International Journal of Veterinary Science and Agriculture Research
Volume 8 Issue 4, July-August 2026
ISSN: 2582-4112, Available at www.ijvsar.com

From Farmer Adaptation to Sustainable Cocoa Agribusiness: The Mediating Role of Agribusiness System Management in North Kolaka, Indonesia

Muhammad Idrus[1], Syafiuddin[2]*, Mohammad Natsir[2], Ratnawati Tahir[2], Jumiati[2]

[1]*Doctoral Program in Agribusiness, Postgraduate Program, Universitas Muhammadiyah Makassar, Makassar, Indonesia*
[2]*Agribusiness Doctoral Study Program, Universitas Muhammadiyah Makassar, Makassar, Indonesia*

***For Correspondence**

Syafiuddin
Agribusiness Doctoral Study Program, Universitas Muhammadiyah Makassar, , Jln. Sultan Alauddin No. 259, Makassar 90221, Indonesia.

syafiuddin_saleh@unismuh.ac.id

Keywords: *agribusiness system, cocoa, farmer adaptation, mediation, sustainability*

Abstract: *Smallholder cocoa sustainability depends on farmers' adaptive capacity and on whether that capacity is translated into coordinated agribusiness functions. This study examined the mediating role of agribusiness system management in the relationship between farmer adaptation and cocoa agribusiness sustainability in North Kolaka Regency, Southeast Sulawesi, Indonesia. A cross-sectional survey of 100 cocoa farmers in Ngapa, Porehu, and Tolala was analyzed using partial least squares structural equation modeling with a two-stage hierarchical component approach and 5,000 bootstrap subsamples. Farmer adaptation significantly improved agribusiness system management (β = 0.816, t = 33.656, $p < 0.001$), and agribusiness system management significantly improved sustainability (β = 0.729, t = 5.233, $p < 0.001$). The direct adaptation-sustainability path was not significant (β = 0.039, p = 0.705), whereas the indirect effect was significant (β = 0.595, t = 5.092, 95% CI [0.349, 0.811]). The model explained 66.6% of agribusiness system management and 57.9% of sustainability variance. The findings demonstrate indirect-only mediation, indicating that adaptive capacity generates sustainable outcomes when institutionalized through functioning input, production-processing, marketing, and support arrangements.*

I. INTRODUCTION

Cocoa is a globally important perennial commodity whose production is concentrated in tropical smallholder systems. The sector links rural livelihoods, export earnings, food manufacturing, and increasingly demanding sustainability standards. Yet cocoa production is exposed to climatic stress, ageing trees, pests and diseases, volatile input costs, uneven market power, and persistent gaps between farm-level interventions and downstream value capture. Recent reviews emphasize that climate change and production constraints can no longer be treated as purely agronomic problems because their effects propagate through farmer livelihoods and cocoa value chains [1-4].

Indonesia remains an important cocoa-producing country, and national statistics show that cultivation is overwhelmingly based on smallholder agriculture [5]. North Kolaka Regency in Southeast Sulawesi is one of the country's established cocoa landscapes. Official regional statistics reported approximately 78,969 ha of cocoa and 64,889 tonnes of production in 2024, equivalent to an aggregate yield of about 0.82 t ha−1 [6]. These figures underscore the economic importance of cocoa while also indicating scope for productivity, quality, and value-chain improvements.

The sustainability challenge is multidimensional. At the farm level, cocoa growers need to adapt to rainfall variability, heat stress, pest pressure, soil degradation, labour constraints, and changing input requirements. Adaptation also has social and economic dimensions: farmers need access to information, producer organizations, finance, quality incentives, and market channels that reduce exposure to risk. Evidence from cocoa-producing countries shows that adaptation choices are shaped by both farmer characteristics and enabling conditions, including access to extension, organizations, climate information, and financial resources [7, 8].

However, adaptive capacity does not necessarily translate directly into sustainable outcomes. A farmer may know how to conserve soil but lack affordable inputs or labour; may aim to improve bean quality but lack fermentation facilities or differentiated buyers; or may participate in a farmer group that has little commercial function. Research in cocoa value chains increasingly shows that value-chain relationships, institutional arrangements, training quality, market incentives, and producer organization affect the implementation and benefits of sustainable practices [9, 10]. Recent evidence from Indonesia similarly indicates that sustainability interventions generate stronger farm-level outcomes when monitoring, market-based incentives, and capacity-building are implemented in a complementary manner [11].

This suggests a missing meso-level mechanism between individual adaptation and system-level sustainability. Agribusiness system management provides such a mechanism because it connects input provision, primary production, post-harvest handling, marketing, and supporting services. The systems perspective proposed in agribusiness theory views agricultural performance as the result of coordination across interdependent subsystems rather than as the outcome of farm production alone [12]. In cocoa, this perspective is particularly relevant because quality, price formation, market access, and ecological practices depend on interactions among farmers, groups, traders, processors, extension services, financial institutions, and public agencies.

