World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Risks of Rice Farming Production in Karanganyar Regency, Central Java, Indonesia

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World Journal of Advanced Research and Reviews, 2025, 27(03), 1277-1284

Publication history: Received on 10 August 2025; revised on 14 September 2025; accepted on 18 September 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.3.3251

Abstract

This study investigates production risk and its determinants in rice farming in Jaten Subdistrict, Karanganyar Regency, Central Java, Indonesia. Data were obtained from 92 purposively selected smallholder farmers through structured surveys covering land use, seed and fertilizer inputs, pesticide applications, and labor. Production risk was assessed using the coefficient of variation (CV), while the Just and Pope heteroskedastic frontier model was applied to estimate the effects of production inputs on both yield and risk. Results indicate that the average rice yield reached 4,722.52 kg with a CV of 22.24%, reflecting relatively low production variability. Land area, rice seeds, and solid pesticides significantly enhanced yield, whereas excessive nitrogen fertilizer reduced productivity. On the risk function, rice seeds and potassium fertilizer significantly mitigated production risk, while other inputs were insignificant. The relatively low explanatory power of the risk model (R-squared = 0.134) suggests that external factors such as climate extremes and pest outbreaks remain the major sources of uncertainty. These findings highlight the importance of optimizing improved seeds and potassium fertilizer, reducing nitrogen overuse, and integrating solid pesticide application into an Integrated Pest Management (IPM) framework. Moreover, the adoption of climate-resilient rice varieties, rainfall-based planting schedules, and pest monitoring technologies is recommended to strengthen resilience and ensure sustainable rice farming.

Keywords: Just And Pope Model; Production Input; Production Risk; Rice Farming; Smallholder Farming

1. Introduction

Rice is a strategic food commodity in Indonesia, serving as the primary source of carbohydrates and a pillar of national food security. Central Java, particularly Karanganyar Regency, is one of the main rice production centers; in 2024, Central Java Province produced approximately 8,891,297 tons of dry harvested rice, accounting for about 16.73% of national rice production (1). Despite its central role, rice farming in the region still encounters various challenges that threaten both productivity and sustainability. One of the most pressing challenges is production risk, which reflects the uncertainty of yields caused by a wide range of internal and external factors. Production risk not only undermines yield stability but also directly impacts the income and welfare of smallholder farmers, who form the backbone of rice production in Indonesia. High variability in yields can discourage farmers from investing in improved technologies, trap households in cycles of poverty, and weaken the resilience of local food systems. For this reason, analyzing the sources of production risk is crucial for identifying strategies that enhance both productivity and stability in rice farming.

Internal factors represent conditions within the farming system that strongly shape production outcomes. Land area and seed quality are fundamental to achieving higher productivity, and efficient land management combined with the

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use of improved seed varieties has been shown to reduce yield variability. Fertilizers and pesticides, when applied in appropriate amounts, help maintain soil fertility and protect crops from pests and diseases; however, overuse often increases production risk by degrading soil health, fostering pest resistance, and reducing long-term productivity. Labor availability and mechanization are equally important: while the use of tractors and other machinery improves efficiency, inadequate management and maintenance can generate additional risks that offset potential gains (2).

External factors, by contrast, originate outside the farming system yet significantly influence rice production and the degree of risk faced by farmers. Climate and weather conditions are particularly critical, as temperature fluctuations, drought, and excessive rainfall can lead to substantial yield losses. Drought and salinity stress are especially damaging, causing osmotic imbalance and deterioration in grain quality (3). Market dynamics and policy interventions also play a decisive role: unstable prices, restricted market access, and inconsistent subsidy or support programs increase uncertainty in farmers' decision-making (4). Socioeconomic characteristics such as education, farming experience, and household income further shape farmers' ability to adopt risk-reducing innovations, while environmental stressors, including declining soil fertility, limited water resources, and pollution, compound production uncertainty and threaten long-term sustainability (5,6).

