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ASSESSING THE POLICY POTENTIAL OF VERY-EARLY MATURING RICE FOR INDONESIA'S FOOD SECURITY THROUGH AGRO-SOCIOECONOMIC AND AGRIBUSINESS APPROACH

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ABSTRACT

Indonesia's rice production is anticipated to face increasing challenges due to heightened climate variability, which manifests as erratic rainfall, droughts, floods, and extreme temperatures. The current production systems and medium-duration rice varieties may struggle to cope. Although the nation's rice output presently surpasses domestic consumption, this balance could become precarious as climate unpredictability disrupts planting schedules and reduces effective growing seasons. As a result, future rice cultivation will need to adopt climate-resilient and very-early-maturing varieties to minimize exposure to end-of-season climatic stress. To support evidence development, a multidisciplinary approach is needed for comprehensive policy development. Therefore, this study assessed the policy potential of very-early-maturing rice using a multidisciplinary approach by agronomic, economic, social, agribusiness, and policy perspectives. The research included field trials in Bajeng, Gowa, South Sulawesi, using a split–split plot design to test planting systems, pruning, fertilization, and varieties; farm business analysis to calculate profitability and R/C ratio; and a survey of 158 South Sulawesi farmers analyzed using RStudio. The findings indicate that the square planting method and broader spacing of 25–30 cm are beneficial for developing ideotype tillers. The combination of nutrient and cultivation management, including balanced fertilization with a focus on nitrogen, compost, lime, and the practice of alternate wetting and drying (AWD), increased productive tillers, improved water efficiency, and improved productivity, resulting in 15 productive tillers. Compost increased yields by ~1 t ha^{-1} and seasonal profits, although R/C ratio growth was limited by rising costs. Economically, Cakrabuana, Padjadjaran, and Inpari 13 showed the highest profitability among very-early varieties. The combined system increased planting intensity and annual profits compared with conventional methods. Socially and agribusiness-wise, farmers highly accepted very-early varieties, citing suitability for short seasons, increased cropping index, and income potential. Young farmers and extension officers were significant in expanding adoption. Policy implications underscore integrating adaptive technologies, strengthening seed systems, agribusiness institutions, inclusive financing and developing premium value chains to support sustainable, climate-adaptive, market-oriented rice agriculture.

Keywords: Early maturity, Farmer, Land optimization, Rice policy, Rice sustainability.

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1. INTRODUCTION

Global food faces complex pressures due to geopolitical conflicts, supply chain disruptions and economic uncertainty (López et al., 2025; Saccone & Vallino, 2025). Regional to international conflicts disrupt food trade, increase commodity price fluctuations and heighten the risk of inflation (Aizenman et al., 2024; Saccone & Vallino,

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2025). Every country needs to strengthen food sovereignty for national economic stability (Cadavid et al., 2024; Osman et al., 2026; Rudy et al., 2026). Indonesia, which relies on rice as its staple food, faces major challenges in maintaining national production amid global pressures (Rachman et al., 2022; Sutardi et al., 2023). According to Agricultural Data and Information Systems Center, Secretariat General of the Ministry of Agriculture (2025), national rice consumption in 2024 reached 26.01 million tons and in 2025 shows a slight decline to 24.91 million tons. Meanwhile, the Indonesian Central Bureau of Statistics (2025) reported that national rice production in 2024 and 2025 were 30.62 and 34.69 million metric tons, respectively. A comparison of consumption and production indicates that Indonesia has already achieved rice self-sufficiency. However, this self-sufficiency is unstable and vulnerable to external shocks. The challenge of rice self-sufficiency in Indonesia is expected to become more severe as global conflicts affect the economy and agribusiness system (Patunru & Ilman, 2020; Prayuginingsih et al., 2024; Fisher et al., 2025; Kiloes et al., 2026). Prolonged conflict alters agricultural production costs through increases in input prices, such as fertilizers, energy, and logistics, and heightens market uncertainty (Winne & Peersman, 2021; Saccone & Vallino, 2025; Vos et al., 2025; Ali et al., 2026; Ayalew et al., 2026). While self-sufficiency of rice is presently attained, it does not guarantee long-term food security due to the effects of climate change. The challenge of sustaining consistent production amidst unpredictable weather conditions remains significant (Janni et al., 2023; Ismail et al., 2025; Tran et al., 2025). In Indonesia, climate change has resulted in frequent droughts, erratic rainfall, and increasing temperatures (Ansari et al., 2023; Abebaw, 2025; Li et al., 2025). These issues emphasize that current self-sufficiency may not be sustainable in the future, thereby necessitating innovation to adapt with current agriculture challenge

Addressing these challenges necessitates agricultural innovations that adhere to the principles of Climate-Smart Agriculture (CSA) and Sustainable Intensification (SI), both of which are widely acknowledged as strategic approaches for sustaining food production amidst changing climatic conditions. Previous research has demonstrated that CSA practices enhance crop productivity while increasing resilience to drought, heat stress, and resource scarcity through integrated management of crops, water, and nutrients (Mpala & Simatele, 2024; Olarewaju et al., 2025). Similarly, sustainable intensification has been advocated in major rice-producing countries to augment production from existing agricultural land without further environmental degradation (Cui et al., 2023; Materu, 2025). In China, integrated agronomic management and improved rice cultivation practices have effectively increased land productivity and resource-use efficiency while mitigating environmental impacts (Dong et al., 2020; Huang et al., 2025). In South Asia, sustainable intensification through improved varieties and optimized management has been shown to enhance cropping intensity and farm productivity despite limited land and water resources (Emran et al., 2022; Yadav et al., 2024). Furthermore, studies in Southeast Asia have demonstrated that the combination of climate-resilient cultivars with improved agronomic practices can significantly bolster the resilience and sustainability of rice production systems (Noviana et al., 2021; Musa et al., 2023, 2025). Collectively, these previous findings suggest that optimizing existing agricultural land through technological innovation and enhanced crop management has become a crucial strategy for sustaining rice production while addressing the rising food demand under climate change.

The Indonesian government has prioritized the optimization of agricultural land as a strategic approach to enhance national food security, in alignment with the principles of CSA and SI. This program aims to improve land utilization in terms of both productivity per unit area and annual cropping intensity. The land optimization program initiated by the Ministry of Agriculture encompasses various initiatives, such as the development of new rice fields, the rehabilitation and modernization of irrigation networks, and the installation of pumping systems in water-scarce areas (Arif et al., 2019; Yasar et al., 2019; Vadilaksono et al., 2024). However, an infrastructure-based land optimization approach is considered not fully optimal if it is not accompanied by appropriate cultivation strategies, particularly regarding variety selection (Mastur et al., 2020). Varieties and seeds are fundamental components of the agricultural production system. Several study shows that the contribution of varieties and seeds to determining yield is estimated to reach 40–60% of total production (Evenson & Gollin, 2003; Qian & Zhao, 2017; Noviana et al., 2021; Musa et al., 2023, 2025; Anbes & Asredie, 2025), the contribution of varieties and seeds to determining yield is estimated to reach 40–60% of total production. Therefore, variety selection is key to the success of land optimization programs.

Among the technological innovations designed to enhance agricultural land optimization, very early-maturing rice varieties emerge as a particularly promising option for Indonesia. In contrast to conventional rice cultivars, these varieties complete their growth cycle in less than 100 days from sowing (Anshori et al., 2024a). Biologically, very early-maturing varieties are characterized by a faster growth rate, with an overlap between the vegetative and reproductive phases (Rebolledo et al., 2012; Shi et al., 2020). This allows the growth rate of tillering to synergize with panicle initiation (Anshori et al., 2024b; Yuan et al., 2024). Agronomically, very early-maturing varieties can accelerate panicle initiation and ensure adequate grain-filling strength during the grain-filling period. This results in

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increased harvest indices and yield per unit of time, despite a shorter growing season (Chen et al., 2019; Yun, 2023). These characteristics are particularly advantageous for Indonesia, where increasing rice production depends primarily on maximizing productivity from existing agricultural land rather than expanding cultivated areas. Furthermore, their shorter growth cycle enables crops to escape terminal drought and heat stress, contributing to greater climate resilience, increased cropping intensity (CI), and improved planting calendar (Korres et al., 2017; Liang et al., 2024).

Several very early-maturing rice varieties that have been reported to be effective in Indonesia include Cakrabuana, Padjadjaran, and Inpari 13 (Anshori et al., 2024a; 2024b). However, the potential of these very early-maturing rice varieties is highly dependent on the growing environment and cultivation technologies (Noviana et al., 2021; Anshori et al., 2024a). Several studies have explored nutrient optimization and field practice engineering, such as Musa et al. (2023) on the optimization of NPK and compost fertilization, and Musa et al. (2025) on the optimization of nitrogen and compost fertilization. However, the cultivation technology for very early-maturing rice varieties is not determined solely by technical aspects. A comprehensive assessment of policy directions, agribusiness potential and export potential in the development of very early-maturing rice varieties also plays a role as a strategic instrument in national food security and rice agribusiness development policies (Ng'endo et al., 2022; Liang et al., 2024).

Policy direction and agribusiness potential are crucial components of the downstream processing of agricultural products, including crop varieties. According to several studies, policy direction significantly determines the scalability of adoption and the sustainability of agricultural innovations, especially when implementing new rice varieties (Sulaiman et al., 2025; Fudjaja et al., 2026). This concept also encompasses economic and agribusiness potential in supply chain management, rice quality standards, and market access, including export potential (The Anh et al., 2020; Jamaludin et al., 2021). All these aspects influence the effectiveness of downstream processing, which in turn affects farmer and business actor incentives. Although several studies have reported on agribusiness systems for very early-maturing rice varieties (Connor et al., 2023; Hien & Kim, 2024). These studies were conducted independently, focusing solely on specific components of the innovation system. Agronomic research infrequently assessed whether the optimization of variety and technology leads to farmer acceptance, economic feasibility, or agribusiness opportunities. In contrast, socioeconomic and agribusiness studies typically did not consider varietal performance, cultivation technology, or biological characteristics as factors influencing adoption and policy effectiveness. Consequently, the interactions among agronomic performance, economic viability, farmer perception, agribusiness development, and policy support remain inadequately understood. This study addresses this gap by enhancing the existing body of knowledge through a multidisciplinary approach that integrates agronomic, socioeconomic, and agribusiness perspectives to evaluate the policy potential of very-early maturing rice for Indonesia's food security.

