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ARIMA-Based Forecasting of Rice and Maize Production and Its Implications for Food Security in Kutai Kartanegara Regency

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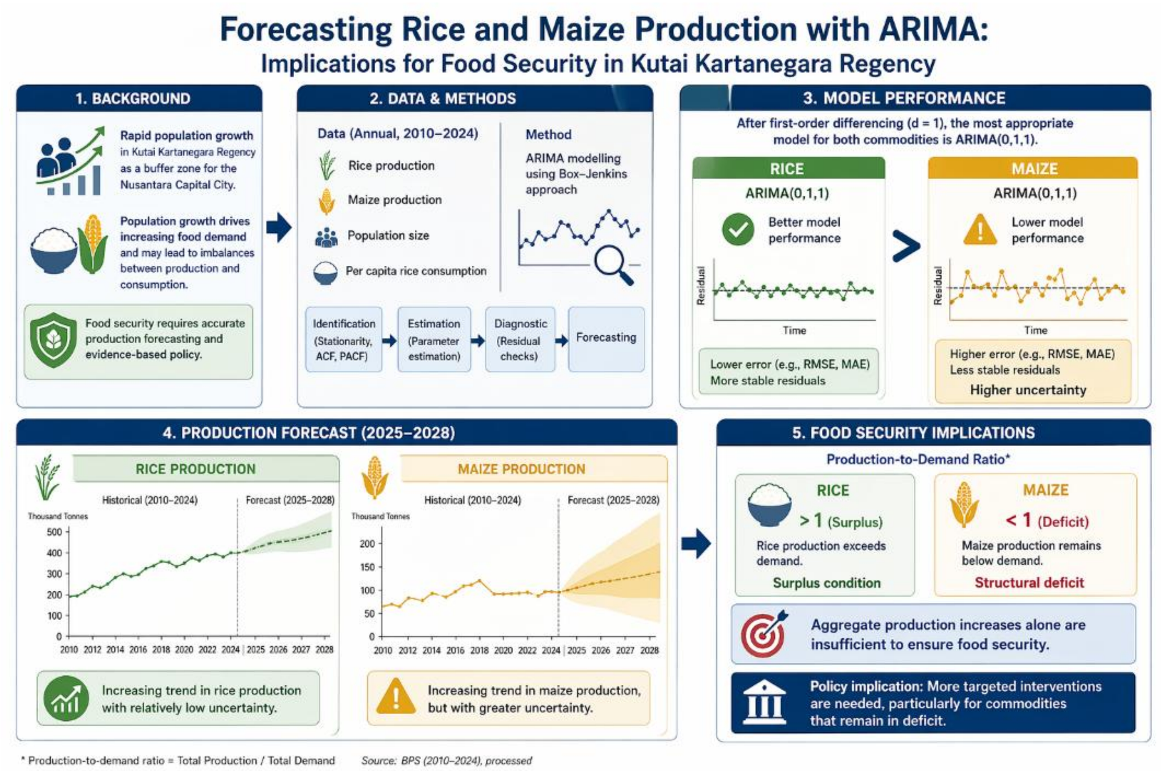
ABSTRACT

Food security remains a strategic issue in regions experiencing rapid population growth, including Kutai Kartanegara Regency, a buffer region for the development of the Nusantara Capital City. Population growth increases food demand and may create imbalances between production and demand. This study aimed to apply the Autoregressive Integrated Moving Average (ARIMA) model to forecast rice and maize production, compare forecasting performance across commodities, and analyse implications for regional food security using the production-to-demand ratio. Annual time-series data from 2010 to 2024 on rice and maize production, population size, and per capita rice consumption were analysed using the Box–Jenkins approach. ARIMA(0,1,1) was selected for both commodities after first-order differencing. The model provided a stronger statistical representation for rice, whereas the non-significant MA(1) parameter for maize indicated greater uncertainty. Forecasts for 2025–2028 indicated increasing rice production from 326,651 to 349,003 tons and maize production from 37,383 to 41,144 tons, with greater uncertainty for maize. The production-to-demand ratio indicated that rice production exceeded estimated demand, whereas maize production remained below estimated demand throughout the forecast period. These findings indicate that production forecasts should be interpreted alongside food demand, as increasing production does not necessarily eliminate commodity-specific deficits. Therefore, regional food security policies should maintain rice production while strengthening maize productivity and production capacity to reduce the projected maize deficit.

