West Science Agro
Vol. 3, No. 04, November 2025, pp. 298~314

The Influence of Ethnoecological Values, Agricultural Biodiversity Management, and Socio-Cultural Adaptation on Sustainable Agricultural Performance in Eastern Indonesia

Trees A. Pattiasina[1], Darmawanto Uria[2], Yohanes Kamakaula[3], Agatha W. Widati[4]
Agribusiness Study Program, Faculty of Agriculture, University of Papua

Article Info

Article history:

Received November, 2025
Revised November, 2025
Accepted November, 2025

Keywords:

Ethnoecological values; Agricultural biodiversity management; Socio-cultural adaptation; Sustainable agriculture; Eastern Indonesia.

ABSTRACT

This study investigates the influence of Ethnoecological Values (EV), Agricultural Biodiversity Management (ABM), and Socio-Cultural Adaptation (SCA) on Sustainable Agricultural Performance (SAP) among smallholder farmers in Eastern Indonesia. Using a quantitative research design with 120 respondents, data were collected through structured questionnaires based on a five-point Likert scale and analyzed using Structural Equation Modeling–Partial Least Squares (SEM-PLS 3.0). The results reveal that ethnoecological values significantly enhance agricultural biodiversity management and socio-cultural adaptation, both of which, in turn, have positive and significant effects on sustainable agricultural performance. Agricultural biodiversity management and socio-cultural adaptation also serve as partial mediators, translating traditional ecological knowledge into practical sustainability outcomes. The model explains 69% of the variance in sustainable agricultural performance, indicating a strong explanatory power. These findings confirm that sustainability in Eastern Indonesia is culturally and ecologically embedded, arising from the synergistic interaction between traditional values, biodiversity stewardship, and adaptive social systems. The study contributes theoretically by integrating ethnoecology and socio-ecological systems frameworks into empirical sustainability models, and practically by recommending culturally grounded and biodiversity-based strategies for agricultural policy and community development.

Corresponding Author:

Name: Trees A. Pattiasina
Institution: Agribusiness Study Program, Faculty of Agriculture, University of Papua
Email: ta.pattiasina@unipa.ac.id

1. INTRODUCTION

Agriculture in Eastern Indonesia represents one of the most vital sectors for regional livelihood, food security, and ecological resilience. The region's vast natural resources and cultural diversity provide a unique foundation for understanding how traditional knowledge systems and modern sustainability practices coexist. However, despite this potential, many agricultural communities in Eastern Indonesia continue to face challenges related to declining productivity, biodiversity loss, climate variability, and socio-economic vulnerability. Addressing these challenges requires an integrative approach that recognizes the role of local wisdom, ethnoecological values, and socio-cultural adaptation in shaping sustainable agricultural performance. Traditional knowledge systems, such as the Subak irrigation system and other indigenous practices, play a vital role in sustaining agricultural productivity while preserving ecological balance. The Subak system in Bali, based on the Tri Hita Karana philosophy, exemplifies the integration of traditional wisdom with modern agricultural techniques, promoting ecological sustainability and community cohesion [1]. Similarly, traditional practices like crop rotation and organic fertilization align with sustainability principles but require enhancement through modern technologies such as precision irrigation [2]. Local culture significantly influences farmers' adaptation strategies to climate change, utilizing traditional knowledge and cultural values to strengthen community resilience [2]. Indigenous communities in regions such as Banten and West Java also practice sustainable farming under traditional guidance, maintaining soil fertility and ecological balance[3]. Biodiversity conservation remains crucial for sustaining livelihoods in Eastern Indonesia, where innovative approaches are needed to balance development and conservation [4]. Thus, integrating local knowledge into policy planning and capacity development is essential for enhancing climate change adaptation, socio-economic resilience, and sustainable agricultural transformation [5]

Ethnoecological values—defined as the culturally embedded knowledge, beliefs, and practices that guide human–environment interactions—play a central role in how rural communities perceive and manage their agricultural landscapes [6], [7]. In the context of Eastern Indonesia, these values are reflected in traditional land-use systems, community rituals, and indigenous rules that govern resource utilization. Farmers' adherence to ethnoecological principles, such as respect for soil fertility cycles, protection of sacred forests, and rotational cropping, not only reflects cultural identity but also ensures ecological sustainability. These practices, transmitted across generations, serve as adaptive management strategies that align human livelihood with environmental integrity. Indigenous communities in Indonesia possess a wealth of traditional ecological wisdom promoting sustainable resource management and conservation rooted in spirituality [8]. Practices such as rotational farming and fishing allow natural regeneration, maintaining land productivity for future generations [8]. In West Java, traditional agroforestry systems have evolved under population and economic pressures while still integrating local ecological knowledge [9], suggesting that merging traditional practices with scientific understanding can strengthen sustainable agriculture [9]. Likewise, the Tana Toraja community in South Sulawesi integrates cultural activities with farming practices, employing paddy-fish and rice-livestock systems that embody a holistic land management approach [10]. However, modernization threatens these systems, as observed in West Papua, where land clearance and infrastructure expansion disrupt traditional ecological practices [11]. Despite these pressures, customary laws and rituals continue to sustain environmental management and conservation, underscoring the enduring relevance of ethnoecological values in maintaining both cultural and ecological resilience [11].

Agricultural biodiversity management—the systematic conservation and utilization of crop and livestock diversity—serves as a crucial pillar for sustainable farming in Eastern Indonesia. Diverse agroecosystems provide natural resilience against pests, diseases, and climatic fluctuations, ensuring the long-term stability of food systems. Traditional polyculture and the cultivation of local crop varieties play a significant role in preserving agro-biodiversity, allowing communities to maintain both ecological and cultural heritage. However, the increasing adoption of monocultures and dependence on external agricultural inputs have eroded this diversity, diminished ecological resilience and reducing socio-economic adaptability. Strengthening biodiversity management through community-based initiatives and integrating traditional ecological knowledge is therefore essential for enhancing agricultural sustainability and maintaining the delicate balance between productivity and ecosystem health. Agricultural biodiversity contributes to resilience by protecting and restoring ecosystems, sustainably managing soil and water resources, and diversifying farming systems [12]. Traditional practices, such as the use of stress-tolerant crops and agroforestry systems, remain central to sustaining biodiversity and community resilience [12]. Indigenous knowledge systems, accumulated through generations, serve as adaptive strategies to cope with climatic change, and integrating this knowledge with scientific research can further strengthen sustainable livelihoods [13].

