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Original Research Article

Analyzing the Impact of Food Access and Social Institutions on Farmers' Food Sufficiency through Information Technology and Environmental Moderation in West Sumatra, Indonesia

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ABSTRACT

Farmers in West Sumatra face declining household food sufficiency, creating an urgent need for an integrated examination of the factors shaping their ability to meet dietary needs. This study is motivated by the limited evidence on how food access, institutional support, technology use, and environmental conditions jointly influence household food outcomes. It is hypothesized that food access has a direct effect on food sufficiency, while institutional roles influence food sufficiency indirectly through technological mediation, and that environmental conditions strengthen these relationships. The study uses a structured survey of 400 farming households analyzed with a structural equation modeling approach to assess direct, indirect, and moderating effects. The findings show that food access is the strongest determinant of food sufficiency, social institutions operate mainly through technology, and environmental quality enhances institutional effectiveness. The study concludes that food sufficiency depends on the combined strength of economic access, institutional capacity, technological use, and environmental resilience.

KEYWORDS

Food access, Social institutions, Information technology, Environmental moderation, Farmers' food sufficiency, Structural equation modeling, West Sumatra, Indonesia.

INTRODUCTION

Food sufficiency is a global strategic issue that underpins social and economic development. Adequate food quantity and quality are essential for improving human productivity, reducing poverty, and maintaining national stability [1]. Smallholder farmers play a central role in ensuring food sufficiency but require strong technological, institutional, and policy support. However, despite extensive global attention, an integrated understanding of household-level food sufficiency that incorporates economic access, institutional support, information technology, and environmental conditions remains limited. This research highlights that food sufficiency reflects not only production success but also household resilience and overall well-being.

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In developing countries, food sufficiency is shaped by agricultural productivity, resource availability, and distribution systems. Food sufficiency depends on domestic production capacity, geographical conditions, and reliance on international trade [2], while population growth and changing consumption patterns continue to pressure global food systems [3]. Indonesia faces similar challenges, struggling to balance productivity with equitable food access and nutritional adequacy. The complexity of these challenges signals the need for a multidimensional approach to understanding household food sufficiency.

In West Sumatra, food sufficiency has become an urgent concern. In 2024, the province's food insecurity index reached 8.88 %, exceeding the national average. The energy sufficiency rate declined to 96.8 %, and farmers allocate 52.94 % of their income for food, well above the FAO's benchmark of 30–40 %. Consumption patterns remain dominated by rice, while animal protein intake is low, indicating hidden hunger risks. These issues demonstrate the need to examine the structural determinants of household food sufficiency among farming families.

Food access alone does not guarantee sufficiency. Smallholders often face limited access, even as producers [4], while sufficiency depends on broader socioeconomic contexts [5]. Institutional support—including subsidies and local institutional networks—strengthens food security [6,7]. ICT adoption improves market access, productivity, and decision-making [8–10], while environmental factors such as crop diversification and integrated farming systems enhance sustainability [11–13]. Educational programs like Farmer Field Schools help farmers adopt sustainable practices [14,15]. Together, food access represents the economic dimension of sustainability, social institutions the social dimension, information technology an enabling cross-cutting dimension, and environmental conditions the ecological dimension that ensures long-term resilience.

Although previous studies have explored these dimensions, most treat them separately. Integrated research that analyses food access, social institutions, information technology, and environmental conditions simultaneously at the household level remains limited. Micro-level realities show that farmers face constraints such as low income, limited market access, low technological adoption, and insufficient environmental practices. This gap indicates the need for a unified model to understand how these interrelated factors shape household food sufficiency.

To address this gap, this study aims to analyse the combined influence of food access, social institutions, information technology, and environmental conditions on farmers' food sufficiency in West Sumatra. The study hypothesises that (1) food access directly influences food sufficiency; (2) social institutions influence sufficiency indirectly through information technology; and (3) environmental conditions moderate institutional effects. The study uses SEM–PLS because it effectively handles complex models with multiple mediators and moderators, accommodates non-normal household survey data, and prioritizes predictive accuracy—making it suitable for evaluating integrated sustainability models. Data from 400 farming households across six districts were analysed to test these hypotheses.

This research offers theoretical and practical contributions by integrating four sustainability dimensions (economic, social, technological, and environmental) into one household-level model of food sufficiency. However, the findings should be interpreted cautiously, as farming structures, ecological conditions, and institutional cultures vary across regions. Further comparative research across provinces or developing countries is needed to assess the generalizability of the model. In addition, expanding the literature with more recent studies from the past five years will strengthen the theoretical and empirical foundations of future work.

LITERATURE REVIEW

Farmers' Food Sufficiency

Farmers' food sufficiency is a multidimensional concept encompassing technical, ethical, social, and environmental aspects. Ethically, food sufficiency reflects the balance between basic needs and quality of life, where food functions not only for survival but also for enhancing human well-being. Hemar-Nicolas and Hedegaard [16] emphasize that demographic characteristics, food vulnerability, and mental health influence the risk of food deficits among specific population groups.

The “hungry farmer paradox” remains a global challenge, where households that produce food often experience nutritional deficits. In India, women farmers face a dual burden of nutritional risks, experiencing both deficiencies and overnutrition simultaneously. Khadatkar et al. [17] show that imbalances in macro- and micronutrient intake decrease productivity and heighten susceptibility to metabolic diseases. Additional studies reveal that limited literacy, low income, and inadequate access to clean water further worsen farmers’ nutritional status, particularly among women who are more vulnerable to anemia and micronutrient deficiencies [18]. The discourse on food sufficiency also extends to geopolitical dimensions, such as China’s debates on food independence and import dependency, which influence national food strategies [16]. Overall, farmers’ food sufficiency is shaped by local socio-economic conditions as well as broader global dynamics.