Taken together, these internal and external drivers highlight the multifaceted nature of production risk in rice farming. The interplay between input management, environmental variability, and socioeconomic conditions not only determines productivity but also dictates the level of uncertainty that farmers must navigate. A deeper understanding of how these factors interact is therefore essential for developing efficient, resilient, and sustainable rice farming strategies. In this context, the present study investigates production risk and its determinants in rice farming in Jaten Subdistrict, Karanganyar Regency, Central Java. By applying the Just and Pope heteroskedastic frontier model, the study not only examines how production inputs affect yields but also how they contribute to or mitigate production risk. The findings are expected to provide insights for improving input management and designing strategies that strengthen the resilience and sustainability of rice farming systems.

2. Material and methods

The research was conducted in Jaten District, Karanganyar Regency. The selection of the location is purposively based on the consideration of farmers in Jaten District, Karanganyar Regency, who plant rice three times a year, actively and routinely participate in agricultural counseling, and manage rice farming business using intensive production inputs. The research data used primary data collected through a questionnaire that contained information on rice production, land area, rice seeds, organic fertilizers, NPK fertilizers, liquid and solid pesticides, and internal and external labor used by farmers during one farming season. A sample of 92 respondents was deliberately selected based on data on active farmers in farmer groups and routinely participated in counseling from the Agricultural Extension Center of Jaten District, Karanganyar Regency. This study analyzes production risks and production factors that affect rice production risk in Jaten District, Karanganyar Regency.

Risk measurement in rice production in this study was carried out through the Coefficient of Variation (CV), which is a measure of relative risk by dividing the standard deviation by the estimated average value. The Coefficient of Variation (CV) formula is presented as follows

$$\text{CV} = \frac{\sigma}{\bar{X}}$$

$$\sigma = \sqrt{\frac{\sum(X-\bar{X})^2}{n}}$$

Information

- CV: Coefficient of Variation
- σ: Standard Production Deviation
- X : Rice Production (kg)
- $\bar{X}$: Average Rice Production (kg)
- N: Total Farmer Sample

The magnitude of the influence of the utilization of production factors on risk can be analyzed using multiple linear regression models using the heteroscedasticity method by Just and Pope (1979) (7). The estimation model used to analyze the factors determining the risk of rice production is:

$$\text{Ln } Y = \text{Ln } \alpha0 + \alpha1 \text{ Ln } X1 + \alpha2 \text{ Ln } X2 + \alpha3 \text{ Ln } X3 + \alpha4 \text{ Ln } X4 + \alpha5 \text{ Ln } X5 + \alpha6 \text{ Ln } X6 + \alpha7 \text{ Ln } X7 + \alpha8 \text{ Ln } X8 + \alpha9 \text{ Ln } X9 + \alpha10 \text{ Ln } X10 + \varepsilon_1$$

$$(\varepsilon_1 2) = \text{Ln } \beta0 + \beta1 \text{ Ln } X1 + \beta2 \text{ Ln } X2 + \beta3 \text{ Ln } X3 + \beta4 \text{ Ln } X4 + \beta5 \text{ Ln } X5 + \beta6 \text{ Ln } X6 + \beta7 \text{ Ln } X7 + \beta8 \text{ Ln } X8 + \beta9 \text{ Ln } X9 + \beta10 \text{ Ln } X10 + \varepsilon_2$$

Information

- Y: Rice Production (kg)
- $\varepsilon_1 2$: Rice Production Risk
- X1: Rice Seeds (kg)
- X2: Land Area (ha)
- X3: Organic Fertilizer (kg)
- X4: N Fertilizer (kg)
- X5: P Fertilizer (kg)
- X6: K Fertilizer (kg)
- X7: Liquid Pesticide (Liter)
- X8: Solid Pesticide (kg)
- X9: Internal Labor (working people's day)
- X10: External Labor (working people's day)
- α0, β0: intersex
- αI, βI: Koenidine regress, I = 1, 2, 3, …, 10
- $\varepsilon_1, \varepsilon_2$: error term

Estimated regression coefficient values

- -β1-β10 < 0

Uji Hypothesis

- H0: βI = 0, The I input does not affect production risk
- H1: βI ≠ 0, The I input exerts an influence on the production risk.

