International Journal of Agriculture and Biosciences 2025 14(6): 1122-1136.
https://doi.org/10.47278/journal.ijab/2025.094

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Analysis of Sustainability of Porang *(Amorphophallus Muelleri B)* in Madiun, Indonesia

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ABSTRACT

Madiun Regency is the largest porang producing region in Indonesia, with the widest area of cultivated land. The region is expected to serve as a sustainable porang agribusiness development model, encompassing increased production, improved farmer income, and alignment with ecological conservation principles. This study aims to assess the sustainability status and identify the most sensitive attributes influencing the sustainability of the porang agribusiness in Madiun Regency. A survey was conducted with 368 porang farmers, and data were analyzed using the Multidimensional Scaling (MDS) method with the RAP-Porang Agribusiness approach. The analysis covered five dimensions: economic, social, ecological, institutional, and cultural. The results indicate that the porang agribusiness in the region falls into the "less sustainable" category with a sustainability index score of 46.01. The cultural dimension recorded the highest score (57.46), reflecting the deep-rooted traditional values associated with porang farming. In contrast, the ecological dimension showed the lowest score (28.14), highlighting the urgent need to enhance farmers' ecological awareness to ensure long-term sustainability. The findings underscore the importance of targeted interventions, particularly in environmental management, to promote the sustainable development of porang agribusiness in the region.

Keywords: Agribusiness, Amorphophallus muelleri B, Multidimensional Scaling, Porang, Sustainability.

Article History
Article # 25-034
Received: 30-Jan-25
Revised: 21-May-25
Accepted: 12-Jun-25
Online First: 04-Jul-25

INTRODUCTION

One of the challenges faced in the agricultural sector is reducing dependence on rice through diversification (Mustafa et al., 2019). Diversifying food sources from carbohydrate foods other than rice is one way to achieve food security (Nurunisa & Baga, 2012). Food consumption has been increasingly growing and diverse in Asian countries, along with economic development. This results from elevated population growth, a substantial rise in household income, and profound lifestyle alterations stemming from fast urbanization (Rae, 1997). The sustainability of agricultural practices, problems like rising energy prices, soil erosion, low-income agriculture, groundwater contamination, decreased productivity, depletion of fossil fuel supplies, and hazards to human health and wildlife habitats are among the concerns in food production. A systems-level approach is needed to understand the complex interactions in agricultural ecology to support sustainable agriculture (Reganold et al., 1990). There are three parts to sustainable development: improving people's quality of life in a way while ensuring environmental preservation, utilizing natural resources sustainably, and safeguarding these resources for the benefit of future generations (Holden et al., 2014). The main focus of sustainable development is the the complex relationship of the economy, ecology, and society. Sustainability is a multidimensional concept and can be

Cite this Article as: Suhardedi C, Karyani T, Wulandari E and Saidah Z, 2025. Analysis of sustainability of porang (*Amorphophallus Muelleri B*) in Madiun, Indonesia. International Journal of Agriculture and Biosciences 14(6): 1122-1136. https://doi.org/10.47278/journal.ijab/2025.094

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quantified at multiple dimensions in space and time to provide a broad field for finding measurement methods aimed at different aspects of sustainability (Mori & Christodoulou, 2012).

Commodities with prospects as alternative food ingredients are beginning to be developed, driven by the rising demand for food. The purpose of developing alternative foods is so that people do not only depend on rice (cereals) for their staple food needs but also on other food sources such as tuber plants. One type of tuber plant that increasingly being cultivated is the porang plant (Padusung et al., 2020; Rahayuningsih, 2020). Porang plants are included in the Araceae family, a tuber plant used as food and provide high-value industrial raw materials, especially for the export market. Porang plants have a high polysaccharide (glucomannan) content (around 35%). Glucomannan can be used for food and various industries, chemical laboratories, and medicines (Hidayat et al., 2013). The porang agribusiness system that is developed must not only be competitive and meet increasing market demand but must also be sustainable (Riptanti et al., 2021). The definition of agribusiness should contain a sustainable system. As sustainability-related issues and criticisms grow in response to recent global trends, sustainable agribusiness is emerging as a new and essential paradigm (Borsellino, 2020).

Sustainable agribusiness must contain three aspects, namely economic aspects, ecological aspects, and technological aspects. From an economic aspect, agribusiness development must be firmly rooted in local economic resources and organizations, and farmers' innovation and creativity must be a source of growth. From an ecological aspect, it must preserve natural resources and biodiversity, which are part of agribusiness development. From a technological aspect, the technology developed must be environmentally friendly (green technology). Therefore, agribusiness development is for more than short-term and long-term interests (Székács, 2017; Zegar & Wrzaszcz, 2017; Faqih et al., 2020). The development of the agribusiness system must be distinct from the sustainability aspect designed for sustainable agricultural development. The porang agribusiness system depends on the synergy of the entire subsystem to support each other. The obstruction of one subsystem will affect the success of other subsystems and can even cause the failure of the entire agribusiness system. Therefore, porang agribusiness is an interrelated system between subsystems and involves various stakeholders (Sjah et al., 2021).

The significant potential of the porang plant, along with its emerging role as a prospective export commodity, offers promising opportunities to develop porang-based products with greater added value and to promote alternative food innovations. Due to its attractive economic returns, in recent years, porang cultivation has expanded among farmers in various agroecosystems, such as rice fields, drylands, and forest areas. This development is expected to contribute meaningfully to improving the livelihoods of rural communities, particularly smallholder farmers. Despite this promise, many farmers remain hesitant to cultivate porang intensively or on a large scale. This reluctance largely stems from limited access to reliable information and guidance on porang agribusiness systems. Moreover, there are growing concerns about the long-term sustainability of porang cultivation, particularly regarding the excessive use of chemical inputs and the dominance of short-term, yield-oriented agricultural practices. These practices may negatively affect economic, social, ecological, institutional, and cultural dimensions. There is a lack of comprehensive understanding regarding the sustainability status of the porang agribusiness and the critical factors influencing its long-term viability. Without such insight, the development of porang as a sustainable and scalable agribusiness model remains constrained. This study aims to analyze the sustainability of porang agribusiness in Madiun Regency by examining key attributes across five dimensions: economic, social, ecological, institutional, and cultural, using the Multidimensional Scaling (MDS) approach with the RAP-Porang Agribusiness technique. The study also seeks to identify the most sensitive attributes that significantly affect the overall sustainability status to inform targeted interventions and policy recommendations for future development.

MATERIALS & METHODS

This study was conducted at the Madiun Regency, East Java Province, Indonesia (Fig. 1). Madiun Regency was chosen as the research location because it is one of Indonesia's central areas producing porang (Hidayat et al., 2024). This study uses a survey method. The study sampled 368 farmers using proportional stratified random sampling.

This study uses sustainability analysis utilizing the MDS (multi-dimensional scaling) method, a statistical tool for assessing the proximity of items (Suerdem, 2021). The stages of data analysis in this study encompass attribute identification, evaluation of each attribute, ordination analysis utilizing MDS, evaluation of the sustainability index and status, a sensitivity analysis (also called a leverage analysis), and an uncertainty analysis (also known as a Monte Carlo analysis) (Ariyon et al., 2024).