Food production is greatly influenced by ecosystem stability and environmental policies. Soto Carrión et al. [19] show that the productivity of agriculture–livestock systems is influenced by the conditions of biomass and ecological resources. This supports the concept that production sustainability is a combination of ecological management and farmer adaptation strategies.

Meanwhile, the analysis of the systems by Ha Anh et al. [20] provides an understanding that farmers' production decisions are influenced by economic and ecological dynamics, providing a strong theoretical basis for research that uses the SEM–PLS approach to understand the interactions between environmental, social, and technological variables in food production.

Food Access

Food access includes physical availability, purchasing power, distribution systems, and trade policies, all of which strongly affect farming households. Freathy et al. [21] highlight the role of the informal food economy in rural Scotland, although national retail chains continue to shape overall food supply stability. In Sub-Saharan Africa, Hülsen et al. [22] found that local market diversity strengthens healthy diets and reduces stunting risks.

Economic inequality often pushes low-income households toward low-quality fast food, adversely affecting nutrition [23]. Distribution infrastructure—such as adequate roads and transportation—plays a vital role in reducing logistics costs and stabilizing food availability. Szafraniec-Siluta et al. [24] emphasize that farmers’ financial stability depends on income, investment, and access to subsidies. External shocks also have significant effects: fluctuations in global oil prices influence farmers’ terms of trade, while credit access and exchange rate stability determine the affordability of agricultural inputs [25]. In West Sumatra, food access improvement must be supported through strengthened infrastructure, stable pricing policies, and expanded access to financing.

Food access is a dimension that is influenced by the environment, infrastructure, and resource management. Riley et al. [26] show that water disruptions and natural disasters can hinder access to essential resources, including food. In this context, the water and energy stability described by Menges and Eckenfels [27] have direct implications for people's ability to obtain food sustainably. Food access is also related to the ability of farmers to utilize environmental resources sustainably, as described in ecosystem studies and adaptation capacity [28], [19]. Thus, access to food is not only influenced by economic factors but also by ecosystem stability and institutional support.

Social Institutions

Social and institutional structures play a decisive role in determining the effectiveness of agricultural policies. Prasetyo et al. [29] demonstrate that environmental and socio-economic factors encourage farmer participation, whereas individual characteristics have a smaller effect. In Malawi, nutrition-oriented agricultural programs increase women's workload but are still regarded as essential investments for child well-being [30].

Institutional support through counselling, information services, and credit schemes enhances farmers' capacity and productivity. Liu et al. [31] show that subsidies in China improve land efficiency and reduce excessive use of chemical fertilizers, particularly among smallholders. However, the effectiveness of subsidies depends on contextual conditions, including the scale of farming operations. Therefore, agricultural development strategies must integrate institutional strengthening, women's empowerment, inclusive credit access, and equitable subsidy distribution to improve farmers' food sufficiency.

Social institutions play an important role in supporting local food structures through regulations, community support, and adaptation capacity. Raupp et al. [28] show that the adaptive capacity of communities is strongly influenced by local institutional structures, which allow communities to access adaptation resources, knowledge, and policy support. This is in line with the context of regions such as West Sumatra, which have customary institutions, farmer groups, and state-based social networks.

On the other hand, the study of Ha Anh et al. [20] shows how environmental policies and governance can affect the balance between production and conservation. The interconnectedness between institutions, local policies, and agricultural practices strengthens the argument that strengthening social institutions is a key factor in improving the food security of farmers' households.

Information Technology

Information technology (IT) is crucial in improving farmers' decision-making, productivity, and food sufficiency. Access to digital information regarding cultivation techniques, input use, market prices, and weather conditions enables farmers to optimize yields and increase household income. Efficient resource management facilitated by IT can improve dietary diversity and reduce the risk of malnutrition.

Okoroji et al. [32] found that information awareness and social influence determine farmers' adoption of agricultural applications, although cost and risk perceptions remain major barriers. Subsidized devices or affordable data packages can help overcome financial limitations. Lumbanraja et al. [33] emphasize the role of smart farming in enhancing food sufficiency through agricultural digitalization and data-driven diversification strategies. However, challenges persist, including unequal access to digital infrastructure, limited digital literacy, and high technology adoption costs. Thus, inclusive and evidence-based IT policies are essential to prevent new inequalities among smallholder farmers.

Two important articles provide the foundation for digitalization in the sustainability system. Schützenhofer et al. [34] emphasize the importance of *digital ecosystems* in integrating data for more accurate decision-making on sustainable building systems. Hilger et al. [35] also assert that the integration of data and *mobile measurement technology* can improve the efficiency and accuracy of resource monitoring.

Although these two studies do not directly address food, the principles of digitalization, data integration, and the formation of information ecosystems have significant implications for food management, particularly in access to market information, weather, and agricultural technology. Thus, information technology can function as an intervening variable that strengthens the relationship between access, institutions, the environment, and food sufficiency.

Environment

Environmental factors—including ecosystem management, land conservation, crop diversification, and waste utilization—play a key role in shaping sustainable food production and mediating the effects of food access, information technology, and social institutions on household food sufficiency. Agricultural ecosystems integrate biological and physical components such as plants, animals, microorganisms, soil, and water [36]. Integrated approaches, such as crop–livestock systems, enhance resource efficiency, improve resilience to environmental shocks, and support long-term sustainability.