3. Results and discussion

Table 1 Rice Production Risks

Variable	Production Risk
Average Production (kg)	4,722.52
Standard Deviation	1,050.55
Coefficient of Variation	0.2224
CV (%)	22.24

Source: Primary Data Analytics (2025)

Farmers in Jaten District use the Inari 33 rice variety. The average production was 4,722.52 kg in the form of harvested dry grain. The risk of rice production was measured by dividing the standard value of production deviation by the average value of production results at the research site. Based on Table 1, the value of the coefficient of variation is 22.24%. This shows that the variation in the average value of production is relatively low. Production risks can be caused by both internal and external factors. These risks can arise due to excessive or insufficient allocation of production inputs, as well as climatic factors such as unpredictable weather. Climate change can also trigger pest attacks or diseases that have the potential to cause crop loss.

Table 2 Factors Affecting Rice Production and Production Risk

Variable	Production Function			Risk Function		
	Coefficients	t-count	Sig.	Coefficients	t-count	Sig.
Land Area	1.358***	6.033	0.000	0.064	1.414	0.161
Rice Seeds	0.408***	2.969	0.004	-0.057**	-2.075	0.041
Organic Fertilizer	-0.012**	-2.271	0.026	0.001	0.551	0.583
N Fertilizer	-0.482***	-2.900	0.005	0.044	1.315	0.192
P Fertilizer	-0.047	-0.303	0.763	-0.002	-0.073	0.942
K Fertilizer	0.077	1.435	0.155	-0.024**	-2.279	0.025
Liquid Pesticides	0.016	1.537	0.128	0.000	0.239	0.812
Solid Pesticides	0.042*	1.756	0.083	-0.003	-0.657	0.513
Internal Labor	0.002	0.222	0.825	0.001	0.456	0.650
External Labor	-0.022	-0.444	0.658	0.001	0.132	0.895
C	-2.527**	-1.991	0.050	-0.454*	-1.776	0.079
R-squared	0.898			0.134		
Adjusted R-squared	0.885			0029		
F-count	71.954***		0.000	1.273		0.259

Information: *** : significant at level α 1% (2.373); **: significant at level α 5% (1.664) : significant at level α 10% (1.292); F table : significant at level α 1% (2,54)

The factors influencing production and their risk were analyzed using the heteroscedasticity method of the multiple linear regression formulation model predefined by Just and Pope. Table 2 shows the results of factors that affect rice production. The coefficient of determination (R-squared) of 0.898 shows that the variation of the variable of rice production can be explained by 89.8% by the variation of the free variables in the model (land area, rice seeds, organic fertilizer, N fertilizer, P fertilizer, K fertilizer, liquid pesticides, solid pesticides, internal labor, and external labor), while the remaining 21.2% is explained by the variation of other independent variables outside the model. This shows that the regression model used is quite good in explaining the variation in corn production. In addition, the results of the F-test with an F-calculation value of 71,954 (F-table α 1% = 2.54) showed that the overall model (land area, rice seeds, organic fertilizers, N fertilizers, P fertilizers, K fertilizers, liquid pesticides, solid pesticides, internal labor, and external labor) had a significant effect on corn production. The variable is significant at the level of α 5% with a coefficient of -2.527. The value of the constant variable that has been anti-Ln yields a number of 0.080. This value shows the minimum value of corn production at the research site of 0.080 kg.

Partially, several variables have been shown to significantly affect rice production. The land area has a positive and significant influence at the level of 1% with a coefficient of 1,358, which means that the addition of the land area used directly increases production output. This is consistent with the classical production theory, where land as the main production factor allows for increased business scale and more optimal allocation of inputs. This is in line with the theory of production, where the increase in land factors directly increases output. Likewise, research by Dewati and Wilayat (2018) states that farmers with larger land have a greater chance of increasing the number of rice clumps planted. With effective agricultural management, rice production can be increased (8).

Similarly, rice seeds had a significant positive effect at the level of 1% with a coefficient of 0.408, indicating that an increase in seed use of 1% optimally encouraged an increase in yield by 0.408%. This result is in line with the results of the research of Novitaningrum et al. (2019) and Sudaryanto et al. (2015) which stated that the number of rice seeds shows a real positive influence on rice production (9,10). The rice seeds used by farmers are superior varieties of seeds. Superior variety seeds have several advantages over ordinary seeds, which can increase productivity and quality of agricultural products. The main advantages include high yield potential, resistance to pests and diseases, and better yield quality. According to Sahir and So Mantri (2016), the use of superior varieties is able to reduce the use of pesticides (11).