Key Messages:

- The novelty of this study lies in the comparative evaluation of ARIMA model performance across commodities and its integration with food demand analysis.
- The ARIMA model provides a stronger statistical representation for rice but is more limited in capturing the dynamics of maize production.
- Production-to-demand balance across commodities provides important insights into regional food security; therefore, forecasting results can support evidence-based policy planning.

GRAPHICAL ABSTRACT



INTRODUCTION

Food security is a strategic issue in regional development, particularly in areas experiencing rapid population growth and dynamic demographic pressures. Population growth directly increases food demand, making production availability a key factor in maintaining the balance between supply and demand. Previous studies have shown that imbalances between food production and demand can affect the stability of food security, especially in regions with high growth rates (1–3). In this context, rice and maize were selected because they are strategic food commodities with complementary roles in regional food systems. Rice is the primary staple food, while maize contributes to food diversification and the livestock sector. Their contrasting production characteristics also provide an opportunity to evaluate forecasting performance under different production dynamics (3).

Kutai Kartanegara Regency, as one of the supporting regions for the development of the Nusantara Capital City (IKN), faces significant population growth dynamics. The population increased from approximately 626 thousand in 2010 to nearly 750 thousand in 2024, with an annual growth rate of around 1.53%. This increase may intensify pressure on food availability, necessitating more targeted efforts to ensure that food production can sustainably meet the needs of the population (4,5).

On the other hand, food production in Kutai Kartanegara Regency shows an increasing trend, although with different patterns across commodities. Rice production has increased significantly, while maize production has also grown but on a smaller scale. Despite these positive trends, such increases do not necessarily guarantee that food demand will be optimally met. Differences in growth dynamics between commodities indicate the potential for imbalances between production and demand, which may ultimately affect regional food security conditions (1,2,6).

To better understand these dynamics, time-series forecasting approaches have been widely applied. Among these, the Autoregressive Integrated Moving Average (ARIMA) model was selected because it is a well-established method for forecasting univariate time-series data and effectively captures temporal patterns using historical observations without requiring additional explanatory variables. This characteristic makes ARIMA particularly suitable for regional agricultural production data, where long-term and consistent explanatory variables are often limited. The ARIMA model remains a commonly used method due to its ability to capture trends and fluctuations in data. Several studies indicate that ARIMA continues to be relevant for forecasting

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agricultural commodities, including rice and maize (1,7). However, recent developments in forecasting methods show that machine learning approaches and hybrid models are increasingly being adopted to improve prediction accuracy (8). This suggests that ARIMA performance may vary depending on the characteristics of the data being analysed (9,10).

Nevertheless, most previous studies have focused on forecasting either production or food demand separately and often at broader scales. Studies that comparatively evaluate forecasting model performance across commodities at the regional level remain limited. Furthermore, the integration of production forecasting results with food demand analysis within the context of regional food security has not been widely explored. Such integration is essential to ensure that forecasting outcomes can effectively inform more accurate and evidence-based policymaking (11).

Addressing these gaps, this study applies the ARIMA approach to forecast two key food commodities, rice and maize, which exhibit different production characteristics at the regional level. The novelty of this study lies in the comparative evaluation of ARIMA forecasting performance across rice and maize production series, rather than in comparing different forecasting methods. In addition, the forecasting results are integrated with food demand analysis using the production-to-demand ratio, thereby providing a more comprehensive understanding of the implications of production forecasting for regional food security. This approach highlights the applicability of the ARIMA model under different commodity production dynamics and its relevance in supporting data-driven policymaking.

Accordingly, this study aims to apply the ARIMA model to forecast rice and maize production in Kutai Kartanegara Regency, to conduct a comparative evaluation of ARIMA forecasting performance across the rice and maize production series, and to analyse the implications of the forecasting results for regional food security using the production-to-demand ratio.

METHODS

This study employed a quantitative approach using time-series analysis to model and forecast food production, as well as to evaluate model performance. In addition, the forecasting results were interpreted to assess their implications for regional food security.

Data and Variables

The data used in this study were secondary aggregated data obtained from official publications of the Indonesian Central Statistics Agency (BPS). The analysis was conducted for a single study area, Kutai Kartanegara Regency, using annual time-series data from 2010 to 2024 (15 observations). The variables included rice production (tons), maize production (tons), total population (persons), and per capita rice consumption (kg/capita/year). Rice and maize production were the main variables, while population and per capita rice consumption were used to estimate food demand.

