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Gender Dimensions of Food Security and Agricultural Productivity: A Regional Geography Analysis of West Jawa

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ABSTRACT

The interconnected dynamics of agricultural productivity and gender equity present complex challenges and opportunities for food security in agrarian regions. In Indonesia, West Java is a leading rice producer, yet food security disparities persist, highlighting the need to examine both production capacity and gender development. This study analyzes the impact of rice harvested area and the Gender Development Index (GDI) on food security across 27 districts/cities in West Java from 2018 to 2022. Using panel data and fixed-effects regression, the study evaluates both additive and interaction effects while controlling for GDP per capita, poverty, and population. The interaction model explains substantial variation (R^2 = 0.721). Rice harvested area (β = 0.024) and GDI (β = 30.874) each positively influence food security. The interaction term (β = 0.087) confirms that higher gender development strengthens the positive impact of agricultural production. Marginal analysis indicates that increases in rice production have stronger effects in high-GDI regions, where women have greater access to resources and economic opportunities. Conversely, poverty negatively affects food security (β = −0.281), limiting household access to food regardless of production levels. These findings suggest that uniform agricultural policies are insufficient. High-GDI regions should prioritize value-chain development and income diversification, while low-GDI regions require simultaneous investment in agricultural capacity and women's empowerment. Achieving equitable and sustainable food security requires integrated policies that balance agricultural development with gender equality.

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1. Introduction

Indonesia, as an agricultural country with a significant agricultural land area, has made food security one of its national development priorities. In this context, West Java holds a strategic position as one of the national rice granaries, contributing significantly to national rice production. However, despite this status, food security challenges persist in several areas, indicating disparities in food security distribution and access (Odoms-Young et al., 2024). Food security issues are not limited to production dimensions but are closely related to socioeconomic aspects of society, including gender dimensions (Mirzabaev et al., 2023). Food security is defined by Safitri & Suhartono, (2025) the Food and Agriculture Organization (FAO) as a condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2023). In Indonesia, the concept of food security is outlined in Law Number 18 of 2012 concerning Food, which emphasises food independence and food sovereignty as integral parts of national food security. Although food production, particularly rice, continues to increase, food security challenges at the consumption level remain an issue that needs to be addressed (Valentina et al., 2024).

harvested rice area is an important indicator for measuring the food production potential of a region. In West Java, with regional characteristics dominated by fertile highlands and lowlands, the rice-harvested area experiences dynamics from year to year. Factors such as climate change, agricultural land conversion, and infrastructure development policies affect fluctuations in the harvested rice area (Hamdiah & Robbaniyyah, 2025). Research conducted by shows that there is a correlation between the area of rice harvested and the level of food production and availability in a region. However, increased food production does not always correspond directly with improved food security at the household level.

The harvested area for rice is a crucial indicator for measuring food production and food security in a region. Effendi et al., (2025) demonstrated that harvested area is directly related to rice availability as a staple food source, which in turn affects the level of food security among the population. Explains that the harvested area of rice is positively correlated with national rice production, which forms the basis of food security in Asian countries, including Indonesia (Abdoellah et al., 2023). An increase in the harvested area will increase rice availability in the market, lower prices, and enhance food accessibility for poor households. Shobur et al., (2025) found that areas with higher harvested areas tended to have better food security levels because of improved local food availability.

In contrast, gender aspects in development have also become a global concern, including in Indonesia. The Gender Development Index (GDI) measures disparities in human development achievements between men and women in three basic dimensions: health, education, and standard of living. In the context of food security, the role of women is vital, especially in household food management and distribution (Mane, Macchioni, et al., 2025; Sibamenya et al., 2025). Dwomoh et al.'s (2023) and Tesafa et al.'s (2025) research shows that women's empowerment and gender equality are positively correlated with improved household food security. The GDI measures gender inequality in human development achievements, including health, education, and standard of living. A higher GDI indicates better gender equality, which has significant implications for household food consumption patterns (Tambunan et al., 2025). The (Food nd Agriculture Organization FAO, (2023) in its report, "The State of Food and Agriculture, " affirms that gender equality is key to reducing hunger and improving food security. Women play a central role in food production, processing, and distribution within households. When women have equal access to education, health, and economic resources (reflected in a high GDI), they are better able to make improved food decisions and allocate household resources for adequate nutrition (Fikre & Tsige, 2025; Kyeremateng et al., 2024; Tantoh et al., 2025).

