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MODELLING OF FOOD SECURITY IN BENGKULU PROVINCE USING MULTIPLE LINEAR REGRESSION AND ROBUST REGRESSION ANALYSES WITH M-ESTIMATION

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Abstract. This paper aims to evaluate the state of food security in Bengkulu Province in 2022, analyse the factors influencing food security, and identify the optimal food security model for Bengkulu Province. This study employs multiple linear and robust regression analyses using M-estimation. This study yields both qualitative and quantitative data analyses. The qualitative data analysis includes descriptive statistics of rice harvest area, rice productivity, rice prices, and rice consumption in Bengkulu Province in 2022. The quantitative data analysis involves the food security modelling for Bengkulu Province. The study's findings reveal that, based on the food ratio calculated from the ratio of rice productivity to rice consumption, Bengkulu Province's food security in 2022 is at a level of security but is vulnerable. Partial parameter testing indicates that the area of rice harvest (X_1), rice production (X_2), rice price (X_3), and the amount of rice consumption (X_4) significantly affect food security in Bengkulu Province. Outliers in the data are addressed using robust regression with M-estimation, applying weights to the residuals. The best food security model was achieved using Huber weighting, resulting in the equation: $\hat{y} = 1161.47 + 0.06X_1 + 38.74X_2 + 0.04X_3 - 0.75X_4$. This new food security model in Bengkulu Province is the main contribution of this paper.

2020 Mathematics Subject Classification. 62J05; 62K25.

Key words and phrases. food security model; multiple linear regression; robust regression; M-estimation; Huber; Tukey bisquare.

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1. Introduction

According to the World Food Programme, Indonesia is a Southeast Asian nation categorized as lower-middle-class. Despite significant progress towards eliminating hunger, the country faces challenges including inadequate food access, malnutrition, gender inequality, climate change, and susceptibility to natural disasters. The COVID-19 pandemic has worsened these issues, impeding progress in reducing poverty and food insecurity. In 2020, the national poverty rate climbed to 10%, delaying the country's development by three years. Similarly, malnutrition prevalence, which had decreased to 7% in 2019, increased to 8% after the pandemic [1].

Bengkulu Province, located west of the Bukit Barisan mountains, covers approximately 1,991,933 ha (hectares) or 19,919.33 km^2. Of this, 2.78% (55,705 ha) are rice fields, while the remaining 97.2% (1,936,228 ha) are not. Bengkulu Province is the second smallest province in Sumatra and ranks 27th in Indonesia, with a population of 2,010,670 and a projected growth rate of 1.55% over the next ten years [2]. The province comprises ten cities/regencies, significantly impacting food demand.

In 2021, the energy consumption per capita at Bengkulu Province was 3,254 kcal/day, exceeding the recommended energy adequacy rate of 2,400 kcal/day. Protein consumption was 122 grams/day, surpassing the standard of 63 grams/day. However, the food diversity score was 86.52, below the ideal of 100. The availability of rice, tubers, nuts, and oily seed fruits was below standard, with some areas at Bengkulu Utara, Bengkulu Tengah, Rejang Lebong, Kepahiang, and Muko Muko identified as vulnerable to food insecurity [3].

Bengkulu Province is prone to natural disasters, such as floods and landslides. In 2019, 14 floods negatively impacted rice production [2]. The population's high rice consumption and the belief that a meal is incomplete without rice are deeply ingrained. Additionally, Bengkulu Province is earthquake-prone, with 30 earthquakes reported from August 7 to September 9, 2022 [4].

Food is a fundamental human need, and the 1945 Constitution guarantees it is essential for producing quality human resources. Law No. 18 of 2012 mandates that the state ensures every household's food needs are met, emphasizing sufficient, accessible, varied, healthy, nutritious, and culturally acceptable food [5]. This regulation addresses food security issues, necessitating a study of factors influencing food security. Local food resources, such as rice production, land area, and consumption levels, are critical for food security in different regions of Bengkulu Province. Government Regulation No. 68 of 2002 highlights the importance of clear information on food supply as a food security indicator.