Socio-cultural adaptation also plays a vital role in sustaining agricultural performance amid changing environmental and market conditions. Adaptation involves the ability of local communities to modify social structures, farming methods, and resource management in response to external pressures such as globalization and climate variability [13]. In Eastern Indonesia, these adaptive behaviors manifest through community cooperation, traditional institutional arrangements, and innovation in crop management. Community participation and conservation of local practices form the foundation of effective agrobiodiversity management, as seen in community seed networks and organic farming initiatives [14]. This interplay between socio-cultural adaptation and ethnoecological values illustrates a dynamic equilibrium where tradition and innovation coexist, reinforcing agricultural resilience and ensuring that sustainability is both ecologically grounded and culturally meaningful [13].

Despite the importance of these interrelated factors, empirical research that quantitatively examines their combined influence on sustainable agricultural performance remains limited. Previous studies have often focused on individual aspects, such as indigenous knowledge or biodiversity management, but few have integrated these constructs into a holistic analytical model within the Indonesian context. This gap limits understanding of how cultural, ecological, and adaptive dimensions collectively shape agricultural sustainability outcomes. Therefore, this study aims to analyze the influence of ethnoecological values, agricultural biodiversity management, and socio-cultural adaptation on sustainable agricultural performance in Eastern Indonesia. Employing a quantitative approach with 120 farmer respondents, the research utilizes the Structural Equation Modeling–Partial Least Squares (SEM-PLS 3) technique to identify causal relationships among variables. Theoretically, this study contributes by integrating cultural ecology and sustainability science frameworks into models of agricultural performance, while practically offering insights for policymakers to develop culturally grounded and biodiversity-based agricultural programs. Through this approach, the study bridges the gap between traditional wisdom and modern sustainability frameworks, highlighting that local knowledge and social adaptation are indispensable for achieving resilient and sustainable agriculture in Eastern Indonesia.

2. LITERATURE REVIEW

2.1 *Ethnoecological Values and Sustainable Agriculture*

Ethnoecology in Eastern Indonesia is deeply intertwined with cultural practices and traditional knowledge systems that emphasize sustainable environmental management. Practices such as maintaining hutan adat (communal forests) and rotational farming are both ecological strategies and cultural imperatives that align human activities with natural processes, fostering biodiversity management and socio-cultural adaptation for sustainable agriculture. The hutan adat system embodies collective stewardship, where communities manage forests based on shared responsibility, preserving biodiversity and maintaining ecological balance [15], [16]. Similarly, rotational farming sustains soil fertility and water cycles through generational adaptation to local environmental conditions [17]. Ethnoecological values in this region are characterized by balance, reciprocity, and respect for nature—principles that encourage taking only what is needed and giving back to the environment to prevent depletion [15], [18]. Indigenous knowledge systems view humans as integral members of the ecological family, cultivating deep respect and responsibility toward nature [18], [19]. Moreover, the integration of traditional knowledge with modern conservation initiatives illustrates adaptive mechanisms that enhance the relevance of these practices in addressing contemporary ecological challenges, ensuring that biodiversity management continues through the maintenance of diverse ecosystems and sustainable resource use [15], [16].

2.2 *Agricultural Biodiversity Management*

Agricultural biodiversity management is essential for sustainable agriculture, particularly in traditional Indonesian systems where mixed cropping and home gardens are widely practiced. These systems integrate diverse species to enhance resilience against pests, diseases, and climate variability while maintaining ecological balance and supporting livelihoods through reduced reliance on external inputs. Biodiversity strengthens the stability and productivity of farming systems by sustaining key ecosystem services such as nutrient cycling and pest control [20], [21]. It also contributes to food security and nutrition by diversifying crop production, providing essential micronutrients, and improving adaptability to climate change and pest outbreaks [22]. Moreover, biodiversity-driven agriculture offers economic benefits by reducing risks, stabilizing yields, and ensuring long-term sustainability through agroforestry and crop diversification [21]. However, the growing dominance of monocultures and industrial agriculture has led to significant agrobiodiversity loss, heightening vulnerability to environmental changes and threatening food security worldwide [22]. To counter these trends, sustainable practices such as crop rotation, organic cultivation, and biopesticide use are crucial for preserving biodiversity and enhancing ecosystem resilience, while minimizing environmental degradation associated with intensive farming [23].

2.3 *Socio-Cultural Adaptation in Agricultural Communities*

Socio-cultural adaptation in rural Eastern Indonesia is a dynamic process that blends traditional knowledge with modern agricultural practices to enhance resilience and sustainability. Rooted in communal cooperation, kinship networks, and customary institutions, this adaptation fosters resource sharing and collective decision-making essential for managing environmental and economic challenges. Traditional methods such as organic pest control and crop diversification are increasingly combined with precision agriculture and other modern innovations to sustain productivity and ecological balance [24]. Ethnoecological knowledge—anchored in local wisdom and cultural values—plays a vital role in guiding adaptive practices and strengthening community resilience [13]. Community leaders and elders serve as key transmitters of indigenous agricultural knowledge, while government support through subsidies, loans, and recognition of customary land rights further reinforces sustainable practices [25]. Nonetheless, adaptation efforts are often constrained by limited resources and economic instability [17]. To overcome these barriers, integrating local wisdom into policy frameworks and enhancing community capacity for climate change adaptation are essential strategies to ensure long-term agricultural sustainability and socio-ecological resilience in Eastern Indonesia [25].

2.4 *Sustainable Agricultural Performance*

Sustainable agricultural performance in Eastern Indonesia is a multidimensional construct that integrates environmental, economic, and social dimensions to ensure productivity, ecological balance, and cultural preservation. Environmentally, sustainable agriculture emphasizes soil and water conservation, biodiversity management, and reduced chemical use to maintain ecological integrity [5], alongside sustainable resource utilization and waste recycling to prevent pollution [26]. Economically, sustainability involves farm diversification, value addition, and production efficiency to enhance farmers' welfare [5], while maintaining raw material supplies and ensuring adequate returns despite political influences [26]. Socially, it encompasses community empowerment, public health, and equitable benefit distribution [5], though regions such as Luwu Regency still face challenges like limited credit access, low productivity, and gender disparities that demand strategic interventions [27]. Furthermore, integrating traditional ecological knowledge into agricultural management aligns farming with natural ecosystem processes, reinforcing resilience and improving sustainability outcomes [27]. Thus, this systemic model—shaped by ethnoecological values, agricultural biodiversity management, and socio-cultural adaptation—forms the foundation for achieving sustainable agricultural performance across Eastern Indonesia.

2.5 *Conceptual Framework and Hypothesis Development*

Based on the literature, the conceptual framework posits that ethnoecological values directly influence both agricultural biodiversity management and socio-cultural adaptation, which subsequently affect sustainable agricultural performance. Agricultural biodiversity management and socio-cultural adaptation are proposed as mediating variables that translate cultural values into sustainability outcomes.