This study sought to address the existing gap by incorporating agronomic performance, economic feasibility, farmer perception, agribusiness potential, and policy direction into a unified analytical framework for assessing very early-maturing rice in Indonesia. The findings are anticipated to offer a scientific foundation for evidence-based policy formulation and strategic decision-making, thereby supporting agricultural land optimization and enhancing long-term national food security.

2. MATERIALS AND METHODS

This research was systematically designed using three study concepts: (i) a case study on the agronomic and economic potential for optimizing the cultivation of very early rice varieties; (ii) a questionnaire study on agribusiness and social concepts; and (iii) a reference and secondary data study related to agronomic and agribusiness potential.

2.1. Case Studies Related to Agronomic and Economic Potential in Optimizing the Cultivation of Very Early Maturing Rice Varieties

2.1.1. Research Procedure: Case studies took place in an irrigated rice field in Maradekaya Village, Bajeng Subdistrict, Gowa Regency, South Sulawesi, Indonesia (Fig. 1) with varieties used are Cakrabuana and Inpari. These varieties were selected because they are among the very early-maturing rice cultivars that have been distributed and cultivated in several major rice-producing regions, including South Sulawesi. Their proven field deployment provides a suitable basis for assessing the feasibility of scaling up very early-maturing rice as a policy option to support cropping intensification and Indonesia's land optimization program.

The location of the experimental site is 5°16'54.04"S 119°26'40.60"E. Conducted from May to August 2025, the study coincided with the dry season in South Sulawesi, focusing on irrigated lowland rice cultivation. The rice was harvested 85 days after planting (DAP). The field was flooded, ploughed to a depth of 20 cm using a tractor,

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and left to rest for two days. Second ploughing was then performed using a harrow to level the soil and incorporate the mud in the rice field. Before planting, soil samples were collected to determine the initial physicochemical characteristics and weather data of the experimental field, which are presented in Table 1 and 2. After soil preparation, rice seeds were then soaked in a bucket containing clean water for 24 hours and then germinated in sacks for 24 hours; subsequently, the germinated seeds were spread in the nursery. When the seedlings were 18 days after sowing (DAS), they were transplanted according to the planting distance treatment. Fertilization was carried out according to the treatment, which was divided into two stages: the first stage involved applying fertilizer when the seedlings were 7 DAP, amounting to 25% of the total chemical fertilizer treatment and 100% of the compost fertilizer at 3 DAP. The second application was given when the seedlings were 28 DAP, amounting to 75% of the total chemical fertilizer treatment. For biofertilizer application, it was administered five times at 3 DAP, 18 DAP, 33 DAP, 48 DAP, and 53 DAP.

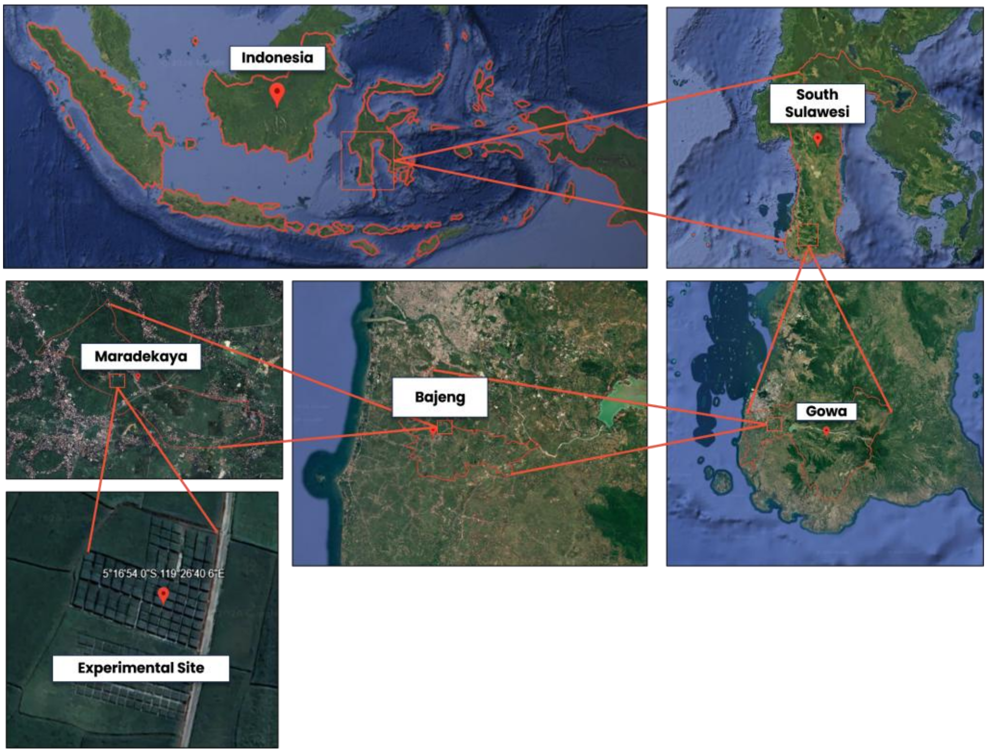

Fig. 1: Geographic location of the case study rice field in Maradekaya Village, Bajeng Subdistrict, Gowa Regency, South Sulawesi, Indonesia.

Table 1: Initial soil physicochemical properties of the experimental field before planting

Soil depth (cm)	pH (H_2O)	Organic C (%)	Total N (%)	C/N ratio	Available P_2O_5 (ppm)	Ca (cmol(+) kg^{-1})	Mg (cmol(+) kg^{-1})	K (cmol(+) kg^{-1})	Na (cmol(+) kg^{-1})	CEC (cmol(+) kg^{-1})	Base saturation (%)	Soil texture
0–10	4.56	1.65	0.17	10	7.95	3.45	0.95	0.35	0.10	20.25	24	Silty clay loam
10–20	5.42	1.85	0.12	15	9.15	4.15	0.75	0.16	0.15	18.65	28	Silty clay loam

Notations (a,b) differed significantly (P<0.05).

Table 2: Monthly climatic conditions during the experimental period (May–August 2025)

Parameter	Source	Unit	May	Jun	Jul	Aug	Mean
ALLSKY_SFC_SW_DWN	CERES SYN1deg	MJ m^{-2} day^{-1}	17.38	15.02	18.58	20.67	17.91
GWETPROF	MERRA-2	Index (0–1)	0.83	0.82	0.83	0.67	0.79
IMERG_PRECTOT	MERRA-2	mm day^{-1}	5.22	5.70	5.96	1.83	4.68
RH2M	MERRA-2	%	79.97	80.75	80.76	75.93	79.35

Monthly climatic variables during the study period (May–August). ALLSKY_SFC_SW_DWN = CERES SYN1deg All Sky Surface Shortwave Downward Irradiance (MJ m^{-2} day^{-1}); GWETPROF = MERRA-2 Profile Soil Moisture (dimensionless index, 0–1); IMERG_PRECTOT = MERRA-2 Total Precipitation (mm day^{-1}); RH2M = MERRA-2 Relative Humidity at 2 m above ground level (%). Data were obtained from the NASA POWER and MERRA-2 datasets.

Crop management to ensure optimal growth included weeding, irrigation, and pest and disease control. Weeding was performed 18 days after planting (DAP) by mechanically pulling weeds or removing moss around the plants. Irrigation was performed at 13 DAP, with water levels reaching 5 cm above the soil surface; irrigation was halted during the second fertilization, and the soil was allowed to dry to support root aeration and enhance fertilizer absorption. Irrigation was resumed 5 days after fertilization. During the primordial phase, the water level was raised to 10 cm above the soil surface to suppress the growth of new tillers.

Pest and disease control were carried out mechanically by removing snail eggs, spraying molluscicides, and controlling pests and rats by installing nets and plastic rolls during the grain-ripening period. Disease control was also performed by spraying fungicides and insecticides. Harvesting was performed after the grains reached physiological maturity, indicated by yellowing straw and hardening of the base of the grains, using a combine harvester. The number of productive tillers was observed in this case study.

2.1.2. Experimental Design, Treatment and Plot Size: The experimental design used in this case study was a split-split-plot design nested within the cropping system. The hierarchical structure of this design placed pruning as the main plot, consisting of three levels: no pruning, pruning at 25 DAP), and pruning at 35 DAP. Furthermore, fertilization was placed as a subplot consisting of four levels: no fertilizer, chemical fertilizer, chemical fertilizer with compost, and chemical fertilizer with compost and biofertilizer. The early-maturing rice variety factor served as subplots consisting of two types, namely the Cakrabuana variety and the Inpari 13 variety. These three components were nested within the planting system or spacing as their primary environment. The planting system was divided into three types: 20 × 20 cm square spacing, 40x20x10 cm double row, and 40x20x20 cm double row. The combination of these factors produced 72 distinct treatment combinations. These were organized into three replications, resulting in a total of 216 experimental plots. Each plot had dimensions of 3 m by 3 m, with a 50 cm buffer zone between adjacent plots and a 100 cm separation between replications.

2.1.3. Statistical Analysis: Before conducting the analysis, the assumptions for analysis of variance (ANOVA), such as the normality of residuals and the homogeneity of variance, were checked to confirm that the data met the criteria for parametric analysis. The variable of productive tiller underwent ANOVA using STAR version 2.0.1 (Statistical Tool for Agricultural Research, IRRI, Philippines). If significant effects of treatments were found, the treatment means were distinguished using the Least Significant Difference (LSD) test at a 5% probability level within the same software.