This study categorizes certain attributes into five dimensions: economic, social, ecological, institutional, and cultural. These attributes are categorized according to the criteria of "good" or "bad," which are then ordinated using the RAP-Porang Agribusiness (Rapid Appraisal for Porang Agribusiness) ordination technique, adapted from the Rapid Appraisal for Fisheries program (RAPFISH) (Kavanagh & Pitcher, 2004). The study's findings are shown as a sustainability index for porang agribusiness. It has five parts, and each one is shown with a kite diagram and a score on a scale from 0 to 100. The results of the MDS analysis, shown as a sustainability index, can be used to measure the level of sustainability based on the given sustainability level category. Table 1 shows the categories for setting the level of sustainability.

Table 1: Sustainability Level Categories Based on RAP-Porang Agribusiness Index Results

Index Value	Category
0-25	Bad (Unsustainable)
25.01-50	Less (Less Sustainable)
50.01-75	Sufficient (Sufficiently Sustainable)
75.01-100	Good (Highly Sustainable)

Source: Saragih et al. (2020).

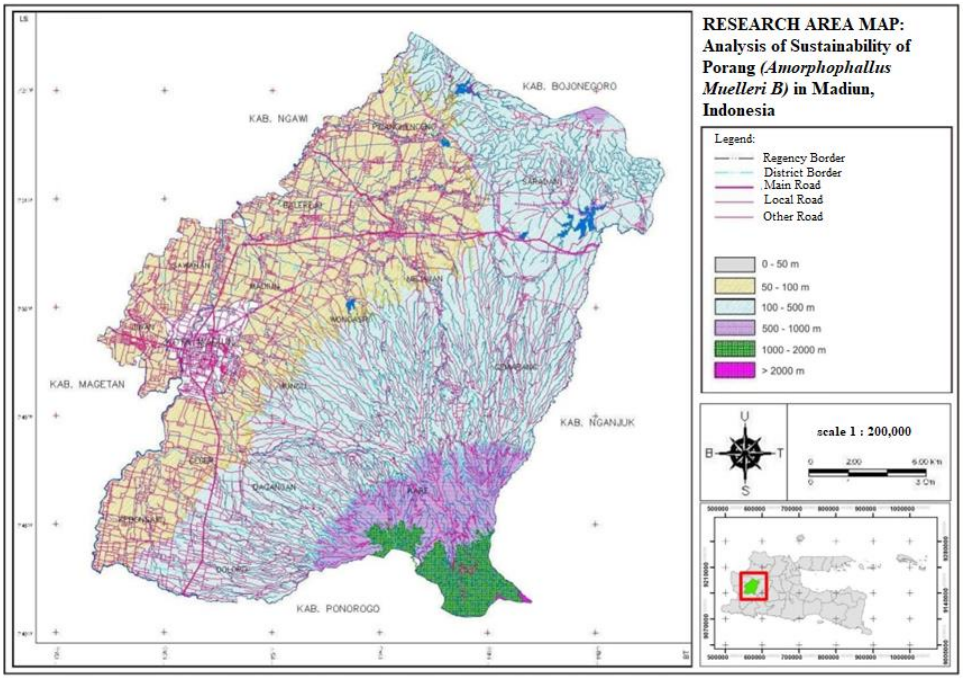

Fig. 1: Research Area Map.

The Standardized Residual Sum of Squares (S-Stress) value and the coefficient of determination (R^2) are both given by the MDS analysis. These show how accurate (goodness of fit) the analysis was. These metrics also check whether more attributes need to be added or whether the ones that are already there are good enough to show how accurate each analyzed dimension is. A low S-Stress value means the match is good, while a high one means it's not (Fauzi & Anna, 2005). The model works if the S-Stress value is less than 0.25 and the R^2 value is close to 1 (100%), which means that these factors can explain almost all of the current model (Purnomo et al., 2024).

Leverage analysis shows how sensitive each attribute is to the sustainability value and is used to find attributes that are sensitive. By changing the Root Mean Square (RMS) ordination along the X-axis, or sustainability scale, you can get sensitive characteristics. A higher RMS change value after losing a certain feature shows that the attribute is more important in building the sustainability index (Narendra et al., 2019). Following the previous step, Monte Carlo analysis is used as a simulation method to check how random errors affect all dimensions (Mahmudiono et al., 2022). Monte Carlo analysis is used to Fig. out what errors will mean with a 95% confidence level, which takes uncertainty into account. After that, the MDS index value is compared to the Monte Carlo index value. A smaller difference between the Monte Carlo index value and the MDS index value means that the MDS analysis has a lower error rate. Rapfish 3.1 software from www.Rapfish.org was used for MDS, leverage, and Monte Carlo studies.

RESULTS

The sustainability paradigm refers to many areas, such as agriculture, economics, or, in a more general field, human activities. Meanwhile, sustainable development has many definitions and interpretations. This concept distinctly delineates sustainable agriculture, indicating that its definition arises from diverse social perspectives. The primary consideration, strongly underscored from an ethical standpoint, is the fulfillment of the needs of the present generation while ensuring the well-being of future generations. The idea of sustainability is multifaceted and may be assessed across numerous spatial and temporal dimensions, offering a comprehensive domain for exploring measurement methodologies targeting various aspects of sustainability (Purvis et al., 2019). Sustainability is needed to create a balance between nature and humans. Neglecting the interaction between nature and humans can incur high costs and reduce human welfare. The primary consideration of sustainability can be seen in the benefits and costs. The benefits aspect of applying the principle of sustainability, in addition to providing benefits at present, also ensures the availability of resources in the future. If the principle of sustainability is not applied, the cost aspect will incur higher costs (Fauzi, 2019).

A model is deemed satisfactory when the S-Stress value is below 0.25 and the R2 approaches 1 (100%). The S-Stress value produced in each dimension or across multiple dimensions is below 2.50. The S-Stress value shows improvement as the distance from 0.25 decreases (Ananda et al., 2021). The S-Stress and R^2 values indicate that all attributes employed and examined both dimensionally and multidimensionally have met the statistical criteria and are effective in clarifying the sustainability of porang agribusiness in Madiun Regency.

Table 2 indicates that the S-Stress value ranges from 0.16 to 0.18, while the R^2 value is between 0.92 and 0.93, suggesting that the goodness of fit criterion in the RAP-Porang Agribusiness analysis has been satisfied. The coefficient of determination (R^2) indicates the extent to which the variable elucidates and enhances the sustainability of the examined system. Upon meeting the S-Stress value, the attribute configuration can accurately represent the original data, ensuring that the evaluated indications are precise and statistically valid (Aris et al., 2020).