Sustainability itself should be assessed as a balance among economic viability, social inclusion, and environmental integrity. This logic is consistent with the triple bottom line framework, which treats profit, people, and planet as interdependent dimensions rather than substitutable outcomes [13, 14]. Studies of Indonesian cocoa have shown that sustainability performance may vary substantially across dimensions, reinforcing the need for integrated assessment rather than a single production indicator [15].

This study examines the effect of farmer adaptation on cocoa agribusiness sustainability and tests whether agribusiness system management mediates that relationship. Farmer adaptation is modeled as a multidimensional higher-order capability comprising environmental, social, and economic adaptation; agribusiness system management as an intermediate higher-order mechanism comprising input, production-processing, marketing, and support subsystems; and sustainability as a higher-order outcome comprising economic, social, and environmental dimensions. This architecture permits an explicit assessment of whether adaptation produces sustainability directly or primarily through the functioning of the agribusiness system.

II. THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

2.1 Farmer adaptation as a multidimensional capability

Adaptation is commonly understood as the capacity to adjust practices, decisions, and resource use in response to changing conditions. In cultural ecology, adaptation emerges from interactions among environmental pressures, technology, and social organization [16, 17]. Applied to smallholder cocoa, this concept extends beyond climate response. Environmental adaptation includes farm management responses such as shade regulation, pruning, integrated pest management, soil fertility management, and rehabilitation. Social adaptation includes participation, collective learning, information exchange, and partnerships; substantive participation also involves engagement in decision-making, implementation, benefit sharing, and evaluation [18]. Economic adaptation includes cost management, access to finance, quality upgrading, income-risk management, and strategic responses to price conditions.

The three dimensions are complementary. Environmental practices often require investment and labour; economic flexibility is strengthened by access to social networks and institutions; and social learning is more effective when farmers have viable opportunities to implement what they learn. Research on cocoa adaptation supports this multidimensional interpretation. Studies in Ghana show that farmer adaptation is affected by access to information, organizational membership, financial resources, and perceived climate risks, while climate-oriented practices frequently coexist with diversification and livelihood strategies [7, 8]. Therefore, adaptation can be conceptualized as an integrated capability rather than a list of isolated farm practices.

2.2 Agribusiness system management as a transformation mechanism

Agribusiness systems theory emphasizes interdependence among input supply, farm production, processing, marketing, and supporting services [12]. In smallholder cocoa, these functions are often fragmented across farmers, informal traders, farmer organizations, extension agencies, input suppliers, financial institutions, and processors. Fragmentation may reduce transaction transparency, weaken quality incentives, and limit the ability of farmers to capture value from improved practices.

This system perspective helps explain why farm-level capacity may fail to produce sustainable outcomes. In Indonesia, institutional voids in market access, finance, technology, and information can constrain smallholder inclusion even when farmers remain active producers [9]. Cross-country cocoa evidence also indicates that value-chain factors can influence sustainable practice implementation beyond farmer and farm characteristics [10]. Similarly, stronger combinations of training, incentives, and implementation mechanisms have been associated with improved production and income outcomes in Indonesian cocoa certification schemes [11]. These findings imply that agribusiness system management can convert adaptive capacity into operational access to inputs, quality management, coordinated marketing, and institutional support.

2.3 Sustainability as an integrated economic-social-environmental outcome

The triple bottom line framework defines sustainability through the joint performance of economic, social, and environmental dimensions [13]. Economic sustainability in cocoa concerns farm viability, income stability, efficiency, quality premiums, and the ability to reinvest. Social sustainability concerns participation, equitable access to benefits, trust, organizational capacity, and the inclusion of farmers in programs and decisions. Environmental sustainability concerns soil fertility, shade and biodiversity management, reduced ecological risks from chemical inputs, and the resilience of farms to climatic stress.

The three dimensions are interdependent. Agroforestry and organic soil management can provide biodiversity, microclimate, and soil-quality benefits, but their long-term adoption depends on labour, yield, and income incentives [19-21]. Likewise, cooperative participation and sustainability certification are more effective when market and organizational arrangements generate tangible benefits for farmers [22]. Therefore, sustainability is treated here as a higher-order construct whose economic, social, and environmental components jointly describe the durability of the cocoa agribusiness system.

2.4 Hypotheses

The theoretical model proposes that adaptive farmers are better able to engage with and improve the agribusiness system because they can adjust production practices, use information and networks, and manage economic risks. Accordingly, H1 states that farmer adaptation has a positive effect on agribusiness system management.

A better-managed agribusiness system should, in turn, improve economic viability, social inclusion, and environmental practice by coordinating inputs, production-processing, marketing, and support services. Accordingly, H2 states that agribusiness system management has a positive effect on cocoa agribusiness sustainability.

Farmer adaptation may also be associated directly with sustainability because adaptive practices can improve resilience and livelihoods. Accordingly, H3 states that farmer adaptation has a positive direct effect on cocoa agribusiness sustainability.

Nevertheless, the central proposition is that a substantial portion of the adaptation-sustainability relationship is transmitted through agribusiness system management. Accordingly, H4 states that agribusiness system management mediates the effect of farmer adaptation on cocoa agribusiness sustainability.