2.2. Economic and Agribusiness Analysis of Early Maturing Rice Varieties Potential

2.2.1. Research Procedure: The economic analysis focused on collecting primary data related to cost components in the cultivation of very early maturing rice varieties in Gowa. All data were converted into USD using an exchange rate of 1 USD = Rp 17,300. All cost calculations were compared with the income obtained from the conversion of productivity results. Subsequently, the data were analyzed for profit potential, revenue-to-cost ratio, and profit comparison between fertilization and non-fertilization technologies.

2.3 Farmer Social Perception on Adopting Early Maturing Rice Varieties

2.3.1. Study Area, Sampling Procedure, and Data Collection: South Sulawesi is a major rice-producing region outside Java and contributes substantially to rice production in eastern Indonesia (Fudjaja et al., 2026). Owing to its strategic role in national rice production, the province was selected as the study area to investigate farmers' perceptions and acceptance of early-maturing rice varieties. A cross-sectional survey design was employed in this study. Respondents were selected using a convenience sampling approach that targeted active rice farmers across multiple districts in South Sulawesi. Eligible respondents were individuals engaged in rice farming activities and willing to participate voluntarily in the survey.

Questionnaire administration adhered to the principles of voluntary participation, anonymity, and confidentiality. Prior to participation, prospective respondents were informed about the objectives of the study, the nature of the questionnaire, and their right to withdraw from the survey at any stage without penalty. Informed consent was obtained from all participants before questionnaire completion. During the study, data collection posed practical challenges because farmers often had limited and unpredictable availability during the cropping season. To facilitate respondent recruitment, the researchers collaborated with agricultural extension officers operating throughout South Sulawesi. These extension officers helped identify and contact farmers who met the study criteria and were willing to participate.

To reduce the risk of questionnaire loss during distribution and collection and to facilitate participation across geographically dispersed locations, the survey was administered through an online questionnaire platform. Survey links were distributed directly to prospective respondents through contact information obtained from extension officers. Only questionnaires that were completed and submitted through the online platform were included in the final dataset. A total of 158 completed questionnaires were collected and deemed valid for analysis (Supplementary 1).

2.3.2. Survey Instrument: The survey instrument comprised both quantitative and qualitative sections. The

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quantitative section was designed to measure farmers' perceptions and acceptance of early-maturing rice varieties using structured closed-ended statements. The perception construct (X) comprised 19 indicators (Q01–Q19), whereas the acceptance construct (Y) comprised three indicators (Y01–Y03). Responses were measured using a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"), with higher scores indicating more positive perceptions and greater acceptance of early-maturing rice varieties.

A complete list of questionnaire items and measurement indicators is provided in Supplementary 2 to facilitate transparency, reproducibility, and future application of the instrument in similar studies.

2.3.3. Data Processing and Statistical Analysis: Data processing and statistical analyses were conducted using R version 4.6.0 in RStudio IDE version 2026.04.0 Build 526. The *psych* package was used for reliability analysis, including Cronbach's alpha and McDonald's omega coefficients, as well as descriptive psychometric statistics (Revelle, 2013, 2026). The *rstatix* package was employed for statistical testing and assumption checking, including normality tests, homogeneity of variance tests, and independent-sample t-tests (Okoye & Hosseini, 2024). The *likert* package was utilized to summarize and visualize Likert-scale responses, facilitating the interpretation of respondent perceptions and acceptance levels (Komperda, 2017).

Descriptive statistics were calculated to summarize respondent characteristics and item responses. Item-level analysis included mean, median, and standard deviation (Supplementary 3). The internal consistency of the quantitative constructs was assessed using Cronbach's alpha and McDonald's omega coefficients. Cronbach's alpha was used to evaluate the overall reliability of the measurement scale (Gadermann et al., 2012), whereas McDonald's omega was employed as a complementary reliability estimate because of its reduced sensitivity to assumptions of tau-equivalence (Hayes & Coutts, 2020). Reliability coefficients greater than 0.70 were considered indicative of acceptable internal consistency (Hajjar, 2018). Differences in perception scores among respondent groups were assessed using independent-samples t-tests. The independent-samples t-test was used to compare mean perception scores between farmers who planted early-maturing rice varieties and those who did not.

Composite perception scores (X) and early maturing rice varieties acceptance scores (Y) were calculated for each respondent by averaging Likert-scale responses across their respective indicators (Warmbrod, 2014) (1), where S_i is score of the *i-th* questionnaire item, and n are total number of items within the construct. To improve interpretability, acceptance scores were transformed into a standardized 0–100 Acceptance Index using linear score rescaling (2).

$$\text{Composite Score of Construct} = \frac{\sum_{i=1}^{n} S_i}{n} \qquad (1)$$

$$\text{Acceptance Index} = \frac{\text{Y - Ymin}}{\text{Ymax - Ymin}} \text{ x } 100\% \qquad (2)$$

Respondent profiles were subsequently grouped into analytical categories, including age, education level, farming experience, landholding size, and land ownership status, to facilitate a comparative analysis based on profile and acceptance index.

3. RESULTS

3.1. Agronomic Performance of Very Early-maturing Rice

In Indonesia, six officially released varieties of very early-maturing rice are grown, with harvest times spanning from 87 to 105 days and potential yields between 8.0 and 11.0 t ha^{-1} (Table 3). The regions designated for seed production differ significantly among these varieties, with Cakrabuana and M70D covering the most extensive multiplication areas, suggesting they are more widely accessible for farming.

Table 3: Very early-maturing rice varieties widely cultivated in Indonesia, along with their growth periods and yield potential

Variety	Day to Harvest	Yield potential (t/ha)	Area of the breeding facility (ha)
BK Situbondo 01 Agritan	100	9.83	5.00
Cakrabuana Agritan	104	10.20	90.86
Cikawasen	102	8.00	30.00
INPARI SIDENUK	103	9.10	25.00
M 70 D	87	9.39	65.85
Padjajaran Agritan	105	11.00	19.10

Table 4: Analysis of the increase in productive tiller number in response to fertilization treatment in very early maturing rice varieties

Fertilizer treatment	Cakrabuana	Inpari 13
No Fertilizer	10.70a	12.04a
Chemical Fertilizer	11.07a	12.36a
Chemical Fertilizer + Compost	14.14b	15.76b
Chemical Fertilizer + Compost +Biofertilizer	15.44b	15.24b

Notations (a,b) differed significantly (P<0.05).

Grain yield was notably affected by planting spacing in the experimental setup (Fig. 2). The highest grain yield was achieved with square spacing of 20 × 20 cm, while the double-row system of 40 × 20 × 20 cm yielded the least. The double-row configuration of 40 × 20 × 10 cm had a moderate yield, which was not significantly different from the square spacing method. A similar pattern was evident in the formation of productive tillers after fertilization (Table 4). Both Cakrabuana and Inpari 13 varieties showed a positive response to nutrient application, with treatments combining as shown in Fig 3.

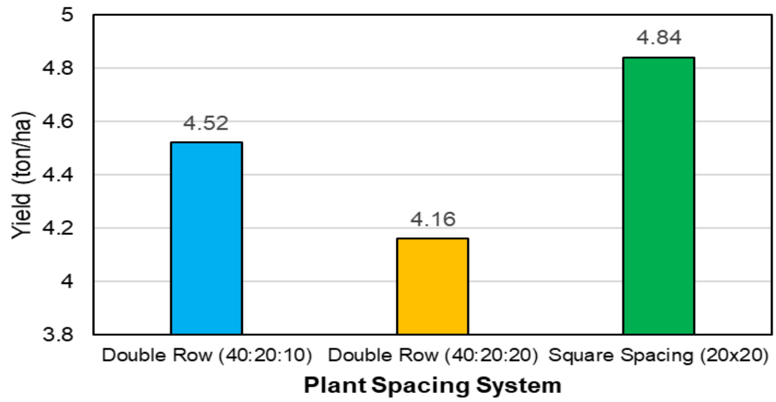

Fig. 2: The effect of planting spacing and pruning on rice productivity potential.

3.2. Economic, Agribusiness and Seed Production Potential of Very Early-maturing Rice

Optimizing the cultivation of very early-maturing rice varieties has implications for annual profits. This is particularly effective when there are no water issues in the region. Several studies have shown that cultivating these varieties further minimizes losses due to drought and optimizes the cropping index in a given region. These results were presented by Anshori et al. (2024a), who found that early-maturing rice varieties can be planted 3–4 times per year, assuming water is available annually. When calculated using farm business calculations, the average very early-maturing rice variety yields a profit of approximately USD 7, 523.17 (Table 5). This Fig. is significantly higher than that of medium-maturing varieties, such as Inpari 32 and Ciherang, which generate profits of USD 6, 888–7, 091, respectively. The very early-maturing rice varieties deemed profitable are Cakrabuana (USD 7, 886), Padjajaran (USD 8, 197), and Inpari 13 (USD 7, 940). These calculations are based on data from three planting locations (Gowa, Soppeng, and Bone) and two growing seasons. Meanwhile, the M70D and Inpari 19 varieties, known as very early maturing, yield very low annual profits compared to the control varieties Inpari 32 and Ciherang.