Table 2: Results of the Sustainability Status of Porang Agribusiness in Madiun Regency

Criteria	MDS	Monte Carlo	Difference	S-Stress	R^2
Multi-dimensional	46.01	45.44	0.57	0.17	0.93
Economy	51.13	50.83	0.30	0.16	0.93
Social	52.12	50.80	1.32	0.16	0.93
Ecological	28.14	27.41	0.73	0.16	0.93
Institutional	32.76	32.58	0.18	0.17	0.93
Culture	57.46	56.76	0.70	0.18	0.92

Source: Primary Data (processed).

The disparity between the MDS and Monte Carlo at a confidence level of 95% or a 5% error rate ranges from 0.18 to 1.32, showing that the impact of scoring mistakes on the analysis is very minimal. The differential value of this study is less than 5%, indicating that the MDS analysis results are sufficient in the role of assessing the sustainability index (Papilo et al., 2018). The multidimensional RAP-Porang Agribusiness analysis, employing the Multidimensional Scaling (MDS) method, yielded a sustainability index value of 46.01 for porang agribusiness in Madiun Regency. This value falls within the range of 26-50, categorizing it as "less sustainable," with an S-Stress value of 0.17 and an R^2 value of 0.93. The RAP-Porang Agribusiness research, depicted in Fig. 2, reveals that the multidimensional sustainability index value for porang agribusiness in Madiun Regency is 46.01. This value is ascertained through a thorough examination of all dimensions (economic, social, ecological, institutional, and cultural), known as multidimensional analysis. As a result, porang agribusiness is somewhat less sustainable. Several researchers have reported that the multidimensional sustainability index of agribusiness possesses the potential for enhanced sustainability (Leha et al., 2019; Riptanti et al., 2022; Puspitaningrum et al., 2024).

Every dimension possesses qualities that serve as sustainability parameters (Fig. 3). The sustainability index value of porang agribusiness is derived from an evaluation of 23 sustainability criteria across each dimension, as elaborated in detail (Fig. 4). The sustainability index value for each dimension depicted in the kite diagram indicates that the larger the distance of the sustainability point from 0, the higher the sustainability value. The kite diagram, commonly referred to as a "radar" diagram, indicates that as the analysis distance approaches the zero point, sustainability diminishes, and conversely (Suardi et al., 2022). The kite diagram indicates that the ecological component has the lowest sustainability index value, followed by the institutional, economic, and social dimensions, with the cultural dimension exhibiting the greatest value. The sustainability index value for each dimension, as indicated by the kite diagram, requires precision, signifying that the application of each sustainability dimension has not been uniform or balanced. The kite diagram can elucidate the sustainability state of porang agribusiness by incorporating multiple elements of sustainability, such as economic, social, ecological, institutional, and cultural aspects. The results of the calculations are illustrated in Figs. 2-4.

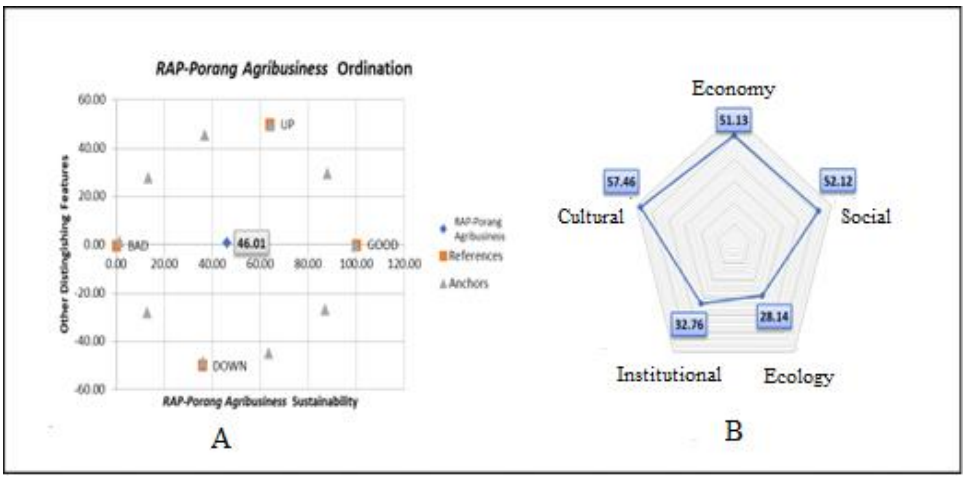

Fig. 2: Sustainability index (A) and kite diagram (B) of porang agribusiness in Madiun Regency.

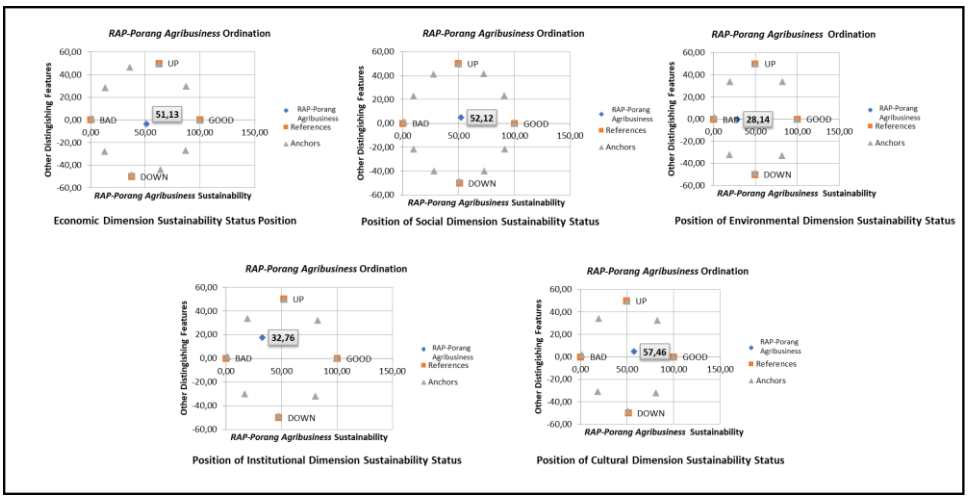

Fig. 3: Level of Sustainability for Each Dimension.

Fig. 4: Leverage Analysis Value of Each Dimension.

DISCUSSION

The Economic Dimension

Economic dimension are one of the critical dimension in the establishment of sustainable porang agribusiness. The economic dimension is the ability of agricultural agribusiness to sustainably meet farmers' needs (Wojewódzka-Wiewiórska et al., 2020). Good or sustainable agricultural agribusiness is defined as one that enhances the economic well-being of the community (Mariyono, 2020). Agribusiness development has the potential to unlock a broad range of economic opportunities in all regions. In the economic dimension of the RAP-Porang Agribusiness analysis, there are five measurement attributes: a) Productivity, b) Price, c) Income, d) Porang agricultural business prospects, and e) Porang market opportunities (Santoso et al., 2018; Pawiengla et al., 2020; Setiawan et al., 2023).