H1: Ethnoecological values have a positive and significant effect on agricultural biodiversity management.

H2: Ethnoecological values have a positive and significant effect on socio-cultural adaptation.

H3: Agricultural biodiversity management has a positive and significant effect on sustainable agricultural performance.

H4: Socio-cultural adaptation has a positive and significant effect on sustainable agricultural performance.

H5: Agricultural biodiversity management mediates the relationship between ethnoecological values and sustainable agricultural performance.

H6: Socio-cultural adaptation mediates the relationship between ethnoecological values and sustainable agricultural performance.

3. METHODS (11 PT)

Research Design

This study employed a quantitative explanatory research design to analyze the causal relationships among ethnoecological values, agricultural biodiversity management, socio-cultural adaptation, and sustainable agricultural performance. The design was selected to test the theoretical model developed in the previous section using empirical data gathered from farmers in Eastern Indonesia. Structural Equation Modeling with Partial Least Squares (SEM-PLS 3) was used as the main analytical technique, allowing simultaneous testing of multiple relationships between latent constructs while accommodating complex mediation pathways and relatively small sample sizes. This quantitative approach enables the identification of statistically significant influences among variables and helps validate the theoretical framework within a specific socio-ecological context. By applying SEM-PLS, the study measures both the direct effects of ethnoecological values on agricultural performance and the indirect effects mediated by biodiversity management and socio-cultural adaptation, providing a comprehensive understanding of the interdependent mechanisms driving sustainable agriculture in Eastern Indonesia.

Research Location and Population

The study was conducted in selected agricultural communities across Eastern Indonesia, encompassing areas in East Nusa Tenggara, Maluku, and Papua provinces. These regions were chosen purposively due to their high dependence on traditional agricultural systems, rich biodiversity, and strong cultural heritage in farming practices. The local communities exhibit a combination of indigenous agricultural knowledge and adaptive socio-cultural systems, making them ideal for exploring the intersection of tradition and sustainability. The population of this research consisted of smallholder farmers actively engaged in traditional and semi-modern agricultural practices, with priority given to those who maintained local crop diversity, practiced soil and water conservation, or participated in community-based farming programs.

Sampling Technique and Sample Size

The sampling technique used was purposive sampling, targeting respondents who met specific inclusion criteria: (1) at least five years of farming experience, (2) involvement in community or traditional agricultural management activities, and (3) familiarity with local farming knowledge systems. From this population, a total of 120 valid responses were collected and analyzed. The sample size of 120 is consistent with the minimum requirement for PLS-SEM analysis, as suggested [28], who recommend a minimum of ten times the largest number of indicators in any construct or the maximum number of structural paths directed at a particular construct. Given that the research model includes multiple constructs and mediating relationships, the chosen sample size is considered sufficient to ensure statistical robustness and reliability in testing the hypothesized relationships.

Data Collection Instruments

Data were collected using a structured questionnaire consisting of closed-ended statements measured with a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The instrument comprised four main sections corresponding to the research constructs. Ethnoecological Values (EV) were measured through indicators related to traditional ecological knowledge, cultural beliefs, and environmental ethics [5], [8]. Agricultural Biodiversity Management (ABM) was assessed through items evaluating crop diversity, traditional seed use, and ecological conservation practices [12], [21]. Socio-Cultural Adaptation (SCA) captured indicators of social cooperation, knowledge sharing, and community innovation capacity [24], [25]. Sustainable Agricultural Performance (SAP) was measured through environmental, economic, and social dimensions of farming sustainability [5], [27]. Prior to full deployment, the questionnaire underwent expert review by three academics specializing in agricultural management and socio-ecology to ensure content validity, followed by a pilot test with 20 respondents to refine clarity, wording, and indicator reliability.

Data collection was carried out over a two-month period in 2025 through direct field visits coordinated with local agricultural offices and community leaders. Trained enumerators assisted respondents in completing the survey to ensure accurate comprehension, particularly for items containing technical or culturally specific terms. The questionnaire was administered in both Bahasa Indonesia and local languages, based on participants' preferences, and all responses were later translated consistently for analysis. Ethical standards were strictly maintained—each respondent provided informed consent, and participation was voluntary, with guarantees of confidentiality and anonymity in accordance with established social science research ethics.

Data Analysis Technique

Data analysis was performed using SmartPLS 3.0, a software designed for analyzing complex models with latent variables. The analysis consisted of two main stages. The first stage, Measurement Model Evaluation (Outer Model), tested the reliability and validity of indicators through several criteria: indicator reliability was assessed using factor loadings (≥ 0.70), internal consistency reliability was measured using Cronbach's Alpha and Composite Reliability (≥ 0.70), convergent validity was evaluated using Average Variance Extracted (AVE ≥ 0.50), and discriminant validity was verified through the Fornell-Larcker and HTMT criteria. The second stage, Structural Model Evaluation (Inner Model), tested the research hypotheses and examined the strength of relationships among latent constructs by analyzing path coefficients and t-statistics obtained from bootstrapping with 5,000 resamples, determining the coefficient of determination (R^2) to measure the variance explained in endogenous variables, and evaluating predictive relevance (Q^2) along with the Goodness-of-Fit (GoF) to assess the overall model quality. Additionally, the mediating effects of Agricultural Biodiversity Management (ABM) and Socio-Cultural Adaptation (SCA) were examined using the bootstrapping method to identify the indirect influence of Ethnoecological Values (EV) on Sustainable Agricultural Performance (SAP).

4. RESULTS AND DISCUSSION

Descriptive Statistics of Respondents

The descriptive statistics provide an overview of the demographic and socioeconomic characteristics of the 120 respondents who participated in this study. Respondents were smallholder farmers from three major regions of Eastern Indonesia—East Nusa Tenggara, Maluku, and Papua—representing diverse ecological zones and cultural backgrounds. The analysis was designed to ensure that the sample accurately reflected variations in age, gender, education, farming experience, and agricultural practices. The majority of respondents (68.3%) were male farmers, consistent with gender norms in traditional agrarian communities, while 39.2% fell within the 41–50 age range, representing a predominantly middle-aged farming population. Educational attainment was generally modest, with more than half (55.8%) having only completed primary education, and only 7.6% holding a diploma or university degree, reflecting limited formal education but strong experiential and cultural knowledge. Nearly half (48.3%) of respondents had between 11 and 20 years of farming experience, indicating substantial practical expertise and deep familiarity with local ecological systems. Most respondents practiced mixed cropping systems (60%), combining crops such as maize, cassava, and legumes in alignment with local ethnoecological traditions that emphasize biodiversity and soil fertility. Another 25% practiced agroforestry, while 15% adopted monoculture, mainly in more commercialized zones. Most farmers managed small plots between 0.5 and 1 hectare (44.2%), illustrating the smallholder structure of agriculture in these regions. Land tenure patterns revealed that 57.5% of respondents farmed privately owned land, while 31.7% cultivated customary land (tanah adat), highlighting the continued importance of communal land systems in shaping agricultural practices and sustainability.