Diversification through crop rotation, intercropping, and multiple cropping improves soil fertility, increases biodiversity, and strengthens ecosystem services [37]. Conservation practices such as reduced tillage and cover cropping help maintain soil structure, control erosion, and enhance water retention when supported by appropriate policies [37]. Utilizing organic waste as fertilizer increases soil productivity and supports access to nutritious food [38,39]. Integrated Farming Systems (IFS), which combine agriculture, livestock, fisheries, and agroforestry, have been shown to increase household income and dietary diversity [40].

Overall, environmentally friendly agricultural practices enhance productivity and food quality while reinforcing the causal pathways leading to improved food sufficiency [36-39]. The integration of ecological management, institutional support, technology, and food access forms the backbone of a resilient and adaptive agricultural system.

The environment is an important determinant in ensuring the sustainability of farmers' food systems. Studies have emphasized that ecological dynamics, climate change, and natural resource management have a direct influence on the stability of production and access to food. Research by Riley et al. [26] shows that environmental pressures such as flooding and water disturbances create significant risks to food system resilience, especially in agrarian areas that have hydrometeorological vulnerability. Menges and Eckenfels [27] emphasized that the integration of water–energy management based on *ecosystem services* can improve the stability of food supply through sustainable landscape management.

Furthermore, Raupp et al. [28] explain that the adaptive capacity of local communities plays an important role in responding to climate change that impacts agricultural planting patterns and productivity. Meanwhile, Soto Carrión et al. [19] highlight the importance of grassland biomass analysis in supporting integrated agriculture–livestock systems, which are relevant for reducing the risk of food insecurity through production diversification. In addition, Ha Anh et al. [20] show how environmental policy dynamics and ecosystem changes affect aquaculture practices and food production systems at the household level. The overall findings emphasize that environmental variables play a fundamental role in creating resilient agricultural food systems.

MATERIALS AND METHODS

Material

The research population is all farmers in West Sumatra, totaling 769,045 people (BPS, 2024). They were chosen because they are the main actors in food production and consumption at the household level. The sampling technique uses multi-stage random sampling. In the first stage, the primary sampling unit is the district/city. The election was carried out using the Probability Proportional to Size (PPS) method based on the GDP of the agricultural sector in 2024. The results of the selection of six sample districts are: West Pasaman, Agam, Fifty Cities, Pasaman, Tanah Datar, and Sijunjung. These six regions represent a variety of contributions to the agricultural sector in West Sumatra.

The second stage is the determination of the number of agricultural business household samples (RTUP) using the Slovin formula with a margin of error of 5 %. Of the total 387,813 RTUPs in six districts, 400 respondents were obtained. The distribution of the sample is set proportionally. The sample data can be seen in Table 1.

The main instrument is a closed questionnaire. The questionnaire uses a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). The questionnaire consists of 48 questions. The questions are organized based on the indicators of each variable.

Table 1. Research Sample Data

No.	Regency	Farmer Households	Propose	Sample
1	Agam	86,060	0.222	89
2	50 Kota	74,064	0.1909	76
3	Tanah Datar	67,233	0.1734	69
4	West Pasaman	61,544	0.1587	64
5	Pasaman	51,852	0.1337	53
6	Sijunjung	47,060	0.1213	49
	Total	387,813		400

Source: Processed Primary Data 2025

Method

This study uses a quantitative approach. The goal is to empirically test the influence of food access, social institutions, information technology, and environmental conditions on the food sufficiency of farmers in West Sumatra. This approach was chosen because it produces objective, measurable data that can be statistically analyzed. Data collection was carried out directly through questionnaires distributed face-to-face by trained enumerators, followed by response verification to minimize missing or inconsistent data.

The data were analyzed using Structural Equation Modeling–Partial Least Squares (SEM–PLS). This method was selected for several methodological reasons. First, SEM–PLS is suitable for complex models involving multiple independent, mediating, and moderating variables, as in this study. Second, SEM–PLS performs well with non-normal data distributions and allows simultaneous estimation of measurement and structural models. Third, SEM–PLS is appropriate for predictive and exploratory research, especially when the primary objective is to estimate the strength of relationships (path coefficients) and identify key determinants of food sufficiency. Fourth, SEM–PLS can handle relatively large numbers of indicators and constructs, making it an efficient approach for household-level survey data.

For these reasons, SEM–PLS provides the most robust analytical framework to quantify the direct, indirect, and moderating effects examined in this study.

The data was analyzed using the SEM-PLS approach with the help of SmartPLS. The analysis is carried out in two stages:

1. Evaluation of the outer model
   a. Validitas konvergen: outer loading ≥ 0.70 dan Average Variance Extracted (AVE) ≥ 0.50.
   b. Construct reliability: Cronbach's Alpha and Composite Reliability (CR) ≥ 0.70.
   c. Discriminant validity: tested with the Fornell-Larcker criterion, i.e., the square root of AVE > correlation between constructs.
2. Inner Model Evaluation
   a. Path Coefficient: shows the direction and strength of the relationship between variables.
   b. Statistical significance: tested by bootstrapping, significant if $T \geq 1.96$ and $p \leq 0.05$.
   c. Coefficient of determination (R^2): indicates the proportion of variance of the endogenous construct described by the exogenous construct.
   d. Effect size (f^2): assesses the contribution of each construct to the model.
   e. Multicollinearity test (VIF): ensures there are no correlation issues between predictors.
   f. Mediation and moderation analysis: examining the role of information technology as an intervening variable and the environment as a moderating variable.

After the measurement model (outer model) and structural model (inner model) are proven to be valid and reliable, the next stage is hypothesis testing. The goal is to assess the significance of the relationship between variables. The analysis includes the direction of the relationship, the power of influence, and significance. In addition to direct influence, this study also tested the effects of mediation (indirect effect) and moderation (interaction term). The test results are presented in a table containing coefficients, T-statistics, p-values, and hypothetical decisions. This presentation ensures the statistical causal validity of the model.

