

Assessing Actual Coffee Farmers' Food Security: Adaptation Strategy toward Food Estate Development in Gayo Highlands, Indonesia

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ABSTRACT

Food estate programs in the Gayo Highlands have the potential to disrupt traditional coffee farming practices by promoting monoculture systems, which may undermine local knowledge and cultural values. This shift increases farmers' vulnerability to market fluctuations, climate change, and agrarian conflicts, posing significant financial stability and food security risks. This study assesses food security indicators amidst food estate program development, offering location-specific strategies to enhance coffee farmers' resilience. A quantitative approach was employed from June to October 2024 in Aceh Tengah and Bener Meriah, Indonesia, involving 240 coffee farmers as respondents. Data were collected through self-administered questionnaires and analyzed using Principal Component Analysis (PCA), validated through the Kaiser-Meyer-Olkin (KMO) measure (0.535) and Bartlett's Test of Sphericity ($\chi^2 = 66.245$; $p = 0.048$) confirm the model's adequacy for dimensionality reduction. The study identified six important key of food security indicators: vehicle ownership (food availability), the share of food expenditure (food access), household size (food utilization), dwelling conditions, household head's education level, and the age of the household head's wife (food stability). The PCA results extracted three principal components, explaining 56.70% of the total variance (Factor 1 = 19.78%, Factor 2 = 18.93%, Factor 3 = 17.99%). The findings reveal that coffee farmers prioritize household conditions over farming investments, focusing on short-term survival strategies rather than long-term sustainability. This trade-off limits their ability to adapt to market volatility and climate change. Therefore, a balanced approach integrating improved farming practices with economic literacy, market access skills, and climate adaptation strategies is essential to strengthen agricultural resilience and ensure sustainable livelihoods.

Key words: Adaptation strategy; coffee growers; food resilience; household self-sufficiency.

1 INTRODUCTION

Since 2022, Indonesia has been developing a policy framework to establish food estate areas that integrate agriculture, plantations, and livestock sectors within a single region. The food estate program represents a major government initiative to strengthen national food security, particularly in response to challenges posed by the COVID-19 pandemic and potential food crises (Maskun et al., 2021; Yuliantika; Imamulhadi; Sekarwati, 2022). However, this program has faced significant criticism due to its misalignment with the principles of food sovereignty, environmental degradation (Maskun et al., 2021), and socio-cultural disruptions among local producers and indigenous communities (Siborutorop, 2023). While previous studies have examined the socio-economic impacts of food estate programs (Siborutorop, 2023), there is limited research on how these programs affect food security among coffee-dependent households. This study fills this gap by identifying key food security indicators in coffee farming communities and proposing strategies tailored to local economic conditions.

For instance, in North Sumatra, the food estate program has displaced traditional agricultural practices and local knowledge systems, a phenomenon referred to as "epistemicide," where monoculture farming systems replace indigenous and sustainable methods. This shift undermines

local food systems and threatens farmers' livelihoods reliant on traditional farming methods (Krisnadi; Wijanarko, 2024). Despite reports of relatively high community participation in areas like Ria-Ria Village, concerns persist regarding the adequacy of resources and institutional support necessary for the program's success (Syahputra; Siburian; Anggraini, 2023). These challenges highlight the need to closely evaluate food estate development, particularly its potential to exacerbate farmers' vulnerabilities and its implications for fostering a more sustainable agricultural sector.

Several studies have identified the vulnerabilities of Gayo Highland farmers, particularly regarding income fluctuations caused by natural factors (Anhar et al., 2020; Rahmaddiansyah et al., 2022), as well as price volatility and unpredictable market demand (Baihaqi et al., 2022; Hasibuan et al., 2023). In Aceh Province, the agricultural sector employs approximately 35% of the workforce, with 70% of rural households relying on it for their livelihoods. However, the sector is heavily dominated by the plantation subsector, which occupies around 1.1 million hectares, compared to only 390,000 hectares allocated for paddy fields (Statistic Indonesia -SI, 2024). Coffee is the leading commodity in the plantation subsector and is predominantly cultivated by smallholder farmers (Aulia et al., 2024; Purba; Alwi; Arif, 2023; Ruslan; Prasetyo, 2021). The Gayo Highlands are particularly well-

suited for coffee cultivation due to their favorable climate, environmental conditions, and fertile soils (Hanan et al., 2024; Muyassir; Helmi; Rahyunnisa, 2023). However, large-scale monoculture initiatives, such as the food estate program, have reduced the availability of arable land for local farmers, reducing financial income and leading to food insecurity (Widianto et al., 2024; Yesicha; Faruk; Wahyono, 2023).

Food security is closely linked to a household's self-sufficiency and is traditionally assessed based on the ability to meet caloric needs, poverty levels, and the availability of food resources (Chegini et al., 2021). However, localized adaptations and unique community conditions may introduce additional food security indicators. In particular, social, cultural, and economic dimensions are critical in determining household food security (Firdausy; Budisetyowati, 2022; Satapathy; Nayak; Mahakud, 2020). Furthermore, food security is often assessed through the four dimensions proposed by the FAO: food availability, access, utilization, and stability (Food and Agriculture Organization - FAO, 2008). These pillars provide a foundation for evaluating vulnerabilities among smallholder farmers. Studies from rural Africa (Usman; Haile, 2022) and Latin America (Anderzén et al., 2020) indicate that food security among coffee farmers is highly influenced by access to markets and economic diversification. Market accessibility plays a more dominant role than vehicle ownership alone, implying that other infrastructural factors (such as road quality and market linkages) should be explored in future research. This study applies these concepts to the Gayo Highlands context, examining how monoculture expansion under food estate programs affects coffee farmers' resilience.