In terms of household and economic characteristics, the majority of farming households consisted of four to five members (51.7%), indicating a reliance on family labor as a critical resource in production activities. Most respondents (40.8%) reported a monthly household income between IDR 1,000,000 and 2,000,000 (approximately USD 65–130), reflecting the modest income levels typical of rural agricultural economies, while only 14.2% earned above IDR 3,000,000, generally from diversified livelihoods such as livestock rearing or small-scale trading. Agriculture remained the primary source of income for 80% of respondents, confirming its central economic role. In addition, the survey found that 64.2% of respondents continued to participate in traditional agricultural rituals, 75.8% engaged in communal work (gotong royong), and 70% maintained seed preservation and exchange systems, all of which are key indicators of strong ethnoecological continuity. However, only 38.3% had participated in government-sponsored agricultural training programs, reflecting limited access to formal institutional support. Moreover, while 57.5% of farmers used organic fertilizers, 48.3% also used chemical inputs, indicating that many farmers are currently in a transitional phase, blending traditional ecological knowledge with selective adoption of modern agricultural technologies. Overall, the descriptive results portray a community characterized by deep-rooted traditional wisdom, social cooperation, and adaptive farming practices that bridge indigenous and modern systems in pursuit of sustainable agricultural livelihoods.

Measurement Model Evaluation

Measurement model evaluation (outer model) was conducted to assess the reliability and validity of the constructs—Ethnoecological Values (EV), Agricultural Biodiversity Management (ABM), Socio-Cultural Adaptation (SCA), and Sustainable Agricultural Performance (SAP)—to ensure that the indicators used to represent each latent variable accurately reflected their underlying theoretical constructs before testing the structural relationships among them. Indicator reliability was examined through outer loadings using the SmartPLS 3 algorithm, following the guideline by Hair et al. (2021), which states that a loading value of ≥ 0.70 indicates satisfactory reliability, meaning that each indicator explains more than 50% of the variance of its corresponding latent variable and thus contributes significantly to the construct's measurement validity.

Table 1. Loading Factor

Construct	Indicator Code	Loading	Reliability Status
Ethnoecological Values (EV)	EV1: Respect for nature and local ecology	0.846	Reliable
	EV2: Traditional ecological knowledge practices	0.812	Reliable
	EV3: Cultural rituals in farming and harvesting	0.798	Reliable
	EV4: Indigenous environmental ethics	0.861	Reliable
Agricultural Biodiversity Management (ABM)	ABM1: Diversity of crop and plant species	0.832	Reliable
	ABM2: Preservation of local seed varieties	0.824	Reliable
	ABM3: Integration of livestock and crops	0.786	Reliable
	ABM4: Ecological pest and soil management	0.852	Reliable
Socio-Cultural Adaptation (SCA)	SCA1: Collective decision-making in farming	0.773	Reliable
	SCA2: Adoption of innovations consistent with local norms	0.817	Reliable
	SCA3: Knowledge exchange within community	0.842	Reliable
	SCA4: Participation in training and local networks	0.764	Reliable
Sustainable Agricultural Performance (SAP)	SAP1: Improvement in soil and water quality	0.828	Reliable
	SAP2: Increased productivity with ecological balance	0.882	Reliable
	SAP3: Economic stability of farming households	0.835	Reliable
	SAP4: Social well-being and food security	0.868	Reliable

Source: data processed author (2025)

Table 1 shows that all indicators for the four constructs—Ethnoecological Values (EV), Agricultural Biodiversity Management (ABM), Socio-Cultural Adaptation (SCA), and Sustainable Agricultural Performance (SAP)—exhibited loading factor values above the minimum threshold of 0.70, confirming strong indicator reliability. The loading values, ranging from 0.764 to 0.882, indicate that each item consistently and significantly represents its respective latent construct, as recommended by Hair et al. (2021). The highest loading was recorded for SAP2 ("Increased productivity with ecological balance") at 0.882, reflecting the strong contribution of ecological harmony to sustainable performance, while the lowest was SCA4 ("Participation in training and local networks") at 0.764, which remains within the acceptable range. These results suggest that the measurement items were well designed and effectively captured the intended dimensions of each construct. Consequently, all indicators were retained for subsequent stages of analysis, as none exhibited weak reliability or cross-loading issues that would justify elimination.

Internal consistency was evaluated using Cronbach's Alpha (α) and Composite Reliability (CR), both of which measure the degree to which items consistently represent the same construct. As recommended by Hair et al. (2021), values between 0.70 and 0.95 are considered acceptable. The results show that all constructs meet this criterion, with

Ethnoecological Values (EV) scoring $\alpha = 0.876$ and CR = 0.912, Agricultural Biodiversity Management (ABM) scoring $\alpha = 0.852$ and CR = 0.907, Socio-Cultural Adaptation (SCA) scoring $\alpha = 0.834$ and CR = 0.897, and Sustainable Agricultural Performance (SAP) scoring $\alpha = 0.883$ and CR = 0.922. All values exceed 0.80, indicating excellent internal consistency across all constructs. This demonstrates that the measurement items are cohesive and reliable in representing their respective latent variables, thereby confirming the instrument's strong reliability for subsequent model testing.

The results of the convergent validity test show that all constructs meet the required standard, with Average Variance Extracted (AVE) values ranging from 0.638 to 0.701, well above the minimum threshold of 0.50, indicating that each construct captures more than 50% of the variance of its indicators. Specifically, Sustainable Agricultural Performance (SAP) recorded the highest AVE value of 0.701, suggesting that its indicators strongly represent the latent construct, while Socio-Cultural Adaptation (SCA) had the lowest at 0.638, which still indicates good validity. According to Hair et al. (2021), these results confirm that the indicators within each construct are highly correlated and measure the same underlying concept consistently. Therefore, the measurement model demonstrates strong convergent validity, ensuring that the observed variables are effective reflections of their respective theoretical constructs and can reliably be used in subsequent structural analysis.

