Food Availability Model for Technology Adoption, Farmer Support, and Geographic Variability in North Sumatra

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Abstracts

This study aimed to assess the influence of geographic variation, farmer organization support, and technology adoption on food availability. Conducted in Percut District, Deli Serdang Regency, North Sumatra, from January to July 2023, the research employed partial least squares structural equation modeling (PLS-SEM) for data analysis. The findings reveal that food availability is significantly and positively influenced by institutional support, reflected in the number of farmer groups, the intensity and competency of extension services, and the availability of extension workers. Geographic variation, determined by factors such as harvested area, climate, pests, and natural disasters, also significantly enhances food availability. However, the adoption of agricultural technologies and irrigation systems has a limited effect on the food supply, which is further supported by food production, imports, reserves, and aid.

Keywords: Competence, Extension, Farmer groups, Whether variation, Worker.

1. Introduction

The application of appropriate technology has a substantial positive impact across various sectors (Sufa et al., 2019). The adoption of modern agricultural technologies plays a pivotal role in improving rural household welfare by increasing consumption expenditures, reducing poverty, enhancing food security, and strengthening resilience to risks (Asfaw et al., 2012). Innovation, especially in technology, is essential for addressing challenges in the food sector and ensuring sustainable development that meets community needs in the rapidly evolving modern world (JudiJanto et al., 2023). North Sumatra Province, Indonesia, renowned for its significant agricultural potential, is positioned as a key area for agricultural development in the Sumatra region (Fitriawan, 2023). However, the region encounters difficulties in fully realizing the benefits of technological advancements in agriculture.

Precision agriculture technologies, such as autosteer systems, introduce distinct challenges compared to other agricultural innovations, requiring customized strategies to facilitate their adoption (D'Antoni et al., 2012). Research indicates that the adoption of agricultural technologies is more prevalent in regions with well-established rural infrastructure, functioning markets, and a strong presence of commercial agriculture (Massresha et al., 2021). Despite the importance of agricultural technology adoption, persistent challenges remain (Sanders et al., 2022). Farmers in North Sumatra face significant barriers to technology adoption, including high initial investment costs, knowledge deficits, and limited access to broadband services, further complicated by geographic variability and a lack of clarity regarding the role of farmer organizations.

This study seeks to address these challenges by examining the adoption of agricultural technologies, the influence of farmer organizations, and the impact of geographic variability on food availability in North Sumatra (K. Dissanayake et al., 2022). By analyzing these factors, the research aims to develop a comprehensive model that will inform policy and practices to enhance food security in the region (Zhao et al., 2021).

The literature emphasizes the critical role of innovative technologies in advancing agriculture and tackling food security issues, with government investments in research and development fostering an ecosystem conducive to technological progress (Ong et al., 2022). However, a closer review of the literature reveals gaps that this study seeks to address. While precision agriculture offers benefits such as increased farm profitability and improved environmental sustainability, barriers like initial costs and knowledge deficits continue to hinder its adoption (Sanders et al., 2022). Additionally, the effectiveness of farmer organizations in North Sumatra in promoting technology adoption and improving food availability has not been adequately examined, leaving a significant gap in understanding.

This research aims to develop a holistic model of food availability in North Sumatra by investigating the factors influencing technology adoption, the effectiveness of farmer organizations, and geographic variability. Using a novel approach, the study examines the interactions between these elements to understand their impact on food availability. The findings are intended to assist policymakers in creating targeted interventions to enhance food security in the region.

The theoretical framework guiding this study is grounded in the Agricultural Knowledge and Innovation System (AKIS) and the Diffusion of Innovations theory. AKIS provides an in-depth understanding of how knowledge, innovation, and communication systems function within the agricultural sector (Bilali et al., 2021). This framework is instrumental in analyzing the role of farmer organizations in facilitating knowledge dissemination and supporting technological advancements. The Diffusion of Innovations theory elucidates the process by which new ideas and technologies spread within a community.