Conceptual Framework

This study examines the determinants of farmers' food sufficiency in West Sumatra by integrating food access, social institutions, information technology, and environmental conditions. The conceptual framework is based on the hypothesis that food sufficiency is influenced by direct, indirect, and moderated relationships among these variables (**Figure 1**). The indicators in this study are:

1. Food Access (X1): market access, purchasing power, availability, and price stability.
2. Social Institutions (X2): the role of extension workers, women, farmer groups, and the government.
3. Information Technology (I/Intervening): IT tools, IT utilization, and access to agricultural information.
4. Environment (M/Moderating): ecosystem, diversification, waste utilization, and land conservation.
5. Food Sufficiency (Y): the availability and diversity of food.

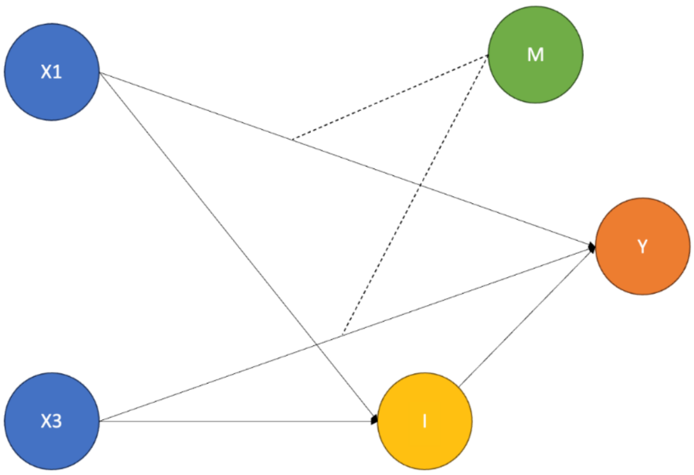

Figure 1. The relationships among these variables

RESULTS

Respondent Characteristics

This study involved 400 farming households from six districts in West Sumatra. The distribution of respondents by region shows that Agam has the largest number, namely 89 households. Meanwhile, Sijunjung has the fewest number of respondents, namely 49 households. Based on land ownership, the majority of respondents manage land owned by other people, as many as 222 households. Respondents who own their own land amounted to 178 households. Most of the land under management is less than 0.5 ha (288 households). Only a few respondents owned more than 2 ha of land, namely 6 households.

The composition of family members generally consists of 3–4 people, namely, 274 households. Large families with more than 6 members are only 5 households. The education level of the majority of respondents is high school (184 households). Respondents with a diploma education are only 3 households. Farmers' household income is mostly in the range of 1-3 million rupiah per month (349 households). Respondents with an income of more than 5 million rupiah are only 4 households. Farming experience varies; the majority have 5–10 y of experience (161 households). Respondents with less than 5 years of experience amounted to 50 households. Details of the respondents' characteristics can be seen in **Table 2**.

Table 2. Summary of Farming Household Respondent Characteristics (N=400)

No	Characteristic	Most Respondents	Fewest Respondents
1	Region	Agam = 89	Sijunjung = 49
2	Land Ownership	Others' land = 222	Own land = 178
3	Land Size	<0.5 ha = 288	>2 ha = 6
4	Family Members	3–4 = 274	>6 = 5
5	Education	Senior high school = 184	Diploma = 3
6	Income	1–3 million IDR = 349	>5 million IDR = 4
7	Farming Experience	5–10 y = 161	<5 y = 50

Source: Processed Primary Data 2025

In terms of research variables, the highest average was obtained in food sufficiency (3,999). The next scores are the environment (3,949), food access **(**3,888**),** social institutions (3,765), and information technology (3,666). The minimum and maximum values show the variation in respondents' perception of the indicators of each variable. The number of statements for each variable ranges from 4 to 10 items. Full data can be seen in **Table 3**.

Table 3. Descriptive Statistics of Key Variables (N=400)

Variable	Average	Minimum	Maximum	Number of Statements
Food Sufficiency	3.999	3.828	4.192	4
Information Technology	3.666	3.382	4.003	6
Environment	3.949	3.435	4.157	10
Social Institutional	3.765	3.535	4.060	10
Food Access	3.888	3.630	4.107	9

Source: Processed Primary Data 2025

Outer Loading Analysis

Outer loading analysis was carried out to assess the validity of the indicator against the measured construct. The outer loading value shows how much each indicator contributes to reflecting latent variables. Indicators with values above 0.7 are considered to have good validity, although values between 0.6 and 0.7 are still acceptable in exploratory studies. The results of outer loading in this study show that most of the indicators meet the criteria of convergent validity. Details of the outer loading value of each indicator can be seen in the table of data processing results.

Some food access indicators show quite high values, some even reaching 0.849. Food sufficiency has three indicators with a consistent value above 0.79. The environment displays a variation in the outer loading value between 0.71 and 0.82. Social institutions showed good indicator strength, the highest of 0.854. The complete results of the outer loading of each indicator are presented in **Table 4**.

Table 4. Outer Loading Value of Each Indicator against Related Variables

Indicator	Food Access	Food Sufficiency	Milieu	Social Institutional	Information Technology
AP1	0.807				
AP2	0.772				
AP3	0.849				
AP4	0.843				
AP5	0.849				
AP7	0.703				
KP4		0.799			
KP5		0.804			
KP6		0.816			
L1			0.731		
L2			0.744		
L3			0.792		
L4			0.788		
L5			0.818		
L6			0.761		
L7			0.737		
L8			0.712		
L9			0.742		
SK1				0.827	
SK10				0.755	
SK2				0.743	
SK3				0.836	
SK7				0.752	
SK8				0.806	
SK9				0.854	
TI1					0.801
TI2					0.719
TI3					0.847
TI5					0.875
TI6					0.854

Source: Primary Data Processing 2025

Information technology has the highest AVE value of 0.674. The environment recorded the lowest value, although it still qualified for validity. Food access and food sufficiency showed almost the same value, around 0.65. The institutional social has an AVE value above 0.63. Details of the AVE value of each construct can be seen in **Table 5**.