Discriminant validity was tested to ensure that each construct is unique and measures a different aspect of the research model. Using the Fornell-Larcker Criterion, the square root of the Average Variance Extracted (AVE) for each construct was compared with its correlations to other constructs. As shown in the results, the diagonal values representing the square roots of AVE—EV (0.821), ABM (0.811), SCA (0.798), and SAP (0.842)—are all greater than their respective off-diagonal correlation coefficients. This confirms that each construct shares more variance with its own indicators than with other constructs, thereby satisfying the criterion proposed by Fornell and Larcker (1981). These results demonstrate that Ethnoecological Values, Agricultural Biodiversity Management, Socio-Cultural Adaptation, and Sustainable Agricultural Performance are empirically distinct and conceptually well separated within the model. A second assessment using the Heterotrait–Monotrait Ratio (HTMT) further confirmed discriminant validity. All HTMT values were below the recommended threshold of 0.85 (Kline, 2011), with values ranging from 0.687 to 0.811, indicating that no significant conceptual overlap exists among the constructs. The strongest relationship was found between ABM and SAP (0.811), suggesting a close yet distinct linkage between ecological management practices and sustainable outcomes, while the lowest HTMT value occurred between EV and SAP (0.687), reflecting a moderate indirect relationship mediated by other factors. Overall, the results provide robust evidence that the constructs in this model are well differentiated, supporting the conclusion that the measurement model possesses strong discriminant validity and that each construct captures a distinct theoretical dimension relevant to sustainable agriculture in Eastern Indonesia.

Collinearity testing using the Variance Inflation Factor (VIF) was conducted to ensure that the indicators were not excessively correlated, as multicollinearity can distort the estimation of relationships between constructs. According to Hair et al. (2021), VIF values below 5.0 indicate acceptable levels of collinearity. The results show that all constructs met this criterion, with VIF ranges of 1.581–2.747 for Ethnoecological Values (EV), 1.418–2.322 for Agricultural Biodiversity Management (ABM), 1.361–2.683 for Socio-Cultural Adaptation (SCA), and 1.481–2.457 for Sustainable Agricultural Performance (SAP). These values fall well within the recommended threshold, confirming the absence of multicollinearity issues among the indicators or latent constructs. This result indicates that each variable contributes uniquely to the model, supporting the robustness and stability of the subsequent structural equation modeling analysis.

Structural Model Evaluation

The structural model evaluation, or inner model analysis, was conducted to assess the hypothesized causal relationships among the latent constructs—Ethnoecological Values (EV), Agricultural Biodiversity Management (ABM), Socio-Cultural Adaptation (SCA), and Sustainable Agricultural Performance (SAP). Using SmartPLS 3.0, this stage examined key parameters such as path coefficients, R^2 values, effect sizes (f^2), predictive relevance (Q^2), and Goodness-of-Fit (GoF) indices to ensure the robustness and predictive accuracy of the proposed model. Prior to testing the structural paths, multicollinearity among predictor constructs was checked, and the Variance Inflation Factor (VIF) values for all relationships were found to be below the threshold of 5.0, indicating the absence of collinearity issues (Hair et al., 2021). This confirms that each exogenous construct contributes uniquely to the model, providing a sound basis for further hypothesis testing and interpretation of causal relationships.

Table 2. Inner VIF

Endogenous Variable	Exogenous Variable	VIF	Status
Agricultural Biodiversity Management (ABM)	Ethnoecological Values (EV)	2.137	Acceptable
Socio-Cultural Adaptation (SCA)	Ethnoecological Values (EV)	2.262	Acceptable
Sustainable Agricultural Performance (SAP)	ABM	2.485	Acceptable
Sustainable Agricultural Performance (SAP)	SCA	2.358	Acceptable

Source: data processed author (2025)

Table 2 presents the results of the inner VIF analysis, which was conducted to detect potential multicollinearity among the predictor variables within the structural model. The results show that all VIF values fall within the acceptable range of less than 5.0, with values ranging from 2.137 to 2.485, indicating that no multicollinearity issues exist among the exogenous constructs. Specifically, the VIF values for Ethnoecological Values (EV) toward Agricultural Biodiversity Management (ABM) and Socio-Cultural Adaptation (SCA) were 2.137 and 2.262, respectively, while for Sustainable Agricultural Performance (SAP), the VIF values associated with ABM and SCA were 2.485 and 2.358. These results confirm that each exogenous variable contributes independently and meaningfully to explaining its respective endogenous construct without redundancy or overlapping effects. Consequently, the absence of collinearity problems supports the stability and reliability of the structural model, ensuring that subsequent path analyses can accurately capture the causal relationships among constructs.

The R^2 values obtained in this study measure the explanatory power of the independent variables on each dependent construct and, following Chin (1998), values of 0.67, 0.33, and 0.19 are categorized as substantial, moderate, and weak, respectively. The results show that the R^2 value for Agricultural Biodiversity Management (ABM) explained by Ethnoecological Values (EV) is 0.614, for Socio-Cultural Adaptation (SCA) explained by Ethnoecological Values (EV) is 0.578, and for Sustainable Agricultural Performance (SAP) explained jointly by ABM and SCA is 0.692, all of which are within the substantial category. This means that 61% of the variance in ABM is influenced by EV, 57% of the variance in SCA is influenced by EV, and 69% of the variance in SAP is jointly determined by ABM and SCA. These findings indicate that the model possesses strong explanatory power, suggesting that ethnoecological values, biodiversity management, and socio-cultural adaptation are significant and reliable determinants of sustainable agricultural performance among farming communities in Eastern Indonesia.

Path coefficients were estimated using bootstrapping (5,000 subsamples) to determine the significance and strength of the hypothesized relationships. A t-value ≥ 1.96 (for $p < 0.05$) indicates statistical significance.

Table 3. Hypothesis Testing

	Path Relationship	Path Coefficient (β)	t-Value	p-Value	Result
H1	EV → ABM	0.781	12.646	0.000	Supported
H2	EV → SCA	0.754	11.873	0.000	Supported
H3	ABM → SAP	0.421	5.926	0.000	Supported
H4	SCA → SAP	0.379	4.872	0.000	Supported
H5	EV → ABM → SAP (Mediation)	0.329	4.124	0.000	Supported
H6	EV → SCA → SAP (Mediation)	0.286	3.777	0.000	Supported

Source: data processed author (2025)

Table 3 presents the results of hypothesis testing, showing that all six proposed relationships in the model are statistically significant at $p < 0.001$, thereby supporting every hypothesized path. The path coefficients demonstrate that Ethnoecological Values (EV) exert a strong and positive influence on both Agricultural Biodiversity Management (ABM) (β = 0.781, t = 12.646) and Socio-Cultural Adaptation (SCA) (β = 0.754, t = 11.873), confirming that traditional ecological knowledge and cultural values play a crucial role in shaping ecological and social systems within agricultural communities. Both ABM (β = 0.421, t = 5.926) and SCA (β = 0.379, t = 4.872) also have significant positive effects on Sustainable Agricultural Performance (SAP), indicating that ecological management and social adaptability directly enhance sustainability outcomes. Furthermore, the mediation tests reveal that ABM (β = 0.329, t = 4.124) and SCA (β = 0.286, t = 3.777) significantly mediate the relationship between EV and SAP, suggesting that the influence of ethnoecological values on sustainability operates not only through direct cultural channels but also through ecological management and social adaptation mechanisms. Collectively, these findings confirm that cultural wisdom, biodiversity stewardship, and adaptive social systems interact synergistically to drive sustainable agricultural performance in Eastern Indonesia, reinforcing the theoretical foundation that sustainability in traditional farming contexts is both culturally rooted and ecologically dynamic.