In conclusion, this study explores the adoption of agricultural technologies, the role of farmer organizations, and the influence of geographic variability on food availability in North Sumatra.

It aims to develop a comprehensive model that can inform policy and practice, offering critical insights for policymakers and stakeholders in designing effective interventions to improve food security in the region.

2. Theoretical Background

Theory/Calculation

The study, titled "Food Availability Model for Technology Adoption, Farmer Organization Support, and Geographic Variability: A Case Study in North Sumatra," is grounded in various theoretical frameworks and models that illuminate the intricate dynamics of food availability, technology adoption, and the role of farmer organizations.

Diffusion of Innovations Theory

One of the key theories informing this research is Everett Rogers' Diffusion of Innovations theory (2003), which suggests that the adoption of new ideas, behaviors, or technologies follows a predictable pattern over time within a social system. The theory classifies adopters into categories innovators, early adopters, early majority, late majority, and laggards based on their readiness to adopt innovations. Several factors influence the rate of adoption, including the perceived advantages of the innovation, its compatibility with existing values and practices, its complexity, the possibility of trialability, and the observability of results. In the context of North Sumatra, this theory explains the varying rates of agricultural technology adoption among farmers and the factors facilitating or hindering this process (Murray, 2009). The theory has been applied across various fields, including renewable energy adoption (Franceschinis et al., 2017), public health interventions (Moseley, 2004), organic agriculture (Tomaš-Simin & Janković, 2014), and higher education (Bakkabulindi, 2014). It emphasizes the role of communication channels, adopter preferences, attitudes, and social networks in the diffusion process (Manzano & Pérez, 2023).

Rogers' theory highlights the importance of innovation characteristics, adopter categories, diffusion networks, opinion leaders, and organizational adoption in influencing the diffusion process (Murray, 2009). It stresses the necessity of evaluating innovations for their suitability to specific contexts and stages of development (Greenhalgh et al., 2004). The theory has been instrumental in closing the gap between research and practice across various fields, facilitating the adoption of innovations (Murray, 2009).

In agriculture, the Diffusion of Innovations theory has played a crucial role in analyzing the adoption and dissemination of agricultural technologies, guiding research on innovation adoption, and explaining the dynamics of technology transfer in farming practices (Tomaš-Simin & Janković, 2014). The theory also extends to public health, where it informs strategies for implementing health interventions and promoting behavioral change (Moseley, 2004). Moreover, it has been revisited and endorsed for its foundational role in guiding research on innovation diffusion (Bakkabulindi, 2014).

Overall, the Diffusion of Innovations theory remains an essential model for understanding the spread of innovations, driving social change, and guiding the adoption of new practices across various sectors and disciplines.

Agricultural Knowledge and Innovation System (AKIS)

The Agricultural Knowledge and Innovation System (AKIS) framework underscores the significance of knowledge exchange and networks among key stakeholders in the agricultural sector, such as farmers, research institutions, extension services, and policymakers (Bilali et al., 2021). This framework is particularly relevant for analyzing the role of farmer organizations in North Sumatra. These organizations function as essential nodes within the AKIS, facilitating the dissemination of innovative practices and technologies, providing training and resources, and improving market access. By applying the AKIS framework, this study investigates how farmer organizations contribute to food availability and the effective adoption of agricultural technologies.

AKIS represents a vital concept for promoting innovation and knowledge transfer within agriculture. It involves intentional network interactions among various actors within the agricultural sector and along value chains (Knierim et al., 2015). The system fosters cooperation between stakeholders such as extension services, research institutions, professional organizations, and others, emphasizing collaboration and the sharing of knowledge (Knierim & Birke, 2023).

Research highlights the importance of the AKIS approach in the adoption of Good Agricultural Practices (GAPs) and in spreading innovations to farmers (Hasan et al., 2022). The evolving agricultural landscape, driven by changing societal demands, globalized food systems, and technological advancements, has transformed AKIS to better address contemporary challenges (Ingram et al., 2021). In European policy discussions, the AKIS concept has gained recognition for its macro-level role in fostering agricultural innovation and sustainability (Fieldsend et al., 2020).