Analytical Framework

The analysis followed the Box–Jenkins procedure, including model identification, parameter estimation, diagnostic testing, and forecasting. Stationarity was assessed using the Augmented Dickey–Fuller (ADF) test, where the null hypothesis (H_0) stated that the series contained a unit root (non-stationary) and the alternative hypothesis (H_1) stated that the series was stationary. First-order differencing was applied until stationarity was achieved ($d = 1$) before model identification and estimation.

Candidate ARIMA models were identified using the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF). Model selection was performed sequentially by first comparing the Akaike Information Criterion (AIC), followed by evaluating parameter significance and residual diagnostics using the Ljung–Box test. The final model was required to have the lowest AIC, statistically significant parameters, and residuals satisfying the white noise assumption. Based on these criteria, ARIMA(0,1,1) was selected for both commodities.

$$\varphi(B)(1 - B)^d Y_t = \theta(B)\varepsilon_t$$

For the ARIMA(0,1,1) model, the equation becomes:

$$(1 - B)Y_t = (1 + \theta_1 B)\varepsilon_t$$

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Model parameters were estimated using the Conditional Least Squares method. Candidate models were evaluated sequentially based on the Akaike Information Criterion (AIC), parameter significance (t-test), and residual diagnostic testing using the Ljung–Box test. The final model was required to have the lowest AIC, statistically significant parameters, and residuals satisfying the white noise assumption. No data transformation was applied because the variance of the time series was considered sufficiently stable. The selected model was then used to forecast rice and maize production for the 2025–2028 period.

Analysis of Food Security Implications

The implications for food security were analysed using the ratio of production to food demand, formulated as:

$$\text{Ratio} = \text{Production} / \text{Demand}$$

A ratio > 1 indicates a surplus condition, = 1 indicates equilibrium, and < 1 indicates a deficit.

Software

All analyses were conducted using SAS OnDemand for Academics (SAS Institute Inc., Cary, NC, USA) for statistical testing, model development, evaluation, and forecasting.

RESULTS

Production Data Patterns

The analysis indicates that rice and maize production in Kutai Kartanegara Regency during the 2010–2024 period exhibited an overall increasing trend. Rice production ranged from 213,050 tons to 319,452 tons, while maize production ranged from 18,294 tons to 36,275 tons. This pattern suggests the presence of a long-term trend, indicating that the data in its original form did not satisfy the stationarity assumption.

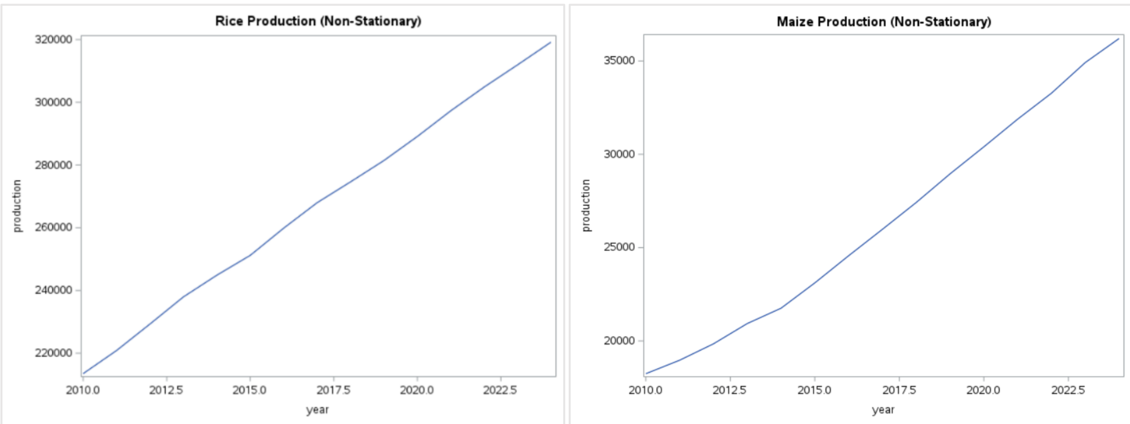

Figure 1. Trends in rice and maize production (2010–2024)

Stationarity Test

The Augmented Dickey–Fuller (ADF) test results show that, at the level form, both rice and maize production data were non-stationary ($p > 0.05$). After first-order differencing ($d = 1$), both variables became stationary, with statistically significant probability values ($p < 0.05$). This indicates that the differencing process successfully removed the trend component, making the data suitable for ARIMA modelling.