Thus, further research is required to identify food security indicators for coffee farmers in the Gayo Highlands and understand the potential socioeconomic impacts of food estate development on these communities. Hence, this study aims to evaluate food security indicators of coffee farmers in the Gayo Highlands, Aceh Province, Indonesia, as a strategic response to planned food estate development in the region. The research seeks to analyze the relationships between key attributes of coffee-farming households in the Gayo Highlands and their tendencies toward food insecurity. The findings are expected to support the formulation of location-specific food security policies that preserve local values, cultural heritage, and sustainable farming practices.

2 MATERIAL AND METHODS

This study employed a quantitative approach with a case study model to assess the resilience of farmers in the Gayo Highlands (Figure 1). This study was conducted in Aceh Tengah and Bener Meriah Regencies, Aceh Province, Indonesia, from June to October 2024. These areas were chosen due to their economic dependence on coffee farming

and the implementation of food estate programs, which potentially impact food security among local farmers. To ensure a representative and unbiased sample, a stratified random sampling approach was applied across ten sub-districts in the Gayo Highlands.

A total of 240 coffee farmers were selected based on the following inclusion: 1) coffee farmers with ≥ 0.25 hectares of cultivated land to ensure that respondents are active contributors to coffee production; 2) at least five years of coffee farming experience; 3) coffee farming contributing $\geq 50\%$ of household income, ensuring the sample reflects economic dependence on coffee production; and 4) willingness to participate voluntarily and provide informed consent for the survey.

The study applied specific exclusion criteria to ensure the relevance and consistency of the sample. Farmers who operate solely as coffee traders, middlemen, or processors rather than primary producers were excluded, as their role in the coffee supply chain differs from the study's focus. Additionally, farmers with landholdings smaller than 0.25 hectares were not included, as they are more likely to depend on alternative income sources rather than coffee farming. Households engaged exclusively in subsistence farming without market integration were also excluded, as their economic characteristics do not align with the study's objectives. Lastly, respondents who did not complete the questionnaire, resulting in missing or inconsistent data, were removed from the sample to maintain data integrity.

2.1 Food Security Analysis Based on the Characteristics of Farming Communities in the Gayo Highlands

The study began with a preliminary literature review of food security indicators, referencing the Proteus Composite Index (PCI) (Caccavale; Giuffrida, 2020). Respondents were asked to select socioeconomic variables that could potentially influence food security conditions and are likely to occur in the Gayo Highlands. Following this, focus group discussions (FGDs) with farmers group representation of each sampling site ($n = 40$) were conducted with respondent to validate and identify which food security factors are considered most crucial and impactful by farmer communities in the Gayo Highlands. During the focus group discussion (FGD), respondents agreed on 12 key indicators of food security that were most commonly observed and relevant to farming communities in the Gayo highlands (Table 1). These key concepts were identified inductively based on respondents' explanations, insights, and analyses of strategies for ensuring future food availability. The 12 indicators reflect experiences related to the causes and impacts of hunger, as well as strategies that Gayo highland farmers have employed to address food insecurity. Additionally, they highlight farmers' efforts to adapt to future plans for food estate development.