The sustainability index value for the economic dimension (Table 3) of the porang agribusiness is 51.13, which falls within the sufficiently sustainable category in accordance with the value range of 51-70, as determined by the RAPFISH software analysis of all attributes (Wen et al., 2020). The economic dimension ordination analysis with a number of iterations of 2 (two) results in an R^2 value of 0.93 and an S-Stress value of 0.16, or 16%. Consequently, the economic dimension analysis in this study demonstrates the condition of goodness of fit in the sufficient (fair) category. If the S-Stress value is less than 25% or (<0.25) and the R^2 value approaches 1 or 100%, the analysis in Multi-Dimensional Scaling (MDS) is considered satisfactory and acceptable. This suggests that the economic dimension's attributes can either approximate or elucidate the original model's 100% model. The RAPFISH software's leverage analysis method of economic dimension sensitivity analysis reveals that of the five attributes tested, income and price have the greatest impact on the sustainability of porang agribusiness in Madiun Regency, with an RMS value of 8.832 and 7.329, respectively. The attribute's influence on sustainability is more sensitive as the leverage analysis value increases (Sukmawati et al., 2020). It is evident from the preceding description that these two attributes must be taken into account in order to enhance the sustainability status of the economic dimension. Income is the initial economic factor that significantly impacts the sustainability of porang agribusiness. The evaluation of porang income depends on whether it serves as the principal income source or if alternative income sources exist. The average porang cultivator utilizes this commodity as an additional source of income and exclusively depends on the sale of porang seeds and large tubers. These findings are consistent with the study by Kurniati et al. (2021), which indicates that in addition to cultivating porang, farmers also grow other crops such as rice and maize.

The average income of farmers from porang farming is IDR 16,225,020 per season or IDR 1,352,085 per month. Additionally, they have an average land area of 0.2 to 1 hectare, which is insufficient to satisfy their household requirements. Nevertheless, the administration of porang income is not conducted effectively. If an agribusiness is inefficient in the preparation of inputs and the optimization of land, it will pose an economic threat to its sustainability. The study by Ridhanto et al. (2023), highlights that farmers' income serves as a mediating factor in determining their ability to respond to external pressures in porang agribusiness. Income levels not only affect farmers' capacity to sustain their agricultural enterprises but also influence their ability to invest in more sustainable farming systems. The attribute that most significantly impacts the sustainability of porang agriculture in the economic dimension is price. Porang prices exhibit significant volatility based on field conditions, generally trending downward. Based on information from farmers, the average farm-gate price of porang tubers at the study location was IDR 3,000 per kilogram. The prices received by farmers ranged between IDR 2,000 and IDR 5,000 per kilogram, influenced by factors such as harvest timing, tuber quality, and grade. However, farmers perceive the current market price as relatively low, particularly when compared to the peak price of IDR 13,000 per kilogram recorded in 2020.

Table 3: Economic Dimension

	2D MDS Results			Rotated		& Flipped & Scaled	
R1	0.06	-0.11		0.03141	-0.11864	**51.13**	-3.67
GOOD	-1.13	-1.02		1.520261	-0.01056	**100.00**	0.00
BAD	1.15	1.00		-1.52646	-0.01056	**0.00**	-0.07
UP	-1.25	0.85		0.375424	1.465194	**62.42**	50.00
DOWN	1.27	-0.85		-0.38852	-1.48218	37.35	-50.00
ANCHORS:	-1.12	-1.01		1.507121	-0.01439	99.57	-0.20
	-1.42	-0.10		1.129601	0.863046	87.18	29.57
	-1.25	0.84		0.381638	1.453383	62.63	49.60
	-0.57	1.31		-0.44025	1.364908	35.65	46.60
	0.29	1.36		-1.11796	0.826819	13.41	28.34
	1.09	1.01		-1.49065	0.033467	1.18	1.42
	1.40	0.13		-1.13295	-0.83288	12.92	-27.97
	1.24	-0.81		-0.38826	-1.43117	37.36	-48.27
	0.55	-1.26		0.423186	-1.302	63.99	-43.89
	-0.30	-1.34		1.11641	-0.80443	86.74	-27.00
Stress =	0.15522857		Iteration	Stress	Delta		
Squared Correlation (RSQ) =	0.934482634		1	0.246795	9E+20		
Number of iterations =	2		2	0.246029	0.000766		
Memory needed (words) =	3902						
Return value (error if > 0)	0						
Rotation angle (degrees) =	221.5040436						
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Row# of 1st anchor fishery =	376						
# attributes =	5						
Column letter of 1st attribute =	D						

The study by Restina et al. (2023), highlights these price fluctuations are often driven by external market factors, such as export constraints-most notably, when China, the largest importer, temporarily halted imports due to quality concerns, causing prices to drop sharply.

The marketing structure further compounds this issue: most farmers sell their porang produce to collectors, while traders play a significant role in determining prices at the farm gate. This dynamic places farmers in a weak bargaining position, making their income highly susceptible to market shocks and the influence of intermediaries (Riptanti et al., 2022; Restina et al., 2023). As a result, the volatility of porang prices directly affects farmers' revenues, undermining the economic sustainability of porang cultivation. The high market value of porang remains an attractive incentive for farmers, as improvements in price components contribute to increased farmer income. Rising demand and favorable price trends further enhance economic benefits for porang farmers. However, the current price structure requires optimization to ensure long-term sustainability. This condition reflects the nature of commodity trading, where prices are determined by international market mechanisms. As a result, both sellers and buyers primarily function as price takers, with limited control over pricing dynamics (Wahyudi et al., 2021).

The study by Hidayat et al., (2024), highlights the sustainability challenges faced by porang farmers due to market price fluctuations, emphasizing the need for policy interventions such as price stabilization mechanisms and improved access to subsidized agricultural inputs. The transition from traditional farming systems to more sustainability-focused, market-oriented approaches requires farmers to adapt quickly to changing economic conditions, necessitating a deeper understanding of market dynamics, efficient cultivation techniques, and quality assurance measures. Strengthening farmers' capacity through targeted training programs and technological support can enhance their resilience, ensuring the sustainability of porang agribusiness in Madiun Regency. A comprehensive framework integrating economic, environmental, and policy considerations is essential for optimizing agricultural productivity and securing farmers' livelihoods in a sustainable manner.