Digitalization has had a profound impact on AKIS, reshaping the roles and capabilities of stakeholders who provide advice to farmers, and utilizing data analytics to optimize agricultural practices (Ingram & Maye, 2020). Several countries, including Italy and Bulgaria, have conducted studies to assess the dynamics, incentives, governance, and efficiency of their respective AKIS to enhance innovation and the application of knowledge in agriculture (Bachev, 2020; Materia, 2012).

Furthermore, the AKIS framework has played a key role in fostering multi-actor co-innovation partnerships within European agriculture, promoting diversity while identifying common features among organizational innovation systems (Fieldsend et al., 2020). In countries like Bulgaria, the governance, efficiency, and development of AKIS have been extensively examined to pinpoint needs and implement targeted interventions (Bachev, 2020; BACHEV, 2023). In conclusion, the Agricultural Knowledge and Innovation System (AKIS) is a critical mechanism for promoting collaboration, knowledge exchange, and innovation within agriculture. By fostering partnerships, enhancing governance, and addressing emerging challenges, AKIS plays a central role in advancing sustainable agricultural development and improving the sector's competitiveness.

Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework (SLF) provides a comprehensive approach to understanding how households sustain their livelihoods by emphasizing the interaction between different forms of capital, including human, social, financial, natural, and physical (Wubayehu, 2020). In the context of this study, SLF is employed to examine how the adoption of technology and support from farmer organizations can strengthen farmers' livelihood strategies, thereby enhancing food availability. Additionally, it offers insights into the resilience of farming households to environmental and economic shocks, which is particularly pertinent given the geographic variability in North Sumatra.

The SLF serves as an extensive analytical tool that evaluates and improves livelihoods by considering various factors influencing sustainable development. The framework addresses multiple dimensions such as livelihood assets, vulnerability context, policies, institutions, processes, livelihood strategies, and outcomes (Wubayehu, 2020). It recognizes the critical role of natural resource capital in rural livelihoods and acknowledges the impact of environmental stressors on livelihood stability and vulnerability (Newman et al., 2020).

SLF has been applied across diverse contexts, including community-based tourism, disaster risk reduction strategies, and sustainable land use change scenarios (Alexander et al., 2006; Kunjuraman, 2022; Pasanchay, 2021). The framework emphasizes the importance of livelihood diversification, cultural adaptation, and the role of indigenous knowledge in promoting sustainable livelihoods (Arumdati, 2023; Shang et al., 2021). It highlights the relationship between livelihood capital, strategies, and outcomes, demonstrating how various factors contribute to livelihood sustainability (Apine et al., 2019; Pratiwi et al., 2022).

Studies utilizing the SLF have examined shifts in rural livelihoods, particularly in resource-dependent communities, and assessed the effects of environmental and health risks on sustainable livelihoods (Nayak, 2017; Yang et al., 2021). Through the application of SLF, researchers have been able to evaluate poverty alleviation strategies, assess the livelihood sustainability of farm households, and explore the sensitivity of livelihood strategies to different forms of capital (Deng et al., 2018; Mao et al., 2020; Su et al., 2021). Additionally, SLF has been crucial in examining the impact of ecotourism on rural households and in developing sustainable livelihood models for community-based ecotourism (Kunjuraman, 2022; Shi et al., 2022). Overall, the Sustainable Livelihoods Framework remains a valuable tool for understanding, analyzing, and enhancing livelihoods across various contexts, offering a holistic approach to sustainable development and resilience.

Socio-Ecological Systems (SES) Framework

The Socio-Ecological Systems (SES) Framework is an analytical tool that comprehensively examines the interactions between human societies and ecosystems, highlighting the interconnectedness and interdependence of social and ecological components. This framework incorporates various dimensions, such as governance, institutional analysis, and the dynamics of social-ecological systems (McGinnis & Остром, 2014; Ostrom, 2009). SES models offer a valuable approach for understanding the relationships between humans and nature, addressing both socio-economic and ecological dimensions (Vigna et al., 2021).