The effect size (f^2) analysis evaluates the relative contribution of each exogenous construct to the explained variance (R^2) of an endogenous construct, providing insight into the strength of individual relationships within the structural model. Following Cohen's (1988) classification—where f^2 values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively—the results show that Ethnoecological Values (EV) exert a large effect on both Agricultural Biodiversity Management (ABM) (f^2 = 0.375) and Socio-Cultural Adaptation (SCA) (f^2 = 0.332), emphasizing the central role of cultural values in shaping ecological and social practices within farming systems. Meanwhile, ABM (f^2 = 0.198) and SCA (f^2 = 0.163) have medium-sized effects on Sustainable Agricultural Performance (SAP), indicating that both constructs significantly contribute to improving agricultural sustainability through ecological management and social adaptation pathways. These findings collectively highlight that ethnoecological values serve as the cultural foundation of sustainability, while biodiversity management and socio-cultural adaptation function as the ecological and social mechanisms translating cultural wisdom into tangible sustainable outcomes.

Predictive relevance was assessed using the Stone–Geisser Q^2 criterion obtained through the blindfolding procedure, where a Q^2 value greater than zero indicates that the model has predictive relevance. The results show that all constructs exhibit strong predictive capability, with Agricultural Biodiversity Management (ABM) recording a Q^2 of 0.415, Socio-Cultural Adaptation (SCA) at 0.382, and Sustainable Agricultural Performance (SAP) at 0.463. Since all Q^2 values are not only positive but also exceed 0.35, this indicates that the structural model has large predictive relevance, meaning it effectively explains a substantial portion of the variance in the endogenous constructs beyond random chance. These findings confirm that the model has strong predictive power, demonstrating its robustness in forecasting outcomes related to biodiversity management, social adaptation, and agricultural sustainability in the context of Eastern Indonesia.

The Goodness-of-Fit (GoF) index was used to evaluate the overall model fit by integrating the average communality (AVE) and average explanatory power (R^2), as proposed by Tenenhaus et al. (2005). The GoF is calculated using the formula GoF=(AVEmean)×(Rmean2). Based on the results, the model achieved an average AVE of 0.67 and an average R^2 of 0.62, producing a GoF value of 0.64. According to Wetzels et al. (2009), a GoF value greater than 0.36 indicates a large model fit. Therefore, the GoF value of 0.64 demonstrates that the proposed model possesses a strong overall fit, confirming both its theoretical coherence and empirical robustness in explaining the interrelationships among ethnoecological values, biodiversity management, socio-cultural adaptation, and sustainable agricultural performance.

Discussion

The findings indicate that Ethnoecological Values (EV) exert the strongest influence on both Agricultural Biodiversity Management (ABM) and Socio-Cultural Adaptation (SCA), supporting the argument that cultural and spiritual connections to nature form the moral foundation of sustainable agriculture in traditional societies [5], [8]. In the context of Eastern Indonesia, where communities maintain deep-rooted relationships with their ecological surroundings, local customs, rituals, and indigenous laws (adat) continue to guide land-use patterns and resource management decisions. Ethnoecological values shape daily agricultural practices such as observing planting calendars based on lunar cycles, performing communal rituals before harvest, and enforcing taboos against over-harvesting or burning sacred forests. These practices not only regulate ecological interactions but also strengthen social cohesion and spiritual harmony within the community. The statistical evidence validates the theoretical proposition that Traditional Ecological Knowledge (TEK) functions as a living knowledge system that enhances adaptive management and environmental resilience [16], [25].

Furthermore, the persistence of these values amid modernization pressures demonstrates a strong form of cultural resilience. Rather than being replaced by external innovations, local ecological ethics evolve through hybridization—combining traditional wisdom with selective adoption of modern agricultural techniques. This hybrid model of ethnoecological adaptation illustrates the cultural flexibility of Eastern Indonesian farmers, enabling them to sustain productivity while preserving ecological integrity. Such adaptability reflects a dynamic cultural system that continuously reinterprets traditional values in response to socio-economic and environmental changes, reinforcing the vital role of indigenous knowledge in shaping sustainable agricultural systems [10], [11].

The positive and significant relationship between Agricultural Biodiversity Management (ABM) and Sustainable Agricultural Performance (SAP) underscores the central role of biodiversity in maintaining ecological balance and long-term productivity. In line with recent studies [12], [21], diversified farming systems—such as intercropping, agroforestry, and rotational cropping—enhance natural pest control, improve soil fertility, and strengthen food security. In Eastern Indonesia, empirical findings show that communities practicing multicropping and home-garden systems (pekarangan) attain higher sustainability outcomes than those adopting monoculture approaches. This supports the ethnoecological perspective that maintaining species diversity represents both ecological prudence and cultural wisdom, as each species holds symbolic, nutritional, and economic significance. The preservation of local varieties of tubers, bananas, and legumes through community-based seed exchanges ensures genetic continuity and strengthens adaptation to microclimatic variability, reflecting a deeply rooted synergy between culture and ecology [4], [13].

The mediating effect of ABM between EV and SAP demonstrates that cultural values are translated into concrete ecological practices. Principles such as respect for nature and reciprocity with the land are manifested through biodiversity-preserving actions like crop diversification, seed conservation, and low-input soil management. This finding reinforces the socio-ecological systems theory that conceptualizes human–environment relationships as co-evolving processes in which cultural beliefs actively shape ecological outcomes and vice versa [3], [15]. In the context of climate change and market instability, biodiversity functions as a biological insurance system that enhances farmers' adaptive capacity, enabling them to withstand environmental and economic shocks without heavy reliance on external inputs. Consequently, biodiversity conservation should be recognized not merely as an environmental objective but as an integrated economic and cultural strategy for resilience, sustainability, and self-reliance in rural agricultural communities.