The Social Dimension

Social dimensions are critical in the establishment of sustainable porang agribusiness. The social dimension is a fundamental aspect of sustainable development that can enhance rural development and reduce poverty (Mensah, 2019). Meanwhile, findings from studies Wojewódzka-Wiewiórska et al. (2020) conducted in Poland, the study emphasizes that future agricultural and rural development policies should place greater focus on the social dimension to achieve sustainable development. This study employs six attributes to evaluate the sustainability of porang agribusiness in Madiun Regency within the social dimension: a) Communication patterns, b) Farmer empowerment, c) Family support, d) Farmer regeneration, e) Conflict of interest among farmers, and f) Cooperation activities (Iskandar et al., 2018; Mamat et al., 2019; Saragih et al., 2020). The RAP-Porang Agribusiness analysis,

Table 4: Social Dimension

	2D MDS Results			Rotated		& Flipped & Scaled	
R1	0.00	0.13		0.055761	0.121051	**52.12**	4.77
GOOD	1.40	0.58		1.512827	-0.02342	**100.00**	0.00
BAD	-1.39	-0.63		-1.53042	-0.02342	**0.00**	0.01
UP	-0.62	1.36		-0.02576	1.489478	**49.44**	50.00
DOWN	0.62	-1.41		0.011958	-1.53685	50.68	-50.00
ANCHORS:	1.39	0.57		1.502887	-0.02463	99.67	-0.03
	0.87	1.11		1.238074	0.674828	90.97	23.08
	0.13	1.40		0.676809	1.229452	72.53	41.41
	-0.60	1.35		-0.01257	1.481077	49.88	49.72
	-1.12	0.84		-0.69481	1.219043	27.46	41.06
	-1.40	0.12		-1.24007	0.666086	9.54	22.79
	-1.38	-0.58		-1.49639	0.018311	1.12	1.39
	-0.87	-1.11		-1.24229	-0.67571	9.47	-21.55
	-0.14	-1.40		-0.68913	-1.23017	27.64	-39.87
	0.59	-1.36		0.002215	-1.48492	50.36	-48.28
	1.12	-0.85		0.689938	-1.22749	72.96	-39.78
	1.41	-0.12		1.240974	-0.67272	91.07	-21.45
Stress =	0.163844094		Iteration	Stress	Delta		
Squared Correlation (RSQ) =	0.934595168		1	0.244696	9E+20		
Number of iterations =	2		2	0.244055	0.000641		
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Column letter of 1st attribute =	D						

considering six attributes within the social dimension, indicates that the sustainability index value for porang agribusiness in Madiun Regency is 52.12 (Table 4). This falls within the range of 51-75, categorising the social dimension as entirely sustainable (Barska et al., 2020). The RAP-Porang Agribusiness research indicated that the sustainability rating of the porang agribusiness under the social component was 52.12. The ordination analysis indicated a satisfactory goodness of fit, categorised as sufficient (fair), with a determination coefficient of R^2 = 0.93 and an S-Stress value of 0.16 or 16%. The findings conform to the statistical criteria established in the Multidimensional Scaling (MDS) study.

The sensitivity analysis findings indicate that three of the six social dimension qualities possess the highest leverage value. The most sensitive features are communication patterns, exhibiting an RMS value of 2.227; cooperative activities, with an RMS value of 1.329; and conflicts of interest among farmers, presenting an RMS value of 1.057. A sensitivity analysis (leverage) was performed to identify the most influential characteristics affecting the sustainability of porang agriculture within the social dimension. A greater fluctuation in the RMS value indicates a heightened sensitivity of the attribute's involvement in enhancing sustainability status. The patterns of communication represent a sensitive attribute that impacts the sustainability status of the social dimension. Effective communication is necessary to provide the community with the opinion leadership necessary for the level of interpersonal involvement required. Face-to-face communication in groups is considered to have a written social presence or new media-based communication, which still needs to be higher among porang farmers. Skaalsveen et al. (2020), state that interpersonal networks are essential for farmers because they influence learning and decision-making. Farmers often rely on fellow farmers as their primary source of information. Farmers who act as intermediaries play an important role in increasing the flow of information and knowledge exchange among different groups in the farmer network. These intermediaries are also the most influential Fig.s because they are often farmers with high levels of experiential knowledge and are seen as important sources of information by other farmers.

Judging from the field conditions, porang farmers have a communication pattern only among farmers who are close/relatives so that information about porang development does not spread widely. The communication pattern applied is with a daily interaction approach or joint discussion to exchange information in disseminating information on porang agribusiness development both formally and informally because the characteristics of rural communities are high in togetherness, helping each other so that the development of porang agribusiness in the social dimension can increase. The following sensitive attribute is cooperation activities; Madiun Regency is one of the sources of porang producers in East Java in agricultural activities carried out together, involving family and neighbors. Based on observations in the field, the farming community is still active in repairing or making

farm roads. Activities are carried out in cooperation, which manifests the farmers' solidarity attitude, but several other farmers are no longer involved in these activities.

The cooperation activities that farmers should carry out are less actualized properly. In addition to the ineffective participation of other farmers, there are also several changes related to the habit of helping each other, which is social in nature, shifting to individualistic. If this cooperation activity runs well, it will significantly affect the sustainability of the porang agribusiness system in the social dimension. According to Latifa & Mahida (2024), it is recommended that the intention of cooperation be increased, starting from the easiest behavior, namely, respecting the surrounding environment. If this behavior has become a habit, cooperation can become a local wisdom value that encourages a more inclusive and sustainable future. The following sensitive attribute that affects the sustainability of the social dimension is the conflict of interest between farmers. Conflicts among farmers are rare/no longer found, especially in porang farming land. This is very important in porang farming because if land conflicts often occur, it will disrupt the sustainability of porang farming.

Porang agricultural land in Madiun Regency is located in a forest area with potential conflict, so anticipatory steps must be taken to prevent conflict on porang production land. The factors causing conflict in the use of land for forest plantations are the lack of understanding of perceptions regarding forest area boundaries between the community, corporations and the government, some forest areas are still limited to designations, there is no boundary or determination of forest areas, there is an element of ignorance of the community in the forest area, there is an element of intent by exploiting the weaknesses of the government, corporations and communities around the forest area to control the land and there is a delay in granting permits by the government in the forest area (Mustofa & Bakce, 2019). Porang farmers must understand anticipatory steps and knowledge about the potential for land conflicts to ensure the continuity and sustainability.

The Ecological Dimension

The preservation of the original function of natural resources is a requirement for the sustainable use of natural resources (Sesa, 2018). It must also adhere to ecological efficiency requirements, signifying economic and environmental efficiency. The research by Uneze & Onuoha (2021), identifies the consequences of land degradation as food insecurity, diminished soil fertility, deterioration of soil structure, heightened poverty levels, and decreased income. Sustainable porang management must include the surrounding natural resources before land removal and throughout ongoing management. The ecological component is crucial as it influences the equilibrium of natural resource use and ecological services. Ecological variables are selected to illustrate the influence of natural resource utilisation and ecological factors on sustainability (Najmi et al., 2019). The assessment of the Madiun Regency's porang agribusiness's sustainability within the ecological dimension employs four measuring attributes: a) Land use, b) Average plant age, c) Farmer environmental awareness, and d) Utilisation of organic fertilisers (Andriani et al., 2017; Susanto et al., 2022; Suhartini et al., 2024).