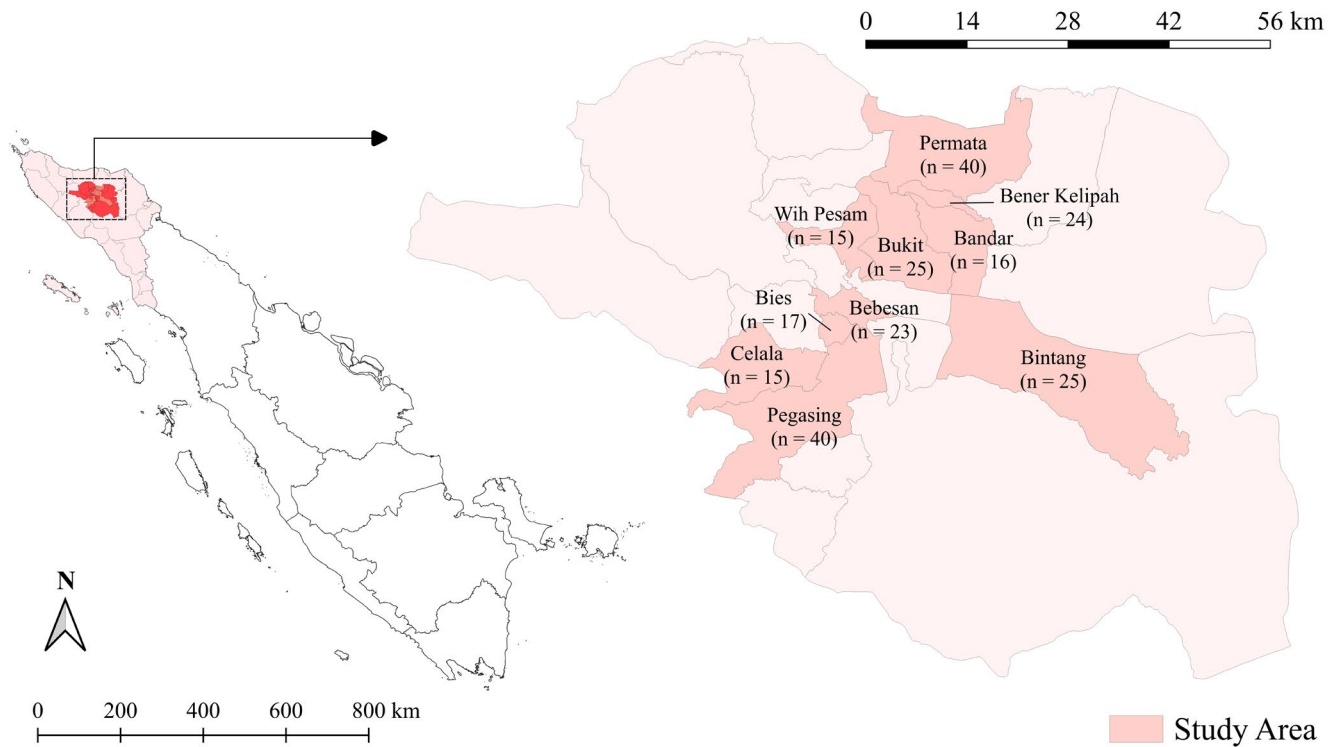


Figure 1: Gayo Highlands area, Aceh Province, Indonesia (highlighted in the dark red) and the ten sub-districts of the research location (n = sample size).

Table 1: Adaptation of food security indicators derived from PCI components through community consensus in the Gayo Highlands, Aceh Province.

PCI's Indicators	Communally agreed indicator	Justification
Food Availability (X1)	Land size (X1.1)	Reflects household production capacity for food commodities.
	Vehicle ownership (X1.2)	Relates to transportation for distributing or selling agricultural products.
Food Access (X2)	Share of food expenditure (X2.1)	The percentage of expenditure on food indicates the level of economic accessibility.
	Household income (X2.2)	Income determines the purchasing power of food.
	Vehicle ownership (X1.2)	(Also, relevant here): Serves as an economic asset to support accessibility to markets or food sources.
Food Utilization (X3)	Milk consumption (X3.1)	Indicator of nutritious food consumption.
	Meat consumption (X3.2)	Measures the level of animal protein intake linked to household nutritional status.
	Household size (X3.3)	Affects food distribution and adequacy at the individual level.
	Household head's/wife's education level (X3.4)	Nutritional knowledge is often associated with the wife's education level as household food managers.
Food Stability (X4)	Household head's Education level (X4.1)	The household head's ability to adapt to economic shocks or climate changes.
	Dwelling conditions (X4.2)	Reflects long-term economic stability, which supports food security.
	Household head's age (X4.3)	Often associated with experience in managing food security risks.
	Age of the household head's wife (X4.4)	Like the household head's age, it focuses on the wives' role in maintaining food consumption stability.

Note: Referring to Caccavale and Giuffrida (2020) and Manikas, Ali and Sundarakani (2023) with adjustments to field conditions.

The variables identified through the FGD were compiled into a self-assessment questionnaire using Guttman scale, which was then reviewed and validated by local agricultural experts and community leaders to ensure cultural and contextual relevance. This step ensuring that 1) terminology used was clear and locally understood, avoiding misinterpretation; 2) the questions accurately reflected the economic and agricultural conditions of the respondents; and 4) the instrument was practical and suitable for assessing food security at the household level. Enumerators provided assistance to respondents who faced difficulties in completing the questionnaire or understanding the questions, particularly those with low literacy skill and elderly participants.

The collected data were then tested for suitability using the KMO test and Bartlett's Test of Sphericity to evaluate the appropriateness of the sample for factor analysis (Shrestha, 2021; Thao; Van Tan; Tuyet, 2022; Ul Hadia; Abdullah; Sentosa, 2016). The KMO value ranges from 0 to 1, where values closer to 1 indicate a sufficiently strong correlation pattern among variables, which supports the continuation of factor analysis (Table 2). When the data meets this criterion, it suggests a structure suitable for dimensionality reduction through factor analysis (Shrestha, 2021).

Meanwhile, Bartlett's Test of Sphericity was used to test the null hypothesis (H_0) that the correlation matrix is an identity matrix (i.e., there are no relationships between variables). If the p -value < 0.050 at a 95% or higher confidence level, H_0 is rejected, indicating significant correlations between variables. This result means the data are suitable for factor analysis (Shrestha, 2021).

2.2 Food Security Data Analysis

The data, verified as suitable through the KMO and Bartlett's Test of Sphericity, was analyzed using PCA. The steps of PCA included dimension reduction, pattern identification, and data transformation, all conducted using SPSS version 23. The Principal Component method was applied during the extraction process to identify the minimum number of factors that account for the maximum variance in the dataset, facilitating multivariate analysis (Kamala et al., 2023). The Varimax rotation method was employed to ensure more interpretable results, mainly when factors are independent (Acal; Aguilera; Escabias, 2020).

A Communality analysis was conducted if the KMO value fell below 0.600, indicating weak relationships among variables. Indicators with communality values below 0.500 were excluded due to their low relevance or poor contribution to the factor structure (Table 3). Meanwhile, indicators with communality values ≥ 0.500 were retained as significant food security indicators for subsequent PCA analysis (Shrestha, 2021; Widaman; Helm, 2023).

Indicators with communalities extraction values of ≥ 0.500 were included in the factor variance comparison using the Eigenvalues and Cumulative Variance Explained (ECVE). A

factor is considered valid and retained if it meets one or more of the following criteria: 1) the Eigenvalues value is more significant than 1.000; 2) the cumulative variance proportion exceeds 50%; or 3) the indicator falls within the range preceding the elbow of the scree plot (Shrestha, 2021). The "elbow" refers to the point where the eigenvalue's rate of decline begins to level off. A higher cumulative variance proportion indicates that the resulting factors can effectively represent the remaining variables.

