Determinants of Local Food Resilience: Evidence from Cassava-Based Agricultural Practices in Pati Regency, Central Java Province

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Abstract. Cassava production contributes significantly to local food resilience in Pati Regency, Central Java. However, challenges such as fluctuating yields and inconsistent input use pose a threat to long-term sustainability. This study examines the determinants of cassava production and its sustainability, employing a descriptive quantitative approach. The Cobb–Douglas model, estimated using Ordinary Least Squares (OLS), was employed to identify production factors, while sustainability was measured using the coefficient of variation (CV). Data were collected from 136 farmers across three major cassava-producing subdistricts. The results show that land area, seed quantity, and fertiliser have a significant influence on production, while labour and pesticides have no significant effect. Production sustainability is generally moderate, with variations across regions. Diversification practices, technology adoption, cooperative participation, and farming experience significantly enhance yield stability, whereas access to extension services shows no significant impact. Based on these findings, strengthening cassava sustainability requires integrated strategies, including the application of appropriate technologies such as site-specific fertiliser recommendations and simple mechanisation tools, as well as institutional reinforcement through farmer cooperatives, collective input procurement, and structured technology adoption programs. These operational measures are crucial for building a more adaptive, productive, and resilient cassava farming system that supports local food security.

1 Background

The global food system is becoming increasingly vulnerable to climate change, geopolitical instability, and fluctuations in international markets, compelling developing countries to

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enhance their domestic food security strategies [1]. Indonesia promotes food diversification to reduce dependency on rice, with cassava positioned as a strategic local carbohydrate source due to its adaptability to marginal land and relatively low production costs [2,3]. Cassava also serves as an important raw material for household and small-scale industries, making it a key commodity not only for food security but also for rural economic resilience.

Central Java Province is among the leading cassava-producing regions, with Pati Regency consistently ranking as one of the most significant contributors to provincial cassava output. The harvested area in 2024 exceeded 16,102 hectares [15]. However, despite the large cultivation area, productivity in several subdistricts has shown stagnation and even decline. These conditions indicate structural challenges within the farming system, including variation in agroecological conditions, unequal access to inputs, and limitations in farmer institutions. Variations in yield stability among subdistricts Gembong, Margoyoso, and Cluwak suggest differences in topography, infrastructure, and farming practices. For example, Gembong, located in a hilly upland area, benefits from relatively fertile soils and stronger farmer group networks; Margoyoso has more diversified farming systems and easier market access; while Cluwak, with more fragmented land and limited irrigation, faces higher production variability. However, previous studies rarely incorporate such regional heterogeneity into the analysis.

To understand cassava performance, previous research has primarily focused on agronomic determinants, including land area, seeds, labour, and fertiliser [4–6]. Although these factors remain essential, they do not fully explain production stability over time, which is increasingly important given climate uncertainty. Sustainability is frequently measured using indicators such as yield stability, production risk, and socio-economic robustness. This study uses the coefficient of variation (CV) to capture yield fluctuation across seasons due to its simplicity and widespread use in agricultural risk analysis [2,7,8]. However, CV has limitations: it does not capture structural or socio-economic drivers of risk, nor does it distinguish between controllable and uncontrollable sources of variability. Alternative indicators such as the production risk index, resilience score, or socio-economic vulnerability indicators could provide a more holistic picture. However, they require longitudinal or cost-based data, which are often unavailable at the smallholder level. Therefore, explaining the limitations of CV is essential in interpreting sustainability within this research context.

Despite the growing interest in cassava sustainability, relatively few studies integrate production determinants with sustainability indicators in a single analytical framework. More importantly, institutional and behavioural factors such as technology adoption, cooperative membership, and farming experience have been shown to influence both productivity and stability [9], These factors shape farmers' adaptive capacity when facing climatic, market, or input-related uncertainty. For instance, the adoption of recommended cultivation technologies increases consistency of yields; cooperatives improve access to inputs and markets; and experienced farmers are better at mitigating production risks.

Nonetheless, empirical evidence that quantifies these relationships, particularly in cassava-based systems in Indonesia, remains limited [4,6–8]. Furthermore, extension services play a critical role in supporting farmers' technical and managerial competencies. However, in many regions, extension programs may be irregular, understaffed, or insufficiently tailored to the specific needs of commodities. This can explain why access to extension appears insignificant in some analyses, as the service quality may not align with farmers' operational challenges or be delivered with insufficient intensity. A deeper contextual explanation is therefore necessary to interpret statistically insignificant variables such as extension access.