An evaluation system, the Food Security Index, has been established to assess an area's food security and its components. The Ministry of Agriculture's Food Security Agency updated the index to provide comprehensive data at the district/city and provincial levels [6]. [7] noted that rice is a key factor in Indonesia's food security, impacting the national food supply. [8] described food security through the ratio of rice productivity to consumption. [9] investigated the rice balance by comparing the value of rice production to consumption. These insights motivate further research on food security in Bengkulu Province.

This study will examine the food security condition in Bengkulu Province and identify the influencing factors. Regression analysis, a statistical method for assessing relationships between variables, will be the primary analytical tool [10]. Assumptions for causal regression analysis must be tested. [11] highlighted M-Estimation as a robust regression method for its thorough results.

Several studies have used regression analysis to model food security. [10] modelled food security in Bantul using multiple linear regression and logistic regression on rice production data. [12] used a Multivariate Adaptive Regression Spline to model factors affecting Indonesia's Food Security Index. [13] applied panel data regression to predict rice availability in Bojonegoro. [14] used Probit Orbital Regression to model factors affecting food security in Indonesian cities and districts using the Food Security Index in 2018. However, very limited research has been found modelling food security in Bengkulu Province. Therefore, this study aims to evaluate the food security condition in Bengkulu Province in 2022, identify influencing factors, and determine the best food security model for Bengkulu Province.

2. Methodology

This study is a quantitative research project employing multiple linear regression analysis and robust regression analysis with M-estimation. Combining multiple linear regression and robust regression with M-estimation can construct a well-rounded and accurate model of food security in Bengkulu Province. Multiple linear regression provides a clear understanding of the relationships and impacts of various factors, while robust regression ensures that these findings are reliable and unaffected by data anomalies. This dual approach ultimately leads to more effective policy recommendations and strategies for improving food security in Bengkulu Province.

The data used are secondary data sourced from the central bureau of statistics, the agriculture offices, and the logistics affairs agencies in Bengkulu Province. The data collected include information on the area of the rice harvest, productivity, price, and the amount of rice consumption in 2022 across 10 cities/regencies in Bengkulu Province: Muko Muko, Lebong, Bengkulu Utara, Rejang Lebong, Bengkulu Tengah, Kepahiang, Kota Bengkulu, Seluma, Bengkulu Selatan, and Kaur.

This study includes one dependent variable and four independent variables. The dependent variable (Y) is the ratio of rice availability at Bengkulu Province, while the independent variables are the area of rice harvest (X_1), rice production (X_2), rice price (X_3), and amount of rice consumption (X_4). The collected data were analysed using multiple linear regression analysis to develop a model that illustrates the relationship between the area of harvest, rice productivity, rice price, and the amount of rice consumption to the rice availability ratio [10,12]. Subsequently, classical assumption tests were conducted, including tests for multicollinearity, homoscedasticity, autocorrelation, and normality. The multicollinearity test was performed using the variance inflation factor test, the homoscedasticity test with the Glejser test, the autocorrelation test with the Durbin-Watson test, and the normality test using the Kolmogorov-Smirnov test [15, 16].

After fulfilling all assumptions in the multiple regression analysis, the data were checked for outliers. The presence of outliers can reduce the precision of regression parameter estimators, making their identification crucial. Robust regression analysis was used for this purpose. To obtain the best food security model, this study employed robust regression analysis with the M-IRLS estimation method, utilizing Huber and Tukey bisquare weightings.

3. Results and Discussion

This section presents the statistical analysis results of both qualitative and quantitative data. First, the qualitative data, including the area of rice harvest, rice production, rice price, and the amount of rice consumption in Bengkulu Province in 2022, are described. Then, the quantitative data on these same variables are modelled using multiple linear regression analysis. Finally, robust regression analysis is performed to obtain the best food security model for Bengkulu Province.