Table 5: Economic analysis of farming operations in USD regarding annual profits from the cultivation of very early-maturing rice

Cultivation activity	Cakrabuana	Padjajaran	M70D	Inpari 13	Inpari 19	Means	Inpari 32	Ciherang
Cropping Index	4	4	4	4	4	4	3	3
Soil preparation	462.43	462.43	462.43	462.43	462.43	462.43	346.82	346.82
Transplanting	231.21	231.21	231.21	231.21	231.21	231.21	173.41	173.41
Fertilizer	312.14	312.14	312.14	312.14	312.14	312.14	234.10	234.10
Pesticides	346.82	346.82	346.82	346.82	346.82	346.82	260.12	260.12
Production	27.32	28.24	24.12	27.48	24.08	26.25	23.97	23.37
Harvesting	1026.47	1061.04	906.24	1032.49	904.74	986.20	900.61	878.06
Cost	2379.08	2413.64	2258.84	2385.09	2257.34	2338.80	1915.06	1892.51
Farming Income	10264.74	10610.40	9062.43	10324.86	9047.40	9861.97	9006.07	8780.64
Profit	7,886	8,197	6,804	7,940	6,790	7523.17	7,091	6,888

Source: Anshori et al. (202a; 2024b).

The concept of full-cycle, very early-maturing rice varieties was difficult to implement optimally in the early stages of its development. However, this concept is rational when optimizing the potential over a two-year planting cycle. Generally, planting can be carried out five times over two years using the Inpari 32 variety. However, the integration of early-maturing rice varieties can increase the planting potential to six times over two years. A comparison of these potentials is shown in Table 6 and 7. Based on this table, the first scheme (13,216.3

USD) has a higher profit potential than the second scheme (11,818.4 USD). The profit difference between the two schemes is 1,397.9 USD.

Table 6: Comparison of costs, production, and profit across two rice cultivation schemes (2-Year Period; In USD)

Cultivation Activity	The First Scheme						Total in 2 years
	Inpari 32	Inpari 32	Very Early Maturing Rice	Inpari 32	Inpari 32	Very Early Maturing Rice	
Soil preparation	115.6	115.6	115.6	115.6	115.6	115.6	693.6
Transplanting	57.8	57.8	57.8	57.8	57.8	57.8	346.8
Fertilizer	78.0	78.0	78.0	78.0	78.0	78.0	468.2
Pesticides	86.7	86.7	86.7	86.7	86.7	86.7	520.2
Production	7.99	7.99	7.06	7.99	7.99	7.06	46.08
Harvesting	300.2	300.2	246.5	300.2	300.2	246.5	1693.9
Cost	638.4	638.4	584.7	638.4	638.4	584.7	3722.8
Farming Income	3002.0	3002.0	2465.5	3002.0	3002.0	2465.5	16939.1
Profit	2363.7	2363.7	1880.8	2363.7	2363.7	1880.8	13216.3
Cultivation activity	The Second Scheme						Total in 2 years
	Inpari 32	Inpari 32	Inpari 32	Inpari 32	Inpari 32	No Cultivation	
Soil preparation	115.6	115.6	115.6	115.6	115.6	0.0	578.0
Transplanting	57.8	57.8	57.8	57.8	57.8	0.0	289.0
Fertilizer	78.0	78.0	78.0	78.0	78.0	0.0	390.2
Pesticides	86.7	86.7	86.7	86.7	86.7	0.0	433.5
Production	7.99	7.99	7.99	7.99	7.99	0.00	39.95
Harvesting	300.2	300.2	300.2	300.2	300.2	0.0	1501.0
Cost	638.4	638.4	638.4	638.4	638.4	0.0	3191.8
Farming Income	3002.0	3002.0	3002.0	3002.0	3002.0	0.0	15010.1
Profit	2363.7	2363.7	2363.7	2363.7	2363.7	0.0	11818.4

Table 7: Economic analysis in USD of the impact of fertilizer technology on profits and revenue from very early-maturing rice cultivation per season

Cultivation Activity	Raining Season				Dry Season			
	Without	ChF	ChF+CoF	ChF+CoF+BF	Without	ChF	ChF+CoF	ChF+CoF+BF
Cakrabuana								
Soil preparation	116	116	116	116	116	116	116	116
Transplanting	58	58	58	58	58	58	58	58
Fertilizer	0	78	251	309	0	78	251	309
Pesticides	87	87	87	87	87	87	87	87
Production	2.65	2.87	4.32	4.64	3.20	4.66	6.03	6.59
Harvesting	100	108	162	174	120	175	227	247
Cost	360	446	674	744	380	513	738	817
Farming Income	997	1,077	1,622	1,745	1,204	1,752	2,267	2,475
Profit	637	631	948	1,001	823	1,239	1,529	1,658
R/C	2.77	2.42	2.41	2.35	3.16	3.41	3.07	3.03
Control comparison	1.00	0.99	1.49	1.57	1.00	1.51	1.86	2.01
Inpari 13								
Soil preparation	116	116	116	116	116	116	116	116
Transplanting	58	58	58	58	58	58	58	58
Fertilizer	0	78	251	309	0	78	251	309
Pesticides	87	87	87	87	87	87	87	87
Production	2.97	3.50	4.64	6.13	3.64	5.57	7.05	6.34
Harvesting	112	132	174	230	137	209	265	238
Cost	372	470	686	800	397	548	776	808
Farming Income	1,117	1,315	1,742	2,302	1,368	2,094	2,648	2,382
Profit	745	845	1,056	1,502	971	1,546	1,871	1,575
R/C	3.00	2.80	2.54	2.88	3.45	3.82	3.41	2.95
Control comparison	1.00	1.13	1.42	2.02	1.00	1.59	1.93	1.62

A thorough analysis of the cultivated area for early maturing rice varieties and very early maturing rice varieties in Indonesia reveals a concentration in certain regions as shown in Table 9. West Java emerged as the province with the largest cultivated area, at 111.50 hectares, followed by South Sulawesi with 48.05 hectares and Central Kalimantan with 33.00 hectares. Nationally, the total cultivated area reaches 245.61 hectares, with early maturitng rice varieties covering 179.96 hectares and very early maturing rice varieties covering 65.65 hectares. Although cultivation areas are currently limited to regions such as West Java and South Sulawesi, these varieties have the potential to increase production, particularly in areas with limited growing seasons and climatic conditions. Furthermore, as this innovation is still in its early stages, stronger institutional, technological, and policy support is urgently needed to optimize the utilization of this technology throughout Indonesia. This was further strengthened

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by the evidence of farmer perception of the very early-maturing rice agribusiness potential, as shown in Fig. 4

Fig. 3: Differences in nitrogen content between the very early-maturing rice varieties Cakrabuana and Padjajaran in response to drone-image-based pruning treatments.

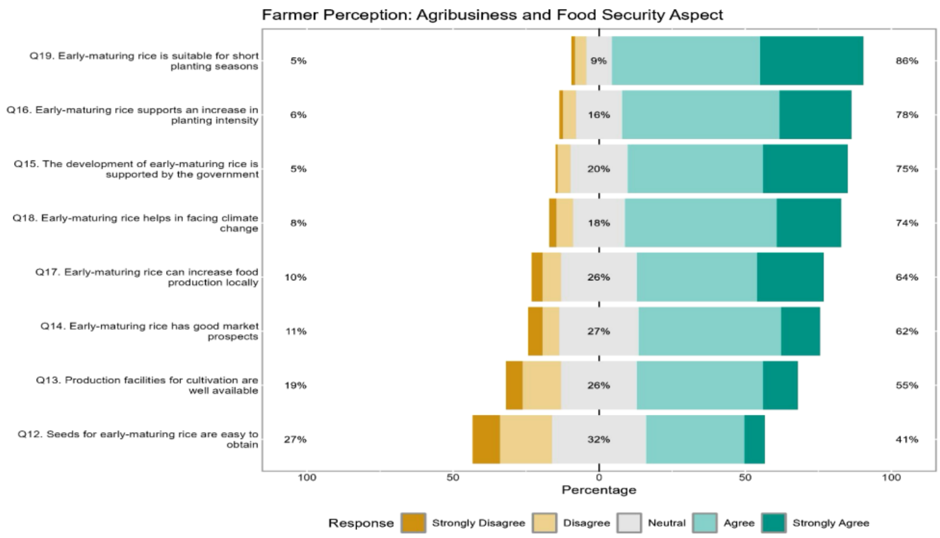

Fig. 4: Farmer perception to agribusiness potential of early maturing rice varieties.

Table 8: Provincial allocation of seed production areas for very early and early maturity rice varieties in Indonesia (ha)

Province	Area of Seed Production Field (ha)		
	Early Maturity Rice	Very Early Maturity Rice	Total Area
DIY	5.50	-	5.50
Jawa Barat	61.50	50.00	111.50
Jawa Tengah	5.41	15.85	21.26
Kalimantan Tengah	33.00	-	33.00
Maluku	10.00	-	10.00
NTT	18.50	-	18.50
Sulawesi Selatan	46.05	-	46.05
Indonesia	179.96	65.85	245.81

The availability of seeds in various production areas is crucial for the growth of very early-maturing rice. At present, early-maturing varieties dominate seed production, while the multiplication of seeds for very early-maturing rice is limited to a small number of provinces (Table 8). West Java has the most extensive area dedicated to producing seeds for very early-maturing rice, indicating significant potential for increasing seed production in other regions where rice is cultivated.

3.3. Social Acceptance and Adoption Potential of Very early-maturing Rice

The social analysis revealed that the acceptance of very early-maturing rice among farmers differed based on their demographic traits (Fig. 5). Younger farmers generally showed higher acceptance, while middle-aged individuals displayed more variability. Those with more education, larger farms, and extensive farming experience were also more likely to accept the rice. Additionally, male farmers demonstrated a marginally higher acceptance compared to female farmers, indicating variations in acceptance among different farmer groups.

