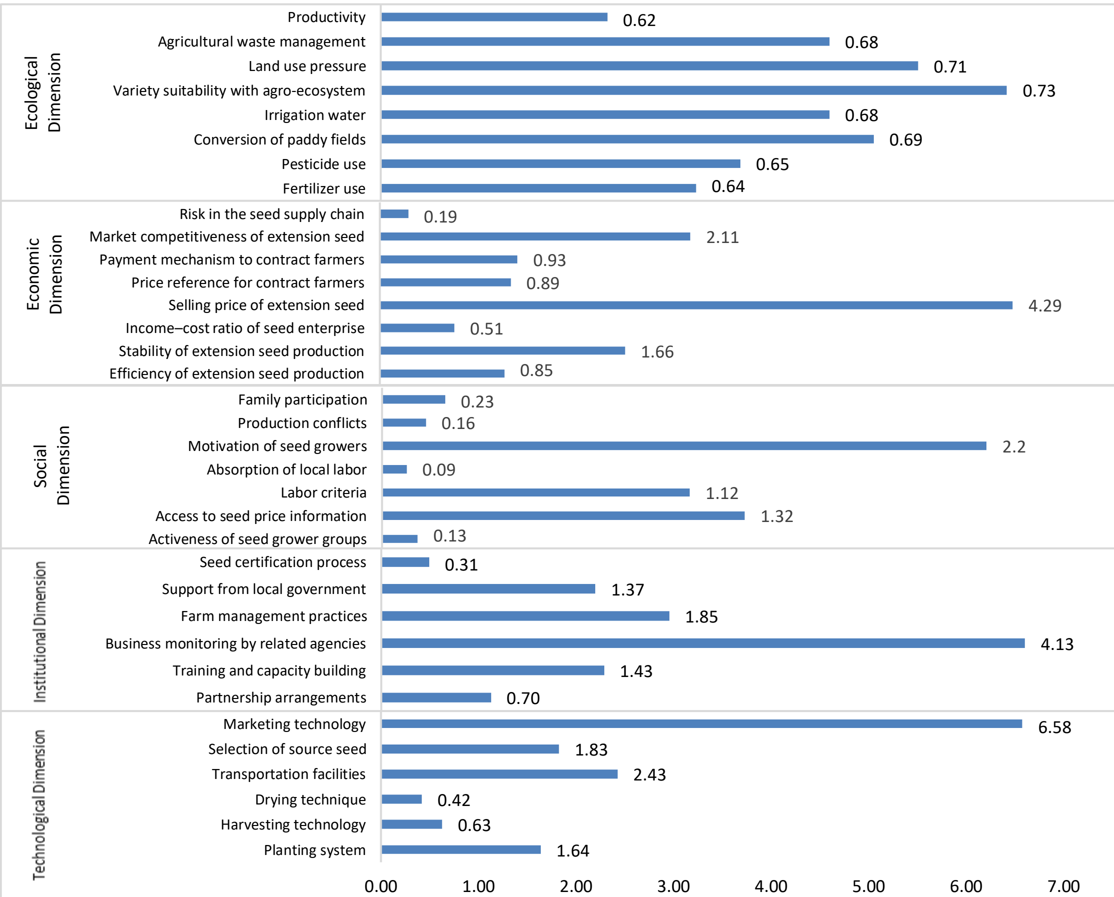


Figure 5. Leverage analysis of the sustainability of extension rice seed production in West Lombok Regency. Source: Processed primary data using RAPHYTON (2025).

3.2 Discussion

The sustainability status of extension seed production in West Lombok, which is categorized as moderately sustainable, reflects a condition of systemic transition in which seed production remains operationally viable yet vulnerable to social, economic, and institutional pressures. This condition illustrates the dual character of the extension seed production system: on one hand, it demonstrates resilience through social capital, institutional support, and technological diffusion; on the other hand, it continues to face vulnerabilities due to market demand fluctuations, limited capital, and dependence on external interventions. Therefore, the extension seed system in West Lombok can be characterized as a hybrid system that balances formal mechanisms, such as certification and regulation, with informal mechanisms in the form of farmers' social networks that support the dissemination of superior varieties and local adaptation. This aligns with Westengen et al. (2023), who emphasized that the sustainability of local seed systems depends on the capacity of local actors to integrate formal innovation with socially and ecologically embedded practices.