3.1. **Descriptive Statistics.**

3.1.1. *Area of Rice Harvest in Bengkulu Province in 2022.*

Figure 1 shows that the two areas with the highest rice harvest areas are Seluma, with 10,750 ha, and Bengkulu Selatan, with 10,625 ha. Seluma's large harvest area is attributed to it comprising 6.2% of Bengkulu Province's total area. Conversely, the area with the lowest harvest area is Kota Bengkulu, at 1,191 ha. This is due to Kota Bengkulu having the highest population density in the province, with 371,828 people per km^2.

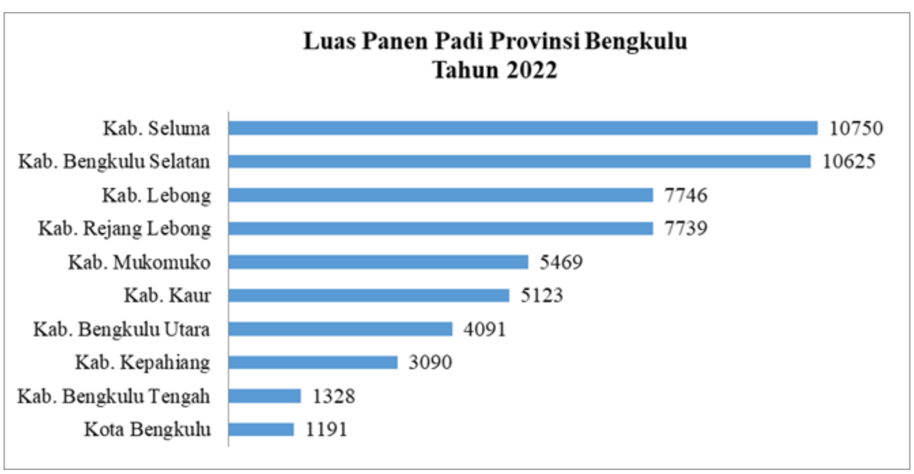

Figure 1. Bar graph of area of rice harvest in Bengkulu Province in 2022.

3.1.2. *Rice Production in Bengkulu Province in 2022.*

The differences in rice productivity across Bengkulu Province are not very pronounced. Figure 2 shows that Lebong has the highest rice productivity at 29,093 kW/ha, indicating that Lebong has effectively maximized production from its available land. In 2021, Lebong contributed 6.7% to Bengkulu Province's food supply, justifying its status as a key food buffer area in the province. Although Kota Bengkulu has the smallest harvest area, as shown in Figure 1, it achieves a higher productivity of 3,346 kW/ha compared to Bengkulu Tengah, which has the lowest productivity in 2022. Despite this, Kota Bengkulu's productivity has generally increased over the years, though it saw a decline in 2022 due to extreme weather conditions.

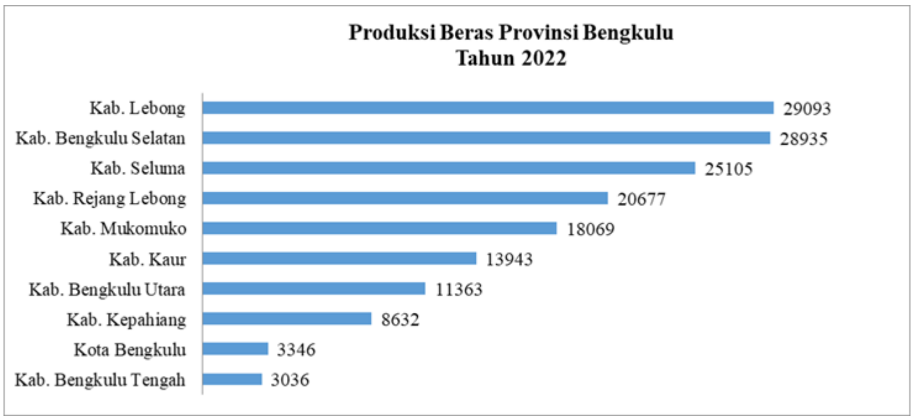

Figure 2. Bar graph of rice production in Bengkulu Province in 2022.