The suitability of the indicators for the most optimal factor variance was determined by the factor loading (FL) value, where $FL \geq 0.500$ indicates strong alignment with the factor variance. Higher FL values signify better alignment (Table 4). Model accuracy was assessed using the Component Transformation Matrix (CTM), where the correlation of a factor with itself must be ≥ 0.500 and higher than its correlation with other factors (Shrestha, 2021).

3 RESULTS

3.1 Respondent Characteristic

This study involved a total of 240 coffee farmers, comprising 172 male farmers and 68 female farmers. Most respondents were within the productive age range, particularly the Millennial age group (28–43 years old), representing nearly half of the participants (46.67%). Furthermore, 11.67% (28 respondents) were from Generation Z, under 27 years. These findings underscore the younger generation's significant interest and active involvement in coffee farming activities in the Gayo Highlands, Aceh Province, Indonesia (Table 5).

The majority of respondents (46.67%) belong to the millennial age group (28–43 years old), which suggests a high level of labor force participation in coffee farming. However, only 15% have completed higher education, which may influence their access to agricultural innovations and financial management strategies. This highlights the agricultural sector as the primary source of income for the Gayo Highlands community. Furthermore, employment data reveal that coffee farmers predominantly focus on coffee production rather than distribution and marketing. This finding is evident from the small percentage of respondents working as coffee traders or collectors, which accounts for only 4.58% of the total sample.

Regarding education levels, more than half of the respondents (50.83%) have completed senior high school, while only 15.00% have graduated from college or other higher education institutions. This educational background likely influences the knowledge and skills required to manage coffee farming businesses effectively, although further research is needed to confirm this relationship. Additionally, most respondents have less than ten years of farming experience (33.75%), suggesting that many are still learning and adapting as they adopt improved agricultural practices.

Table 2: Kaiser-Meyer-Olkin (KMO) correlation criteria for sample suitability in factor analysis.

KMO Score	Correlation Pattern Criteria	Interpretation
≥ 0.900	Excellent	The data is highly suitable for factor analysis. Correlations between variables are robust, suggesting a clear structure.
$0.800 - 0.899$	Good	The data is suitable for factor analysis. Correlations between variables are sufficient to extract meaningful factors.
$0.700 - 0.799$	Average	The data is moderately suitable for factor analysis. While acceptable, results may require careful interpretation.
$0.600 - 0.699$	Mediocre	The data is marginally suitable for factor analysis. Improvements in data quality (e.g., larger sample size or better measurement) may be needed.
< 0.600	Unsuitable	The data is unsuitable for factor analysis. Correlations between variables are weak, indicating no clear structure.

Table 3: Acceptable threshold values and interpretation of communalities results.

Communalities Score	Criteria	Interpretation
> 0.700	High	Strongly related to the factor structure, with a significant contribution.
$0.500 - 0.700$	Moderate	Moderately related to the factor. It is still acceptable to retain.
< 0.500	Low	Low contribution to the factor structure. Consider removing.

Table 4: Factor loading score interpretation.

Magnitude	Criteria	Interpretation
≥ 0.500	High loadings	Indicate a strong relationship between the variable and the component. It means that the variable contributes significantly to the definition of the component. The factor sufficiently captures the variance of that variable.
$0.300 - 0.500$	Moderate loadings	Suggest a moderate relationship, indicating a moderate contribution of the variable to the component.
< 0.300	Low loadings	Considered weak or negligible, suggesting minimal contribution of the variable to the component.

The household economic structure of respondents is influenced by the number of dependents, with 59.17% reporting three to five family members. This family structure impacts decision-making in farming operations and pursuing supplementary income sources. Notably, more than 57% of respondents report having additional household income contributed by other family members, which helps sustain the household economy. The coffee farming sector remains a significant source of income for the Gayo Highlands community, with respondents reporting an average landholding size of 1.10 hectares. Plantation ownership typically ranges from 0.50 to 1.00 hectares, with 44.58% of these plantations owned by men and 15.42% by women. Larger plantation areas exceeding 1.00 Ha are predominantly owned by men (Figure 2).

The difference in land ownership between men and women in the Gayo region is primarily influenced by local cultural norms. In Gayo's agrarian society, men typically have greater inheritance and land ownership rights than women. This disparity allows men to dominate in managing larger plots of land, making agricultural decisions, and addressing agrarian issues. In contrast, women's access to land is often limited due to social norms and inheritance rights restrictions.

3.2 Factors Influencing Food Security in the Gayo Highlands

The respondents' responses were used as primary data to assess food security, which was then analyzed using the KMO test and Bartlett's Test of Sphericity to determine the suitability of the data for factor analysis. Although the KMO value (0.535) is below the optimal threshold of 0.6, Bartlett's Test of Sphericity ($\chi^2 = 66.245$; $p = 0.048$) confirms that the data are suitable for factor analysis (Table 6).

The KMO value indicates that the food security data from the Gayo Highlands in Aceh Province falls into the "weak" category, approaching the lower threshold for suitability in factor analysis. This suggests that the relationships between variables are relatively weak, making factor analysis potentially less ideal. However, Bartlett's Test of Sphericity reveals significant correlations among the variables, supporting the feasibility of performing factor analysis. To address this limitation, a communalities analysis was performed, ensuring that only variables with extraction values ≥ 0.500 were retained. The communalities analysis measures the variance of each indicator explained by the extraction value, reflecting

the strength of its relationship with the overall factor structure. Based on the results, only six out of the 12 indicators met the significance criterion for extraction values (≥ 0.500), and these indicators were deemed suitable for inclusion in the factor analysis (Table 7).