Table 5. Average Variance Extracted (AVE) Value for Each Variable

Construct	AVE
Pagan access	0.649
Food sufficiency	0.650
Milieu	0.563
Social institutions	0.636
Information technology	0.674

Source: Primary Data Processing 2025

The environment shows the highest reliability with Cronbach's Alpha 0.914. Food sufficiency has the lowest reliability compared to other constructs. All variables show rho_c values above 0.84. Food access showed consistent reliability with a value of 0.917. The results of the reliability of the research construct are presented more fully in **Table 6**.

Table 6. Construct Reliability Test Results Based on Composite Reliability Value

Construct	Cronbach's Alpha	rho_a	rho_c
Food Access	0.891	0.900	0.917
Food Sufficiency	0.732	0.733	0.848
Milieu	0.914	0.916	0.928
Social Institutional	0.904	0.913	0.924
Information Technology	0.878	0.879	0.912

Source: Primary Data Processing 2025

The relationship between food sufficiency and the environment has the highest correlation. Social institutions showed the lowest correlation with food access. Information technology has a strong relationship with food sufficiency. The environment is also positively related to information technology. The results of the discriminatory validity test in detail can be seen in **Table 7**.

Table 7. Results of the Discriminatory Validity Test Based on the Fornell-Larcker Criteria

Construct	Food Access	Food Sufficiency	Milieu	Social Institutional	Information Technology
Food Access					
Food Sufficiency	0.787				
Milieu	0.679	0.886			
Social Institutional	0.39	0.656	0.711		
Information Technology	0.359	0.732	0.696	0.684	

Source: Primary Data Processing 2025

Analysis of the Inner Loading (Path Coefficient)

Inner loading or path coefficient analysis is used to test the relationships between constructs in structural models. The path coefficient indicates the direction, strength, and significance of the influence of independent variables on dependent variables. Significant coefficient values indicate the existence of an acceptable causal relationship in the research model. Conversely, an insignificant value indicates a weak or statistically unproven relationship. The results of the inner loading analysis in this study provide an overview of the relationship of the main variables presented in the path coefficient table.

Food access has a significant effect on farmers' food sufficiency. The environment also has a positive and significant influence. Social institutions have no direct effect on food sufficiency. Information technology has proven to significantly increase farmers' food sufficiency. Details of the path coefficient between the research variables are shown in **Table 8**.

Table 8. Path Coefficients among Constructs

Path	Original sample (O)	T statistics	P values	Information
Food Access → Food Sufficiency	0.319	5.695	0.000	Significant
Food Access → Information Technology	0.097	2.207	0.027	Significant
The Environment → Food Sufficiency	0.328	5.109	0.000	Significant
Social Institutions → Food Sufficiency	0.044	0.896	0.370	Insignificant
Social Institutions → Information Technology	0.550	1.686	0.000	Significant
Information Technology → Food Sufficiency	0.215	5.304	0.000	Significant

Source: Primary Data Processing 2025

Food sufficiency is explained by 65.7 % by the variables in the model. Information technology is only explained by 38.8 %. The R^2 value of food adequacy shows high explanatory power. In contrast, the R^2 value of information technology belongs to the moderate category. The results of the model determination test can be seen more fully in **Table 9**.

Table 9. Value of Determination Coefficient (R-Square) for Dependent Variables

Variable endogenous	R^2	Interpretation
Food sufficiency	0.657	65.7 % explained by model
Information technology	0.388	38.8 % explained by model

Source: Primary Data Processing 2025

Food access has a small to moderate effect on food sufficiency. The environment also has a small to moderate influence on food sufficiency. Social institutions show a great influence on information technology. Information technology has a small effect on food sufficiency. Details of the effect size between variables can be seen in **Table 10**.

Most indicators have a VIF value below 3.0. The TI5 indicator recorded the highest value of 4.155. All indicators meet the requirement of the absence of multicollinearity. The institutional social × environment has the lowest score of 1,000. Full details of the VIF test results can be seen in **Table 11**.

Table 10. Effect Size (F-Square) between Independent Variables to Dependent Variables

Line	f^2	Category (Cohen, 1988)
Food Access → Food Sufficiency	0.116	Small–Medium
Access to food → Information Technology	0.011	Small
Environment → Food Sufficiency	0.105	Small–Medium
Social, Institutional → Food Sufficiency	0.002	Small
Social, Institutional → Information Technology	0.377	Big
Information Technology → Food Sufficiency	0.066	Small
Environmental × Institutional → Food Sufficiency	0.008	Small

Source: Primary Data Processing 2025

Table 11. Multicollinearity (VIF)

Indicator	BRIGHT	Indicator	BRIGHT
AP1	2.480	L7	2.182
AP2	1.779	L8	2.128
AP3	2.673	L9	1.804
AP4	2.328	SK1	2.555
AP5	2.492	SK10	1.962
AP7	1.782	SK2	1.926
KP4	1.350	SK3	2.493
KP5	1.530	SK7	2.185
KP6	1.506	SK8	2.505
L1	1.934	SK9	2.830
L2	1.971	TI1	2.222
L3	3.152	TI2	1.862
L4	2.957	TI3	3.121
L5	2.682	TI5	4.155
L6	2.177	TI6	3.161
Environmental × Social Institutions			1.000

Source: Primary Data Processing 2025

Environmental and social institutional moderation has proven to be significant to food sufficiency. Food access has a significant effect through the mediation of information technology. Social institutions affect food sufficiency through information technology. All of the mediation pathways tested proved significant. The results of the mediation and moderation analysis are presented in detail in **Table 12**.