Model Identification and Estimation

Model identification was conducted using the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) after differencing. The ACF exhibited a cut-off at lag 1, while the PACF showed a tailing-off pattern, indicating that ARIMA(0,1,1) was the appropriate model for both commodities.

Parameter estimation results show that, for rice production, the MA(1) parameter was −0.77192 and statistically significant ($p < 0.05$), indicating that random fluctuations from the previous period contribute to explaining the current production series. In contrast, for maize production, the MA(1) parameter was −0.50211 and not statistically significant ($p > 0.05$), suggesting that the MA(1) component provides limited explanatory power for the temporal dynamics of maize production and reflects greater uncertainty in the model.

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Model ARIMA

For clarity, the ARIMA model estimation results for both commodities are presented in Table 1.

Table 1. ARIMA Model Estimates

Commodity	Model	MA(1)	p-value	AIC
Rice	ARIMA(0,1,1)	-0.77192	<0.05	224.73
Maize	ARIMA(0,1,1)	-0.50211	>0.05	197.39

Model Diagnostic Test

Diagnostic test results indicate that the residuals of the rice model generally did not exhibit significant autocorrelation, although minor indications were observed at certain lags. Nevertheless, the model can still be considered to satisfy the white noise assumption.

For the maize model, the Ljung–Box test indicated no significant autocorrelation in the residuals, suggesting that the residuals satisfy the white noise assumption. However, the non-significant MA(1) parameter indicates that the moving average component contributes only weakly to explaining the temporal dynamics of maize production. Therefore, although the model satisfies the residual diagnostic requirements, its forecasting performance should be interpreted with caution.

Model Performance Evaluation

The evaluation results indicate that the ARIMA model for rice production has statistically significant parameters and satisfies the residual diagnostic tests, suggesting that it provides an acceptable statistical representation of the observed time series. In contrast, the maize model has a non-significant MA(1) parameter, indicating greater uncertainty in the estimated model despite satisfying the residual diagnostic requirements. These findings suggest that the statistical adequacy of the rice model is stronger than that of the maize model, although the forecasting results for both commodities should be interpreted with appropriate caution.

Production Forecast Results

Based on the selected ARIMA model, the point forecasts for the 2025–2028 period indicate an overall increasing trend in the production of both rice and maize. Rice production is estimated to increase from 326,651 tons in 2025 to 349,003 tons in 2028, while maize production is projected to increase from 37,383 tons to 41,144 tons over the same period. However, these point forecasts should be interpreted together with their prediction intervals. The relatively narrow prediction intervals for rice indicate greater forecast precision, whereas the substantially wider intervals for maize reflect higher forecast uncertainty. Therefore, although both commodities are projected to exhibit increasing production trends, the future trajectory of maize production should be interpreted with greater caution.

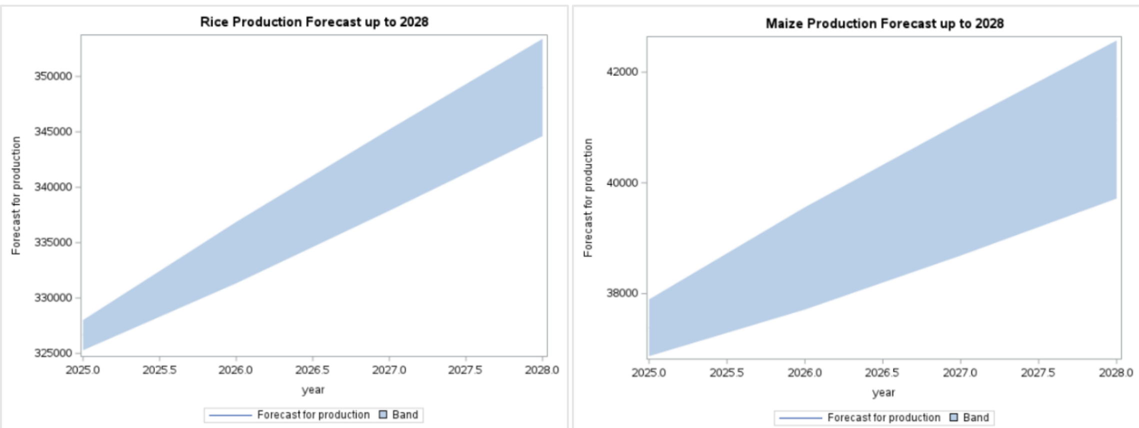

Figure 2. Forecast of rice and maize production (with confidence intervals)