Researchers have applied the SES Framework across a range of contexts, including forest fire risk management, food systems research, and cross-sector partnerships for developing sustainable business models (Dentoni et al., 2020; Iqbal et al., 2021; Marshall, 2015). The framework facilitates interdisciplinary communication on sustainable resource management and appropriation, promoting a holistic understanding of common-pool resources (Marshall, 2015). By adopting a complex adaptive systems perspective, the SES Framework enables researchers to explore how sustainable business models can enhance socio-ecological resilience through strategic partnerships (Dentoni et al., 2020).

Furthermore, the SES Framework has been instrumental in analyzing long-term social-ecological research, marine protected areas, and the vulnerability of socio-environmental systems (Collins et al., 2010; Gallacher et al., 2016; Laterra et al., 2016). By integrating social and ecological dynamics, the framework supports the assessment of management performance, social-ecological benefits, and sustainability outcomes in various contexts (Picone et al., 2020). In addition, the SES Framework has been applied to studies on disability trends, pastoral systems, and water management, demonstrating its versatility in addressing a wide array of socio-ecological challenges (Gu et al., 2014; Kakinuma et al., 2019; Ojiem et al., 2006). Overall, the Socio-Ecological Systems Framework serves as an essential tool for analyzing the complex interactions between human societies and ecosystems, guiding research, policy development, and sustainable management practices in diverse socio-ecological contexts.

Integration of Theoretical Frameworks

The integration of these theoretical frameworks establishes a strong foundation for the study. The Diffusion of Innovations theory offers valuable insights into the patterns and determinants of technology adoption among farmers. The AKIS framework underscores the crucial role of farmer organizations in promoting innovation adoption and enhancing food availability. Meanwhile, the Sustainable Livelihoods Framework and the Socio-Ecological Systems framework collectively provide a comprehensive understanding of the broader socio-economic and environmental contexts within which these processes unfold. By combining these theoretical perspectives, the study aims to develop a nuanced model of food availability that captures the interactions between technology adoption, farmer organization support, and geographic variability. This integrated approach enables a more in-depth analysis of the compounded effects of these factors on food security in North Sumatra, offering significant insights for policymakers and stakeholders.

Related Theories and Empirical Studies

Empirical research has highlighted the crucial role of technology adoption in improving agricultural productivity and food security. For instance, (Asfaw et al., 2012) demonstrated that the adoption of modern agricultural technologies enhances household welfare by increasing consumption expenditure and reducing poverty. Similarly, (Massresha et al., 2021) found that technology adoption is more widespread in regions with well-developed infrastructure and markets, underscoring the importance of supportive regional policies.

Studies on farmer organizations have also shown their vital role in providing farmers with essential resources, training, and market access (Belay & Neway, 2021; Tesfay, 2020). These organizations help facilitate the shift toward sustainable agricultural practices by incorporating knowledge and innovation systems (Bilali et al., 2021). Additionally, geographic variability has a significant impact on agricultural practices and food security, as local environmental conditions shape the success of technology adoption (Zhao et al., 2021).

In conclusion, the theoretical and empirical foundations presented by these frameworks and studies emphasize the need for a multifaceted approach to understanding food availability in North Sumatra. By addressing the interconnected factors of technology adoption, farmer organization support, and geographic variability, this study aims to contribute to the development of effective strategies for improving food security in the region.

3. Materials and Methods

Quantitative Research Methods

This study adopts a quantitative research design to construct a comprehensive model of food availability in Percut District, Deli Serdang Regency, North Sumatra, conducted between January and July 2023. The model focuses on the key factors of technology adoption, support from farmer organizations, and geographic variability. A cross-sectional survey method was used to gather data from farmers across various sub-regions in North Sumatra. To analyze the relationships among the variables and test the proposed hypotheses, Structural Equation Modeling (SEM) was performed using Smart PLS.