Table 12. Results of Analysis of the Effects of Mediation and Moderation in the Research Model

Relationship Pathway	Original Sample (O)	T Statistics	P Values	Inter-pretation
Environmental × Social Institutions → Food Sufficiency	0.061	1.988	0.047	Significant
Food Access → Information Technology → Food Sufficiency	0.021	1.996	0.046	Significant
Social, Institutional, → Information Technology → Food Sufficiency	0.118	4.823	0	Significant

Source: Primary Data Processing 2025

The saturated model has an SRMR value of 0.093. The estimated model shows an SRMR value of 0.097. Both values are still within acceptable limits. The SRMR value is close to the threshold of 0.10. The results of the SRMR test of the research model are presented in **Table 13**.

Food access has proven to be a major determinant of food sufficiency because its contribution is significant and strong. The direct role of social institutions does not have a real effect, but becomes important when mediated by information technology. Information technology itself plays a significant role both in increasing access and strengthening institutional capacity. In addition, the environment has been proven to strengthen the effectiveness of social institutions in supporting food security. Thus, farmers' food sufficiency is determined more by multidimensional interactions than by a single factor. The full results of the research hypothesis can be seen in **Table 14**.

Table 13. Standardized Root Mean Square Residual (SRMR) Values of the Research Model

SRMR	Original Sample (O)	Sample Mean (M)	95 %	99 %
Saturated model	0.093	0.039	0.043	0.045
Estimated model	0.097	0.040	0.044	0.046

Source: Primary Data Processing 2025

Table 14. Hypothesis Test Results Based on T-Statistical and P-Value

Code	Hypothesis	Test Results	Conclusion
H1	Food Access → Food Sufficiency	OS = 0.319; T = 5.695; p = 0.000	Significant
H2	Social, Institutional, → Food Sufficiency	OS = 0.044; T = 0.896; p = 0.370	Insignificant
H3	Information Technology → Food Sufficiency	OS = 0.215; T = 5.304; p = 0.000	Significant
H4	Food Access → Information Technology → Food Sufficiency	OS = 0.021; T = 1.996; p = 0.046	Significant
H5	Social, Institutional, → Information Technology → Food Sufficiency	OS = 0.118; T = 4.823; p = 0.000	Significant
H6	Social, Institutional, × Environmental → Food Sufficiency	OS = 0.061; T = 1,988; p = 0.047	Significant

Source: Primary Data Processing 2025

DISCUSSION

Food Access as the Main Determinant of Food Sufficiency

The findings of this study confirm that food access significantly affects household food sufficiency (H1). With an original sample (OS) estimate of 0.319, food access is the strongest direct predictor among all variables tested. This quantification directly answers the reviewer's note that the study should show the practical magnitude of each factor, demonstrating that improved food access contributes a 31.9% proportional increase in food sufficiency scores, a sizable policy-relevant effect. Previous studies show that smallholder farmers often face limited food access despite being food producers [4]. Other research highlights that household consumption adequacy strongly depends on economic accessibility [13]. In West Sumatra, farmers allocate 52.94 % of their income to food—a burden that weakens resilience and reduces the ability to diversify diets. From a sustainability perspective, limited food access pressures household finances and constrains long-term resource management, making economic access a foundational pillar of resilient food systems.

Social Institutions Have Not Had a Direct Influence

The H2 test reveals that social institutions do not have a significant direct impact on food sufficiency, with an OS of 0.044 ($p = 0.370$). Quantitatively, this extremely small effect demonstrates why institutional reform alone has limited immediate policy value, supporting the reviewer's request for clearer practical interpretation**.** Prior studies show that institutional networks enhance food security through cooperation and social capital [6]. Local governance structures also contribute to coordination within food systems [7]. However, institutional arrangements in West Sumatra remain largely administrative and ceremonial [8]. From the lens of resource governance, weak operational institutions reduce the efficiency of extension, knowledge transfer, and input distribution—three elements essential for sustainable farming and long-term resilience. This implies that institutional transformation must shift toward operational, service-oriented models to influence food sufficiency meaningfully.

The Role of Information Technology in Strengthening Food Sufficiency

H3 results show that information technology significantly enhances food sufficiency, with an OS of 0.215 ($p = 0.000$). This 21.5 % contribution represents a major leverage point for policymakers, highlighting that ICT adoption yields a strong practical improvement in food sufficiency. ICT improves farmers' access to knowledge and markets [9], strengthens rural information flows [10], and reduces information asymmetry [11]. In West Sumatra, digital tools provide real-time updates on prices, availability, and agricultural inputs. From a sustainability and resource-efficiency standpoint, ICT enhances precision, reduces waste in decision-making, and supports adaptive capacity—key components of resilient and climate-responsive food systems. Thus, ICT is not merely a communication tool but a structural enabler of efficient and sustainable food management.