Several previous studies have examined the relationship between food security and gender aspects (Wei et al., 2026). For example, Koller et al. (2022) explain that gender inequality in access to productive resources, such as land and credit, impacts food production and household food security. Meanwhile, Antriyandarti et al. (2024) emphasise that women's empowerment in agriculture can improve the efficiency of food production and distribution. However, research that explicitly analyzes the relationship between food security, harvested rice area, and the Gender Development Index is limited, especially in West Java. The interaction between the harvested rice area and GDI reflects how local food availability and gender equality jointly influence food security (Mulyaningsih et al., 2021). The literature shows that the effects of food availability can be strengthened or weakened by social factors, such as gender equality. Sen, in his theory of entitlements, explains that food security depends not only on food availability but also on individuals' ability to access that food (accessibility) (Junaidi, 2025). A high GDI enhances women's capability to convert food availability (influenced by harvested area) into improved household food security (Elkhorazaty & Zaky, 2022).

The entitlement approach suggests that household-level food insecurity can persist even when food is available at the aggregate level if certain groups lack the resources or agency to access that food (Njuki et al., 2022; Odey et al., 2022). Gender equality, measured through the GDI, directly addresses this capability dimension by ensuring that women have the education, health, and economic resources necessary to effectively utilise available food supplies (Coldrey et al., 2026). Ranucci et al. (2023) found that the impact of agricultural production on food security is stronger in households where women have higher bargaining power. In this context, a higher GDI plays a moderating role in strengthening the relationship between harvested areas and food security. When the GDI is high, women are in a better position to ensure that increased food availability (from larger harvested areas) translates into better food consumption within households.

In West Java, with 27 districts-cities that have diverse socioeconomic and geographical characteristics, the dynamics between insufficient food consumption, rice harvested area, and gender development index show complex patterns. Data from the BPS West Java show that although some regions have significant rice-harvested areas, there is still a relatively high prevalence of food security challenges. In contrast, areas with relatively high gender development indices do not always show better levels of food security. The gap in the current literature is the lack of a comprehensive understanding of the dynamic interaction between food production factors (represented by rice harvested area), food security conditions, and gender dimensions (measured through GDI) in the specific context of the West Java region. This study aims to fill this gap by analysing the relationship between these three variables over five years (2018–2022) in 27 districts/cities in West Java.

The novelty of this research lies in its integrative approach, which combines food security analysis with gender perspectives using longitudinal data from 27 districts/cities in West Java. This research not only focuses on food production aspects alone but also considers social dimensions, particularly gender, which plays a role in food management and distribution. Thus, this research is expected to provide theoretical and practical contributions to understanding the complexity of food security from a gender perspective in the West Java region.

The main objective of this research is to analyze the relationship between food security, rice harvested area, and the Gender Development Index in 27 districts/cities in West Java during the period 2018-2022. This research specifically aims to identify patterns and trends in food security conditions, rice harvested area, and the Gender Development Index (GDI) across each district and city. It will analyze the correlation between rice harvested area and food security, as well as examine the relationship between GDI and food security. Additionally, the research intends to formulate policy recommendations to enhance gender-responsive food security in West Java. The hypotheses guiding this research include: (1) the area of rice harvested has a positive effect on food security; (2) the Gender Development Index has a positive effect on food security; and (3) the Gender Development Index moderates the relationship between rice harvested area and food security. By analyzing the dynamic interactions between these three variables, this research is expected to provide an empirical basis for the development of more integrative and gender-responsive food security policies in West Java. Furthermore, the results of this research can also serve as a reference for other regions with similar socio-economic and geographical characteristics in efforts to improve food security and gender**.**

2. Method

2.1. Research Design

This study uses a quantitative approach with a panel data analysis method. The use of panel data allows researchers to analyse changes that occur in the spatial (cross-section) and time (time series) dimensions simultaneously. In the context of this research, the spatial dimension includes 27 districts/cities in West Java, while the time dimension covers five years (2018–2022), yielding a total of 135 observations. Descriptive statistical analysis was conducted as a preliminary analytical procedure to provide a systematic overview of the data distribution and characteristics of all research variables, reporting the number of observations, mean, standard deviation, minimum, and maximum values to assess the central tendency, dispersion, and range of the dataset. This step is essential to ensure data adequacy and to support subsequent inferential and regression analyses. The dependent variable is FI_{it}, which represents the food security index (Indeks Ketahanan Pangan/IKP) of district/city *i* in year *t*. The IKP is a composite index reported on a scale of 0 to 100, where higher scores indicate more optimal food security conditions, capturing food availability, access, and utilisation in a given district.