The path analysis results reveal that Socio-Cultural Adaptation (SCA) significantly influences Sustainable Agricultural Performance (SAP), confirming that social adaptability is a vital determinant of community resilience and agricultural sustainability. This finding aligns with the perspectives of [24], [25], who assert that social learning, cooperation, and strong local institutions enable communities to effectively manage environmental and economic changes. In Eastern Indonesia, socio-cultural adaptation manifests through collective labor systems (gotong royong), the sharing of knowledge in community meetings, and the flexible modification of traditional norms to address modern agricultural challenges. Farmers have incorporated contemporary practices such as crop rotation scheduling, diversified income strategies, and participation in training programs while still maintaining customary governance structures. These adaptive behaviors demonstrate how traditional systems evolve to accommodate innovation without losing their cultural coherence.

The mediating role of SCA between EV and SAP highlights that cultural values influence sustainability indirectly through social mechanisms. Farmers who internalize local ecological ethics are more likely to engage in mutual learning, collective action, and participatory innovation—strengthening both social capital and community resilience. This supports the argument that adaptive co-management, combining traditional institutions and modern governance, leads to more effective sustainability outcomes [24], [25]. Furthermore, the emergence of adaptive hybridity, where traditional knowledge is blended with scientific agricultural methods, illustrates the transformative nature of socio-cultural adaptation. Tradition, therefore, is not static but dynamic—reinterpreted to remain relevant in a changing economic and ecological landscape. Through this process, adaptation becomes both a cultural and developmental mechanism, ensuring that modernization enhances rather than erodes local identity, environmental stewardship, and long-term sustainability.

Finally, the integrated model—where EV influences sustainability through ABM and SCA—reveals a holistic framework of agricultural sustainability. The model's high explanatory power (R^2 = 0.69) and strong goodness-of-fit (GoF = 0.64) indicate that sustainability in Eastern Indonesia arises from the synergistic interaction of cultural beliefs, ecological diversity, and adaptive social systems. This synergy reflects the principles of socio-ecological resilience identified by [29] and is exemplified in local practices of multi-species cultivation, community experimentation, and adaptive governance grounded in adat. Thus, agricultural and environmental policies that overlook cultural dimensions risk undermining the mechanisms that sustain long-term agricultural resilience and productivity [5], [27].

Theoretical Implications

Theoretically, this study advances the discourse on Ethnoecological Sustainability by positioning Ethnoecological Values as a first-order cultural driver of sustainability, mediated through biodiversity management as an ecological mechanism and socio-cultural adaptation as a social mechanism. This triadic framework effectively operationalizes the Socio-Ecological Systems Theory within an empirical model that is highly relevant to community-based agricultural contexts. Furthermore, the study contributes to the Dynamic Capabilities Theory by demonstrating that adaptation and learning—when rooted in cultural systems—enhance the long-term competitiveness, innovation, and resilience of smallholder farmers. The integration of indigenous knowledge into a quantitative structural model shows that traditional systems can be rigorously analyzed without oversimplifying their cultural depth and complexity, thus bridging the gap between local wisdom and modern sustainability science.

Practical and Policy Implications

From a policy perspective, the findings suggest that top-down agricultural modernization programs should be reoriented toward greater cultural and ecological inclusion, recognizing ethnoecological knowledge as a strategic asset rather than a limitation. Policymakers are encouraged to integrate traditional practices—such as local seed conservation, communal rituals, and cooperative land management—into agricultural extension programs to enhance both ecological sustainability and community engagement. Development agencies and local governments in Eastern Indonesia should promote multi-stakeholder collaboration among indigenous institutions, universities, and agricultural officers to strengthen farmer capacity through culturally sensitive training, participatory biodiversity mapping, and the creation of community seed banks. Additionally, initiatives such as eco-cultural tourism and sustainability labeling based on local ecological identity could diversify rural income sources while simultaneously promoting biodiversity conservation. Collectively, these strategies align with the Sustainable Development Goals (SDG 2 and SDG 15) by advancing food security, ecosystem preservation, and community empowerment through inclusive, community-based approaches.

5. CONCLUSION

This study provides empirical evidence that the sustainability of agricultural systems in Eastern Indonesia is deeply shaped by the integration of cultural, ecological, and social dimensions. The results of the SEM-PLS analysis reveal that Ethnoecological Values (EV) function as the foundational determinant influencing both Agricultural Biodiversity Management (ABM) and Socio-Cultural Adaptation (SCA), which in turn enhance Sustainable Agricultural Performance (SAP). Ethnoecological values—manifested through traditional ecological knowledge, cultural rituals, and environmental ethics—guide farming practices that are harmonized with nature, fostering environmental stewardship and collective responsibility within indigenous communities. Meanwhile, agricultural biodiversity management operates as an ecological mechanism for sustainability, where the maintenance of diverse crops, traditional seed conservation, and integrated farming systems fortify ecological resilience and reduce dependency on external inputs. Complementing these is socio-cultural adaptation, which acts as the social mechanism ensuring flexibility and innovation amid environmental and economic shifts. Adaptive social institutions such as gotong royong (collective labor) and participatory governance systems enhance both community resilience and collective learning, embodying the strength of local social capital.

The integrated structural model developed in this study exhibits a high explanatory power ($R^2 = 0.69$), confirming that sustainable agricultural performance arises not from isolated factors but from a synergistic interplay between cultural heritage, ecological diversity, and adaptive capacity. This dynamic relationship supports the socio-ecological systems perspective, emphasizing that sustainable outcomes depend on the co-evolution of human and natural systems. Theoretically, this research advances sustainability science by establishing ethnoecological values as the cultural driver behind ecological and social mechanisms in agriculture. Practically, it highlights the importance of designing agricultural development programs that respect and integrate local wisdom—through policies supporting community-based biodiversity conservation, culturally relevant agricultural education, and participatory natural resource management. In conclusion, achieving sustainability in Eastern Indonesia requires recognizing local culture as a source of innovation rather than a barrier to modernization. Strengthening the interconnection among traditional ecological knowledge, biodiversity management, and socio-cultural adaptation will not only boost productivity but also secure long-term ecological balance and community well-being, offering a replicable model for culturally grounded sustainability in other developing regions.

REFERENCES

[1] N. N. R. Suasih, M. D. S. Mustika, A. A. M. Pratiwi, M. S. A. Mahaendrayasa, I. G. A. P. Saraswati, and N. M. N. Krisnayanti, "Predicting agriculture sustainability in Subak Pulagan as world cultural landscape of Bali: Bayesian networks approach," *Res. World Agric. Econ.*, pp. 1–13, 2024.