The study concentrates on smallholder farmers in North Sumatra engaged in diverse agricultural activities. A stratified random sampling approach was utilized to ensure adequate representation of different geographic regions and agricultural practices. The sample size was determined to meet the requirements of SEM, with a target of at least 300 respondents to ensure robust statistical analysis. Data collection involved the distribution of questionnaires to 100 respondents, derived from the total population of 357 paddy farmers in Percut District, which constituted the study's population.

Data Collection

Data collection involves administering structured questionnaires to the selected farmers. The questionnaire is designed to capture detailed information on the following areas:

1. Technology Adoption: Types of agricultural technologies adopted, the rate of adoption, factors influencing adoption, and the impact on food production and productivity.

2. Farmer Organization Support: Structure, functions, and activities of farmer organizations, the support provided to farmers, and the perceived impact on food availability.

3. Geographic Variability: Environmental, climatic, and soil conditions, and their influence on agricultural practices and food availability.

The questionnaire includes both closed-ended and Likert-scale questions to quantify the variables of interest. Data collection is conducted through face-to-face interviews with the farmers, ensuring clarity and completeness of responses.

Data Codification Process

The collected data is analyzed using Smart PLS (Partial Least Squares Structural Equation Modeling). PLS-SEM is selected due to its capability to manage complex models and its suitability for exploratory research with smaller sample sizes. The analysis follows these steps:

1. Measurement Model Assessment: The reliability and validity of the measurement scales are evaluated. This involves assessing internal consistency reliability (using Cronbach's alpha and composite reliability), convergent validity (through average variance extracted), and discriminant validity (using the Fornell-Larcker criterion).

2. Structural Model Assessment: The hypothesized relationships between the constructs are tested. Path coefficients are estimated to assess the direct and indirect effects of technology adoption, farmer organization support, and geographic variability on food availability. The significance of these path coefficients is evaluated through bootstrapping techniques with 5,000 resamples.

3. Moderating Effects: The potential moderating role of geographic variability on the relationships between technology adoption, farmer organization support, and food availability is examined. Interaction terms are incorporated into the model to test these moderating effects.

4. Model Fit and Predictive Relevance: The overall model fit and predictive relevance are assessed using indicators such as R-squared, Q-squared, and the Goodness-of-Fit index.

Ethical Considerations

Ethical approval was secured from the appropriate institutional review board prior to the initiation of the study. Informed consent was obtained from all participants, ensuring they were fully informed about the study's purpose, procedures, and their rights, including the right to withdraw at any point. Data confidentiality was upheld by anonymizing responses and securely storing all collected data.

The study acknowledges certain limitations, including the potential biases inherent in self-reported data and the constraints of the cross-sectional design, which limits causal inference. Nevertheless, the application of SEM and rigorous statistical techniques mitigates some of these limitations.

This research method adopts a systematic approach to examining the factors influencing food availability in North Sumatra. By utilizing Smart PLS SEM, the study aims to offer a detailed analysis of the interactions between technology adoption, farmer organization support, and geographic variability, contributing valuable insights to the fields of agricultural development and food security.