3.1.3. *Rice Price in Bengkulu Province in 2022.*

The price of rice remains highly susceptible to market fluctuations. During harvest periods, prices can drop significantly due to overproduction, forcing farmers to sell at low prices since rice is perishable and cannot be stored indefinitely. To mitigate these fluctuations and ensure households can meet their food needs, as stipulated in PP RI No. 68 of 2002 concerning Food Security Article 12, the government regulates rice prices. This regulation is implemented through the Regional Division Bulog, which purchases grain from farmers before prices fall below the Government Purchase Price, thereby protecting farmers from severe financial losses. The average rice price in Bengkulu Province is Rp 11,710/kg. Figure 3 shows that some regions have rice selling prices below this average, indicated by orange and yellow colours. Bengkulu Selatan sells rice at the lowest price of Rp 11,250/kg, while Kota Bengkulu has the highest price at Rp 12,300/kg, followed by Bengkulu Tengah at Rp 12,000/kg. This variation in prices can be linked to the harvest area conditions in Bengkulu Tengah.

3.1.4. *Rice Consumption in Bengkulu Province in 2022.*

Rice remains an irreplaceable staple food. Despite government efforts to reduce high rice consumption patterns, they have been unsuccessful. The belief that "if you haven't eaten rice, you haven't eaten" is deeply ingrained among the residents of Bengkulu Province. If this trend continues, there is a concern

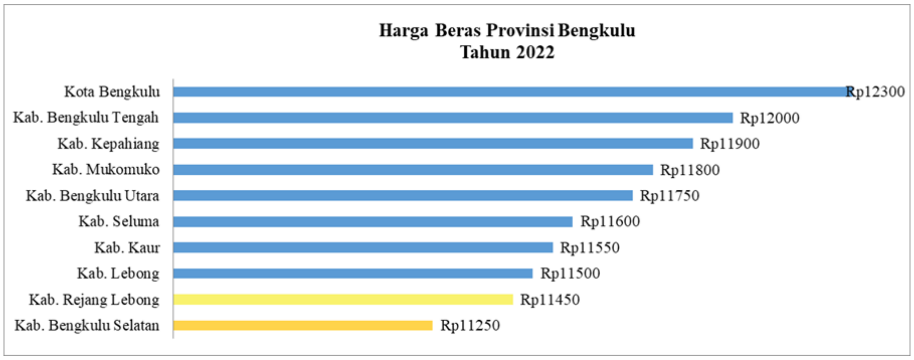

FIGURE 3. Bar graph of rice price in Bengkulu Province in 2022.

that rice production may fall short of consumer demand, echoing the Malthusian Theory. Figure 4 illustrates that in 2022, Kota Bengkulu had the highest rice consumption at 37,140.13 tons. The graph shows only slight differences in rice consumption among other regions. Notably, Lebong had the lowest rice consumption in 2022, at 11,401 tons. This low consumption, combined with high productivity, makes Lebong a crucial support area for food security in Bengkulu Province.

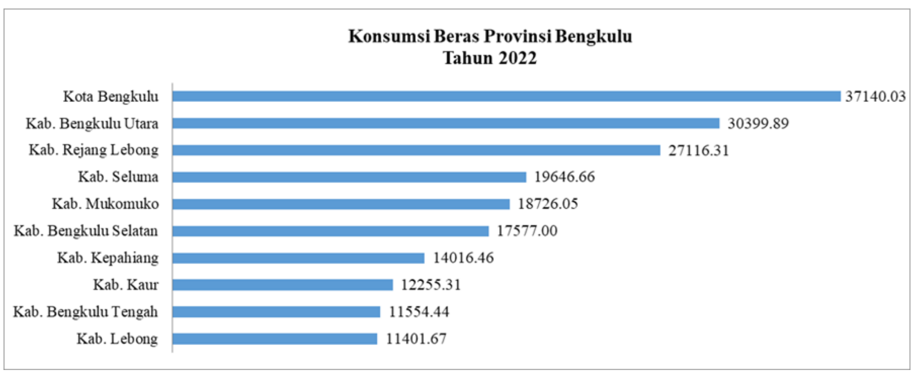

FIGURE 4. Bar graph of rice consumption in Bengkulu Province in 2022.