Given the importance of cassava for household food supply, agroindustry inputs, and income stability in Pati Regency, understanding the factors that influence both production level and sustainability is crucial. This study aims to fill this gap by: (1) estimating the determinants of cassava production using the Cobb–Douglas model; (2) evaluating the sustainability of production using the coefficient of variation; and (3) analysing socio-economic and institutional factors such as technology adoption, cooperatives, extension access, and experience using a secondary regression analysis.

2 Research Method

This research was conducted from May to June 2025 in Pati Regency, Central Java Province. Three sub-districts, Gembong, Margoyoso, and Cluwak, were selected purposively as the study locations because they are recognised as the primary cassava production centres in the region. The criterion of being consistently high producers was determined using three supporting indicators based on the last three-year district agricultural reports (2022–2024): (1) stable and wide harvested area, remaining among the top contributors to total district cassava cultivation (>1,500 ha per year); (2) high and relatively stable production volume, with each sub-district contributing more than 10% to total district production annually; and (3) relatively stable productivity levels compared with other sub-districts, with fluctuations that were lower than the district average, indicating consistent performance. These indicators collectively justify the selection of the three sub-districts as representative locations for analysing production dynamics and sustainability.

The study population consists of all cassava farmers actively cultivating the crop in the selected sub-districts. Purposive sampling was employed with the criterion that farmers must have cultivated cassava for at least three consecutive seasons and maintained verifiable records of their input use and production output. A total of 136 farmers were selected, with proportional distribution across the three sub-districts to ensure adequate representation.

Primary data were collected through structured questionnaires and direct interviews with farmers. The questionnaires included information on production inputs (land area, seed quantity, fertiliser, labour, and pesticides), outputs (yield per season), and socio-economic attributes such as technology adoption, cooperative participation, and farming experience. Secondary data were obtained from the Pati Regency Agriculture Office and BPS datasets, including trends in harvested area, production volume, and average productivity for the past three years.

A Cobb-Douglas production function model was estimated using the Ordinary Least Squares (OLS) method in log-linear form to analyze the factors influencing cassava production [10,11]. The stages of analysis were carried out as follows:

Data Transformation: All input and output variable data were transformed into natural logarithm (ln) form so that the Cobb-Douglas production function could be estimated in multiple linear regression form.

Model Estimation: The production function equation used is:

$$lnY = lnA + \beta 1 lnX1 + \beta 2 lnX2 + \beta 3 lnX3 + \beta 4 lnX4 + \beta 5 lnX5 + \varepsilon \qquad (1)$$

Information:
Y = Cassava production (kg)
X1 = Land area (ha)
X2 = Seed (kg)
X3 = Labor (HOK)
X4 = Fertilizer (kg)
X5 = Pesticide (liter)
ε = error term
β = elasticity coefficient of each input

Classical Assumption Test: After the model is estimated, classical regression assumption tests are conducted, including multicollinearity test (using VIF), heteroscedasticity (Breusch-Pagan test), and residual normality (Jarque-Bera test) to ensure the validity of the regression model.

Coefficient Interpretation: Each value of βi indicates the elasticity of cassava production to changes in related inputs. A statistically significant value suggests a real effect of the variable on production output.

To analyze the level of production sustainability, the coefficient of variation (CV) is used as a measure of output stability [8]. CV is calculated based on farmers' production data for the last three growing seasons. The calculation formula is:

$$CV = \left(\frac{Standard\ Deviation\ of\ Output}{Mean\ Output}\right) x\ 100\% \quad (2)$$

Low CV values indicate high production sustainability (stable output), while high CV values indicate large fluctuations in yields and risks to local food security. This analysis was conducted individually for each farmer and then averaged to assess general trends at the sub-district and district levels.

3 Results and Discussion

3.1 Factors Affecting Cassava Production in Pati Regency

The results of the multiple linear regression estimation using the Cobb-Douglas model presented in Table 1 show that three of the five input variables tested significantly affect cassava production in Kabupaten Pati. The three variables are land area, number of seeds, and amount of fertilizer. The land area showed the most dominant effect, followed by the amount of seeds used. In contrast, labor and pesticides did not show a statistically significant impact at the conventional confidence level.