Based on the analysis presented in Tabel 8, the indicators with communalities below 0.500 were excluded to enhance the robustness of the PCA model, as they contributed less to the factor structure. This threshold was selected based on standard

PCA practices, ensuring that the extracted components explain a sufficient proportion of variance while minimizing noise from weakly contributing variables. Retaining variables with communalities below 0.500 could introduce instability in the factor structure, reducing interpretability and increasing redundancy. Specifically, the indicator Dwelling Conditions had an extraction value of 60.3%, while Household Size demonstrated a value of 59.5%, contributing significantly to the food security factor. Additionally, Food Expenditure Share

Table 5: Demographic profile of coffee farmer respondents in the Gayo Highlands, Aceh Province.

Characteristics	Male (n = 172)		Female (n = 68)		Total (n = 240)	
	N	%	N	%	N	%
Age (Years old)						
≤ 27 (Gen Z)	18	7.50	10	4.17	28	11.67
28 - 43 (Millennial)	81	33.75	31	12.92	112	46.67
44 - 59 (Gen X)	67	27.92	23	9.58	90	37.50
≥ 60 (Boomers)	6	2.50	4	1.67	10	4.17
Side Occupations						
Agricultural day laborer/farmworker/ farmer	41	17.08	23	9.58	64	26.67
Civil servant/teacher/military/police officer.	5	2.08	1	0.42	6	2.50
Stalls/Grocery/reseller.	10	4.17	8	3.33	18	7.50
Coffee trader/collector.	9	3.75	2	0.83	11	4.58
Horticultural or food crop farmer.	85	35.42	29	12.08	114	47.50
Services: handyman/driver.	10	4.17	2	0.83	12	5.00
Other service occupations.	12	5.00	3	1.25	15	6.25
Educational Background						
Elementary	18	7.50	9	3.75	27	11.25
Junior School	34	14.17	21	8.75	55	22.92
Senior School	90	37.50	32	13.33	122	50.83
College/Higher Education	30	12.50	6	2.50	36	15.00
Family Dependents (Persons)						
0	16	6.67	6	2.50	22	9.17
1 - 2	50	20.83	20	8.33	70	29.17
3 - 5	102	42.50	40	16.67	142	59.17
≥ 6	4	1.67	2	0.83	6	2.50
Family dependents who contribute to household efforts/income						
0	74	30.83	29	12.08	103	42.92
1 - 2	83	34.58	37	15.42	120	50.00
3 - 5	15	6.25	2	0.83	17	7.08
Farming Experiences						
< 10	56	23.33	25	10.42	81	33.75
10 - 20	63	26.25	14	5.83	77	32.08
21 - 30	37	15.42	18	7.50	55	22.92
> 30	16	6.67	11	4.58	27	11.25

Note: N = total respondents; % = percentage of respondents based on group characteristics divided by total respondents (n = 240).

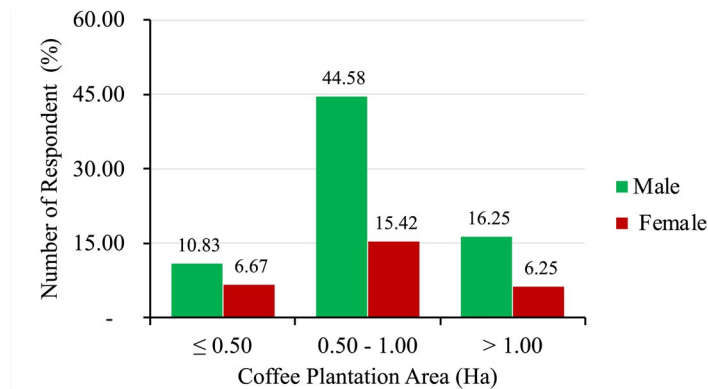


Figure 2: Coffee plantation land size is determined by the gender of coffee farmers in the Gayo Highlands, Aceh Province.

Table 6: Suitable data for factor analysis based on KMO and Bartlett's Test of Sphericity score for food security data in the Gayo Highlands, Aceh Province.

Parameter		Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.535
Bartlett's Test of Sphericity	Approx. Chi-Square (χ^2)	66.245
	df	66
	Sig. (p-value)	0.048

Note: A KMO value of 0.535, although below the optimal threshold (≥ 0.6), was deemed acceptable as Bartlett's Test of Sphericity ($\chi^2 = 66.245$; $p = 0.048$) confirmed that the correlation matrix was suitable for factor analysis.

Table 7: Final selection of food security indicators based on PCA communalities analysis in the Gayo Highlands, Aceh Province.

Indicator	Initial	Extraction
Land size (X1.1)	1.000	0.454
Vehicle ownership (X1.2)	1.000	0.593*
Share of food expenditure (X2.1)	1.000	0.574*
Household income (X2.2)	1.000	0.446
Milk consumption (X3.1)	1.000	0.394
Meat consumption (X3.2)	1.000	0.432
Household size (X3.3)	1.000	0.595*
Household head's wife's education level (X3.4)	1.000	0.460
Household head's education level (X4.1)	1.000	0.557*
Dwelling conditions (X4.2)	1.000	0.603*
Household head's Age (X4.3)	1.000	0.427
Age of the household head's wife (X4.4)	1.000	0.546*

Extraction Method: Principal Component Analysis.