Food security in Bengkulu Province in 2022 is assessed using the food ratio, which compares rice productivity to rice consumption. Figures 2 and 4 show that in 2022, Bengkulu Province produced 162,197 tons of rice, while consumption reached 199,833.82 tons. This results in a food ratio of 0.8, indicating that Bengkulu Province's food security is classified as "food secure but vulnerable." This level of food security signifies that food availability has not surpassed the safe threshold. Consequently, any natural disaster causing a drop in food production could immediately compromise or destabilize food security.

3.2. **Multiple Linear Regression Analysis.**

This study used the Minitab software to perform the multiple linear regression analysis on the quantitative data of area of rice harvest, rice production, rice price, and the amount of rice consumption in

Bengkulu Province in 2022. Table 1 shows the summary of ordinary least squares (OLS) regression model of food security in Bengkulu Province in 2022.

Table 1. Summary of OLS regression model.

Term	Estimate	Error	t-value	p-value
X_1	0.0585	0.0023	25.892	<2e-16
X_2	31.963	11.930	2.680	0.0118
X_3	-0.0204	0.1446	-0.141	0.8888
X_4	-0.8759	0.0927	-9.453	<2e-10

Based on Table 1, the initial model derived from the OLS method is

$$\hat{y} = 2669.00 + 0.06X_1 + 31.96X_2 - 0.02X_3 - 0.88X_4. \tag{1}$$

Equation 1 represents a stochastic model, which can have prediction errors. In this model, the dependent variable cannot be predicted with absolute certainty by the independent variables, due to the presence of residual factors or confounding variables, denoted by ϵ. To ensure the validity, reliability, and interpretability of the model shown in Equation 1, this study performs classical assumption tests such as multicollinearity test, homoscedasticity test, autocorrelation test, normality test, and outlier identification.

3.2.1. *Classical Assumption Test.*

A. Multicollinearity test

Good regression models have predictor variables that are independent or uncorrelated. The Variance Inflation Factor (VIF) is used as a criterion to detect multicollinearity when more than two independent variables are involved. VIF values are the main diagonal elements of the inverse correlation matrix. A VIF value greater than 10 indicates a serious multicollinearity problem. Based on the test results, the VIF values are shown in Table 2.

Table 2. Multicollinearity test results.

Term	Estimate
X_1	1.205518
X_2	1.121076
X_3	1.319796
X_4	1.166860

Table 2 indicates that all variables have VIF values well below the threshold of 10, suggesting no serious multicollinearity issues.

B. Homoscedasticity test

The homoscedasticity test aims to examine the variance of residual values. In a good regression model, the residual values should have constant variance, known as homoscedasticity. To determine the presence or absence of heteroscedasticity, the Glejser test was performed with the following hypotheses:

H_0: No heteroscedasticity problem occurs.

H_1: A heteroscedasticity problem occurs.

Table 3. Homoscedasticity test results.

Test	Test value	p-value
Global Stat	15.53	0.003712
Skewness	5.213	0.022415
Kurtosis	6.481	0.010905
Link Function	3.840	0.050053
Heteroscedasticity	0.0005169	0.981861

Based on Table 3, a p-value of 0.981 was obtained. Since this p-value is greater than 0.05, we fail to reject H_0. This indicates that heteroscedasticity is not present in this model.

C. Autocorrelation test

The autocorrelation test aims to determine if there is a linear relationship between e_i and e_{i-1}. The Durbin-Watson test is used for this purpose. Ideally, the autocorrelation assumption should not be met. If the value of d is between -2 and +2, there is no autocorrelation. The hypotheses for this test are:

H_0: $\rho = 0$ (No autocorrelation)

H_1: $\rho \neq 0$ (Autocorrelation present)

Table 4. Autocorrelation test results.