Meanwhile, organic fertilizers actually showed a significant negative influence on production, each at the level of 5%. This negative effect can be interpreted as excessive or inappropriate use of plants that hinder growth and production, for example, due to nutrient imbalances or the accumulation of substances that are not absorbed efficiently. Wei et al. (2020) stated that organic fertilizers can be used as an effective substitute for inorganic fertilizers, increase crop yields, and are environmentally friendly. Replacing inorganic fertilizers with organic fertilizers significantly increases crop yields. Replacement of organic fertilizers also reduces soil acidification due to the use of inorganic fertilizers (12). However, organic fertilizers often have a slower rate of nutrient release than chemical fertilizers. This can result in nutrient deficiencies during the critical growth stage of rice, resulting in lower yields. The timing of nutrient availability is critical, and if organic fertilizers do not release nutrients when plants need them most, this can negatively impact growth and yield (13).

The use of N fertilizer has a real effect at the level of 1% with a coefficient of -0.482. This shows that the addition of N fertilizer by 1% can reduce rice production by 0.482%. The N fertilizer that is usually used by farmers comes from fertilizers with the trademarks Urea and Phon ska. The use of N fertilizer by farmers is equivalent to the use of urea fertilizer of 292,555 kg/ha and Phon ska fertilizer of 300 kg/ha. The recommended fertilization dose based on Ministerial Regulation No. 40/OT.140/4/2007 is a combination of a single fertilizer of urea of 150-250 kg/ha and a compound fertilizer of Phon ska of 300 kg/ha. The N fertilizer used by farmers exceeds the N fertilization recommendation from the Ministry of Agriculture. This is consistent with the results of the study, which shows that N fertilizer at the research site needs to be reduced. These results are in line with research by Luo et al. (2023), Chen et al. (2021), and Song et al. (2021) that excessive N application results in low nitrogen use efficiency, meaning that most of the nitrogen provided is not utilized by rice plants and is lost to the environment (14–16). Excessive use of N can also lead to reduced grain yields due to poor nitrogen management and increased susceptibility to pests and diseases (17).

The results showed that the use of solid pesticides had a significant positive effect at the level of 10% on rice production with a coefficient of 0.042. This shows that the addition of 1% solid pesticide can increase rice production by 0.042%. This indicates that pest control with solid pesticide formulations, especially granular insecticides, still plays a role in maintaining rice productivity. Granular pesticides are generally applied around the roots or base of the plant so that the active ingredients can be absorbed systemically and protect the plant from the vegetative phase. This strategy is effective in suppressing the population of main pests of rice, such as stem borer (Coprophage inceptual), brown stem leafhopper (Nila Parvata lunges), and sucking pests that have the potential to reduce crop yields. Similar research has also shown the effectiveness of solid pesticides in suppressing pest attacks. Niranjan et al. (2018) reported that the application of a new generation granular insecticide was able to reduce the intensity of stem borer attacks by more than 40% and had a positive impact on increasing grain yields (18). Similarly, Sahu et al. (2020) found that some granular formulations are more effective than liquid insecticides in controlling rice stem borer pests, thus contributing significantly to increased productivity (19).

However, several other variables, such as P fertilizer, K fertilizer, liquid pesticides, and labor within and outside the family, did not show a significant influence on rice production. The insignificance of P and K fertilizers can be caused by soil conditions at the research site that naturally already have sufficient phosphorus and potassium nutrient content, or because the dosage and time of application are not optimal. Meanwhile, liquid pesticides have no real effect because their use is not on target. In the case of labor, both from within and outside the family, this insignificance may be due to low labor efficiency, where a large amount of labor is not always accompanied by high productivity. In addition, the growing mechanization can also reduce the dependence on manual labor.

In terms of risk function, rice seeds have a significant negative coefficient at the level of 5% with a coefficient of -0.057, indicating that the proper use of seeds can reduce production risk. This indicates that increasing the use of appropriate seeds and as recommended, can reduce production risks. High-quality seeds generally have better growth power, are more uniform in growth, and are more resistant to biotic and abiotic stresses. The uniformity of plant growth has implications for a more stable distribution of yields, so that it can reduce production uncertainty faced by farmers.