Table 9: The potential of compost application to increase early maturing rice varieties productivity

Reference	Research Location	Variety	Fertilizer Treatment	Yield (t/ha)
(Musa et al., 2023)	Bone	Padjajaran	No Compost	5.71
		Cakrabuana	No Compost	5.31
		Inpari 13	No Compost	6.51
		Inpari 19	No Compost	4.22
		M70D	No Compost	4.89
		Padjajaran	Compost	5.18
		Cakrabuana	Compost	5.35
		Inpari 13	Compost	7.38
		Inpari 19	Compost	5.51
		M70D	Compost	5.38
	Gowa District	Padjajaran	No Compost	4.50
		Cakrabuana	No Compost	4.05
		Inpari 13	No Compost	4.55
		Inpari 19	No Compost	4.81
		M70D	No Compost	4.64
		Padjajaran	Compost	6.56
		Cakrabuana	Compost	7.05
		Inpari 13	Compost	5.07
		Inpari 19	Compost	5.15
		M70D	Compost	3.85
(Anshori et al., 2025)	Barru District	Padjajaran	No Compost	3.05
		Cakrabuana	No Compost	5.20
		Padjajaran	Compost	4.14
		Cakrabuana	Compost	6.70
Anshori et al. (2026)	Bantaeng District	Cakrabuana	No Compost	6.17
		Cakrabuana	Compost	7.22

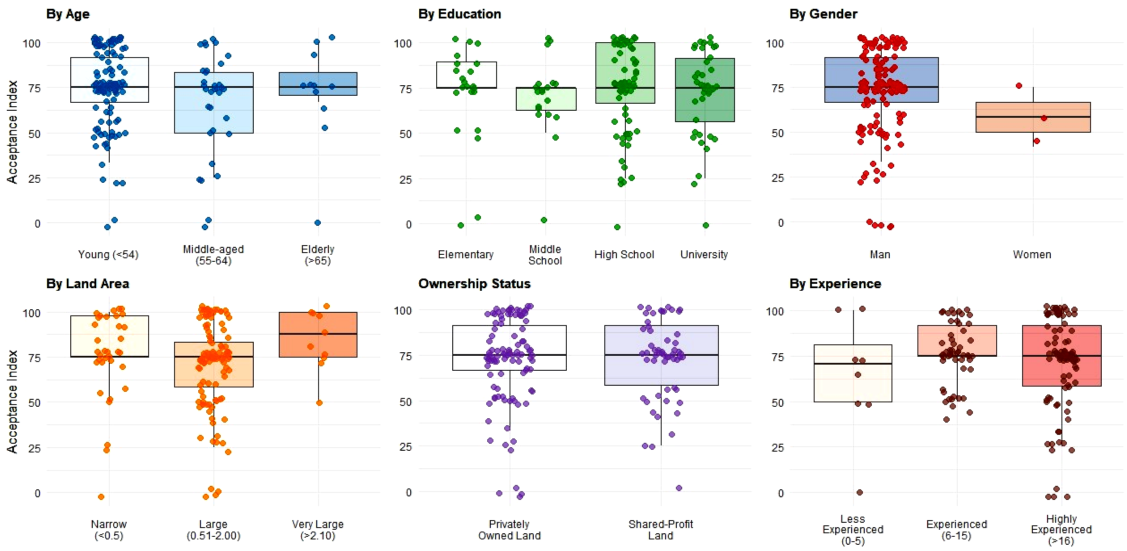

Fig. 5: Distribution of the acceptance index of very early-maturing rice varieties across different farmer profiles.

Farmers generally held favorable views regarding the social dimensions of cultivating very early-maturing rice (Fig. 6). A majority of participants acknowledged the proactive involvement of agricultural extension workers in promoting these varieties. Additionally, decisions about planting were heavily swayed by neighboring farmers and the local community. The community's acceptance and the availability of information were also seen in a positive light. However, there was less consensus on how well these varieties fit with existing local farming practices compared to other social factors. These positive views were linked to a strong intention to adopt very early-maturing rice (Fig. 7). Most participants expressed a desire to increase the area dedicated to these varieties, continue planting them in future seasons, and suggest them to fellow farmers. Overall, these results suggest a high level of acceptance among farmers and a positive inclination toward the broader adoption of very early-maturing rice.

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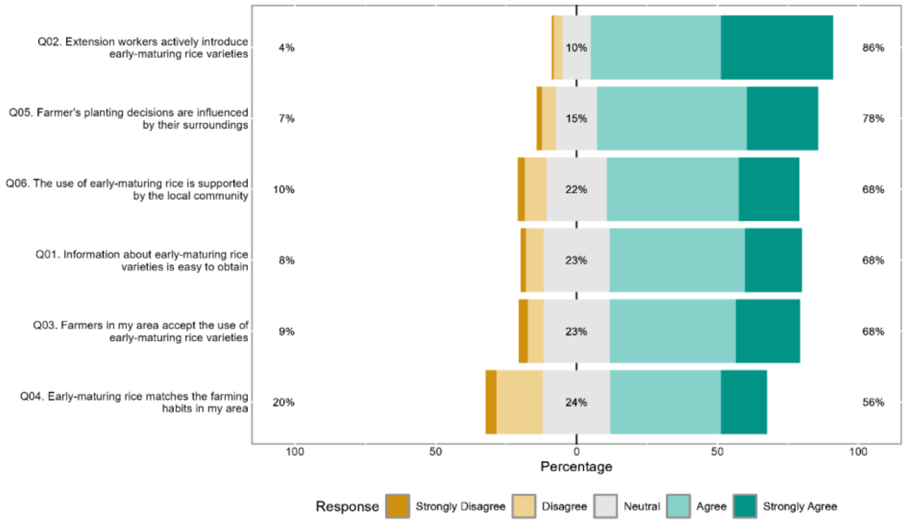

Fig. 6: Farmers' social perceptions of very early-maturing rice adoption.

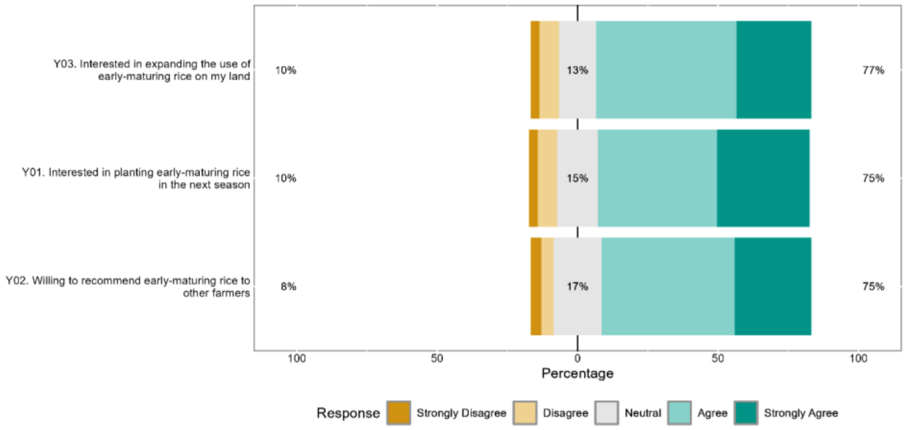

Fig. 7: Distribution of Farmer Acceptance of Early-Maturing Rice Varieties.

4. DISCUSSION

4.1. Optimalization of Very Early Maturing Rice Varieties Cropping

4.1.1. Development of Very Early Maturing Rice Varieties in Indonesia: Very early-maturing rice varieties represent a new ideotype developed to address climate uncertainty (Noviana et al., 2021; Liang et al., 2024). These varieties shorten the vegetative and generative phases of the rice life cycle (Lang et al., 2012; Guo et al., 2020). Generally, vegetative and generative processes occur sequentially in rice. This results in a relatively long growth period, during which rice optimizes its vegetative potential as the primary site of photosynthesis before entering the generative stage (Guo et al., 2020). In contrast, rice cultivation exhibits a distinctive pattern for increasing yield. Increasing rice production within a plant can be optimized by increasing the number of tillers (Huang et al., 2013; Yuan et al., 2024). The tiller system results in a semi-independent growth pattern (Wang et al., 2016; Vakeswaran et al., 2025). Each tillering plant has a specific role in forming panicles, so modifying the tillering pattern is one approach that can be taken to optimize production (Zhao et al., 2020; Yuan et al., 2024). Furthermore, this semi-independent concept allows the cycle between vegetative and generative phases to be manipulated. This method is used to shorten the cropping cycle, enabling rice cultivation to occur significantly earlier than usual (Yun, 2023; Liang et al., 2024). Several very early-maturing varieties developed in Indonesia, along with their yield potential and production areas, are shown in Table 3. Generally, all these varieties have a growing period of less than 100 days after planting, with a yield potential ranging from 8 to 11 tons/ha (Yun, 2023; Baharuddin et al., 2025). This potential has led to the increased production of breeding seeds for these varieties. The largest breeding area is in Cakrabuanana, covering 90.86 ha, which can produce 454 tons of seeds assuming an average productivity of 5 tons/ha (Anshori et al., 2024b; Baharuddin et al., 2025). The output from this breeding operation can cover 15,143 ha of paddy fields, assuming a seed requirement of 30 kg per ha. These results indicate that the utilization of very early-maturing rice varieties is a crucial component in the development of rice production optimization in Indonesia. Therefore, the development and breeding of these high-yielding varieties is one of the ways to ensure the

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sustainability of rice and food self-sufficiency in Indonesia (Liang et al., 2024).

4.1.2. Development of Cultivation Technology for Very Early Maturing Rice Varieties: The average productivity of early-maturing rice is relatively lower than the production potential of most varieties. This is considered reasonable because the vegetative growth potential is relatively faster than the generative growth potential (Anshori et al., 2024a; Baharuddin et al., 2025). However, this potential can be optimized through modifications to cultivation technology that focus on the number of tillers. Several concepts and results of cultivation technology development for early-maturing rice are explained through planting spacing, fertilization technology and its applications and irrigation method

4.1.2.1. Planting Spacing to Support Very Early Maturing Rice Varieties Cultivation: Modification in the optimization of early-maturing rice was carried out by modifying planting spacing (Mondal et al., 2013; Paiman et al., 2024). Production systems based on tillering require wider spacing (Clerget et al., 2016; Yan et al., 2010). This differs from concepts focused on panicle weight potential, such as Inpari 32 or new type rice varieties (Fukushima, 2019; Dulbari et al., 2025). In several studies, early-maturing rice varieties can achieve more than 40 tillers with wider spacing (Anshori et al., 2025). According to the case study in this research (Fig. 1), the yield potential of legowo planting spacing (2:1) is relatively lower compared to square planting. In addition, according to several studies, wider planting spacing yields higher productive tiller potential compared to narrow spacing due to reduced intraspecific competition (Clerget et al., 2016; Sutardi et al., 2023). Based on this, a spacing of 25–30 cm is an optimal option to increase the yield of very early-maturing rice varieties (Paiman et al., 2024; Khan et al., 2025).