Production-to-Demand Ratio

The implications for food security were assessed using the production-to-demand ratio. Annual food demand was estimated based on observed per capita rice consumption reported by the Indonesian Central Statistics Agency (BPS), rather than dietary recommendations or nutritional requirements. Specifically, estimated

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annual demand was calculated by multiplying the total population by the annual per capita rice consumption (kg/capita/year). To ensure consistency between production and demand, the estimated annual demand was converted from kilograms to tons before calculating the production-to-demand ratio. Consequently, both production and estimated demand were expressed in tons per year. The production-to-demand ratio was calculated as follows:

Production-to-demand ratio = Annual production (tons) / Estimated annual demand (tons)

where estimated annual demand (tons) = Total population × Per capita consumption (kg/capita/year) ÷ 1,000.

A production-to-demand ratio greater than 1 indicates that annual production exceeded the estimated annual demand, a ratio equal to 1 indicates that production and estimated demand were approximately balanced, and a ratio less than 1 indicates that annual production was lower than the estimated annual demand. The ratio was used as an indicator of the relationship between production and estimated demand and should not be interpreted as a comprehensive measure of regional food availability or food security.

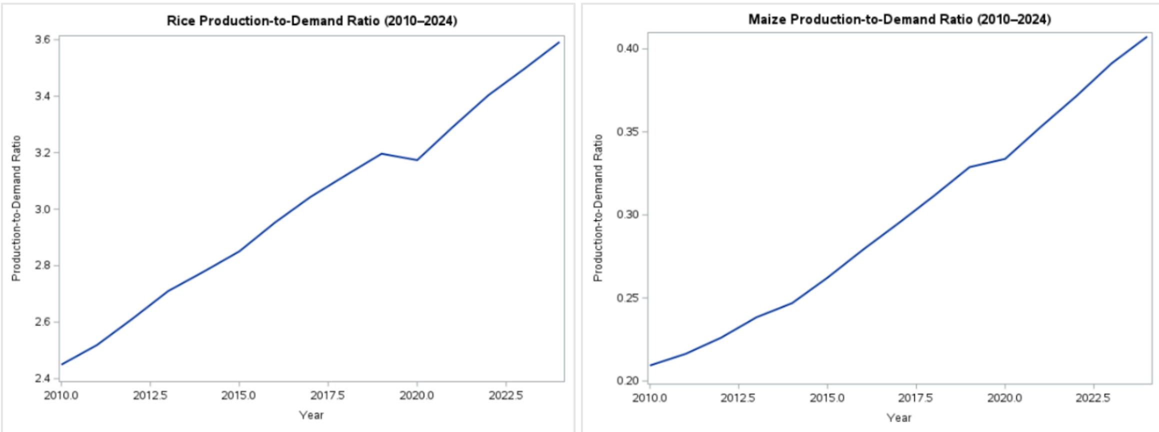

Figure 3. Production-to-demand ratio for rice and maize

DISCUSSION

The increasing production trends of rice and maize in Kutai Kartanegara Regency suggest that agricultural production has been influenced by long-term structural changes rather than short-term fluctuations. Rice production exhibited a more stable upward trend, likely reflecting its strategic role as Indonesia's staple food and the sustained implementation of government support programs, including irrigation improvement, production intensification, and input assistance. In contrast, maize production showed greater temporal variability, which may be associated with fluctuations in cultivated area, farmer planting decisions, market conditions, and climatic variability. Similar differences in production dynamics between staple crops have been reported in previous studies, indicating that cereal commodities respond differently to economic and environmental drivers (12,13).

From a modelling perspective, these long-term trends explain the non-stationary behaviour observed in the original series and justify the use of differencing before ARIMA estimation. Understanding these commodity-specific dynamics is also important for selecting appropriate forecasting models and developing targeted food security policies, as production stability and growth determinants differ between rice and maize.