Table 1. Results of Multiple Linear Regression of Factors Affecting Cassava Production in Pati District

Variable	**Regression Coefficient (β)**	**Std. Error**	**t-value**	**Sig. (p-value)**
Land Area	0.521***	0.078	6.679	0.000
Seed	0.213**	0.096	2.219	0.029
Labor	0.145	0.091	1.593	0.115
Fertilizer	0.096*	0.055	1.745	0.084
Pesticides	0.031	0.046	0.674	0.502
R-squared	**0.792**			
Adjusted R^2	**0.777**			
F-statistic	**52.918**			
Sig. F	**0.000**			

Notes: *Significant at α = 1%, Significant at α = 5%, *Significant at α = 10%

Land area remains the most dominant factor affecting cassava production. This aligns with the production characteristics of Pati Regency, where cassava is widely cultivated in mixed dryland–upland zones with relatively low input intensity. Many farmers have fragmented plots, often ranging from 0.25 to 0.75 ha, which makes land expansion a primary strategy for increasing output rather than intensification. This finding is consistent with studies showing that cassava's response to increased land allocation is stronger than its response to incremental input additions, particularly in semi-subsistence farming systems [12]. The strong elasticity suggests that policies aimed at land consolidation, optimizing fallow lands, and improving land management practices could significantly increase production.

Seed quantity significantly and positively influences production. In Pati Regency, local farmers typically use a mixture of local varieties (e.g., Adira, Darul Hidayah, and Kasetsart clones), which differ in stem quality, disease resistance, and starch content. The availability of high-quality stakes, especially disease-free planting material, is often limited, leading farmers to rely on cuttings from their own previous harvests [4]. The significance of seed quantity highlights the importance of standardised seed selection, proper stem maturity, and the distribution of certified planting material to achieve yield consistency. This supports recommendations for strengthening community-based seed systems and increasing farmer access to certified cassava varieties.

Fertiliser application is significant at the 10% level, indicating a positive yet relatively marginal influence on production. The limited robustness of this significance suggests variability in dosage accuracy, application timing, and nutrient balance. In Pati, many farmers still apply fertilizer based on habit rather than soil test recommendations, and organic matter content in upland soils tends to be low. As a result, fertilizer efficiency may be suboptimal. Research by [9] Although the coefficient suggests that fertiliser remains important, policy implications should be cautious: recommendations should emphasise site-specific nutrient management (SSNM), improved extension support for dosage calibration, and the integration of organic amendments to enhance soil structure and nutrient retention.

Labour does not have a significant effect on cassava production, which may be attributed to the low labour intensity of cassava cultivation. Much of the cassava production cycle, including land clearing, planting, and especially harvesting, is increasingly supported by simple mechanizations, such as mini-cultivators or hired services at the village level. Additionally, household labour is commonly used, leading to limited variation across farmers [13]. This homogeneity reduces labour's explanatory power in the model. Moreover, labour efficiency in cassava farming is relatively high: one worker can manage a large area compared to other food crops, weakening the marginal contribution of additional labour units.

Similarly, pesticide use shows no significant impact. Cassava in Pati Regency is relatively tolerant to pests, with pest pressure typically low and sporadic. Many farmers apply pesticides only as needed rather than prophylactically, resulting in low variability in dosage and timing. Differences in pesticide types, concentrations, and application techniques further decrease the likelihood of detecting a measurable effect. Additionally, major cassava diseases in the area, such as cassava mosaic disease or bacterial blight, are more effectively managed through resistant varieties than through chemical pesticides, which explains the weak statistical association.

Although the model captures five core inputs, it does not include variables such as soil quality, rainfall variability, irrigation access, or technology adoption, all of which are known to influence cassava productivity. Pati Regency has heterogeneous soil conditions, ranging from upland latosols to alluvial soils, which leads to varying nutrient availability and water retention. Irrigation coverage for cassava is limited, making the crop highly dependent on seasonal rainfall. Excluding these factors may result in omitted variable bias. While data limitations restricted their inclusion, acknowledging these factors is essential for interpreting the model's results.

3.2 Sustainability Level of Cassava Farming Production in Kabupaten Pati

The analysis of the sustainability level of cassava production in Kabupaten Pati, presented in Table 2, shows variations in output stability between subdistricts. Sustainability is measured using the coefficient of variation (CV), which indicates fluctuations in cassava production from season to season. In general, the results show that most areas have a level of sustainability in the medium category, with one sub-district showing high sustainability and one sub-district in the low category.