3.2.1 Ecological Dimension

The ecological dimension serves as the environmental foundation for the sustainability of the extension seed production system in West Lombok. This sustainability is primarily supported by adequate irrigation water availability and the suitability of improved rice varieties to local agroecosystems. For instance, the variety Inpari 32 HDB has proven to be highly adaptive and widely adopted, not only in West Lombok but also in other rice-producing regions. This finding aligns with Widyayanti and Pustika (2023), who emphasized that varietal suitability to local agroecosystems is a key determinant of yield stability and production efficiency. Both Inpari 32 HDB and Inpari 48 Blas are known to reduce lodging and enhance yields during the wet season. Moreover, the adoption area of Inpari 32 HDB in Indramayu has reached 30,738 hectares (Cipta, Jaelani, and Sanjaya, 2022), demonstrating the strong potential for cross-regional diffusion of adaptive varieties.

Nevertheless, the ecological aspect is not entirely free from pressure. Excessive intensification practices, particularly the uncontrolled use of fertilizers and pesticides, remain a major challenge. Farmers' risk-averse behavior often leads to deviations from optimal fertilizer doses, ultimately causing soil degradation and lowering economic efficiency (Wu et al., 2021). In addition, the conversion of paddy land to non-agricultural use and the poor management of leftover seeds from previous planting cycles have reduced varietal purity. These ecological vulnerabilities have direct implications for economic efficiency, as the overuse of inputs increases production costs, while farmers' preference for foundation seed over extension seed limits overall demand.

These findings reaffirm that the success of the seed system is highly dependent on the ability of varieties to adapt to specific environmental conditions. This is consistent with the genotype-by-environment interaction theory proposed by De Leon et al. (2016) and further supported by the multilocation study of Sitaresmi et al. (2016), which demonstrated that environmental factors (76.49%) and genotype-by-environment interactions (17.55%) play a far more dominant role than pure genetic factors (5.97%) in determining rice productivity. In other words, maximum yield potential can only be achieved when varieties are cultivated under suitable environmental conditions. This is reflected in the case of Inpari 32 HDB adoption in West Lombok, where the variety has shown strong adaptability and widespread use, both within and beyond the study area. Varieties with broad adaptability facilitate cross-regional diffusion, whereas those with specific adaptation require precise site management to maintain optimal productivity.

Overall, the ecological dimension provides the environmental backbone for the long-term sustainability of the extension seed production system in West Lombok. Strengthening participatory varietal selection policies, promoting context-specific field adaptability trials, and enhancing farmer capacity in environmentally friendly input management are essential strategies to maintain the balance between productivity and natural resource conservation. Such efforts not only ensure ecological resilience but also reinforce the adaptive capacity of the seed system in the face of climate variability and external pressures.

3.2.2 Economic Dimension

The economic dimension reflects the balance between production incentives, market efficiency, and the financial sustainability of extension seed producers. Sayaka and Hidayat (2016) reported that farmers often assume that foundation seed has higher productivity than extension seed, leading to lower demand for certified extension seed. As a result, even though seed producers invest considerable production costs, sales revenues often fail to cover capital expenditures, reducing profit margins and weakening the economic position of the extension seed system. However, Safei, Amanah, and Fatchiya (2021) found that farmers' behavior in producing varieties and quantities according to partner demand indicates a rational economic adaptation, where farmers align their production decisions with market preferences and absorption capacity.