The higher productivity observed under square planting compared with the evaluated double-row systems suggests that uniform plant distribution was more favorable for the development of very early-maturing rice. Tiller formation originates from axillary buds located at the basal nodes, and the subsequent outgrowth of these buds is controlled by light availability, carbohydrate supply, nitrogen status, and hormonal signaling. Uniform spacing reduces localized competition for solar radiation, nutrients, and root space, thereby increasing light penetration into the lower canopy and supporting bud activation. In contrast, narrow within-row spacing in double-row systems may create zones of intense competition, even when wider spaces are present between paired rows. This condition is particularly important for very early-maturing varieties because their short vegetative period provides limited time to compensate for suppressed early tiller growth. The results support previous findings that productive primary tillers are major contributors to panicle number and grain yield, while excessive plant density can increase unproductive tillers and reduce the proportion of tillers that survive to panicle formation (Huang et al., 2020; Yuan et al., 2024; Mmbando, 2025). Therefore, planting arrangement should be designed to maximize productive tiller survival rather than merely increasing plant population.

4.1.2.2. Fertilization Technology and its Application on Very Early Maturing Rice Varieties: Fertilization is a key component of crop growth and production, including rice (Chen et al., 2018; Zhang et al., 2022b). However, fertilization is closely associated with the type, timing, dosage, and method of its application (Chen et al., 2018). These fertilization patterns can be determined based on the growth phase of rice. In general, there are three critical phases of fertilization: the early, elongation, and generative phases (Yi et al., 2020). In the early phase, rice plants focus on adapting to the new environment, especially when planting is conducted using the transplanting system (Lee et al., 2021). This makes this phase highly related to root adaptation, so fertilization should be focused on root system formation (Gao et al., 2023). This is also correlated with tiller stimulation. According to several studies, tiller formation is highly dependent on the root system and root physiological activity (Liu et al., 2018; Yuwono et al., 2025). Optimization of the root system can be achieved through the provision of micronutrients and improvement of soil conditions, so at the beginning of planting the application of organic fertilizer, especially compost, and calcium becomes important (Gouda et al., 2024). According to several studies, organic fertilization can trigger root development and increase the number of rice tillers (Bu et al., 2023; Gouda et al., 2024). This aligns with the findings of this case study, which showed an increase in the number of productive tillers between the treatments with and without compost application in the very early-maturing rice varieties Cakrabuana and Inpari 13 (Table 4). These results correlate with increased productivity, as reported by Musa et al. (2023). The addition of 1–3 metric tons/ha of compost can increase yield by approximately 1 ton/ha (Table 5). Moreover, based on the case study in this research, organic fertilizer application significantly increased yield, especially in the Cakrabuana variety in the Bantaeng Regency. In addition, several studies have stated that calcium application can improve and strengthen the root system and plant signal transduction (Crusciol et al., 2022; Zhang et al., 2023). This potential is also consistent with the case study in this article. Therefore, the application of organic fertilizer and calcium becomes important in the initial stage of growth.

At the elongation stage of growth, the determining factor with regard to fertilization is the proportion of nitrogen application (Xu et al., 2026). Different nitrogen applications for very early-maturing rice varieties are shown in Fig. 3, which leads to different nitrogen contents across treatments. This concept has been reported by several studies (Musa et al., 2023, 2025). The linear application of nitrogen increases the yield of very early-maturing rice varieties, supported by a substantial direct effect on the number of productive tillers (Gu et al., 2022; Zhang et al., 2022b; Zhou et al., 2022). In general, tiller development in rice becomes crucial during the vegetative phase up to the peak vegetative phase; therefore, optimizing fertilization during this stage is critical for increasing the yield of early-maturing rice (Huang et al., 2020; Yun, 2023). In several studies, tiller formation is closely associated with nitrogen availability, soil texture and the composition of micronutrients in a crop stand (Wang et al., 2016; Yuan et al., 2024; Mohapatra et al., 2025b). Nitrogen is the principal macronutrient and is highly mobile during tiller formation (Huang et al., 2021). Furthermore, this fertilizer is highly prone to depletion in the field through leaching and volatilization (Chen et al., 2018; Liu et al., 2023; Xue et al., 2025). Nitrogen is required during the elongation phase of the rice growth cycle, or in other words, during the maximum tillering stage (Xu et al., 2026; Liu et al., 2019). This indicates that nitrogen fertilizer application should have a higher proportion during this phase compared to other phases (Xu et al., 2026). This is crucial for very early-maturing rice varieties, which have an overlap between the vegetative and reproductive phases. Therefore, the proportion of nitrogen should be prioritized during this transitional cycle.

At the generative stage, fertilization primarily focuses on potassium application (Zhang et al., 2025; Hu et al., 2026). Several studies have reported a significant effect of potassium application on increasing rice productivity (Chen et al., 2024; Liu et al., 2025). Generally, potassium plays a role in various processes as an enzyme bioactivator and in the photosynthate loading transfer process (Li et al., 2022; Shen et al., 2022). This advantage will optimize the role of photosynthate mobilization in the grain filling process as the main sink for energy storage. The greater and more effective this process, the higher will be the correlation with increased grain weight and rice productivity (Zhang et al., 2019; Parida et al., 2022), making potassium application important for optimizing the productivity of very early maturing rice varieties. Several studies have reinforced its effectiveness in early maturing rice, as demonstrated by improvements in grain filling, rice quality, and potassium translocation efficiency during the generative phase (Chen et al., 2024; Hu et al., 2026).

4.1.2.3. Irrigation Strategies to Support the Development of Very Early Maturing Rice: Irrigation serves as both a standardizing and limiting factor regarding the potential of a given variety (Sembiring et al., 2023; Bo et al., 2024; Zhou et al., 2025). Low-efficiency irrigation systems cause plants to experience drought, preventing them from maintaining an optimal photosynthate supply to the panicle (Baslam et al., 2023; Hu et al., 2025). Conversely, excess water reduces the oxygen reserves beneath the water (Panda & Barik, 2021; Jiménez & Pedersen, 2023). This slows down root system processes, correlating with the optimization of tiller numbers (Gao et al., 2023; Shafi et al., 2023). Additionally, continuous flooding restricts plant metabolic processes and cannot induce the potential for breaking apical dominance in the root section (Tanaka et al., 2023; Bu et al., 2025). Several effective irrigation methods include maintaining saturated soil conditions and the AWD system (Gao et al., 2024; Baharuddin et al., 2025; Zhou et al., 2025). This system accounts for flooding and drying patterns to provide air space to the roots for their division and development (Cai et al., 2026). Such a strong root system supports the induction of tiller numbers and the culm strength of the clump, thereby preventing lodging (Shafi et al., 2023; Yamuna et al., 2026). Therefore, proper irrigation management, which involves balancing water needs and field conditions, is a key factor in achieving the optimal number of tillers, which directly contributes to rice productivity (Carrijo et al., 2017; Bo et al., 2024). Properly managed AWD can reduce irrigation demand and greenhouse-gas emissions while maintaining yield (Feng et al., 2021; Hossain & Islam, 2022), although the response varies with soil type, climate, groundwater depth, and cultivar.

For rice that matures very early, enhancing root aeration is crucial since root regeneration and nutrient absorption must happen within a brief vegetative period. If root establishment is delayed, it may decrease the number of tillers before the onset of panicle initiation, offering limited chances for later recovery. AWD can thus benefit very early-maturing varieties when the drying phase is mild and aligns with plant growth. Nonetheless, irrigation should be sufficiently maintained during the stages of panicle initiation, flowering, and grain filling, as water shortages during these times can negatively impact spikelet fertility and the transport of assimilates. This indicates that AWD should be implemented as a management strategy tailored to specific growth stages rather than applied uniformly throughout the growing season. Consequently, these cultivation techniques directly enhance economic returns by boosting planting intensity and yield per time unit. Therefore, a systematic investigation into the economic value of cultivation practices for early-maturing rice varieties is urgently needed.