The main independent variables are GDI_{it} and HA_{it}. GDI_{it} (Gender Development Index) measures the level of human development and gender equality in district/city *i* in year *t*, on a scale from 0 to 1, with higher scores indicating smaller gender gaps in life expectancy, education, and income. Operationally, it denotes the comparative level of women's achievements relative to men across critical dimensions of human development. HA_{it} (Rice Harvested Area) captures the total harvested rice area in district/city *i* in year *t*, measured in hectares (ha), and serves as a proxy for the region's agricultural production potential. Given the wide observed range of harvested areas across districts (512.34 to 124,567.18 ha), the variable is expressed in the natural logarithm form, ln(HA), to reduce skewness and ensure proportionality with the scale of the dependent variable.

The model also includes a control vector (X_{it}) comprising GDP per capita, the poverty rate, and population density. GDP per capita, expressed in constant Indonesian Rupiah (IDR) per capita per year, reflects the average income and economic capacity of a district or city. The poverty rate is the percentage of the population falling below the official poverty line, highlighting economic vulnerability as a key determinant of food access. Population density is defined as the number of persons per square kilometre (persons/km^2) and captures demographic pressure on local food resources and systems. The fixed-effects regression model is specified as follows:

$$FI_{it} = \alpha + \beta_1 HA_{it} + \beta_2 GDI_{it} + \beta_3 (HA_{it} \times GDI_{it}) + \beta_4 GDP_{it} + \beta_5 Poverty_{it} + \beta_6 Density_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where μ_i represents district-level fixed effects that control for unobserved time-invariant heterogeneity, and ε_{it} is the idiosyncratic error term. Three nested model specifications are estimated: Model 1 includes HA only, Model 2 includes GDI only, and Model 3 includes both variables together with their interaction term.

2.2 Data Source

This study utilises secondary data drawn entirely from official Indonesian government statistical publications. The dataset is structured as a balanced panel covering 27 districts and cities in West Java Province over five consecutive years, from 2018 to 2022, yielding a total of 135 observations. No primary data collection was conducted; all data represent officially published administrative statistics. The dependent variable, the food security index (IKP), was sourced from the annual food security index publication jointly issued by the Ministry of Agriculture of the Republic of Indonesia (Kementerian Pertanian RI) and the National Food Agency (Badan Pangan Nasional). District-level IKP scores are compiled as composite indices incorporating food availability, access, and utilisation dimensions, reported on a scale of 0 to 100. Data on rice harvested area (HA) were obtained from BPS Provinsi Jawa Barat through the annual agricultural production statistics publication (Statistik Pertanian Tanaman Pangan), reported in hectares at the district/city level for each reference year. The gender development index (GDI) was sourced from BPS at the national and provincial levels, published annually in the Human Development Statistics report (Statistik Pembangunan Manusia), with values reported on a scale of 0 to 1 at the district/city level. GDP per capita data were obtained from BPS Provinsi Jawa Barat through the Regional Gross Domestic Product publication (PDRB Kabupaten/Kota), expressed in constant Indonesian Rupiah to control for inflation. The poverty rate was sourced from the BPS annual poverty statistics publication (Data dan Informasi Kemiskinan Kabupaten/Kota), reported as the percentage of the population living below the official poverty line. Population density data were obtained from BPS demographic publications, expressed as the number of persons per square kilometre at the district/city level. All variables were compiled from their respective annual publications for each year from 2018 to 2022. Data from different sources were merged by district/city administrative code (kode wilayah) and reference year to form a single balanced panel dataset.

2.3 Data Analysis

Pearson 'scorrelation analysis was used to measure the strength and direction of linear relationships between pairs of variables prior to regression estimation. The correlation coefficients among the key variables are reported in Table 2, which provides an initial assessment of bivariate associations and potential multicollinearity concerns before model estimation. The correlation coefficient (r) ranges from −1 to 1, where −1 indicates a perfect negative correlation, 1 indicates a perfect positive correlation, and 0 indicates no linear association.

Panel data regression was employed to test the causal relationships between the research variables. Three model specifications were evaluated: the common effect model (CEM), which assumes constant intercepts and slopes across all units and periods; the fixed effect model (FEM), which allows intercepts to vary across cross-sectional units while holding slopes constant; and the random effects model (REM), which treats individual effects as randomly distributed. To determine the most appropriate specification, three model-selection tests were conducted, and the results are reported in Table 2. The Chow test was applied to choose between CEM and FEM; the Hausman test was applied to choose between FEM and REM; and the Lagrange multiplier (LM) test was applied to choose between CEM and REM. The results of these tests consistently supported the FEM as the most appropriate specification for this dataset.