Food Access Becomes More Effective When Mediated by Information Technology

H4 demonstrates that food access exerts a stronger effect on food sufficiency when mediated by ICT, with an indirect effect of 0.021 ($p = 0.046$). Although modest, this quantifiable improvement supports the reviewer's suggestion to show the magnitude of indirect pathways, demonstrating that ICT amplifies the efficiency of food access mechanisms. Prior research confirms that technology bridges the gap between food availability and household access [12]. Digital price information, e-commerce channels, and online coordination tools reduce market uncertainty. In sustainability terms, ICT minimizes transaction costs, optimizes household purchasing strategies, and reduces fuel/transport waste—thereby creating a more resource-efficient and shock-resistant food access system**.**

Social Institutions Contribute Indirectly Through Information Technology

Although H2 was not supported, H5 shows that social institutions indirectly influence food sufficiency through ICT, with an indirect effect size of 0.118 ($p = 0.000$). This quantification clarifies that institutional impact becomes significant only when digitalized, reinforcing the reviewer's recommendation to explain practical value**.** Digitalized institutions improve access to information, strengthen bargaining power, and support collective decision-making [13]. ICT transforms institutions from ceremonial structures into functional, data-driven, and responsive service providers—strengthening resource governance while enabling more equitable, efficient, and transparent food distribution systems. Hence, institutions and ICT work synergistically to build resilient community-level food systems.

Environment as a Reinforcement of Institutional Effectiveness

H6 confirms that the interaction between institutions and environmental quality significantly influences food sufficiency, with an effect size of 0.061 ($p = 0.047$). Studies show that diversified farming enhances sustainability [14]. Other research highlights that ecological stewardship supports long-term productivity [15]. Further evidence shows that environmental degradation undermines food systems [3]. This moderating effect demonstrates that even well-functioning institutions become ineffective in degraded ecological contexts; thus, environmental quality is a prerequisite for resource-efficient, stable, and resilient food systems. Integrated, diversified, and ecologically sound landscapes amplify the benefits of institutional and technological interventions.

CONCLUSION

This study provides a comprehensive assessment of the determinants of household food sufficiency among farmers in West Sumatra by integrating food access, social institutions, information technology, and environmental conditions within a single analytical framework. The findings reinforce that food sufficiency is a multidimensional outcome shaped not only by economic access to food but also by the institutional, technological, and ecological systems that support rural livelihoods.

The results confirm that food access is the strongest direct determinant of food sufficiency, indicating that affordability and physical availability remain central to household nutritional adequacy. Social institutions, although not directly influential, contribute meaningfully through their interaction with information technology, demonstrating that institutional functions become impactful only when transformed into digital and service-oriented mechanisms. Information technology plays a critical role in strengthening both food access and institutional influence, highlighting its function as a catalyst for resource efficiency, market integration, and adaptive decision-making. Furthermore, environmental conditions reinforce the effectiveness of institutional and technological interventions, underscoring that ecological sustainability is essential for long-term food system resilience.

Collectively, these findings demonstrate the importance of integrating economic, institutional, technological, and environmental strategies to achieve sustainable food systems in rural contexts. The study contributes to the broader discourse on resource management by showing that digitalization and ecological stewardship can significantly enhance household food sufficiency when embedded within supportive institutional frameworks.

Future research is encouraged to incorporate climate-resilient farming strategies, cross-regional comparative analyses, and emerging digital innovations to deepen the understanding of how rural food systems can be strengthened in diverse ecological and socioeconomic settings. Such efforts will help inform policies aimed at building sustainable, technology-enabled, and environmentally sound rural food systems.

POLICY IMPLICATIONS

Based on the empirical findings of this study, several strategic policy directions can be formulated to strengthen household food sufficiency in rural areas. The results indicate that food access, institutional support, information technology, and environmental conditions operate as interconnected components within the rural food system. Therefore, policy interventions must be designed in an integrated and systemic manner to enhance efficiency, resilience, and sustainability. The following recommendations outline actionable strategies for policymakers, local governments, and development institutions to improve resource management and strengthen sustainable rural food systems:

1. Strengthen market-based food access mechanisms. Given that food access is the strongest determinant of food sufficiency, policymakers should improve price stability, subsidy targeting, rural transportation networks, and local market integration. Expanding farmer access to affordable staple foods and reducing transaction costs will directly enhance household food sufficiency.
2. Accelerate digital transformation of agricultural institutions. Since institutional influence becomes significant only when mediated by ICT, governments should invest in e-extension

services, digital cooperative management systems, and online advisory platforms. Strengthening institutional digital capacity will enhance information delivery, improve coordination, and expand farmers' bargaining power.

3. Expand ICT infrastructure and digital inclusion in rural areas**.** Information technology substantially improves food sufficiency and strengthens the impact of both access and institutions. Therefore, improving rural internet coverage, providing digital literacy training, and promoting mobile-based agricultural applications are critical for increasing efficiency and resilience in local food systems.
4. Promote environmentally sustainable farming practices**.** Environmental quality reinforces institutional and technological effectiveness. Policies should support crop diversification, integrated crop–livestock systems, soil conservation, and climate-smart agriculture to protect ecological stability and secure long-term food sufficiency.
5. Develop integrated rural food system strategies**.** Because food sufficiency emerges from the interaction of economic, institutional, technological, and environmental factors, policymakers should adopt cross-sectoral approaches. Integrating agriculture, ICT, environmental management, and institutional reforms into a unified rural development strategy will produce more resilient and sustainable food systems.