Note: An asterisk (*) indicates that underlying factors can explain the indicator.

reached 57.4%, Vehicle Ownership achieved 59.3%, and Household Head Education showed 55.7%, indicating that the household head's costs, mobility, and education level play crucial roles in food security.

In contrast, six indicators, including Milk Consumption (39.4%) and Household Head Age (42.7%), exhibited lower contributions and were not considered significant in explaining the variance in food security. The communalities

analysis revealed that some indicators substantially influence food security in the Gayo Highlands. In contrast, others may require further investigation to enhance their relevance to the overall food security factor analysis. These findings can serve as a foundation for policies or interventions to improve regional food security, focusing on indicators with higher communalities values to guide more effective development strategies.

Further analysis was performed on indicators with communalities values greater than 0.500 to assess their potential influence on factor formation. The results identified three principal components based on Eigenvalues ≥ 1.000 (Table 8), total variance explained, and the scree plot analysis.

Based on the determination of the number of factors using the ECVE method, three factors were identified (Factors 1 to 3). The final PCA model identified three principal components, explaining 56.70% of the total variance (Factor 1 = 19.78%, Factor 2 = 18.93%, Factor 3 = 17.99%), indicating an adequate level of explanatory power. The total variance explained by these three factors is 56.70%, which exceeds the established threshold of 50.0%. These findings are further supported by the scree plot, where Factors 1 to 3 appear before the elbow point (< 1.000), indicating that they should be retained (Figure 3).

Based on the scree plot, the elbow point or decline in the graph occurs at an Eigenvalues less than 1.00, confirming

that factors 1 through 3 are optimal and can be utilized. Further analysis indicates that each indicator is grouped into different factors based on its highest factor loading value (Table 9).

Based on the rotated component matrix analysis, each indicator has at least one factor loading correlation value greater than 0.500 with the identified factors. The household head's wife age indicator shows the highest correlation on Factor 1, with a value of 0.789, followed by vehicle ownership, with a correlation value of 0.506. For Factor 2, the food expenditure share indicator exhibits the highest correlation, reaching 0.815, while Household Size shows a significant negative correlation with a value of -0.646. On Factor 3, Household Head Education is the only indicator with a negative correlation of -0.780.

Although the indicators fall into different categories, the model fit test results demonstrate that the correlation between different factors is lower than the correlation within the same factor (Table 10). These findings suggest that Factors 1, 2, and 3 represent valid factor models.

Table 8: Principal Component Analysis (PCA) result of varian explained by Eigenvalues and Cumulative Variance Explained (ECVE) per each built factor.

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	1.187	19.783	19.783	1.187	19.783	19.783	1.161	19.348	19.348
2	1.136	18.926	38.709	1.136	18.926	38.709	1.140	18.996	38.344
3	1.079	17.991	56.700	1.079	17.991	56.700	1.101	18.356	56.700
4	.996	16.600	73.299						
5	.841	14.010	87.310						
6	.761	12.690	100.000						

Extraction Method: Principal Component Analysis.

Note: Three principal components were retained as they explained a cumulative variance of 56.70%, exceeding the recommended 50% threshold for social science research Indicator numbering is based on the sequence order.

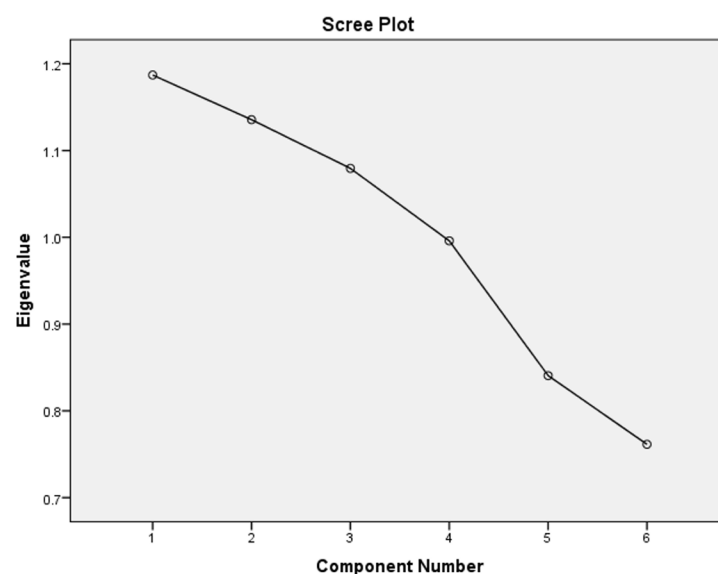


Figure 3: Scree Plot of Factors for Food Security Data of Coffee Farmers in the Gayo Highlands.

Table 9: Component matrix.

Variable/ Indicator	Loading Factor Score					
	Component Matrix ^a			Rotated Component Matrix ^b		
	1 st	2 nd	3 rd	1 st	2 nd	3 rd
Vehicle ownership	.576*	.390	-.236	.506*	.216	.486
Share of food expenditure	-.125	.791*	-.256	.042	.815*	.205
Household size	.581*	-.521*	-.239	.211	-.646*	.453
Dwelling conditions	-.320	-.020	-.248	-.383	.109	.076
Household head's education level	-.102	.064	.826*	.297	-.002	-.780*
Age of the household head's wife	.624*	.285	.396	.789*	.030	-.061

Notes: Extraction Method: Principal Component Analysis. The superscript alphabet (^{a-b}) particular action: a) 3 components extracted; b) Rotation Method: Varimax with Kaiser Normalization with rotation converged in 5 iterations.