4.2. Economic Analysis of Very Early Maturing Rice Cultivation

The results of the second economic analysis indicate that the development of early-maturing varieties has profitable prospects and a potentially favorable R/C ratio for commercial cultivation (**Anshori et al.,** 2024b). This is particularly notable in several very early rice varieties such as Cakrabuana, Padjadjaran, and Inpari 13 (Anshori et al., 2024b; Musa et al., 2025). M70D and Inpari 19 are types of varieties that are not only early but also categorized as very early (Bahrun et al., 2025). However, these two varieties are considered less efficient in economic calculations compared to moderate-maturity varieties such as Inpari 32 and Ciherang, both of which command a large market share in seed distribution (Beding et al., 2021; Agustian et al., 2022). This results in the two varieties being less recommended for areas with stable irrigation systems. However, under unstable irrigation conditions, these varieties can be considered for cultivation prospects (Yassi et al., 2025). Optimization of profits from cultivating very early rice varieties can be emphasized through the application of compost fertilizer. Based on research reports and this case study, application of compost yields a significant increase in production compared to cultivation without compost (Huang et al., 2023). Although profits increase with the use of compost, this increase is not fully reflected in the R/C ratio (Mohapatra et al., 2025a). The significant additional costs incurred when using compost affect the increase in the R/C ratio, so that the increase in income is proportional to the costs involved in generating such income. This indicates that the use of compost provides higher absolute profits but relatively lower cost efficiency compared to several other treatments, especially compared to no fertilizer application (Mohapatra et al., 2025a). Additionally, compost application improves soil properties in the long term, so that continuous composting can stably and sustainably increase rice production (Haque et al., 2021; Ghorbani et al., 2023). Meanwhile in the case studies, biofertilizer application is still considered unstable and does not yield substantial benefits compared to compost treatment. However, biofertilizer application shows a pattern of margin yield improvement compared to using compost alone (Samantaray et al., 2024). This indicates that special studies are needed for optimizing biofertilizer use in very early rice varieties. Although in the long term, biofertilizer application will increase and stabilize sustainable production (Dai et al., 2021; Jiang et al., 2026), so that biofertilizer treatment can be considered in the sustainable production of very early maturing rice varieties. Based on overall economic considerations, the adoption of very early rice varieties is highly recommended for rice cultivation, especially in stable irrigation systems (Agustian et al., 2022; Anshori et al., 2024b). In addition, profit optimization in cultivating very early rice varieties can at least be achieved through compost fertilizer application. Moreover, the use of biofertilizer is also a good option for improving profit margins and production stability. Nevertheless, this concept of economic benefit still needs to be reinforced by agribusiness feasibility, particularly in terms of supply sustainability and market integration.

4.3. Agribusiness Analysis Regarding the Potential of Very early-maturing Rice Varieties

From an agribusiness perspective, developing very early maturing rice varieties can boost household incomes by allowing more frequent harvests and better land use thus increasing rice productivity (Sharma et al., 2025). However, adopting these varieties requires higher initial investments, especially for quality seeds and other inputs. So, access to financing through agricultural financial institutions, the People's Business Credit (KUR) program, and government subsidies is crucial to help smallholder farmers adopt these innovations (Purnawan et al., 2023; Latifah & Sofiani, 2024). Strengthening rural economic institutions is essential for creating an inclusive and sustainable agribusiness system (Triyono, 2025). Besides supporting increased food production, very early maturing rice varieties offers strategic opportunities to integrate the premium rice supply chain in Indonesia (Juliawan et al., 2025). These varieties ensure a continuous supply of high-quality rice throughout the year due to their faster and more predictable harvest cycles (Sharma et al., 2025). In a modern agribusiness system, supply continuity is vital for market stability, especially in the premium rice segment, which requires consistent product quality. With more efficient production patterns, farmers and business owners can better plan distribution and marketing strategies (Hien & Kim, 2024; Sharma et al., 2025). Integration with the premium rice supply chain can increase economic value for farmers (Utami et al., 2023; Juliawan et al., 2025). By forming partnerships that include farmers, modern rice mills, distributors, and food retailers, farmers can achieve market certainty and more stable prices. Agribusiness institutions, such as farmer cooperatives, village-owned enterprises (BUMDes), and farmer groups (Gapoktan), play a key role in maintaining quality standards, ensuring distribution efficiency, and implementing good agricultural practices (GAP) (Triyono, 2025; Karlina et al., 2026). Strengthening the supply chain will boost national rice competitiveness and strengthen farmers' positions in the modern marketing system (Jamaludin et al., 2021; Juliawan et al., 2025). Moreover, very early-maturing rice varieties that adapt to tropical climates have great potential as Indonesia's leading export commodity (Hutapea et al., 2022). Many tropical countries face challenges like climate change, limited planting seasons, and reduced agricultural productivity due to environmental stress (Dhamira & Irham, 2020; Shrestha et al., 2022; Jamal et al., 2023). In these situations, early-maturing varieties suited to tropical environments can be a strategic solution for food agriculture development in developing nations. Indonesia has the potential to become a hub for developing and supplying tropical early-maturing rice seeds through improved research, seed technology innovation, and international agricultural diplomacy.

Based on the results of the agribusiness perspective assessment (Fig. 3), most farmers view short-duration rice

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as a strategic innovation to increase productivity, strengthen food security, and support climate adaptation (Vasavi et al., 2025). The majority of respondents (86%) considered it suitable for short planting seasons. This reflects increased awareness of adaptation strategies to address climate uncertainty and shifts in cropping patterns (Hussain et al., 2020; Saccone & Vallino, 2025). Additionally, 78% of farmers recognized its potential to increase cropping intensity, which can enhance land productivity, accelerate agricultural capital turnover, and reduce the risk of major losses under unpredictable climate conditions (Rezvi et al., 2023; Liang et al., 2024). Government support was acknowledged by 75% of respondents, with the distribution of seeds, extension services, and input assistance having begun to facilitate adoption (Purnawan et al., 2023; Karlina et al., 2026). However, effective institutional support is still considered important. From the perspective of food and climate security, 74% of farmers expressed confidence in the contribution of very early rice varieties to address climate change issues, while 64% were aware of their role in enhancing local production stability (Vasavi et al., 2025). Furthermore, 62% saw promising market prospects, highlighting opportunities for integration into modern agribusiness systems through improved continuity of supply and premium value chains (Hien & Kim, 2024). Yet, adoption remains constrained by structural limitations, including limited seed availability, inadequate production facilities, and uneven agribusiness infrastructure (Vasavi et al., 2025). This indicates that strengthening institutional support, improving input distribution systems, and developing more integrated supply chains are urgently needed (Triyono, 2025). However, the effectiveness of agribusiness development is greatly influenced by farmers' social acceptance and institutional readiness. Therefore, the development of very early maturing rice agribusiness is determined not only by prouction performance, but also by institutional capacity, farmers' adoption behavior, and market integration.

4.4. Social Analysis of the Potential of Very Early Maturing Rice Varieties

Based on the overall results of the social analysis, the adoption process for early-maturing rice varieties has not been uniform. The level of acceptance of very early-maturing rice varieties depends heavily on age, gender, educational level, and experience. Young male farmers who are more highly educated and/or experienced in managing large tracts of land tend to adopt innovations related to these very early-maturing rice varieties more quickly. These characteristics influence the ability to access information, assess benefits, and manage risks in the cultivation of these very early-maturing rice varieties. Several studies mentioned the potential of the category of young farmers with higher education and/or experience plays a role in the adoption of a technology (McKillop et al., 2018; Hoang & Tran, 2023). This indicates that the potential for optimizing very early-maturing rice cultivation technology must target the group of young farmers who are educated and rich in experience during the initial dissemination process. Optimal potential within this group will induce adoption among other groups. Internal determinants related to technology adoption depend heavily on the farmer's age, education, and experience (Mardiharini et al., 2023; Amrullah et al., 2025). Young farmers generally have greater ambition and are willing to take on lower risks compared to older farmers. Older farmers face significant potential risks due to family dependents, making them relatively less likely to adopt new technologies compared to younger farmers. Therefore, education and the dissemination of early-maturing rice varieties must be intensified among educated and/or experienced younger farmers to accelerate adaptation at the broader farmer level.

Technology must be followed by farmer acceptance, in related to the use of very early maturing rice variety, the survey highlighted a significant intention to adopt the new technology (Fig. 5 and 6). There was a notable consensus on social support measures, with many farmers showing enthusiasm for increasing cultivation, replanting these varieties in upcoming seasons, and suggesting them to fellow farmers, indicating a generally favorable acceptance. Thus, this acceptance does not stop at a passive attitude but evolves into an active and sustainable adoption intention. This becomes even more rational when supported by the potential of young farmers and the role of extension workers in strengthening rural social networks. Theoretically, these findings align with the Agricultural Innovation Systems framework (FAO-UN & WEF, 2022), which emphasizes the importance of institutional interactions and social networks in accelerating technology adoption, as well as with the study by Dissanayake et al. (2022), which highlights relative perceived benefits, cultural compatibility, and access to information as key determinants of adoption success. Therefore, the development of very early-maturing rice varieties holds great potential for wider dissemination, with the key lying in the active role of young farmers and extension workers in expanding the acceptance of early-maturing rice cultivation technologies.

4.5. Policy Analysis and Roadmap for the Development of Early-maturing Rice Varieties

The development of very early maturing rice varieties holds strategic relevance to the policy direction of the Ministry of Agriculture, particularly in support of land optimization and national food security programs. Land optimization policies, which have so far focused on infrastructure aspects such as the creation of new rice fields, irrigation network rehabilitation, and pump installation, require a strengthening concept regarding effectiveness in cultivation approaches (Sharma et al., 2025; Triyono, 2025). The cultivation technology for very early maturing rice varieties, with a planting age of under 100 days, becomes an optimal concept for increasing the cropping index (CI), accelerating production cycles, and reducing the risk of crop failure due to extreme climate (Noviana et al., 2021; Amrullah et al., 2025). This makes early maturing varieties a policy instrument that supports efficient land optimization while also strengthening food security.

From an agronomic perspective, the superiority of very early-maturing rice varieties is centered on their early harvest time. However, this potential must be supported by cultivation technologies that can optimize their productivity (Bobihoe et al., 2023; Musa et al., 2023). Early-maturing varieties that focus on tiller formation have essential stages during their vegetative process (Yun, 2023). The use of compost and balanced fertilizer management, particularly nitrogen and calcium, is key to optimizing tiller productivity potential (Dai et al., 2021; Huang et al., 2023; Zhang et al., 2023). Nevertheless, nutrient potential during the generative phase should not be overlooked, with sufficient application of potassium nutrients such as KNO3 (Chen et al., 2024; Liu et al., 2025). Furthermore, the use of water management systems such as alternate wetting and drying (AWD) or saturated soil conditions, also needs to be implemented to improve soil aeration, enhance root growth, and support the formation of productive tillers (Bwire et al., 2024; Gao et al., 2024). This agronomic approach not only increases productivity, but also enhances water use efficiency and crop resilience to environmental stress, making it highly relevant to climate change (Carrijo et al., 2017; Bo et al., 2024). Therefore, the integration of early-maturing varieties and adaptive cultivation practices becomes an important part of modern intensification policy, which focuses not only on yield improvement but also on the sustainability of production systems.