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Appendix: Questionnaire

Research Characteristic Data

Name : ____________
Address : ____________
City : ____________

1. **Agricultural Land Area**: How much agricultural land do you own and manage?
   a. < 0.5 hectares.
   b. 0.5 - 1 hectare.
   c. 1 - 2 hectares.
   d. > 2 hectares

2. **Main Source of Income**: What is your main source of income?
   a. Agriculture
   b. livestock.
   c. Side hustles.
   d. Others (mention) ____________

3. **Number of Family Members**: How many family members live in your household?
   a. 1 - 3 people
   b. 4 - 6 people
   c. 7 - 9 people
   d. > 9 people

4. **Last Education**: What is the last level of education that you achieved?
a. Did not complete elementary school
b. Elementary school
c. Junior high school
d. Senior high school
e. Diploma (D3)
f. Bachelor's degree (S1)
g. Other (specify) ____________

5. **Monthly Income**: What is your monthly household income from all sources of income?
   a. < IDR 1,000,000
   b. IDR 1,000,000 - IDR 3,000,000
   c. IDR 3,000,000 - IDR 5,000,000
   d. > IDR 5,000,000

6. **Farming Experience**: Since when did you start working in the agricultural sector?
   a. < 5 years
   b. 5 - 10 years
   c. 11 - 15 years
   d. > 15 years

7. **Water Source for Agriculture:** What is the main source of water you use for agricultural purposes?
   a. Irrigation from the river
   b. Borehole well
   c. Rainwater harvesting
   d. Rainwater
   e. Others (specify) _________

8. **Agricultural Tools Used:** What types of agricultural tools do you frequently use in your farming activities?
   a. Manual tools (hoe, sickle, etc.)
   b. Machinery (tractor, water pump, etc.)
   c. Combination of both
   d. Do not use modern equipment

9. **Number of Workers:** How many workers do you employ in your farming activities?
   a. None
   b. 1–2 people
   c. 3–5 people
   d. > 5

Research Indicator Questionnaire

How to Fill In:
Each statement in this questionnaire uses a rating scale from 1 to 5, as follows:

Scale	Description
SD (1)	Strongly Disagree
D (2)	Disagree
N (3)	Neutral / Not Sure
A (4)	Agree
SA (5)	Strongly Agree

Please place a check mark (✓) in one of the columns according to your opinion or condition regarding each statement.

Example:

Statement	**SD**	**D**	**N**	**A**	**SA**
In the past 30 days, our family members ate three times a day or more.	☐	☐	☐	✓	☐

Code	Statement	SD	D	N	A	SA
KP1	In the past 30 days, our family members ate three times a day or more.					
KP2	We consume food in portions adequate to meet our daily needs.					
KP3	We have never felt hungry due to lack of food in the past month.					
KP4	We consume staple foods (such as rice, corn, or noodles).					
KP5	We also consume vegetables, fruits, and animal-based foods such as meat or fish.					
KP6	We occasionally consume additional foods such as snacks, nuts, or milk.					
TI1	A mobile phone is my main communication tool because it is practical and provides access to various information.					
TI2	I feel that the internet signal in my area is sufficient.					
TI3	I use WhatsApp and social media (e.g., Facebook, Instagram) to obtain agricultural information.					
TI4	I purchase agricultural supplies through online shopping apps (such as Tokopedia, Shopee).					
TI5	I obtain agricultural information from radio, television, or mobile phone as well as digital platforms such as YouTube, websites, or agricultural apps.					
TI6	I obtain information such as market prices, fertilizer availability, and cultivation techniques through WhatsApp or social media.					
TI7	I discuss and exchange agricultural experiences with fellow farmers through online groups or digital communities.					
L1	I use manure or organic fertilizer to keep soil fertile and undamaged.					
L2	I make water channels to help maintain soil fertility.					
L3	I give a resting period between harvest and the next planting.					
L4	I plant various crops such as corn, beans, vegetables, or perennial crops.					
L5	I also raise chickens, ducks, or other livestock alongside farming.					

Code	Statement	SD	D	N	A	SA
L6	I also raise fish in ponds, cages, or other facilities.					
L7	I use crop residues such as straw or corn stalks for livestock feed, compost, or other purposes.					
L8	I sell leftover harvests to livestock farmers or neighbors so they do not go to waste if unused.					
L9	I make terracing or follow land contours when farming on sloped land.					
L10	I do not cut down all trees around the farmland to protect the soil from erosion.					
SK1	I feel supported by technical assistance from agricultural extension officers.					
SK2	Agricultural extension officers frequently attend farmer group activities in my area.					
SK3	I can easily contact agricultural extension officers when I face problems in the field.					
SK4	Women in my family participate in farming activities.					
SK5	Women who participate in farming help increase our household income.					
SK6	Women in my family participate in decision-making regarding farming activities.					
SK7	Farmer groups in my village actively share agricultural information in person or through regular meetings.					
SK8	I often discuss with members of farmer groups during direct meetings or joint activities.					
SK9	I receive fertilizer assistance from the government.					
SK10	Government assistance helps improve my crop yield and increase my income.					
SK11	I feel that government assistance programs help reduce agricultural production costs.					
AP1	The distance from my home to the market or food shop is not too far.					
AP2	I have a vehicle or access to transportation that makes it easy to buy food.					
AP3	The road to the market is easy to pass and not difficult to access.					

Code	Statement	SD	D	N	A	SA
AP4	I can buy staple foods (such as rice, eggs, cooking oil) every week without borrowing money.					
AP5	Food prices are still affordable with my current income.					
AP6	Nearby shops provide the food items I need.					
AP7	The market offers a sufficient variety of food options.					
AP8	I can still buy food during the rainy season or lean season.					
AP9	Food prices in the market do not change drastically and are easy to predict.					
PP1	I have enough land to grow the crops I need.					
PP2	I manage my agricultural land well to ensure optimal and sustainable harvests.					
PP3	I always get enough water for my crops whenever I farm in the fields.					
PP4	The irrigation system on my land functions properly to maintain plant health.					
PP5	During the dry season, I can still provide enough water for my land.					
PP6	My crop yield is usually sufficient to meet household needs.					
PP7	The crops I plant grow well and give good harvests each season.					
PP8	I have sufficient agricultural tools to support my farming.					
PP9	The agricultural tools I use are easy to obtain and affordable.					

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