The financial sustainability of seed producers depends on maintaining a balance between price, quality, and supply continuity. When prices are not proportional to production costs, producers lose incentives to continue or expand production. Conversely, excessively high prices reduce farmers' purchasing power and limit the potential market for extension seed. This finding aligns with Aisya dan Wijayanti (2024), who identified the presence of a willingness to pay threshold influencing farmers' purchasing decisions, where price affordability becomes a key factor in sustaining demand. In West Lombok, market assurance through government procurement schemes has helped mitigate supply chain risks. However, excessive dependence on government markets creates a new form of vulnerability, particularly when policy support diminishes or procurement priorities shift.

This situation is consistent with Asrol et al. (2024), who emphasized that overreliance on external support increases supply chain risks and undermines system resilience. Geographically, West Lombok faces relatively low physical distribution risks due to government facilitation, yet institutional risks may arise when market mechanisms remain undiversified. Therefore, the economic sustainability strategy for extension seed production in West Lombok should focus on market diversification by integrating producers into non-subsidized commercial seed markets. This approach will reduce dependency on government procurement schemes and expand access to broader distribution networks. Market diversification also enhances the competitiveness of extension seed, which has often been perceived as less attractive compared to foundation seed (Sayaka & Hidayat, 2016).

3.2.3 Social Dimension

In contrast to the relatively fragile economic dimension, the social dimension emerges as the strongest pillar sustaining the continuity of the extension seed system in West Lombok Regency. This strength is derived from social capital built through the active engagement of seed grower groups, family participation, solidarity norms, and collective knowledge about market-preferred varieties. These elements serve as a social mechanism that maintains relational stability among actors and enhances the effectiveness of seed distribution at the local level. This finding aligns with the studies of Kataren (2017), Sudarmono (2021), and Safei, Amanah, and Fatchiya (2021), who emphasized that social capital reinforces farmer group cohesion, facilitates the flow of market information, and reduces transaction costs in the seed supply chain. Consequently, farmer social networks act not merely as coordination instruments but as adaptive mechanisms that ensure the continuity of seed production systems.

Furthermore, the motivation of seed producers stands out as a key attribute underpinning this social dimension. Non-economic factors such as pride in being seed producers, the desire to maintain reputation, and the aspiration to contribute to sustainable agricultural development serve as important drivers of system sustainability. This observation is consistent with Bopp et al. (2019), who found that intrinsic motivation strengthens farmers' perseverance and business resilience. Similarly, Rachman et al. (2022) highlighted that farmers' social motivation is a highly sensitive factor influencing the sustainability of rice production. Therefore, strengthening the social dimension, particularly through initiatives that enhance motivation, solidarity, and recognition of farmers' contributions, should be prioritized in sustainability strategies in West Lombok and other regions with similar social dynamics.

However, not all social components exhibit equal strength. The activity level of grower groups and family participation remains relatively low, reflecting a tendency toward individually oriented seed production practices. This contrasts with the findings of Asrol et al. (2024), which underscore the importance of coordination and institutionally based group support in improving seed system sustainability elsewhere. Such differences suggest that the social structure in West Lombok is still in transition from individual orientation toward collective collaboration. Hence, strengthening social sustainability should focus on revitalizing grower groups, enhancing family involvement, and developing more inclusive institutional mechanisms to ensure that farmer networks function effectively in the long term.

3.2.4 Institutional Dimension

The institutional dimension serves as a critical pillar complementing the sustainability of the extension seed production system, particularly in ensuring seed quality, certification, and credibility. This dimension recorded a significant index value, indicating its substantial contribution to the overall system stability. The presence of regulatory and supervisory bodies such as the Seed Supervision and Certification Agency (UPTD BPSB) plays a strategic role in guaranteeing seed quality from planting to postharvest and distribution stages. The certification mechanisms governed by national regulations (Republic of Indonesia, 2018) ensure seed quality and reduce transaction costs commonly associated with exchanges of goods and services (Kalogiannidis et al., 2024). However, institutional sustainability is not solely determined by formal structures; it also depends on the interaction and synergy with informal social networks at the local level. Consistent with the argument of Westengen, Dalle, and Mulesa (2023), inclusive seed governance requires a balance between formal regulation and local practices to ensure adaptability and responsiveness to field dynamics, as observed in West Lombok.