Practically, very early-maturing rice should be disseminated as a location-specific production package rather than as seed alone. Demonstration plots should compare combinations of variety, spacing, nutrient timing, compost rate, and AWD threshold under farmers' field conditions. Recommendations should also consider irrigation reliability, labor availability, machinery access, soil fertility, and the timing of the following crop. In water-limited areas, the main objective may be to complete the crop before irrigation becomes unavailable, whereas in fully irrigated areas the objective may be to create an additional planting season. Compost recommendations should be based on material quality and local cost, while mineral fertilizer should be synchronized with the compressed growth stages of the variety. This approach would reduce the risk of promoting a technically effective treatment that is economically or operationally unsuitable for farmers.

The policy concept from an economic perspective can be viewed in terms of potential profit generated, either as a sole cropping system of very early maturing rice or as a mixed-variety approach with popular farmer cultivars such as Inpari 32 (Agustian et al., 2022; Musa et al., 2025). Nevertheless, the concept of cultivating very early-maturing rice requires optimal utilization of technological packages (Musa et al., 2023). This concept will increase the R/C ratio and production costs. However, such increases are in line with a significant rise in profitability compared to cultivation without technological intervention in fertilization (Mohapatra et al., 2025a). This aligns with farmers' interest in expanding adoption, replanting, and recommending early-harvesting varieties, highlighting significant opportunities for downstream agribusiness development (Ng'endo et al., 2022; Vasavi et al., 2025). The Ministry of Agriculture can strengthen the seed supply chain through quality regulation, distribution support, and partnerships with state-owned enterprises and private sector actors (Purnawan et al., 2023; Hien & Kim, 2024; Sulaiman et al., 2025; Sule et al., 2025). These measures can increase incentives for farmers while also creating opportunities to export high-quality rice as part of a broader market diversification strategy (Hutapea et al., 2022; Sharma et al., 2025). Inclusive financing mechanisms, such as optimizing the Kredit Usaha Rakyat (KUR) scheme for the agricultural sector, also play a role in reducing capital constraints, especially for smallholder farmers adopting early-maturing varieties that require intensive inputs (Purnawan et al., 2023; Latifah & Sofiani, 2024). Furthermore, very early maturing rice varieties offer great potential to be integrated into premium rice value chains (Juliawan et al., 2025). This is considering that quality and consistency of supply are highly required in such integration (Hien & Kim, 2024). The strengthening of agribusiness institutions such as farmer groups (Gapoktan), cooperatives, and village-owned enterprises (BUMDes) becomes crucial in realizing consistent integration (Karlina et al., 2026). These institutions play a central role in product aggregation, quality standardization, distribution efficiency, and enhancing farmers' bargaining position in modern marketing systems (Hien & Kim, 2024; Karlina et al., 2026). Therefore, agribusiness policies through investment via KUR and BUMDes, as well as the role of gapoktan and the Ministry of Agriculture, are key to optimizing agribusiness using technology for cultivating very early-maturing rice varieties.

Policy from a social perspective can be viewed from survey results, where agricultural extension services and community support play a crucial role in accelerating the diffusion of innovation (Amrullah et al., 2025; Vasavi et al., 2025). This indicates that the Ministry of Agriculture's policy to strengthen the Agricultural Extension Center (BPP) aligns with these findings (Triyono, 2025). Extension officers act as key intermediaries linking technology

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with local farming practices (Dissanayake et al., 2022). However, cultural barriers, particularly among farmers over the age of 50, highlight the need for more adaptive communication strategies (Dissanayake et al., 2022; Chang et al., 2024). These barriers can be addressed by engaging young, educated, and experienced farmers as driving agents and for regeneration in optimizing land based on very early-maturing rice cultivation technology (McKillop et al., 2018; Shafrina, 2026). Practical steps such as demonstration plots, field-based training, and farmer-to-farmer knowledge exchange can enhance the adoption process by ensuring innovation diffusion is participatory (Erythrina et al., 2021; Gusti et al., 2022; Mardiharini et al., 2023). Therefore, social policy through the roles of extension officers and the contributions of young, educated, and experienced farmers is essential for the successful dissemination and utilization of very early-maturing rice cultivation technology.

Based on the overall policy concepts, the development of very early maturing rice varieties can be strategically positioned as an element of the transformation of the national agricultural system toward increased adaptability, efficiency, and market orientation. With integrated policy support, including agronomy, production systems, institutional strengthening, financing mechanisms, and market integration, these very early maturing rice varieties offer broad contributions. These contributions not only help increase food production, but also can improve farmers' welfare and the competitiveness of the Indonesian rice agribusiness sector at the global level. As a basis for policy development, a policy brief in the form of an infographic recommending the adoption of very early maturing rice varieties is presented in Fig. 8.

Fig. 8: Policy Recommendation for Development of Very Early Maturing Rice Varieties.

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4.6. Study Limitation and Wider Applicability

When interpreting the results, it is important to acknowledge several limitations. Initially, the agronomic case study was carried out in a single irrigated setting in South Sulawesi. As a result, the effects of spacing, fertilization, compost, and water management observed may vary in rainfed, upland, saline, flood-prone, or cooler conditions. The primary agronomic parameter analyzed statistically was the number of productive tillers, although yield formation is also influenced by factors such as panicle number, spikelets per panicle, grain filling, grain weight, and harvest index. Thus, an increase in productive tillers should not be presumed to lead to a proportional yield increase in all environments. To develop agronomic recommendations that are widely applicable, evaluations across multiple locations and seasons are necessary.

Second, the economic evaluation relied on observed data and secondary cost–return figures without fully accounting for price fluctuations, climate risks, labor shortages, machinery wear and tear, long-term soil advantages, or environmental side effects. Consequently, the profit scenarios presented should be seen as indicative rather than assured results. Third, the social survey involved 158 participants chosen through convenience sampling with the help of extension workers and was conducted via an online platform. This method might have excluded farmers with limited internet access, minimal interaction with extension services, or low adoption of new technologies. Therefore, the results are best suited for reflecting the views of the surveyed individuals rather than all rice farmers in South Sulawesi or Indonesia. Additionally, the agribusiness and policy implications were drawn from an integrated interpretation and were not validated as causal policy measures.

Although there are constraints, the conceptual framework is applicable beyond Indonesia. Rice that matures very quickly could be beneficial in monsoonal and tropical farming systems across South Asia, Southeast Asia, and certain regions of Africa. In these areas, farmers often deal with late rainfall, end-of-season droughts, seasonal floods, or limited irrigation windows. Additionally, the framework might be pertinent for regions aiming to incorporate rice with pulses, maize, vegetables, or other crops within a constrained annual planting schedule. However, it is important not to assume that Indonesian varieties can be directly transplanted elsewhere. Their effectiveness may vary due to factors like photoperiod, temperature, soil fertility, pest issues, grain quality preferences, and local market demands. Therefore, broader application should emphasize adopting the integrated approach of short growth duration, efficient tillering, coordinated nutrient management, adaptable irrigation, and institutional backing, rather than focusing on a single variety or a rigid technology package.

Future investigations should focus on conducting trials across multiple locations and seasons to assess grain yield, the survival of productive tillers, panicle development, grain filling, grain quality, and yield stability under varying water and soil conditions. It is important to evaluate genotype × management × environment interactions to determine if Cakrabuana, Inpari 13, and other very early-maturing varieties necessitate different spacing, nitrogen levels, compost applications, or AWD thresholds. Long-term research is also essential to assess soil organic carbon, nutrient-use efficiency, irrigation water productivity, greenhouse gas emissions, pest and disease dynamics, and the lasting benefits of compost. Economic studies should consider price volatility, labor limitations, climate risks, and overall farm profitability over several years. Participatory trials and longitudinal surveys of farmers are needed to ascertain if positive acceptance results in sustained adoption, repeated planting, and noticeable improvements in household income. These research avenues would offer more robust evidence for promoting very early-maturing rice as a climate-resilient and economically feasible production strategy.

5. CONCLUSION

The introduction of rice varieties that mature very early presents a promising strategy to enhance food security and optimize agricultural land use in Indonesia. From an agronomic standpoint, the application of adaptive cultivation techniques, such as optimizing plant spacing, applying balanced fertilizers, utilizing compost, incorporating potassium, and implementing water management strategies like alternate wetting and drying (AWD), can significantly improve the development of productive tillers, enhance water use efficiency, and increase overall crop yields. Economically, the Cakrabuana, Padjadjaran, and Inpari 13 varieties demonstrate high profitability, offering the potential to increase planting frequency and annual income for farmers. Socially and within agribusiness, these early-maturing varieties are preferred by farmers due to their compatibility with short growing seasons, their ability to support higher cropping indices, and their potential for integration into premium rice value chains. The study's findings suggest that the development of these rice varieties is essential not only for augmenting food production but also for transforming agricultural systems to be more efficient, adaptable to climate change, and market-oriented. Key factors for the sustainable adoption of this innovation include strengthening the seed system, agribusiness institutions, inclusive financing, and technology dissemination through extension services and the involvement of young farmers. Future research should concentrate on refining location-specific technology packages, enhancing supply chain integration, and assessing the economic and environmental sustainability of very-

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early maturing rice cultivation systems on a larger production scale.

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Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement: This study adhered to ethical standards for research involving human participants. Participation was voluntary, and respondents were assured of anonymity and confidentiality. All participants were informed about the study objectives and their right to withdraw at any time without penalty. Informed consent was obtained prior to questionnaire completion. Thus this research has adhered to ethical standards on research involving human to collect quessionare.

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Attachment: Supplementary Material: 1-3

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