Test	d-value	p-value
Durbin-Watson	1.125	0.003712

Based on Table 4, the computed statistical value for the test is d=1.125. Given that the Durbin-Watson value of 1.125 falls within the range of -2 to +2, it indicates that there is no autocorrelation among the residuals.

D. Normality test

A well-performing regression model is characterized by normally distributed residual values. The normality test employs the Kolmogorov-Smirnov Test to assess whether the residuals follow a normal distribution. The hypothesis for this test is as follows:

H_0: Residuals are normally distributed.

H_1: Residuals are not normally distributed.

Table 5. Normality test results.

Test	Test value	p-value
Kolmogorov-Smirnov	0.1145	0.2915

Based on Table 5, the obtained p-value of 0.2915 is greater than $\alpha = 0.05$, failing to reject H_0. Therefore, it can be concluded that the residuals follow a normal distribution.

3.2.2. *Outlier Identification.*

In this study, the Leverage Method was employed for outlier identification. Outliers were detected using a cutoff value calculated as

$$\frac{2p}{n} = \frac{2(4)}{10} = 0.08, \tag{2}$$

where p represents the number of predictors and n represents the sample size. Any h_{ii} values exceeding the cutoff value were flagged as outliers, see Table 6.

Table 6. Leverage values.

No.	h_{ii}
1	0.8564
2	0.0564
3	0.0558
4	0.1599
5	0.0955
6	0.8679
7	0.0857
8	0.0781
9	0.0683
10	0.2436

According to Table 6, the data points with h_{ii} values exceeding the cutoff value are the 1st and 6th data points. Removing an outlier solely based on statistical grounds may not be advisable, as outliers can often carry valuable information. Therefore, it is important to conduct additional analysis using robust methods that can handle outliers effectively. This approach will lead to more accurate and efficient regression results.

3.3. **Robust Regression Analysis.**

The M-estimation technique necessitates multiple iterations for optimal model refinement. This particular approach, known as M-IRLS estimation, employs two types of weights: Huber weights and Tukey bisquare weights. The estimation process is conducted using Minitab software, and iterations continue until a convergent model is achieved. Details of these iterations are provided in Table 7.

TABLE 7. Iteration results of parameter estimation using Huber function.

Iteration	β_0	β_1	β_2	β_3	β_4
OLS	2669.00	0.06	31.96	-0.02	-0.88
1	1745.55	0.06	38.03	0.01	-0.80
2	1359.26	0.06	39.72	0.02	-0.77
3	1247.99	0.06	39.55	0.03	-0.76
4	1212.03	0.06	38.93	0.04	-0.76
5	1184.64	0.06	38.84	0.04	-0.76
6	1172.60	0.06	38.78	0.04	-0.75
7	1166.66	0.06	38.76	0.04	-0.75
8	1163.81	0.06	38.75	0.04	-0.75
9	1162.44	0.06	38.75	0.04	-0.75
10	1161.78	0.06	38.74	0.04	-0.75

From Table 7, it is evident that the Huber weighting function converged in the 10th iteration, resulting in the best equation using Huber weighting:

$$\hat{y} = 1161.78 + 0.06X_1 + 38.74X_2 - 0.04X_3 - 0.75X_4. \tag{3}$$

Like the Huber weight, the Tukey bisquare weighting also requires several iterations in the process. Table 8 illustrates the convergence of the Tukey bisquare weighting function by the 9th iteration, resulting in the best model obtained using Tukey bisquare weights as follows:

$$\hat{y} = 882.51 + 0.06X_1 + 40.69X_2 + 0.04X_3 - 0.71X_4. \tag{4}$$

3.4. **Best Food Security Model.**

A comparison was made between Huber weights and Tukey bisquare weights to determine the superior model based on the Mean Squared Error (MSE) values obtained from both weighting methods. A lower MSE value indicates a better estimator performance. The MSE values for both weightings are presented in Table 9.