Table 2. Level of Sustainability of Cassava Farm Production in Pati District

Sub-district	Average Production (kg/season)	Standard Deviation (kg)	Coefficient of Variation (%)	Sustainability Category
Gembong	18,452	3,750	20.38	High
Margoyoso	17,236	5,120	29.77	Medium
Cluwak	16,671	6,020	36.27	Low
Average	**17,453**	**4,748**	**28.86**	**Medium**

Note:
- CV < 25% = High sustainability level
- CV 25-35% = Medium sustainability level
- CV > 35% = Low sustainability level

This finding indicates that cassava production in Kabupaten Pati has not been fully stable. Moderate to high levels of fluctuation indicate challenges in maintaining yield sustainability. Various factors can influence this instability, such as dependence on climatic conditions, inconsistent input availability, and farmers' limited access to cultivation technology and markets. Districts with high levels of sustainability are located in areas with better agronomic support and agricultural infrastructure, including irrigation, extension, and more adaptive cultivation practices.

This study's results align with the study by [5], which emphasizes that the sustainability of agricultural production is closely related to the quality of farm management, access to adaptive technology, and climate variability. Production variability increases when farmers have low adaptive capacity to seasonal changes or fail to apply appropriate cultivation techniques. In the context of Kabupaten Pati, this points to the importance of institutional strengthening and extension services to help farmers manage production risks.

Furthermore, imbalances in the distribution of production inputs are also one of the causes of output instability. Research by [12] shows that farmers with limited access to quality inputs, such as superior seeds and fertilizers, tend to experience higher yield fluctuations than those who receive full support from agricultural institutions. This confirms the need for area-based policy interventions that consider the specific conditions of each sub-district, including clustering approaches and strengthening input logistics systems.

From a socio-economic perspective, the low sustainability in some areas can also be attributed to the lack of diversification of farmers' income, resulting in complete dependence on cassava yields as the primary source. The study by [8] found that monoculture systems with a single market are more vulnerable to fluctuations in income and production yields than farming systems combining several commodities or accessing broader markets. Therefore, crop diversification and integration into farmer cooperatives or agricultural value chains can be essential strategies to improve the sustainability of yields.

3.3 Factors Affecting the Sustainability of Cassava Production in Pati Regency

The multiple linear regression analysis in Table 3 shows several essential elements that significantly affect the sustainability of cassava production in Kabupaten Pati. In this model, sustainability is measured using the coefficient of variation (CV), where a lower value indicates a higher level of sustainability. Therefore, a negative regression coefficient indicates a positive contribution to sustainability, as it decreases the CV value. From the estimation results, the variables of crop diversification, technology use, farming experience, and participation in cooperatives were found to have a significant effect on production sustainability. At the same time, access to extension services did not show a significant impact.

Table 3. Results of Multiple Linear Regression of Elements Affecting the Sustainability of Cassava Production

Variable	Regression Coefficient (β)	Std. Error	t-value	Sig. (p-value)
Crop Diversification	-0.281***	0.065	–4.323	0.000
Use of Technology	-0.214**	0.083	–2.578	0.012
Access to Extension	-0.138	0.091	–1.516	0.133
Length of Farming Experience	-0.095*	0.052	–1.829	0.071
Cooperative Participation	-0.167**	0.077	–2.169	0.032
R-squared	**0.612**			
Adjusted R²	**0.589**			
F-statistic	**26.714**			
Sig. F	**0.000**			

Notes: The negative regression coefficient indicates that the higher the score of the independent variable, the lower the CV value (meaning more stable or sustainable production).
*Significant at α = 1%, Significant at α = 5%, *Significant at α = 10%

Crop diversification exhibits the most substantial adverse effect on CV, indicating that farmers practising diversified cropping systems experience more stable cassava yields. Diversification reduces exposure to climate-induced risks, pest outbreaks, and market fluctuations, allowing farmers to allocate resources flexibly among crops during unfavourable conditions. This finding [14], emphasises that diversified farming systems in Indonesian wetlands improve ecological stability. In Pati Regency, where rainfall distribution is irregular, and upland soils vary in fertility, diversified farming serves as a practical buffer mechanism against seasonal uncertainties. This result extends previous studies by quantifying the effect of diversification specifically on cassava yield variability, an area that remains underexplored in the literature.