The leverage analysis revealed that business monitoring by related institutions obtained the highest value within the institutional dimension. This finding highlights the strategic role of BPSB under the Department of Agriculture, which functions not only to ensure seed quality but also to build consumer trust and system credibility. Sayaka et al. (2020) emphasized that formal institutions serve as the guardians of integrity within agricultural value chains. Meanwhile, the relatively high score for farm management and training attributes demonstrates the importance of strengthening both technical and managerial capacities. Nevertheless, the seed certification process showed a relatively lower index, indicating that existing regulations are still perceived as insufficiently adaptive to the needs of small-scale producers. This aligns with Kansiime et al. (2021), who underscored the necessity of more inclusive certification schemes to prevent the exclusion of smallholder seed producers.

Furthermore, Rachman *et al.* (2022) noted that institutional sustainability extends beyond formal regulation, relying heavily on external support and the effectiveness of extension institutions at the field level. Continuous facilitation can enhance coordination among actors and bridge the gap between policy and implementation. In a broader geographical comparison, Salassa, Prasetyo, and Rizki Noor Syafira (2025) found that in rice-producing centers in Java, farmer groups and cooperatives function as coordination hubs among actors, making them the most sensitive institutional attributes influencing system sustainability. Conversely, in West Lombok, institutional strength relies primarily on formal monitoring and certification by BPSB, while the role of farmer groups remains limited.

These contrasts illustrate that institutional strengthening strategies must be context-specific and adaptive. In West Lombok, the focus should be on procedural reform of the certification system to make it more inclusive for small-scale producers while maintaining established quality standards. In Java, however, the emphasis should be placed on empowering farmer groups and cooperatives as coordination centers within the seed value chain. Therefore, future institutional strengthening should extend beyond supervision functions toward a system that is more responsive, collaborative, and locally grounded, ensuring the long-term sustainability of extension seed production systems.

3.2.5 Technological Dimension

The technological dimension demonstrates a crucial contribution to the sustainability of the extension seed production system, particularly in maintaining genetic purity and ensuring the success of seed enterprises. The implementation of technology across various stages, including selection, harvesting, drying, sorting, and storage, has proven essential in preserving seed quality (Rahardjo, Basrum, and Djatna, 2018). Beyond serving as a technical tool, technology also functions as a collective mechanism in the diffusion of innovation. This condition aligns with Kataren (2017), who explained that farmer groups act as the primary medium for accelerating technology transfer while enhancing farmers' adaptive capacity to respond to market and environmental changes. In addition to internal factors, adequate transport infrastructure has facilitated seed distribution to markets, strengthening the overall efficiency of the supply chain. Nevertheless, the sustainability of the seed system does not depend solely on the adoption of formal technology but also on the ability of local actors to integrate technological innovation with traditional practices. This reflects the view of Westengen, Dalle, and Mulesa (2023), who emphasize that the success of modern seed systems relies on harmonizing formal procedures with local knowledge. In West Lombok, this is evident through the coexistence of formal certification procedures and inherited farming practices, creating an adaptive and contextually relevant integration model that supports local needs.

The technological dimension contributes the most to the overall sustainability level, with marketing technology emerging as the most prominent attribute. This finding indicates that the ability to utilize marketing technology is a key factor in ensuring the continuity of the seed system in West Lombok. Studies by Waluyo (2022) and Sebayang et al. (2024) have shown that digital marketing expands market reach and enhances agribusiness product visibility. In the context of West Lombok, which is close to the regional trading center of Mataram, digital marketing technology holds great potential to reduce dependence on limited local markets. Other attributes, such as transportation and source seed selection, also play significant roles due to their direct influence on product distribution efficiency and quality maintenance.