TABLE 8. Iteration results of parameter estimation using Tukey bisquare function.

Iteration	β_0	β_1	β_2	β_3	β_4
OLS	2669.00	0.06	31.96	-0.02	-0.88
1	1745.55	0.06	38.03	0.01	-0.80
2	1359.26	0.06	39.72	0.02	-0.77
3	1247.99	0.06	39.55	0.03	-0.76
4	1212.03	0.06	38.93	0.04	-0.76
5	885.93	0.06	40.76	0.04	-0.71
6	884.41	0.06	40.72	0.04	-0.71
7	883.36	0.06	40.70	0.04	-0.71
8	882.82	0.06	40.69	0.04	-0.71
9	882.51	0.06	40.69	0.04	-0.71

TABLE 9. MSE values comparison.

Weighting	MSE value
Huber	130,021.10
Tukey bisquare	150,021.20

After reviewing the findings presented in Table 9, it was determined that Huber weights should be utilized due to their smaller MSE value compared to the MSE value obtained from Tukey bisquare weighting. The model is represented by Equation 3. Subsequently, overall tests and partial tests were conducted based on Equation 3.

3.4.1. *Overall Test.*

The overall test concurrently assesses all parameters within a regression model. The hypothesis for this test is as follows:

H_0: $\beta_0 = \beta_1 = \beta_2 = ... = \beta_k = 0$ (indicating the regression model is not suitable)

H_1: $\beta_j \neq 0, j = 1, 2, ..., k$ (indicating the regression model is suitable) By employing a significance level of 5% and utilizing weighted data, the overall test results are presented in the following Table 10.

TABLE 10. Overall test results.

Parameter	Estimated Value	Error	p-value	Decision
β_0	11.625	150.27	<1.4e-16	Reject H_0
β_1	0.049	0.001		
β_2	32.420	8.129		
β_3	0.130	0.049		
β_4	-0.612	0.052		

3.4.2. *Partial Test.*

Partial testing is conducted to assess the relationship between individual independent variables and the dependent variable. The hypothesis for this test is:

H_0: $\beta_j = 0, j = 0, 1, 2, ..., k$ (indicating an insignificant parameter in the model)

H_1: $\beta_j \neq 0$ (indicating a significant parameter in the model) The test results, based on a significance level of 5%, are depicted in Table 10, showcasing the constructed test statistics as presented in Table 11.

Table 11. Overall test results.

Parameter	$\|t\|$-value	t-critical	Decision
β_0	0.053	1.132	Do not reject H_0
β_1	29.873		Reject H_0
β_2	4.206		Reject H_0
β_3	2.334		Reject H_0
β_4	12.423		Reject H_0

The calculated $|t|$ values for all parameters exceed the corresponding critical values from the t-critical, leading to the rejection of H_0. This indicates that all these parameters hold significance within the model.

4. Conclusion

Food security remains a critical issue as it is a fundamental human right. The discussion concludes that, based on the food ratio calculated from the ratio of rice productivity to rice consumption, Bengkulu Province's food security in 2022 is secure but vulnerable or not guaranteed. The partial parameter test results indicate that the variables such as the area of rice harvest (X_1), rice production (X_2), rice price (X_3), and the amount of rice consumption (X_4) significantly affect Bengkulu Province's food security in 2022. Outliers in the data were addressed using robust regression with M-estimates by weighting the residuals. The best food security model was obtained using Huber weighting, resulting in the equation: $\hat{y} = 1161.47 + 0.06X_1 + 38.74X_2 + 0.04X_3 - 0.75X_4$. This new food security model in Bengkulu Province is the main contribution of this paper. To follow up on the results of this study, it is recommended that the government and the community focus on the identified variables affecting Bengkulu Province's food security to enhance it. Additionally, in line with government regulations, information on food security should be widely disseminated. The findings of this study can aid the government in educating the public on key factors that need attention to improve food security.

Authors' Contributions

All authors have read and approved the final version of the manuscript. The authors contributed equally to this work.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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