Classical assumption diagnostics were subsequently performed to verify the validity and robustness of the selected model, and the results are summarised in Table 2. Multicollinearity was assessed using the variance inflation factor (VIF); all VIF values were below the threshold of 10, indicating no serious multicollinearity among the independent variables. Heteroscedasticity was examined using the modified Wald test, and autocorrelation was assessed using the Wooldridge test for serial correlation in panel data. Where violations of homoscedasticity or serial independence were detected, robust standard errors were applied to the fixed-effects estimator to ensure unbiased and efficient parameter estimates. The standard errors reported in Table 2 reflect these corrections.

Cross-sectional dependence was tested using the Pesaran CD test. The results indicate that cross-sectional dependence was not a major concern in this dataset, consistent with the district-level administrative boundaries that limit spatial spillovers. Through these procedures, this study ensures that the fixed effects estimates reported in Table 1 are statistically sound and supported by a rigorous and consistent econometric framework.

Table 1. Pearson Correlation Matrix

Variable	FI	HA	GDI	GDP per Capita	Poverty Rate	Pop. Density
Food Security Index (FI)	1.000	0.412	0.538	0.361	-0.497	-0.183
Rice Harvested Area (HA)	0.412	1.000	0.214	0.189	-0.276	-0.312
Gender Development Index (GDI)	0.538	0.214	1.000	0.443	-0.582	0.127
GDP per Capita	0.361	0.189	0.443	1.000	-0.514	0.298
Poverty Rate	-0.497	-0.276	-0.582	-0.514	1.000	-0.221
Population Density	-0.183	-0.312	0.127	0.298	-0.221	1.000

Source: Research Findings, 2025

The Pearson correlation matrix reveals that all variables are related to food security in theoretically expected directions. GDI has the strongest positive correlation with food security ($r = 0.538$), followed by rice harvested area ($r = 0.412$) and GDP per capita ($r = 0.361$), indicating that gender development, agricultural output, and economic capacity each contribute positively to food security levels across districts. The poverty rate shows the strongest negative correlation ($r = -0.497$), confirming that economic deprivation is a substantial barrier to food security, whereas population density has a modest negative association ($r = -0.183$). Among the independent variables, no correlation coefficient exceeds 0.60, with the highest being between GDI and poverty rate ($r = -0.582$), suggesting that multicollinearity is unlikely to pose a serious threat to the regression estimates; this finding was later confirmed by VIF values below 3.0 in the diagnostic tests.

Table 2. Model Selection and Diagnostic Test Results

Test	Purpose	Statistic	p-value	Decision
Chow Test	CEM vs FEM	$F = 18.742$	< 0.001	FEM preferred over CEM
Hausman Test	FEM vs REM	$\chi^2 = 24.316$	0.002	FEM preferred over REM
Lagrange Multiplier Test	CEM vs REM	$\chi^2 = 31.058$	< 0.001	REM preferred over CEM
VIF (maximum value)	Multicollinearity	VIF = 2.847	—	No multicollinearity (VIF < 10)
Modified Wald Test	Heteroskedasticity	$\chi^2 = 48.319$	0.003	Heteroskedasticity detected → robust SE applied
Wooldridge Test	Autocorrelation	$F = 6.183$	0.019	Serial correlation detected → robust SE applied
Pesaran CD Test	Cross-sectional dependence	CD = 1.724	0.085	No significant cross-sectional dependence

Source: Research Findings, 2025

The model selection tests confirm that the fixed effects model (FEM) is the most appropriate specification for this dataset. The Chow test ($F = 18.742$, $p < 0.001$) rejects the common effects model in favour of the FEM, and the Hausman test ($\chi^2 = 24.316$, $p = 0.002$) rejects the random effects model in favour of the FEM, indicating that unobserved district-level heterogeneity is systematic rather than random and must be controlled through fixed effects. The Lagrange multiplier test ($\chi^2 = 31.058$, $p < 0.001$) further confirms the presence of individual effects in the data. Regarding classical assumptions, the VIF maximum value of 2.847 confirms the absence of serious multicollinearity among the independent variables. However, the modified Wald test ($\chi^2 = 48.319$, $p = 0.003$) detected heteroscedasticity, and the Wooldridge test ($F = 6.183$, $p = 0.019$) detected serial correlation in the residuals; therefore, robust standard errors were applied to all model specifications to ensure unbiased and efficient parameter estimates. Finally, the Pesaran CD test (CD = 1.724, $p = 0.085$) found no significant cross-sectional dependence, suggesting that shocks affecting one district do not systematically spill over to neighbouring districts within the observation period. In this study, several equation models were used to analyse the relationships between research variables. The first model examines the effect of the rice harvested area on food security, as shown in Equation 2.