Table 5: Ecological Dimensions

	2D MDS Results			Rotated		& Flipped & Scaled	
R1	0.61	0.05		-0.61376	-0.02061	**28.14**	-0.05
GOOD	-1.55	-0.20		1.56512	-0.01902	**100.00**	0.00
BAD	1.46	0.15		-1.46717	-0.01902	**0.00**	-0.32
UP	-0.21	1.49		0.036285	1.498882	**49.58**	50.00
DOWN	0.14	-1.51		0.028257	-1.51741	49.32	-50.00
ANCHORS:	-1.54	-0.19		1.550838	-0.01398	99.53	-0.16
	-1.13	0.89		1.025896	1.010513	82.22	33.81
	-0.22	1.48		0.050443	1.490815	50.05	49.73
	0.75	1.10		-0.87226	1.011459	19.62	33.84
	1.42	0.19		-1.43198	0.030867	1.16	1.33
	1.00	-0.86		-0.89665	-0.97297	18.81	-31.95
	0.14	-1.47		0.027199	-1.4725	49.28	-48.51
	-0.88	-1.11		0.997777	-1.00702	81.29	-33.08
Stress =	0.163247615		Iteration	Stress	Delta		
Squared Correlation (RSQ) =	0.931240797		1	0.662679	9E+20		
Number of iterations =	5		2	0.313336	0.349342		
Memory needed (words) =	3654		3	0.257425	0.055911		
Return value (error if > 0)	0		4	0.253869	0.003556		
Rotation angle (degrees) =	186,5164948		5	0.253535	0.000334		
RAPFISH PARAMETERS USED FOR THIS ANALYSIS							
# fisheries =	1						
# reference fisheries =	400,00%						
# anchor fisheries =	8,00000						
Row# of 1st fishery =	2,00000						
Row# of GOOD fishery =	372						
Row# of BAD fishery =	373						
Row# of UP fishery =	374						
Row# of DOWN fishery =	375						
Column letter with fisheries names =	A						
Row# of 1st anchor fishery =	376						
# attributes =	4						
Column letter of 1st attribute =	D						

The RAP-Porang Agribusiness analysis on the sustainability of porang agribusiness produced an ecological dimension sustainability index of 28.14 and categorized as less sustainable (Table 5). This shows that farmers' ability to maintain the environment still needs to be improved. The RAP-Porang Agribusiness analysis on the ecological dimension produced an R^2 value of 0.93 and an S-Stress value of 0.16 or 16%. As a result, the ecological dimension analysis in this study indicates that the goodness of fit condition is classified as the sufficient (fair) category. Two of the most sensitive attributes that influenced the sustainability of the ecological dimension were land use and farmer awareness of the environment, with an RMS value of 9.273 and 9.177, respectively, based on the four attributes analysed. This demonstrates that it is imperative to prioritise and evaluate these characteristics in order to enhance the sustainability status of the ecological dimension.

The sustainability of the ecological dimension of the porang agribusiness is influenced by the sensitive attribute of land use. The utilisation of agricultural territory is essential for agricultural enterprises and cultivation production. The efficiency of narrow land ownership or control in agriculture is inferior to that of broader land ownership. The efficacy of cultivation is correlated with the ownership or control of land. As the extent of land control increases, the efficiency of input utilisation increases (Ubaidillah et al., 2021). The revenue of porang cultivators in Madiun Regency is influenced by the land control condition, which encompasses a range of 0.1 to 10 hectares.

Facts on the field show that the area of land cultivated by porang farmers in Madiun Regency is relatively small. Efforts can be made to optimise the existing land, one of which is with an agroforestry plant system. The advantage of porang plants is that they can grow in the shade, making them suitable for development as intercrops between types of woody plants or trees managed with an agroforestry system (Hidayah et al., 2018). The advantages of porang agroforestry are not only in terms of production, but also in ecological aspects. The agroforestry system with porang can increase soil fertility, soil aggregate stability, soil organic matter content, and water infiltration. Porang also acts as a soil conservation agent because of the dense soil cover and the rapid decomposition of porang stems and leaves, which add organic matter to the soil (Kusnarta et al., 2021).

The findings of a study by Dimobe et al., (2025), in Sub-Saharan Africa show that agroforestry systems substantially increase soil fertility, offer a reliable climate change adaptation and mitigation strategy, and provide diversification and strengthen rural livelihoods against climate disturbances. However, what needs to be considered is clarity regarding land ownership and a clear division of boundaries between forest functions for conservation and forests that can be utilised for agriculture. So, agricultural activities in forest areas are sustainable and do not cause environmental damage. The following sensitive attribute is farmers' awareness of the environment. According to Despotović et al. (2021), farmer environmental awareness includes understanding the impact of agricultural activities on the environment and motivating farmers to adopt environmentally friendly practices. Meanwhile, Smiglak-Krajewska & Wojciechowska-Solis (2021), explain that environmental awareness is not just knowledge but attitudes and intentions that encourage farmers to adopt sustainable agricultural practices. With a firm understanding and will, farmers can contribute significantly to maintaining environmental sustainability while increasing agricultural productivity sustainably.

The pollution in the environment that is a effect of the application of agricultural inputs that are not recommended is the focus of this study on environmental awareness. Several farmers were found to have the stigma that using pesticides in high doses would cause grass or weeds to die quickly and be difficult to grow back. Excessive use without personal protective equipment can trigger pesticide exposure in farmers, which can cause various health problems (Pratama et al., 2021; Shaleha et al., 2023). There needs to be strict supervision of pesticide application in the field and training on how to apply pesticides properly, minimizing adverse health effects on operators and environmental contamination (De Graaf et al., 2024). The awareness of porang farmers in Madiun towards environmental sustainability can be seen from several indicators, including using organic materials or organic fertilizers as a priority or choice in porang cultivation. Environmentally conscious farmers prioritize organic fertilizers in porang cultivation, reducing dependence on chemical inputs (Hasri et al., 2023). A study by Purnama et al. (2023), showed that organic fertilizers significantly increased porang growth by improving plant height, stem diameter, leaf sheaths, and lateral roots, especially in nutrient-poor soils. In addition, research by Kasransyah et al. (2025), showed that the application of organic materials such as manure, compost, and biochar improved the physical and chemical properties of the soil, increased the availability of nutrients and water retention capacity, which had a positive impact on the growth and yield of porang.

The Institutional Dimension

The evaluation of porang agribusiness sustainability should be conducted alongside the institutional dimension. The institutional dimension's sustainability is determined by the capacity of group integration in agribusiness to execute institutional functions that facilitate farming activities. Institutional dimensions serve as indicators of the presence of legal and institutional instruments that promote the sustainability of the Utilization of resources from nature and the preservation of nature. From an institutional perspective, the existence of farmer associations, such as cooperatives, short marketing networks, and financial institutions at the village level, is a motivating factor that can encourage farmers to expand the scope of more contemporary economic production with substantial added value (Maulidah, 2012). Institutional dimension are important requirements for farming to be efficient, smooth, and sustainable (Movilla-Pateiro et al., 2021). The role of institutions is essential in enabling farmers to access assistance.