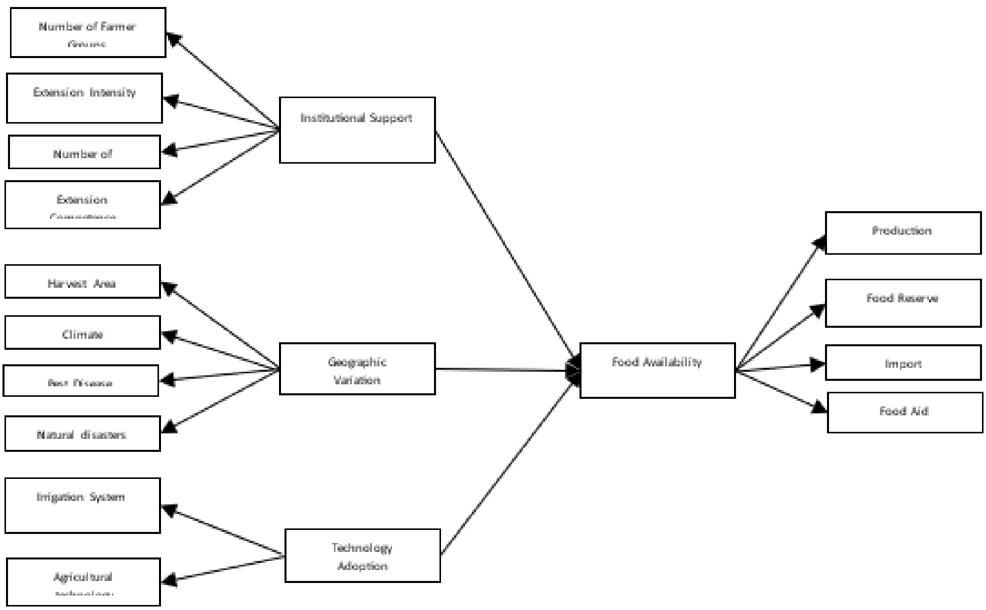

Figure 1. Diagram of Ethical Considerations

Outer model analysis

This model specifies the relationship between latent variables and their corresponding indicators. In essence, the outer model defines how each indicator is associated with its respective latent variable. The following tests are conducted on the outer model:

1. Convergent Validity: Convergent validity is assessed by the loading factor of the latent variable and its indicators, with an expected value greater than 0.7.

2. Average Variance Extracted (AVE): AVE represents the average percentage of variance explained by the indicators of a variable, serving as a summary of the convergent validity of the indicators. For adequate convergent validity, the AVE value should exceed 0.5.

3. Composite Reliability: A composite reliability value greater than 0.7 indicates a high level of data reliability.

Cronbach's Alpha, the reliability test is further supported by Cronbach's alpha, with an expected value exceeding 0.6 for all constructs.

Inner model

The inner model is evaluated by examining the percentage of variance explained, specifically through the R-squared (R^2) value. Changes in the R^2 value are used to assess the impact of independent latent variables on the dependent latent variable, determining whether the effect is substantive. As outlined by Colton, the strength of the relationship between two variables is categorized into four levels, as presented in Table 1.

Table 1. R-Square scale.

R-Square	Relationship strength
0.00–0.25	Weak relationship
0.25–0.50	Medium relationship
0.51–0.75	Strong relationship
0.76–1.00	Very strong/Perfect relationship

4. Results

The validity test evaluates the accuracy of a questionnaire. In this study, validity testing was conducted using convergent validity and the Average Variance Extracted (AVE). Convergent validity was employed to assess the measurement model, with indicator reflections evaluated based on the correlation between item scores or component scores, as calculated by PLS. An individual reflection is considered strong if it demonstrates a correlation greater than 0.7 with the corresponding construct. However, according to Chin (1998), for research in the early stages of measurement scale development, a loading value between 0.5 and 0.6 is considered acceptable. The validity test results indicate that all 14 indicators were valid and utilized (Table 2).

This study employed two types of reliability tests: Cronbach's alpha and composite reliability. Cronbach's alpha measures the lower-bound reliability. The test results demonstrated that all instruments were reliable, with both Cronbach's alpha and composite reliability scores exceeding 0.7 (Table 3).