This finding is consistent with the research of Sudaryanto et al. (2015) which states that the appropriate use of superior variety seeds can increase production efficiency and reduce losses due to pest and disease attacks. Superior varieties have typically gone through a breeding process to increase resistance to certain plant pest organisms, thereby reducing the probability of crop failure (10). In addition, the research of Novitaningrum et al. (2019) also confirms that the use of superior seeds is able to produce a uniform and productive crop population, so that the variability of yields between farmers and between planting seasons is smaller (9). In managing rice production risks, the use of superior seeds plays a role as one of the effective mitigation strategies. Uniform and stress-resistant seeds, risks due to environmental factors such as climate fluctuations or pest attacks can be suppressed. This is in line with the view of Siswanto et al. (2015) who stated that the selection of rice varieties with good genetic resistance is an important component in the management of rice farming to reduce uncertainty of results (20). The results of this study confirm that rice seeds not only function as the main production factor but also contribute significantly to reducing production risk in rice farming.

K fertilizer also has a significant negative effect on production risk at the level of 5%, which shows that potassium plays a role in increasing the resilience of rice crops, thereby reducing crop yield uncertainty. Potassium plays an important role in many plants' physiological functions, such as the regulation of water balance, protein synthesis, enzyme activation, and cell osmotic stability. The availability of sufficient K makes plants able to cope with abiotic stresses such as drought and temperature fluctuations and is better prepared to face biotic disturbances such as diseases and pests. These findings are supported by Ye et al. (2021), who demonstrate that the interaction between nitrogen and potassium improves overall nutrient uptake, which in turn improves the efficiency of fertilizer use and rice yields. The research found that the right combination of N and K significantly increased productivity compared to when K was not added (21). In addition, a study by Chen et al. (2024) shows that the application of K in optimal doses helps to improve the quality and efficiency of nutrient use in rice, so that crop yields not only increase, but also become more stable (22). Popp et al. (2021) also reported that the response of rice yields to K fertilization showed a downward benefit curve beyond the optimal point, but before reaching that extreme, the addition of K provided a return on the reduced risk of yield yield, meaning that the risk of yield loss or shortfall was smaller if K fertilizer was used as recommended (23). Research by Zorb et al. (2014) also showed that potassium not only increases yields but also improves production stability by reducing yield variability between growing seasons (24).

The other variables had no significant effect on risk, and the R-squared value in the risk model of 0.134 indicated that most of the variation in rice production risk was influenced by other factors outside the model, such as extreme weather, climate change, or pest disturbances that were not quantitatively measured in the study. External factors such as extreme weather, changes in rainfall patterns, and extreme climatic events such as floods and droughts make a major contribution to increasing the risk of crop failure. This is in line with the findings of Wassmann et al. (2009), who affirmed that global climate change has a significant impact on rice productivity, especially in Southeast Asia, where rising temperatures and rainfall variability trigger a decline in yields (25). In addition, attacks by plant pest organisms (OPT) such as brown stem leafhoppers, stem borers, and bacterial leaf blight are also a source of risk that is difficult to predict quantitatively, but has the potential to drastically reduce yields (26).

Thus, the low R-squared value suggests that rice production risk is determined more by dynamic environmental and biotic factors, rather than solely by farmer-controlled production inputs. Therefore, risk mitigation strategies are not enough only through input management, but also require a climate adaptation approach, the use of stress-resistant varieties, and the application of Integrated Pest Management principles to deal with uncertainties stemming from these external factors.

4. Conclusion

The findings indicate that rice production is significantly influenced by land size, the use of improved seeds, fertilizers, and solid pesticides. In terms of risk, improved seeds and potassium fertilizer were proven to reduce yield uncertainty, while other variables showed no significant effect. The relatively low R-squared value of the risk model suggests that external factors, such as extreme weather events and pest outbreaks, remain the primary sources of production risk. Based on these results, farmers are advised to optimize the use of improved seeds and potassium fertilizer according to recommended guidelines, avoid excessive nitrogen application, and apply solid pesticides selectively within the framework of Integrated Pest Management (IPM). Furthermore, adopting climate-resilient rice varieties, aligning planting schedules with rainfall patterns, and utilizing pest monitoring technologies are practical strategies to mitigate risks while enhancing the sustainability of rice production.

Compliance with ethical standards

Disclosure of conflict of interest

The author(s) declare no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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