Table 6: Institutional Dimension

	2D MDS Results			Rotated		& Flipped & Scaled	
R1	0.02	0.68		-0.48062	0.477383	**32.76**	17.63
GOOD	-1.09	-1.12		1.561895	-0.05538	**100.00**	0.00
BAD	1.10	0.98		-1.47558	-0.05538	**0.00**	0.07
UP	-1.08	0.98		0.09955	1.453295	**51.86**	50.00
DOWN	1.11	-1.10		-0.03647	-1.56856	47.38	-50.00
ANCHORS:	-1.08	-1.11		1.548026	-0.05199	99.54	0.19
	-1.38	-0.05		1.031708	0.917613	82.55	32.27
	-1.08	0.96		0.111287	1.444568	52.24	49.71
	-0.03	1.30		-0.88341	0.957629	19.50	33.60
	1.04	0.99		-1.44004	-0.01084	1.17	1.55
	1.36	-0.02		-0.96595	-0.96283	16.78	-29.95
	1.08	-1.07		-0.03582	-1.52296	47.40	-48.49
	0.01	-1.41		0.965431	-1.02254	80.36	-31.93
Stress =	0.167505965		Iteration	Stress	Delta		
Squared Correlation (RSQ) =	0.92855984		1	0.252496	9E+20		
Number of iterations =	3		2	0.250926	0.00157		
Memory needed (words) =	3654		3	0.250857	6.98E-05		
Return value (error if > 0)	0						
Rotation angle (degrees) =	223.920105						
RAPFISH PARAMETERS USED FOR THIS ANALYSIS							
# fisheries =	1						
# reference fisheries =	400.00%						
# anchor fisheries =	8,00000						
Row# of 1st fishery =	2,00000						
Row# of GOOD fishery =	373						
Row# of BAD fishery =	374						
Row# of UP fishery =	375						
Row# of DOWN fishery =	376						
Column letter with fisheries names =	A						
Row# of 1st anchor fishery =	377						
# attributes =	4						
Column letter of 1st attribute =	D						

Measuring the sustainability of porang agribusiness within the institutional dimension applies four measurement attributes, which are analyzed through the RAP-Porang Agribusiness analysis, namely a) Participation in farmer groups, b) Accessibility of agricultural extension workers, c) Accessibility to financing institutions and d) The function of government in determining the price of agricultural inputs and production results (Suardi et al., 2022; Al Islami et al., 2024).

Based on the RAP-Porang Agribusiness analysis results, the sustainability index scores for porang agribusiness in the institutional dimension are 32.76, categorizing it as less sustainable. The ordination analysis of the institutional dimension sustainability yields an R^2 value of 0.93 and an S-Stress value of 0.17, or 17% (Table 6). The analysis of the sustainability of porang agribusiness in Madiun Regency within the institutional dimension indicates a satisfactory condition in the sufficient category. The leverage assessment is a subsequent phase following the RAP-Porang Agribusiness analysis. This assessment aims to discover the most sensitive attributes influencing the sustainability of porang agribusiness within the institutional dimension. The leverage assessment results indicate that the three most critical attributes influencing sustainability within the institutional dimension are the accessibility of agricultural extension workers, with an RMS value of 12.617; participation in farmer groups, indicated by an RMS value of 10.964; and access to financing institutions, represented by an RMS value of 10.174.

The accessibility of agricultural extension workers is the most sensitive attribute affecting the sustainability status of the institutional dimension. Agricultural extension institutions already exist in the research location area. However, their activities need to be improved, especially in terms of the frequency of extension and training on porang farming management, in order to move towards a more advanced, intensive, and sustainable direction. Extension to porang farmers on how to cultivate correctly and the community needs to understand several advantages of utilizing this porang commodity. According to Amghani et al. (2025), increasing farmer trust in extension workers and increasing the efficiency of agricultural activities can be achieved by conducting extension services. Agricultural extension workers bridge agricultural science and practice, ensuring farmers can access the latest information and apply more efficient and sustainable techniques.

The following sensitive attribute is participating in farmer groups; most porang farmers in Madiun Regency are members of farmer groups. Farmer participation in farmer groups can be a bridge for farmers to obtain knowledge and technology about farming, which is constantly developing and becoming necessary for farmers (Koampa et al., 2015). Farmer groups play an important role in agricultural innovation, with various functions that support the successful adoption and sustainability of innovation. Based on the research results of Hilmiati (2020), several key factors determine farmer groups' performance in implementing sustainable agricultural innovation, namely strong leadership, transparency, regular meetings, and the ability to generate cash. Farmer groups that have a good institutional system tend to be able to implement innovation more sustainably than groups with poor systems.

The existence of farmer groups is quite important for porang farmers. With farmer groups, farmers find it easier to market their agricultural products, and farmers find it easier to obtain information about porang prices and other information related to porang farming. The study results by Kusnandar et al. (2023), show that empowering farmer groups through fostering independent governance is also an important strategy to face the challenges that farmer groups face in developing countries, including Indonesia. This approach allows farmer groups to organize themselves independently to increase their capacity and bargaining power in the agricultural value chain. The subsequent sensitive attribute influencing the sustainability associated with the institutional dimension is access to financial institutions. To improve the institutional sustainability of porang agribusiness moving forward, it is essential to focus on the attribute of accessibility to financing institutions in porang cultivation. The situation of porang farmers in Madiun Regency necessitates improvement via better access to financial institutions to ensure their agricultural capital is secured. The obstacle arises from the geographical remoteness of the financing institution, leading most farmers to obtain capital from relatives and dealers. According to Karyani et al. (2024), financial technology (fintech) offers new prospects for farmers to obtain other sources of financing apart from established formal financial institutions. Meanwhile, in Kenya, credit unions are a substitute for limited banking services; this trend is also seen throughout African countries where the banking system has not yet reached rural areas (Ngundo, 2024). Meanwhile, according to Putri & Kumbara (2024), the capital assistance provided by the government in the form of credit subsidies is very beneficial for farmers starting a porang farming business. The credit provided is one of the capital sources from the government through banks to help farmers. It is hoped that with capital assistance, farmers will benefit from cultivating porang and the sustainability of their farming business.

The Cultural Dimension

Cultural sustainability pertains to sustainable development. Culture offers the essential transformative element required for the sustainability of the development process (Semiarti, 2022). Sustainable development was originally defined through three dimensions: ecological, economic, and social. Moreover, the social dimension has been interpreted in multiple ways, frequently prioritizing socio-economic resources of development over socio-cultural capabilities. There is a growing interest in establishing cultural sustainability as the fourth pillar of sustainable development (Oktarina & Yulianti, 2022). The sustainability within this cultural dimension pertains to the practices of farmers in cultivating porang, which subsequently influences sustainability outcomes. The assessment of the sustainability of porang agribusiness in Madiun Regency in the cultural dimension uses four assessment attributes, namely a) The influence of community rules on porang cultivation, b) Porang cultivation is a hereditary heritage, c) Farmer awareness in porang cultivation due to the community environment, and d) Farmer awareness in implementing government policies/regulations (Kholil et al., 2015; Arimbawa, 2016; Sari et al., 2024).