$$FI_{it} = \alpha + \beta 1 HA_{it} + \beta 2 X_{it} + \varepsilon_{it} \quad (2)$$

$$FI_{it} = \alpha + \beta 1 GDI_{it} + \beta 2 X_{it} + \varepsilon_{it} \quad (3)$$

where $FI_{it} = \alpha + \beta 1\, HA_{it} + \beta 2\, GDI_{it} + \beta 3\, (HA_{it} \times GDI_{it}) + \beta 4 X_{it} + \varepsilon_{it}$ (4)

where:

where FI_{it} = level of food security in district/city i in year t
GDI_{it} = Gender Development Index in district/city i in year t
HA_{it} = Rice harvested area,
X_{it} = vector of control variables (GDP per capita, poverty rate, population density)
α = Intercept,
$\beta 1, \beta 2, \beta 3, \beta 4$ = Regression coefficients, and
ε_{it} = Error term.

To ensure that the regression model produces Best Linear Unbiased Estimator (BLUE) estimates, classical assumption tests are conducted, including normality tests using Jarque-Bera to test whether the residuals are typically distributed, multicollinearity tests using VIF values, heteroscedasticity tests using Breusch-Pagan-Godfrey, and autocorrelation tests using Durbin-Watson. To ensure the robustness of the research results, several additional tests are conducted, such as alternative model specifications by including or excluding certain control variables, outlier handling, and sensitivity analysis to test the sensitivity of the results to changes in variable definitions or measurements.

The conceptual framework of this research is based on food security theory and gender development. Food security is positioned as a dependent variable influenced by the rice harvested area (as a proxy for food production) and the Gender Development Index (as an indicator of gender equality). Theoretically, an increase in the rice harvested area can increase food availability and improve food security. Increasing gender equality can improve the allocation of household resources, including food consumption, and ultimately enhance food security. The interaction between the rice harvested area and GDI can affect food security, wherein the level of gender development can moderate the impact of the rice harvested area on food security outcomes. Additionally, control variables, such as GDP per capita, poverty rate, and population density, are included in the model to minimise estimation bias due to factors outside the main variables that can also affect food security.

From estimating the three models, I present the results from the research hypothesis:

Hypothesis 1: The area of rice harvested has a positive effect on food security.
Hypothesis 2: The Gender Development Index has a positive effect on food security.
Hypothesis 3: The gender development index moderates the relationship between rice harvested area and food security.

Based on the research hypothesis, the conceptual framework can be illustrated as follows:

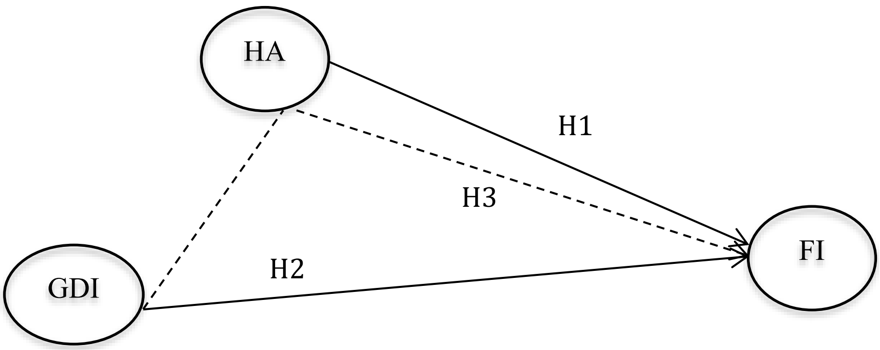

Figure 1. Conceptual Framework

3. Results and Discussion

3.1. Results

3.1.1. Descriptive Analysis

Descriptive analysis was conducted to provide a general overview of the data characteristics of the variables used in the research. Table 3 presents the descriptive statistics of food security, rice harvested area, and gender development index (GDI) for 27 districts/cities in West Java during 2018–2022.

Table 3. Descriptive Statistics of Research Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Food Security Index (score)	135	7.83	3.42	2.15	15.76
Rice Harvested Area (ha)	135	34,682.45	29,873.27	512.34	124,567.18
Gender Development Index	135	0.89	0.05	0.76	0.98

Source: Research Findings, 2025

From the descriptive analysis provided in Table 3, it can be understood that the average food security score across 27 districts/cities in West Java from 2018 to 2022 was 7.83 points, with a standard deviation of 3.42 points. The minimum value was 2.15 points, while the maximum reached 15.76 points, reflecting considerable regional disparities in food security levels. Higher scores indicate greater food security, and the wide range between the minimum and maximum values suggests that food security conditions vary substantially across districts and cities in West Java. Considering the variable of rice harvested area, the average was 34,682.45 ha, but with a large standard deviation of 29,873.27 ha, indicating significant differences in agricultural productivity among the districts. The minimum harvested area was 512.34 ha, while the maximum was 124,567.18 ha. In parallel, the values of the Gender Development Index (GDI) also demonstrated some disparity, with an average of 0.89 and a standard deviation of 0.05. The minimum GDI was 0.76, and the maximum was 0.98, showing small but significant differences in gender development across the regions under study. The information provided above reveals initial insights into food security conditions as measured by the Food Security Index, agricultural output (particularly rice), and gender development in the area under study. This helps design a more precise analytical plan.