Conversely, technical attributes such as drying techniques and harvesting technology recorded relatively low scores. This does not imply that these aspects are unimportant, but rather that they are already considered standard practices among seed producers. However, post-harvest efficiency remains a decisive factor in maintaining seed quality, particularly in the face of climate change, which increases the risk of reduced quality. This finding is consistent with Rahardjo, Basrum, and Djatna (2018), who argue that post-harvest technology determines genetic quality and forms an integral part of the agricultural value chain. Yet, this contrasts with Rachman et al. (2022), who found that drying technology is a key determinant of rice production sustainability in inland areas with limited infrastructure. This divergence can be explained by geographical conditions. In West Lombok, where transport access and post-harvest facilities are relatively well-developed, drying technology is regarded as a standard procedure. In contrast, in regions with limited facilities, such technology becomes a critical factor for maintaining the sustainability of production systems.

Conclusion

The sustainability of certified extension rice seed production in West Lombok Regency is at a moderate level, characterized by a combination of strengths and weaknesses across various dimensions. The social aspect serves as the main foundation, reflected in strong social capital, family participation, and group solidarity among seed producers. Institutional and technological dimensions also remain relatively strong due to structured supervision and the collective dissemination of innovations. Conversely, the greatest challenges lie within the ecological and economic dimensions, particularly concerning dependence on external inputs, land-use conversion, and the lower market competitiveness of extension seed compared to foundation seed.

Several attributes occupy strategic positions in supporting system sustainability, including varietal suitability to agroecosystems, seed price stability, producers' motivation, the effectiveness of institutional supervision, and the utilization of marketing technology. These five attributes indicate that the sustainability of the seed system is not determined by a single factor but rather through cross-dimensional synergies that reinforce one another. This finding strengthens the notion that the combination of formal innovation, local practices, and inclusive institutional governance constitutes the foundation of a resilient and adaptive seed system.

In practical terms, the findings highlight the importance of policy strategies focusing on strengthening the technical and managerial capacities of seed producer groups, ensuring fair economic incentives, and developing adaptive mechanisms to address ecological pressures and market fluctuations. The results also provide important policy implications for regional agricultural governance. Local governments should enhance coordination among agricultural institutions to ensure the consistency of certification and monitoring systems. Performance-based incentive schemes are needed to encourage the participation of young and educated farmers in certified seed production. Public–private partnerships should be promoted to expand market networks and strengthen the branding of extension seed, while the adoption of digital platforms can enhance transparency and traceability in seed distribution. Finally, integrating sustainability indicators into regional agricultural planning will help institutionalize long-term commitments toward developing a more resilient, inclusive, and sustainable seed system.

For future research, it is recommended to broaden the scope of analysis beyond seed producers to include the perspectives of farmers, distributors, and consumers, in order to capture a more comprehensive picture of the seed supply chain. Further studies could also explore the integration of digital technologies for traceability, the role of social innovation in promoting community-based seed systems, and long-term risk assessments under climate change scenarios. Such efforts will contribute to a deeper understanding of how extension seed systems can effectively support food security and the achievement of sustainable development goals.

Limitations

This study has several limitations that should be acknowledged. First, the analysis was limited to West Lombok Regency, which may constrain the generalizability of the findings to other regions with different socio-institutional and agroecological contexts. Second, the assessment applied the Multidimensional Scaling (MDS) approach based on a defined set of attributes and stakeholder responses primarily focused on seed producers; consequently, perspectives from downstream actors such as farmers, distributors, and consumers were underrepresented. Third, although the model's validity was supported by Monte Carlo simulation, the MDS approach remains sensitive to indicator selection and scaling decisions, which can influence the resulting sustainability index and dimension scores. Lastly, this study emphasizes strategic diagnosis and recommendation without empirically evaluating the implementation or impact of the proposed strategies. Therefore, future research is recommended to broaden the scope of actor participation, apply longitudinal and cross-regional comparative analyses, integrate empirical impact assessments of implemented strategies, and explore the role of digital traceability technologies and climate risk scenarios in enhancing the resilience of the extension seed production system.

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