Table 2. Validity test results

Variable		Outer loading	AVE	Description
Institutional support	X1.1	0.788	0.672	Valid
	X1.2	0.988		Valid
	X1.3	0855		Valid
	X1.4	0.681		Valid
Geographic variation	X2.1	0.660	0.771	Valid
	X2.2	0.806		Valid
	X2.3	0.803		Valid
	X2.4	0.968		Valid
Technology adoption	X3.1	0.871	0.648	Valid
	X3.2	0.999		Valid

Food availability	Y.1	0.757	0.763	Valid
	Y.2	0.747		Valid
	Y.3	0.815		Valid
	Y.4	0.994		Valid

Table 3. Reliability test results

Variable	Cronbach alpha	Composite reliability	Description
Institutional support	0.878	0.911	Reliable
Geographic variation	0.926	0.941	Reliable
Technology adoption	0.953	0.944	Reliable
Food availability	0.922	0.948	Reliable

Convergent test validity after modification

The figure below presents the results of the PLS-SEM model calculation after removing indicators that did not meet the required loading factor threshold. As depicted in Figure 2, the factor loading values for the indicators in each variable exceeded 0.6, allowing the analysis to proceed to the discriminant validity test.

R-square test

The coefficient of determination test (R-square) is used to assess the extent to which the endogenous variable is influenced by other variables. According to the data analysis conducted using the Smart PLS program, the R-square value obtained is shown in Table 4. The results indicate an R-square value of 0.978 for food availability (Y), meaning that institutional support, geographic variation, and technology adoption explain 97.8% of the variance in food availability, while the remaining 2.2% is influenced by other variables not addressed in this study.

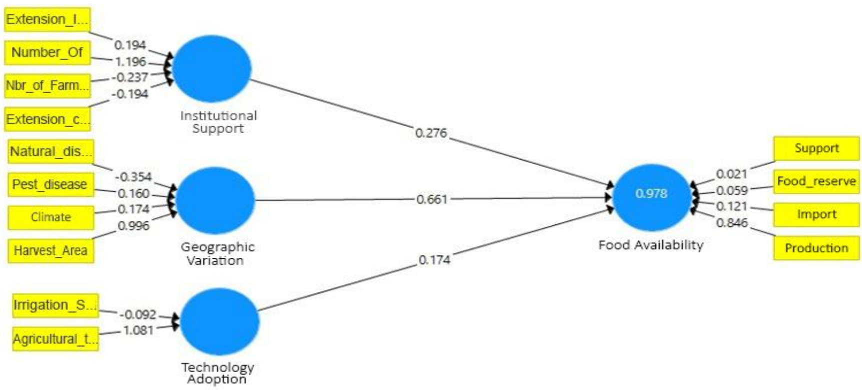

Figure 2. SEM-PLS Output Results

Source: Processed by Researchers (2024)

Table 4. R-square table.

	R-Square	R-Square Adjusted
Food Availability	0.978	0.973

Inner model analysis

Hypothesis testing is conducted by examining the t-statistic and probability values. To test the hypothesis at a 5% significance level (alpha), the t-statistic is compared against the critical value from the t-table.

Table 5. Inner model analysis results.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T-statistics (|O/STDEV|)	P-values
Institutional support on food availability	0.476	0.316	0.316	2.874	0.038
Geographic variation on food availability	0.661	0.570	0.385	6.716	0.009
Technology adoption on food availability	0.174	0.155	0.238	0.729	0.467

An analyzed effect of institutional support on food availability showed that the P-value was 0.038, which is smaller than 0.05; the t-statistic value was 2.874, which is greater than 1.960; and the beta score was 0.476 (Table 5). It is shown that institutional support has a significant positive effect on food availability. The same result is also shown by examining geographic variation effects with P-value, the statistic value, and beta score respectively are 0.009, 6.716, and 0.661. Yet, different results showed in technology adoption factors. It because the P-value is 0.467 (<0.05), the t-statistic value is 0.729 (<1.960), and the beta score is 0.174, consequently, technology adoption has no effect on food availability.

5. Discussion

The analysis of the structural equation model (SEM) using Smart PLS yielded important insights into the relationships between institutional support, geographic variation, technology adoption, and food availability in North Sumatra. The key findings are summarized as follows:

The measurement model was evaluated for reliability and validity. All constructs had outer loadings exceeding the acceptable threshold of 0.60, demonstrating good indicator reliability.