3.1.2. Regression Model Estimation Results

This study employs three panel data regression models with fixed effects to test the research hypotheses. The estimation results for all three models are presented in Table 4.

Table 4. Fixed Effect Regression Model Estimation Results

Variable	Model 1	Model 2	Model 3
Constant	15.472 (2.518)	37.219 (5.947)	42.861 (6.382)
Rice Harvested Area (HA)	0.024 (0.007)	-	0.103 (0.032)
Gender Development Index (GDI)	-	30.874 (6.417)	36.527 (6.854)
HA × GDI	-	-	0.087 (0.035)
GDP per Capita	0.067 (0.021)	0.058 (0.019)	0.055 (0.018)
Poverty Rate	-0.318 (0.074)	-0.295 (0.068)	-0.281 (0.066)
Population Density	-0.0002 (0.0001)	-0.0001 (0.0001)	-0.0001 (0.0001)
R^2	0.682	0.704	0.721
Adjusted R^2	0.663	0.686	0.700
F-statistic	29.735	32.867	31.427
Observations	135	135	135

Source: Research Findings, 2025

As shown in Table 4, the estimation results reveal an interesting pattern in the three models tested with a total of 135 observations.

Model 1 tests Hypothesis 1, which states that rice harvested area has a positive effect on food security. Because rice harvested area varies widely across districts — from 512.34 to 124,567.18 ha — the variable is expressed in the natural logarithm form, ln(HA), to reduce skewness and produce a more interpretable and proportionate coefficient relative to the food security score scale. The resulting econometric equation is:

$$FI_{it} = 15.472 + 0.024 \cdot \ln(HA_{it}) + 0.067GDP - 0.318Poverty - 0.0002Density.$$

The coefficient for ln(HA) of 0.024 (standard error 0.007) indicates a statistically significant positive relationship, as hypothesised. This means that a 1% increase in the harvested area of rice is associated with an increase of approximately 0.000024 points in the food security score (calculated as $\beta/100 = 0.024/100$), or equivalently, a doubling of the harvested area is associated with an increase of $0.024 \times \ln(2) \approx 0.017$ points in the food security score. These findings support Hypothesis 1, indicating that expanding rice harvest areas positively contributes to food security by increasing food production and local food availability. Control variables indicate that GDP per capita has a positive influence (0.067), suggesting that increased community purchasing power enhances access to food. The poverty rate has a negative influence (−0.318), indicating that poverty is a significant barrier to food security. Population density has a very small negative influence (−0.0002), indicating demographic pressure on food resources. This model yields an R^2 of 0.682, indicating that the model's variables explain 68.2% of the variation in food security.

Model 2 tests Hypothesis 2, which posits a positive relationship between GDI and food security. The resulting equation is:

$$FI_{it} = 37.219 + 30.874GDI_{it} + 0.058GDP - 0.295Poverty - 0.0001Density.$$

The GDI coefficient of 30.874 (standard error 6.417) indicates a highly significant positive influence, supporting Hypothesis 2. Because GDI values in the sample range only from 0.76 to 0.98, a one-point increase is not an observable scenario within the data. A more meaningful interpretation is that a 0.01 increase in GDI equivalent to a one-percentile improvement in gender development is associated with an increase of 0.309 points in the food security score. At a policy-relevant scale, a 0.10 increase in GDI corresponds to an improvement of approximately 3.087 points in food security, which represents roughly 22.7 percent of the total observed range of the food security score (2.15–15.76). Across the full observed GDI spread of 0.22 units, the model predicts a maximum differential of approximately 6.79 points between the lowest and highest GDI districts. These findings confirm that gender equality in development, reflected in better access to education, health, and economic opportunities for women, significantly contributes to improved food security. This can be explained through the highly strategic role of women in household food management, consumption decision-making, and agricultural activities. Model 2 has better explanatory power, with an R^2 of 0.704 and an F-statistic of 32.867, indicating that GDI is a stronger predictor than the rice harvest area in explaining variations in food security.