Table 10: Component Transformation Matrix.

Factors	1 st	2 nd	3 rd
1 st	.837	-.311	.450
2 nd	.328	.944	.041
3 rd	.438	-.113	-.892

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

4 DISCUSSION

4.1 Socioeconomic Structure of Coffee Farming Communities

The socioeconomic and environmental challenges coffee farmers face in the Gayo highlands are deeply interconnected, creating a complex landscape that shapes their livelihoods and food security. Demographic and socioeconomic factors, such as land ownership and income levels, significantly influence farmers' vulnerability. Smallholder coffee producers often operate under structural barriers, such as limited access to post-harvest technology, which constrain their productivity and income potential (Agussabti et al., 2023; Harahap; Absah; Aulia, 2024; Tran et al., 2021). Furthermore, environmental challenges, such as land shrinkage due to food estate program or natural disaster, exacerbate their vulnerability and require adaptive capacities to develop resilience (Azzahra et al., 2021). These vulnerabilities are compounded by economic instability caused by both hindering their ability to secure a stable food supply (Rizki; Razali, 2023).

Food security among Gayo coffee farmers is further shaped by their ability to diversify income and diets. Studies have shown that households with higher dietary diversity, often linked to solid socioeconomic conditions, experience better food security outcomes (Deviantony et al., 2024). The interaction between social structures and environmental factors, such as elevation and canopy openness, plays a critical role in determining coffee

yields, which, in turn, influence food security and vulnerability to climate events (Morel; Cartau, 2023; Murniati; Mutolib, 2020). Despite these challenges, the community's relatively high average income, when effectively managed, has enabled some households to maintain a stable standard of living (McClatchey et al., 2023; Sano; Mammen; Houghten, 2021).

The food estate program has led to significant land-use changes in the Gayo Highlands, altering the availability of arable land for coffee farmers. The conversion of traditional coffee plantations into monoculture food estate plots has impacted household food security by reducing land tenure stability (Novianty et al., 2025), limiting access to diversified income sources, and increasing economic vulnerability (Jemal; Callo-Concha; Van Noordwijk, 2022). Farmers who previously relied on smallholder coffee farming for both income and subsistence are now facing greater challenges in maintaining food availability and access. This shift is particularly evident in the food expenditure patterns of affected households. As coffee farming areas shrink, farmers experience reduced yields and fluctuating incomes, may force them to allocate a larger share of household expenses to food purchases rather than reinvesting in agricultural activities. The PCA results confirm that food expenditure share is a significant indicator influencing food security in this region. Additionally, limitations in market access and transportation due to policy-driven land conversion further exacerbate the situation, making it more difficult for farmers to sustain their livelihoods. Given these findings, policy interventions should focus on preserving access to farming land, supporting diversified cropping systems, and ensuring market stability for coffee farmers adapting to food estate development. This approach would enhance long-term food security resilience while maintaining local economic sustainability.

4.2 Variables Involved in the Food Security Vulnerability of Coffee Farmers

This study stated new factors might be involved in coffee growers' security of food need fulfillment. Furthermore, food

security in rural communities, such as the village communities of Gayo Highlands, is shaped by food availability, access, utilization, and stability factors. Each dimension underscores critical socioeconomic and infrastructural influences that dictate the well-being of these communities. By exploring these aspects, related multi-stakeholders can better understand the challenges and opportunities in achieving sustainable food security in rural areas. For example, vehicle ownership enhances food security by improving market access and facilitating the movement of goods. In rural regions with poor infrastructure, such as Gayo, transportation is a critical enabler for reducing food waste, accessing diverse food resources, and securing better farm-gate prices. The findings indicate that vehicle ownership is a significant factor in food security, particularly in facilitating market access and food distribution. This result aligns with studies in Nigeria and Ghana, where transportation plays a crucial role in reducing post-harvest losses and increasing income stability (Khanani et al., 2021; Zakaree, 2022). Similarly, research in Nepal shows that road construction and vehicle access have enhanced food security by supplementing agricultural yields with processed foods and reducing transaction costs (Pandey; Bardsley, 2019). However, while vehicle ownership improves physical access to food, broader socioeconomic policies must address infrastructure development and market integration to ensure equitable and sustainable benefits (Mun'im, 2016; Zulfikar; Ullah; Kamran, 2024).

Market accessibility also emerges as a critical determinant of food security. Proximity to markets reduces transaction costs and increases household income, facilitating the purchase of diverse and nutritious foods. In Malawi and South Africa, better market connectivity has improved the ability of smallholder farmers to participate in market systems, enhancing food security (Hlatshwayo et al., 2022; Matita et al., 2021; Salima et al., 2023). However, poor infrastructure and limited access to market information continue to constrain private traders and reduce the potential benefits of liberalized markets (Babu et al., 2014). Strategic investments in rural road networks and communication systems are essential for improving market participation, increasing agricultural productivity, and achieving sustainable food security in regions like Gayo highlands (Marion et al., 2024).

Household size and the education of family members, mainly wives, are equally significant in shaping food security. Larger households often face greater challenges in maintaining food security due to increased resource demands, as observed in studies from various rural contexts (Antwi; Lyford, 2022; Naz et al., 2020). Conversely, the wives' education has positively impacted food security by improving dietary diversity and utilization. Educated women are more likely to adopt effective food management practices to enhanced household food security. Prior research supports this finding, indicating that higher educational attainment enhances economic resilience

and food security by improving financial literacy, business decision-making, and the ability to access agricultural innovation (Chebuche; Wakhungu, 2021; Olumakaiye; Ajayi, 2006). Interventions to empower women through education and family planning initiatives can significantly improve food security outcomes by balancing household resource demands with economic capacity (Ghosh et al., 2021).