The average variance extracted (AVE) values were all above 0.50, confirming convergent validity. The constructs Institutional Support, Geographic Variation, Technology Adoption, and Food Availability exhibited high composite reliability and Cronbach's alpha values, indicating strong internal consistency and reliability (Table 1).

1. Institutional Support: Outer loadings ranged from 0.681 to 0.988, with an AVE of 0.672.

2. Geographic Variation: Outer loadings ranged from 0.660 to 0.968, with an AVE of 0.771.

3. Technology Adoption: Outer loadings were 0.871 and 0.999, with an AVE of 0.648.

4. Food Availability: Outer loadings ranged from 0.747 to 0.994, with an AVE of 0.763.

Structural Model

The assessment of the structural model revealed high R-squared values for food availability (R^2 = 0.978, adjusted R^2 = 0.973), indicating that the model accounts for a substantial portion of the variance in food availability. The path coefficients, T-statistics, and P-values were analyzed to evaluate the hypotheses.

1. Institutional Support and Food Availability: The path coefficient was 0.476, with a T-statistic of 2.874 and a P-value of 0.038, demonstrating a significant positive relationship between institutional support and food availability.

2. Geographic Variation and Food Availability: The path coefficient was 0.661, with a T-statistic of 6.716 and a P-value of 0.009, confirming a significant positive relationship between geographic variation and food availability.

3. Technology Adoption and Food Availability: The path coefficient was 0.174, with a T-statistic of 0.729 and a P-value of 0.467, indicating that the relationship between technology adoption and food availability was not statistically significant.

These results offer valuable insights into the factors affecting food availability in North Sumatra, underscoring the pivotal roles of institutional support and geographic variation. The implications of these findings are discussed below.

Institutional Support and Food Availability

The significant positive relationship between institutional support and food availability highlights the crucial role of farmer organizations and other institutional bodies in improving food security. These institutions provide vital resources, training, and market connections that empower farmers and

enhance agricultural productivity. These findings are consistent with previous research that underscores the critical role of institutional support in agricultural development (Belay & Neway, 2021; Tesfay, 2020). The high reliability of the institutional support construct (Cronbach's alpha = 0.878, composite reliability = 0.911) further confirms the robustness of these results.

Geographic Variation and Food Availability

Geographic variation was identified as having the most significant impact on food availability, as evidenced by the highest path coefficient and T-statistic. This finding underscores the critical role of environmental, climatic, and soil conditions in shaping agricultural practices and food production. Regions with favorable conditions tend to experience stronger food security, whereas those with less favorable conditions encounter greater challenges. This result aligns with the socio-ecological systems framework, which emphasizes the interplay between human and ecological systems in determining agricultural outcomes (Ostrom, 2009).

Technology Adoption and Food Availability

Contrary to expectations, the relationship between technology adoption and food availability was not statistically significant. This outcome may be attributed to several factors, including obstacles to effective technology adoption, such as high initial costs, knowledge gaps, and limited access to essential infrastructure (Sanders et al., 2022). Although technology adoption plays a critical role in improving agricultural productivity, these barriers must be overcome to fully realize its potential.

Interaction Effects

The study hypothesized that the interaction between technology adoption, institutional support, and geographic variation would produce a compounded effect on food availability. However, the findings reveal that institutional support and geographic variation independently have a more significant impact on food availability than technology adoption. This suggests that, although technology adoption is important, its effectiveness may be enhanced when reinforced by robust institutional frameworks and favorable geographic conditions.

6. Conclusions

The findings of this study offer a comprehensive understanding of the factors affecting food availability in North Sumatra. Institutional support and geographic variation emerge as key determinants of food security, while the influence of technology adoption requires further investigation, particularly in overcoming barriers to its effective implementation. These insights can assist policymakers and stakeholders in crafting targeted strategies to improve food security in the region, highlighting the importance of strong institutional frameworks and tailored approaches to address geographic disparities. Future research should prioritize longitudinal studies to clarify causal relationships and examine the long-term effects of these factors on food availability.

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