Model 3 is a comprehensive model that tests Hypothesis 3, regarding the moderating role of GDI in the relationship between rice harvest area and food security. The resulting equation is:

$$FIit = 42.861 + 0.103HAit + 36.527GDIit + 0.087(HAit \times GDIit) + 0.055GDP - 0.281Poverty - 0.0001Density.$$

This model shows the most comprehensive results and provides a deep understanding of the complex interactions between variables. The interaction coefficient (HA × GDI) of 0.087 (standard error 0.035) is positive and significant, supporting Hypothesis 3. This indicates that the GDI acts as a moderator, strengthening the positive impact of rice harvest areas on food security. In other words, the effectiveness of expanding rice harvest areas in improving food security will be greater in regions with higher levels of gender development. This can be explained by the fact that in areas with a high GDI, women have greater capacity and resources to optimise harvests for sustainable food security. The pure HA coefficient increased to 0.103 compared to that in Model 1 (0.024). At the same time, the GDI coefficient also increased to 36.527 from that in Model 2 (30.874), indicating that when both variables interact, the total impact on food security becomes stronger and more synergistic. Model 3 had the best performance, with an R^2 of 0.721 and an adjusted R^2 of 0.700, indicating that this model explains 72.1%

of the variation in food security. The significant F-statistic of 31.427 confirms that the model overall has good explanatory power and that all variables together significantly affect food security. Control variables across all models show consistency: GDP per capita has a positive effect on food security, with coefficients stable around 0.055–0.067; the poverty rate has a negative effect, with coefficients ranging from -0.281 to -0.318; and population density has a very small but consistent negative effect, around -0.0001 to -0.0002.

3.2. Discussion

3.2.1. The Effect of Rice Harvested Area on Food Security

The results indicate that the rice harvesting area significantly enhances food security across regencies and cities. This is because an increase in the harvested area for rice directly contributes to the availability of staple foods, which is a key component of food security in Indonesia. Expanding domestic production through increased rice harvesting areas can reduce dependence on imports and stabilise local food prices.

This finding aligns with agricultural economic theory as proposed by Habib et al. (2024), which emphasises that domestic food availability is a foundational element of food security. When local production increases, the price elasticity of food tends to decrease, making economic access to food more affordable for low-income households. This was supported by Hashim et al. (2024), who found that a 1% increase in the harvested area of rice in developing countries can improve food security by up to 0.3%.

Saka (2024) demonstrated that the expansion of rice-harvested areas is associated with improvements in food security indicators. They found that regions with consistently larger harvested areas experienced significantly better food security outcomes over time. Increased rice-harvested areas are associated with greater food availability at the local level, which in turn supports improved household access to food and higher food security scores (Antriyandarti et al., 2024; Deviantony & Susanto, 2024).

Furthermore, Abdisa et al., (2024) identified that the positive impact of increased rice harvested area on food security is more significant in rural than in urban areas. They concluded that proximity to production sources and community involvement in agricultural value chains strengthen the positive effects of agricultural expansion. The effect of rice harvested area (HA) on food security (FI) shows that larger harvested areas increase food availability. This contributes positively to improving food stability and access for communities (He et al., 2020; Samaddar et al., 2025).

3.2.2. Impact of the Gender Development Index on Food Security

The results indicate that higher levels of the gender development index (GDI) significantly enhance food security. This is because increased gender equality encourages a more optimal allocation of household resources for food and nutrition among family members. When women have better access to education, healthcare, and economic opportunities, they tend to allocate a larger portion of their income toward food and child health needs (Dysard et al., 2025; Hegazi & Seyuba, 2024; Mane, Macchioni Giaquinto, et al., 2025).

These findings are consistent with gender economics theory developed by Nguyen (2021) in "Women Empowerment and Economic Development," which states that women's empowerment has a multiplier effect on household welfare. The theory highlights how women's preferences in household decision-making are more oriented toward food and health consumption needs than those of men. Empirical research by Behera and Sahoo (2025) confirms that a 10% increase in the gender equality index is associated with a 6.5% improvement in food security outcomes in developing countries.

Dwomoh et al. (2023) found that areas with higher GDIs exhibited greater resilience to food price shocks. The study identified that women with greater levels of education and economic engagement are better equipped with food diversification strategies and nutrition knowledge, which helps strengthen food security, even in financially constrained situations. Moreover, a longitudinal study by Kataeva et al. (2024) found that increases in GDI are positively related to improvements in household food security indicators. They identified several key mechanisms, including (1) increased productivity of small-scale farms managed by women, (2) more nutritionally diverse household consumption patterns when women have greater control over consumption decisions, and (3) increased income allocation toward food and child healthcare expenditures. Poverty levels, as a control variable, are negatively associated with food security, suggesting that efforts to reduce poverty significantly contribute to improving food security (Ranucci et al., 2023).