The use of technology, including proper tillage, mechanised preparation, and recommended fertiliser application, also contributes significantly to production stability. Technology adoption reduces human error, enhances input efficiency, and supports timely cultivation operations, especially in areas vulnerable to rainfall variability. This finding is consistent with those of [2], who highlight that technology adoption increases the consistency of cassava yields in corporate farming systems. In the context of Pati Regency, where mechanisation services are increasingly available through farmer groups and local contractors, technology use helps synchronise planting periods and standardise cultivation practices, ultimately reducing inter-season fluctuations.

Farmers' participation in cooperatives was also shown to reduce CV significantly. Cooperatives are essential in ensuring input and output stability through joint procurement of production facilities, access to capital, and a relatively more organized market. Research by [9,12] confirmed that agricultural cooperatives can increase farmers' bargaining power and create a more sustainable production ecosystem through collaboration and protection against market volatility. In the context of Kabupaten Pati, cooperatives can effectively improve cassava farmers' economies of scale and logistical efficiency.

Farming experience has a negative and significant impact on CV, suggesting that experienced farmers are better at managing risks, adjusting input use, and interpreting local climatic signals. Experience enhances farmers’ ability to anticipate pest cycles, optimise time, and allocate inputs more efficiently. These results corroborate [1], who found that farmer experience supports better decision-making under uncertainty. In Pati Regency, where cassava is cultivated both as a commercial crop and a subsistence buffer, experienced farmers are more capable of sustaining yield levels even during unfavourable seasons.

Cooperative participation contributes significantly to reducing production variability. Cooperatives provide more reliable access to inputs, facilitate joint procurement of fertilisers and seeds, and offer more stable marketing channels. This institutional support reduces uncertainties related to price volatility and input shortages, particularly during peak planting season. The findings reaffirm studies by [12], who show that cooperative membership enhances farmers' market stability. However, the current research expands on this insight by demonstrating its direct contribution to yield sustainability, an underexplored dimension in cassava-focused studies.

The insignificant effect of extension access may be attributed to irregular service frequency, insufficient cassava-specific content, or limited engagement between extension agents and farmers. In many parts of Pati Regency, extension programs focus more on rice and secondary crops, leaving cassava farmers with minimal tailored technical guidance. This suggests that, although extension services exist, their operational effectiveness in supporting cassava sustainability remains limited, a finding consistent with the broader literature on Indonesian smallholder farming [13].

Although the sustainability model focuses on factors influencing CV, insights from the Cobb-Douglas production function help deepen the interpretation of sustainability outcomes. The sum of the statistically significant production elasticities of land area (0.521), seeds (0.213), and fertiliser (0.096) amounts to approximately 0.83, indicating decreasing returns to scale. This suggests that proportional increases in all inputs will lead to less-than-proportional increases in output. Such diminishing returns imply that sustainability-enhancing factors, such as technology, diversification, and cooperative support, become increasingly significant in counteracting natural limitations associated with scale-based intensification.

Furthermore, the structure of the Cobb-Douglas function implies potential substitutability among inputs. For example, increased seed quantity or improved seed quality may partially offset land limitations in areas where plot sizes are small or fragmented, common conditions in Margoyoso and Cluwak. Similarly, improved fertilisation management can temporarily compensate for poor soil fertility, while the adoption of technology can reduce labour requirements and enhance consistency in input application. These substitutive relationships help explain why sustainability outcomes are significantly influenced by institutional and behavioural variables rather than solely by agronomic inputs.

4 Conclusion

This study reveals that cassava production in Pati Regency is primarily influenced by land area, seed quantity, and fertiliser application. In contrast, production sustainability is shaped by diversification, technology adoption, cooperative participation, and farming experience. Among these factors, the most influential technologies in stabilising yields include mechanised land preparation, soil testing–based fertiliser recommendations, and standardised planting techniques using disease-free stems. However, adoption is not uniform: technology use is concentrated among cooperative-affiliated farmers, while many smallholders, especially those in more remote upland areas, continue to rely on traditional practices.

These technologies interact strongly with the environmental characteristics of Pati's cassava-growing areas, which are predominantly upland and marginal lands with low soil fertility and irregular rainfall. Mechanisation and site-specific nutrient management help address these constraints, consistent with findings from similar cassava systems in Togo and Nigeria. Overall, strengthening technological access, cooperative-based institutional support, and farmer capacity-building represents a practical pathway to improving cassava production stability and sustaining local food resilience.

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