Moreover, the education level of household heads plays a crucial role in improving food security and overall socioeconomic stability. Educated heads of households are better equipped to manage resources, secure higher incomes, and improve living standards. This correlation between education and food security is well-documented, with higher educational attainment leading to improved economic prospects and reduced poverty levels (Haidir; Setyari, 2024; Prabowo; Priyarsono; Probokawuryan, 2018). Beyond the household, education at the community leadership level enhances the management of collective resources, such as village funds, which are vital for rural development (Nadia; Mahi, 2023). Thus, prioritizing education in rural communities for individuals and leaders emerges as a strategic approach to enhancing food security and fostering community resilience (Juxiang; Brodovska, 2023). Given these empirical results, the study aligns with previous literature suggesting that improving education levels among coffee farming households can serve as a long-term strategy to enhance food security and economic sustainability.

4.3 Coffee Farmers' Food Security in the Paradigm of the Food Estate Program

This study reveals that coffee farmers in the Gayo Highlands remain susceptible to land-use changes and market instabilities that jeopardize the sustainability of their livelihoods despite relatively high levels of food security and living standards. Furthermore, the study underscores the potential impact of the national food estate program on the food security of coffee farmers and the region's economic structure. However, the food estate program may positively facilitate economic diversification, particularly for farmers whose livelihoods traditionally rely heavily on the on-farm sector. Moreover, income diversification programs are essential to enhance the financial stability of local farmers and mitigate risks associated with global coffee price fluctuations (Anderzén et al., 2020). Previous studies have shown that on-farm dependency is a barrier to income diversification. Therefore, alternative income is a critical adaptive strategy for strengthening farmers' economic resilience amidst market uncertainties (Andani et al., 2022; Yusriadi; Cahaya; Hamzah, 2024; Zulfikri et al., 2024).

On a positive note, developing the food estate program could improve infrastructure in rural areas of the Gayo Highlands. Investments in roads, irrigation systems, and

harvest storage facilities are expected to positively impact the productivity of food crops and coffee. Additionally, the program promotes adopting modern technology and digital tools in farming practices (Fahmid et al., 2022). These advancements enhance crop yields and reduce farmers' vulnerability to crop failures caused by climate change (Fikri; Novita; Gusthomi, 2023). However, concerns remain regarding the potential for agrarian conflicts arising from land appropriation under the food estate program. For decades, coffee farming has been the primary livelihood for the local community. Studies have demonstrated that land-use conversion can marginalize small farmers, exacerbate economic inequality, and trigger agrarian disputes, as evidenced in similar programs across Indonesia (Gaudart; Pasha, 2024; Guslandi, 2023; Sefriani; Thontowi; Wartini, 2023; Yesicha; Faruk; Wahyono, 2023).

The influx of investment and large-scale corporate or crop management often shifts the dynamics of local communities, transitioning from family-based farming systems to corporate models. This transformation can result in unequal access to resources and economic opportunities, altering the socioeconomic structure of the community (Yesicha; Faruk; Wahyono, 2023). Furthermore, it can weaken small farmers' bargaining power, reducing their status from landowners to corporate workers. In the context of the Gayo Highlands, such changes could erode the cultural identity linked to coffee production, diminishing the distinctiveness of the local coffee product that serves as a unique geographic identifier in global markets. Additionally, increased economic diversification toward food crops may reduce the focus on coffee cultivation, undermining its competitiveness in the worldwide market (Poncet et al., 2024). Similar trends observed in Africa and Asia indicate that centralized government interventions often fail to balance local agricultural sectors, adversely affecting specific industries (Olomu; Ekperiware; Akinlo, 2020; Sadeh et al., 2020; Zainol et al., 2024). The loss of institutional support for the coffee sector could reduce farmers' bargaining power within the supply chain, decrease incomes, and heighten their economic vulnerability.

From an environmental perspective, establishing food estates often involve large-scale land clearing, resulting in deforestation, soil erosion, and declining local ecosystem quality (McDonnell, 2021; Silubun; Putri, 2019). In the Gayo Highlands, such land use conversion could negatively affect coffee productivity, as coffee plants depend highly on stable microclimates and fertile soils. Research from various regions highlights that intensive agricultural expansion for monoculture increases the likelihood of ecological disasters, further exacerbating farmers' vulnerability to income reduction, lower crop yields, and food access challenges (Garcia-Chevesich et al., 2020; Rupngam; Messiga, 2024; Zulfiqar; Ullah; Kamran, 2024).

5 CONCLUSIONS

This study identifies six key indicators influencing food security among Gayo Highlands coffee farmers, with vehicle ownership, food expenditure share, and education level as significant factors. It reveals a tendency to prioritize short-term household needs over long-term agricultural investment, highlighting a trade-off that ensures immediate stability but threatens long-term resilience in the context of food estate development.

6 AUTHORS' CONTRIBUTION

Conceptual Idea: Bagio, B.; Athaillah, T.; Methodology design: Bagio, B.; Athaillah, T.; Fazlina, Y.D.; Data collection: Safrika, S.; Atikah, Q.; Baihaqi, A.; Bagio, B.; Data analysis and interpretation: Bagio, B.; Fazlina, Y.D.; Safrika, S.; and Writing and editing: Bagio, B.; Athaillah, T.; Safrika, S.; Atikah, Q.; Baihaqi, A.;

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