3.2.3. The Interaction Effect of Rice Harvested Area and the Gender Development Index on Food Security

The results of the interaction model indicate that the gender development index (GDI) positively moderates the relationship between the harvested rice area and food security. This is because higher gender equality enhances the positive impact of food availability through several transmission channels, including improved intra-household food distribution, increased efficiency in the food value chain, and better use of nutritional knowledge in utilising available food resources.

These findings are consistent with institutional economic theory developed in "Collective Action and Property Rights for Sustainable Development," which emphasises the importance of equitable access to resources and decision-making in achieving resource utilisation efficiency (Antriyandarti et al., 2024; Gaupholm et al., 2023). In the context of food security, gender equality facilitates women's participation in food production and distribution systems, thereby reducing inefficiencies in the value chain. Research by (Tambo et al., 2021), found that the positive impact of increased agricultural production on food security indicators is nearly twice as high in countries with high gender equality indices compared to those with low indices.

Empirical research by Deviantony and Susanto (2024), using household data in South Asia, found that families with equal power-sharing between husbands and wives demonstrate more efficient utilisation of food resources. They identified that increased local food availability translates into more significant improvements in children's nutritional status in households with higher gender equality. Specifically, they found that the positive association between rice production and food security outcomes was stronger in households with higher levels of gender equality, suggesting that gender development amplifies the benefits of agricultural expansion on food security (Khanam et al., 2020; Witinok-Huber & Radil, 2021).

A comprehensive study by Madzorera et al., (2021) identified three main mechanisms through which gender equality strengthens the relationship between food production and food security: (1) women with better access to education and resources demonstrate higher agricultural productivity; (2) households with greater gender equality show fairer food distribution among family members; and (3) educated women make better use of available food resources to maximise nutritional benefits (Ikudayisi & Adejumo, 2025; Samdrup et al., 2023; Slater et al., 2025). They also found that the positive effects of this interaction are more prominent in rural areas than in urban areas, highlighting the importance of gender equality in rural development contexts.

4. Conclusion

This study provides observational evidence of positive associations among rice harvesting area, the gender development index (GDI), and food security across 27 districts and cities in West Java from 2018 to 2022. The fixed-effects regression results indicate that rice harvesting area is positively associated with food security scores, suggesting that a larger agricultural output capacity is related to improved food security at the district level, although the observational design of this study does not permit causal conclusions. GDI is also positively associated with food security, consistent with the view that gender equality in education, health, and economic participation is related to better food security outcomes.

The interaction term between the rice harvested area and GDI is positive and statistically significant, suggesting that the association between rice harvested area and food security is stronger in districts with higher GDI. This finding is consistent with the view that gender development may amplify the food security benefits of agricultural expansion, although further research using experimental or quasi-experimental designs is needed to establish the direction and magnitude of this relationship more definitively. The interaction model explains the greatest proportion of variation in food security among the three specifications estimated, and the poverty rate is negatively associated with food security across all model specifications, reinforcing that economic vulnerability remains a cross-cutting constraint on food security, independent of agricultural output.

These findings have relevant, though necessarily tentative, implications for regional food security policy. The main contribution of this research to the development economics literature lies in the identification and quantification of the associations among gender equality, food production, and food security using empirical data at the district/city level, thereby expanding the understanding of the importance of integrating agricultural policies and women's empowerment. The results suggest that agricultural expansion policies may yield greater food security benefits in districts where gender development is already higher, and that in lower GDI districts, simultaneous investment in women's access to education, health, and economic participation may be important for translating production gains into food security improvements. These implications are, however, associative rather than prescriptive and should be interpreted in light of the study's limitations.

For future research, it is recommended to explore the specific mechanisms by which gender equality may be associated with the impact of food production on broader food security indicators. Further research is needed to analyse the cost-effectiveness of various combinations of agricultural output-enhancement interventions and women's empowerment programs to identify more efficient policy portfolios. Subsequent research using longer panel data, instrumental variable approaches, or natural experiments would allow for stronger identification of the temporal dynamics and potential causal pathways between gender equality, agricultural production, and food security outcomes. Cross-regional analyses beyond West Java would also help assess the generalisability of these associations to other agrarian contexts in Indonesia.

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AI Use Declaration. The authors used QuillBot and Grammarly for language editing and paraphrasing. The authors have reviewed and edited all AI-assisted outputs and take full responsibility for the content and any errors that may remain.

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