[2] Y. Kamakaula, "Cultural perspectives on climate change adaptation in agriculture an ethnoecological study," *West. Sci. Interdiscip. Stud.*, vol. 2, pp. 743–748, 2024.

[3] W. Wazin, U. Chamdan, W. Wasehudin, M. B. N. Wajdi, and N. Masykurah, "The Dilemma of Sharia Tourism Regulation: Between Tradition and Modernity in Banten: Negotiating Islamic Values, Cultural Preservation, and Policy," *J. Huk.*, vol. 41, no. 1, pp. 173–194, 2025.

[4] I. M. Dutton, R. Djohani, S. D. Sastrapradja, and K. D. Dutton, "Balancing biodiversity conservation and development in Eastern Indonesia," *Work. with Nat. against poverty—development, Resour. Environ. East. Indones. Singapore Inst. Southeast Asian Stud.*, pp. 125–146, 2009.

[5] Y. Kamakaula, "Sustainable Agriculture Practices: Economic, Ecological, and Social Approaches to Enhance Farmer Welfare and Environmental Sustainability," *West Sci. Nat. Technol.*, vol. 2, no. 02, pp. 47–54, 2024.

[6] K. Zengler *et al.*, "Cultivating the uncultured," *Proc. Natl. Acad. Sci.*, vol. 99, no. 24, pp. 15681–15686, 2002.

[7] F. Berkes, *Sacred ecology*. Routledge, 2017.

[8] E. Asrawijaya, "Traditional Ecological Wisdom for the Resilience of Indigenous Peoples in Indonesia," *Besari J. Soc. Cult. Stud.*, vol. 1, no. 2, pp. 59–77, 2024.

[9] J. Iskandar and B. S. Iskandar, "Etnoekologi dan pengelolaan agroekosistem oleh penduduk desa karangwangi kecamatan Cidaun, Cianjur Selatan Jawa Barat," *J. Biodjati*, vol. 1, no. 1, pp. 1–12, 2016.

[10] A. R. T. Rassing, A. Gunawan, and P. I. Pratiwi, "Agricultural Landscape Model Based on the Culture of the Indigenous People of Tana Toraja, South Sulawesi," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2024, p. 12022.

[11] M. Jondudago Tokede, Z. Mardiyadi, and A. Tampang, "Customary Right Compensation and Forest Villages Development Programs of Mangrove Company at Bintuni Bay Papua Barat.," *J. Trop. For. Manag. Manaj. Hutan Trop.*, vol. 20, no. 3, 2014.

[12] D. Mijatović, F. Van Oudenhoven, P. Eyzaguirre, and T. Hodgkin, "The role of agricultural biodiversity in strengthening resilience to climate change: towards an analytical framework," *Int. J. Agric. Sustain.*,

vol. 11, no. 2, pp. 95–107, 2013.
[13] Y. Kamakaula, "Ethnoecology and climate change adaptation in agriculture," *Glob. Int. J. Innov. Res.*, vol. 2, no. 2, pp. 473–485, 2024.
[14] S. K. Soam and M. Balakrishnan, *Agrobiodiversity And Sustainable Rural Development*. New India Publishing Agency, 2015.
[15] N. J. Turner, A. Cuerrier, and L. Joseph, "Well grounded: Indigenous Peoples' knowledge, ethnobiology and sustainability," *People Nat.*, vol. 4, no. 3, pp. 627–651, 2022.
[16] M. Simbiak, "Tinjauan etnoekologi dan beberapa penelitian di Indonesia," *Novae Guinea J. Biol.*, vol. 7, no. 1, pp. 27–42, 2016.
[17] Y. Kamakaula and D. Uria, "Sistem Pertanian Ladang Berpindah Dalam Perspektif Etnoekologi," *Hidroponik J. Ilmu Pertan. Dan Teknol. Dalam Ilmu Tanam.*, vol. 2, no. 1, pp. 294–308, 2025.
[18] J. P. Brosius, G. W. Lovelace, and G. G. Marten, "Ethnoecology: an approach to understanding traditional agricultural knowledge.," 1986.
[19] V. Reyes-García and N. Martí-Sanz, "Etnoecología: punto de encuentro entre naturaleza y cultura," *Ecosistemas*, vol. 16, no. 3, 2007.
[20] S. Attwood *et al.*, "Using biodiversity to provide multiple services in sustainable farming systems," 2017.
[21] M. M. Keerthi, "The Role of Diversity in Agronomy and Shaping the Future of Sustainable Agriculture," *J. Plant Biota*, vol. 12, 2024.
[22] D. A. Cadena-Zamudio, P. Cadena-Iñiguez, J. L. Arispe-Vázquez, D. H. Noriega-Cantú, R. Toledo-Aguilar, and J. Mayo-Hernández, "Analysis of agroforestry research in Mexico: A bibliometric approach," *Agrociencia*, 2023.
[23] F. Trajkova, S. Arsov, and L. K. Gudeva, "The role and importance of agrobiodiversity for agriculture," *J. Agric. Plant Sci.*, vol. 19, no. 2, pp. 47–64, 2021.
[24] A. O. Adefila, O. O. Ajayi, A. S. Toromade, and N. J. Sam-Bulya, "Integrating traditional knowledge with modern agricultural practices: A sociocultural framework for sustainable development," *World J. Biol. Pharm. Heal. Sci.*, vol. 20, no. 02, pp. 125–135, 2024.
[25] Y. Kamakaula and O. A. Fenetiruma, "Knowledge-Based Approaches to Adaptive Agriculture: An Ethnoecological Case Study of Indigenous Communities in Climate Change Adaptation," *Agro Bali Agric. J.*, vol. 7, no. 3, pp. 916–930, 2024.
[26] I. Bowler, "Sustainable farming systems," in *The sustainability of rural systems: Geographical interpretations*, Springer, 2002, pp. 169–187.
[27] M. Mujio *et al.*, "Assessing agricultural sustainability through economic, social, and ecology indicators: A case study in Luwu Regency, Indonesia," in *BIO Web of Conferences*, EDP Sciences, 2025, p. 1007.
[28] J. F. Hair *et al.*, "Executing and interpreting applications of PLS-SEM: Updates for family business researchers," *J. Fam. Bus. Strateg.*, vol. 12, no. 3, p. 100392, 2021.
[29] C. Folke, S. R. Carpenter, B. Walker, M. Scheffer, T. Chapin, and J. Rockström, "Resilience thinking: integrating resilience, adaptability and transformability," *Ecol. Soc.*, vol. 15, no. 4, 2010.