The selection of the ARIMA (0,1,1) model for both commodities suggests that the production series are better represented by a moving average component than by an autoregressive component. Within the Box–Jenkins framework, ARIMA models are effective in capturing linear patterns in stationary time-series data (14,15). For rice, the statistically significant MA(1) parameter indicates that the current production series is associated with random disturbances (forecast errors) from the previous period captured by the moving average component. This finding suggests that incorporating the MA(1) component improves the statistical representation of the temporal dependence in the rice production series, rather than providing evidence that the production system itself is more stable or better controlled.

In contrast, for maize, the non-significant MA(1) parameter indicates greater uncertainty in the estimated

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model and suggests that the linear ARIMA approach provides a weaker statistical representation of the maize production series than that of rice. These results indicate that additional sources of variability may influence the maize production series, although these factors were not examined in the present study. Therefore, the forecasting results for maize should be interpreted with appropriate caution (16,10).

These differences highlight that data stability is a key factor in ARIMA model performance. The model is more suitable for relatively stable data, such as rice production, compared to highly volatile data such as maize. Under such conditions, linear ARIMA approaches become less optimal, and alternative methods capable of accommodating nonlinear patterns such as hybrid or machine learning-based models are required (10).

Forecast results indicate that production of both commodities is projected to increase through 2028. However, longer forecasting horizons are associated with increased uncertainty, as reflected by widening confidence intervals, particularly for maize. This phenomenon is a common characteristic of time-series models, where prediction uncertainty increases as the forecast horizon extends (17).

When linked to the production-to-demand ratio, rice production consistently exceeded the estimated annual demand, reinforcing its role as a key commodity in supporting regional food security. This finding suggests that rice production is generally sufficient to meet the estimated demand and may contribute to strengthening regional food availability, particularly in the context of supporting the Nusantara Capital City. In contrast, the projections indicate a persistent production–demand gap for maize, with estimated production remaining below the estimated annual demand throughout the forecast period. Although maize production is projected to increase, the projected growth is insufficient to close the production–demand gap. These findings suggest that strengthening food security requires not only increasing agricultural production but also improving the balance between production and estimated demand across different commodities (3,18).

The forecast results should be interpreted as model-based estimates rather than deterministic values. As with any time-series forecasting model, uncertainty is inherent in future projections and generally increases with longer forecast horizons. Therefore, the projected production-to-demand relationships should be interpreted with appropriate caution and regarded as indicative scenarios for planning rather than precise predictions of future production or food security conditions.

Overall, this study demonstrates that integrating production forecasting with production-to-demand analysis provides a more comprehensive understanding of regional food security conditions. The findings suggest that maintaining rice production should remain a priority to ensure that production continues to meet the estimated annual demand. In contrast, the projected production–demand gap for maize highlights the need for policies aimed at improving maize productivity and strengthening production capacity. In addition, regular monitoring of agricultural production and estimated food demand is essential to support timely planning and policy adjustments. Scenario-based production and demand assessments may also assist local governments in anticipating future food supply challenges, particularly in strategic regions such as Kutai Kartanegara Regency.

This study has several limitations. First, the analysis used annual time-series data, resulting in a limited number of observations for ARIMA model estimation. Second, forecasts for 2025–2028 are subject to increasing uncertainty over longer horizons and assume that historical production patterns will continue; therefore, they should be interpreted as model-based estimates rather than deterministic predictions. Third, the ARIMA model does not account for structural changes, such as those associated with the development of the Nusantara Capital City, that may alter future production and demand patterns. Fourth, the food security assessment was based on the production-to-demand ratio using estimated demand derived from observed per capita consumption and did not consider food stocks, interregional trade, imports, exports, post-harvest losses, or food distribution. Finally, only the ARIMA approach was applied without comparison to alternative forecasting methods. Future studies should evaluate multiple forecasting approaches, including hybrid and machine learning models, to identify the most suitable method for each commodity and improve forecasting performance.

CONCLUSION

This study demonstrates that ARIMA is an effective approach for forecasting regional food production, although forecasting performance varies across commodities due to differences in production dynamics. The findings highlight that production forecasts should be interpreted alongside food demand, as increasing production does not necessarily eliminate commodity-specific deficits. Scientifically, this study provides evidence that commodity-specific forecasting is essential for understanding regional food security. Methodologically, it

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demonstrates the integration of ARIMA-based forecasting with production-to-demand ratio analysis as a practical framework for assessing food security at the regional level. These findings support evidence-based policies that strengthen production and improve the availability of deficit commodities, particularly maize, to enhance sustainable food security in regions supporting the Nusantara Capital City.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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