Table 7: Cultural Dimension

	2D MDS Results			Rotated		& Flipped & Scaled	
R1	0.02	0.23		0.2053	0.112257	**57.46**	4.60
GOOD	0.83	1.25		1.505654	-0.02815	**100.00**	0.00
BAD	-0.81	-1.32		-1.55129	-0.02815	**0.00**	-0.03
UP	-1.29	0.77		-0.04675	1.499171	**49.22**	50.00
DOWN	1.32	-0.83		0.010464	-1.55342	51.09	-50.00
ANCHORS:	0.82	1.24		1.491449	-0.02605	99.54	0.04
	-0.30	1.33		0.9585	0.968633	82.10	32.62
	-1.27	0.77		-0.02997	1.488927	49.77	49.66
	-1.38	-0.27		-0.96711	1.019703	19.11	34.29
	-0.83	-1.26		-1.51137	0.025136	1.31	1.71
	0.29	-1.36		-0.99255	-0.97193	18.28	-30.95
	1.27	-0.80		0.005395	-1.50472	50.92	-48.40
	1.34	0.24		0.922282	-1.00141	80.92	-31.92
Stress =	0.177032873		Iteration	Stress	Delta		
Squared Correlation (RSQ) =	0.923066437		1	0.262776	9E+20		
Number of iterations =	3		2	0.261126	0.001651		
Memory needed (words) =	3654		3	0.26107	5.58E-05		
Return value (error if > 0)	0						
Rotation angle (degrees) =	57.48973846						
RAPFISH PARAMETERS USED FOR THIS ANALYSIS							
# fisheries =	1						
# reference fisheries =	400.00%						
# anchor fisheries =	8,00000						
Row# of 1st fishery =	2,00000						
Row# of GOOD fishery =	372						
Row# of BAD fishery =	373						
Row# of UP fishery =	374						
Row# of DOWN fishery =	375						
Column letter with fisheries names =	A						
Row# of 1st anchor fishery =	376						
# attributes =	4						
Column letter of 1st attribute =	D						

According to the results of the RAP-Porang Agribusiness analysis on the cultural dimension, it is evident that the sustainability index value for porang agribusiness on this dimension is 57.46, falling within the range of 51-70 and categorizing it as reasonably sustainable (Table 7). The analysis of RAP-Porang Agribusiness in the cultural dimension was carried out by producing R^2 = 0.92, and the S-Stress value was 0.18 or 18%. So, the goodness of fit value in the analysis of the sustainability of the cultural dimension of sustainable porang agribusiness is in a fair condition and has met the requirements for a good MDS analysis. An analysis of sensitivity was conducted to identify the most significant attributes that influence the Madiun Regency's porang agribusiness's sustainability in the cultural dimension. Two attributes significantly influence the sustainability of the cultural dimension, as determined by the leverage analysis: porang cultivation, which is a hereditary heritage, and farmer awareness of cultivation.

The main attribute most sensitive to impacting the sustainability of porang agribusiness within the cultural dimension has an RMS value of 7.604, is that porang cultivation is a hereditary heritage. Porang farming activities in Madiun Regency cultivate this commodity as a legacy from their parents. The study by Kurniati et al. (2021), which highlights that the majority of the population in this region engages in agricultural activities, with participation beginning in adolescence. This process reflects a generational transfer of agrarian knowledge, wherein children gradually familiarize themselves with farming practices under the guidance of their parents. They not only acquire technical skills in cultivation but also develop an understanding of managerial, social, and ecological dimensions related to agricultural production. Consequently, farming is not merely an economic activity but an integral component of cultural identity and community sustainability.

The second most sensitive attribute is farmer awareness in cultivation, with an RMS value of 4.844. Farmer awareness in porang cultivation is important because farmer awareness dramatically supports the development of Madiun Regency's porang agribusiness's sustainability. In this case, porang farmers are not only developing but also must be sustainable to achieve their goals and benefits. The development of porang commodities in Madiun Regency shows that public awareness is increasing, especially after community agriculture is oriented towards the porang market. Hermudananto et al. (2019), study showed that farmer awareness in porang cultivation is essential for the success and sustainability of farming businesses. The training and mentoring activities increased environmental knowledge and farmer skills in porang cultivation, including planting techniques and post-harvest management. This approach also strengthens the institutionalization of farmer groups so they are more confident in managing porang farming businesses.

Conclusion

According to the results and discussion of the sustainability analysis of porang agribusiness in Madiun Regency, is categorized as less sustainable. The cultural dimension was the one with the most value. It illustrates that porang agribusiness activities are still dominated by cultural conditions in the farmer's environment, such as the influence of community rules in porang cultivation, porang cultivation is a hereditary heritage, farmer awareness in porang cultivation because of the community environment, and farmer awareness in implementing government policies/regulations. If these conditions are carried out optimally, it will increase the Madiun Regency's porang agribusiness's sustainability. In comparison, the lowest dimension is the ecological dimension. Conditions in the field show that farmers still need to be highly aware of maintaining the environment to sustain porang farming activities. The sustainability of the porang agribusiness, can be improved from the ecological dimension, depends on farmers' effective land management and environmental awareness. The porang agroforestry system increases land use productivity and maintains soil and environmental fertility. Integrating organic fertilizers in porang cultivation is an important strategy for environmentally friendly production. Furthermore, support for training and supervision in using appropriate pesticides is critical to realize sustainable and profitable porang farming. Analysis of the sustainability of porang agribusiness using the Rapfish technique provides a relatively more straightforward analysis. It can be a reference for quickly evaluating the condition of porang agribusiness in Madiun Regency. Given its multidimensional nature, the rapfish technique can be used as a tool to determine a snapshot or preliminary assessment to acquire a thorough understanding of the sustainable condition of these resources. In addition, this study shows that the uncertainty aspect that usually appears in non-parametric analysis can be reduced with Monte Carlo analysis. Policymakers can quickly evaluate the condition of pouring agribusiness resources without having to conduct detailed, complicated qualitative analysis. Finally, the analysis of the sustainability evaluation resulting from the porang agribusiness research shows that with a simple but comprehensive technique, the assessment of the porang agribusiness can be completed. Rapfish results can be replicated and are numerically objective. As a result, the study's findings may be used as a guide to evaluate Porang agribusiness management in other regions. Replication can be carried out to assess the status of porang agribusiness between regions in a wider scope.

DECLARATIONS

Funding: This study did not get any financial support from any organization/agency

Acknowledgement: The authors are grateful to the Ministry of Agriculture of the Republic of Indonesia for supporting this research through the provision of a doctoral scholarship under contract No. 323/KPTS/KP.320/A/05/2021 and to Universitas Padjadjaran for academic and research support.

Conflict of Interest: The authors declare that there is no conflict of interest.

Data Availability: Data will be available at request.

Ethics Statement: The research involving human participants was conducted in compliance with all relevant national regulations and institutional policies, in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the authors' institutional review board or an equivalent ethics committee.

Author's Contribution: CS, TK, EW, and ZS conceived and designed the experiment. CS conducted the study and performed statistical analyses of the experimental data. TK, EW, and ZS supervised and coordinated the experiments, providing guidance on experimental activities. CS prepared the initial draft of the manuscript. All authors critically revised the manuscript and approved the final version.

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

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