III. MATERIALS AND METHODS

3.1 Study area and research design

The study used a cross-sectional quantitative design. Fieldwork was conducted from November 2025 to February 2026 in North Kolaka Regency, Southeast Sulawesi, Indonesia. Three cocoa-producing districts-Ngapa, Porehu, and Tolala-were selected to represent variation in cocoa area, production performance, and local agribusiness conditions. The choice of the study area is relevant because cocoa remains an important smallholder crop in the regency and because production performance differs across local production zones [6].

3.2 Population and sample

The target population comprised households actively managing cocoa farms in the three study districts. Eligible respondents were at least 18 years old, directly involved in cocoa-farm decision-making, had managed cocoa for at least two years, and voluntarily agreed to participate. Farm locations were selected purposively, while respondents were drawn from available village and farmer-group sampling frames with attention to geographic spread and farm-size variation. A total of 100 farmer questionnaires contained complete responses for the 50 scale items and were included in the analysis.

The sample size was considered appropriate for a prediction-oriented PLS-SEM model with a limited number of structural predictors and a hierarchical component specification. PLS-SEM was selected because the study aimed to estimate a predictive mediation model involving higher-order latent constructs and because the sample size was modest relative to covariance-based SEM requirements [23-25].

3.3 Measurement of constructs

All substantive indicators were measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Farmer adaptation (X) was specified as a higher-order construct formed by environmental adaptation (X1), social adaptation (X2), and economic adaptation (X3). Agribusiness system management (M) was specified through four dimensions: input system (M1), production and processing (M2), marketing (M3), and support system (M4). Cocoa agribusiness sustainability (Y) was specified through economic sustainability (Y1), social sustainability (Y2), and environmental sustainability (Y3).

The original instrument contained five items for each lower-order dimension. The final measurement model retained indicators based on outer loadings, construct reliability, average variance extracted (AVE), and conceptual relevance. Some indicators with loadings slightly below the conventional 0.708 guideline were retained when composite reliability and AVE remained satisfactory and the indicator represented substantively important content, following PLS-SEM reporting guidance [23, 24].

3.4 PLS-SEM procedure

The analysis used a two-stage hierarchical component model. In the first stage, the lower-order components were estimated and evaluated. In the second stage, latent variable scores from the lower-order components were used to estimate farmer adaptation, agribusiness system management, and sustainability as higher-order constructs. This procedure is suitable for higher-order models because it separates lower-order measurement from higher-order structural estimation and reduces the complexity associated with repeated indicators [26].

Measurement quality was assessed using outer loadings, Cronbach's alpha, composite reliability (CR), and AVE. As general guidelines, CR values of 0.70-0.95 and AVE values of at least 0.50 were considered satisfactory; indicator loadings near or above 0.708 were preferred, while lower loadings were judged jointly with reliability and content validity [23, 24]. Collinearity in the structural model was assessed using variance inflation factors (VIF). Structural paths were evaluated using standardized path coefficients, 5,000 bootstrap subsamples, t statistics, p values, and 95% bootstrap confidence intervals. Explanatory power was evaluated using R^2, effect size using f^2, and predictive relevance using Q^2.

Mediation was evaluated from the specific indirect effect and its bootstrap confidence interval. Following contemporary mediation guidance, a significant indirect effect combined with a non-significant direct effect was interpreted as indirect-only mediation rather than requiring a significant total or direct effect as a precondition [27, 28].

3.5 Ethical considerations

Participation was voluntary. Respondents were informed about the purpose of the study, their identities were kept confidential, and results were reported only in aggregate form.

Table 1. Operationalization of the hierarchical constructs

Higher-order construct	Lower-order dimensions	Conceptual content	Retained indicators
Farmer adaptation (X)	Environmental (X1); Social (X2); Economic (X3)	Ecological adjustment; participation and networks; financial/market risk management	X1: 4; X2: 5; X3: 3
Agribusiness system management (M)	Input (M1); Production & processing (M2); Marketing (M3); Support (M4)	Input access; production and post-harvest; market coordination; institutional and service support	M1: 4; M2: 4; M3: 5; M4: 3
Sustainability (Y)	Economic (Y1); Social (Y2); Environmental (Y3)	Farm viability; inclusion and welfare; ecological integrity and resilience	Y1: 5; Y2: 5; Y3: 5

IV. RESULTS AND DISCUSSION

4.1 Respondent profile and descriptive patterns

The 100 respondents had a mean age of 46.82 years and an average cocoa-farming experience of 20.28 years. Mean farm size was 1.12 ha, with a median of 1.00 ha, confirming the smallholder character of the sample. Secondary education was the most common formal education level: 51% had completed senior high school, while 17% had primary education, 11% junior high school, 17% an undergraduate degree, and 2% a master's degree; education status was not recorded for two respondents. Eighty-nine percent reported previous participation in a cocoa revitalization program, 7% reported no participation, and 4% did not report this status.

At the lower-order construct level, social adaptation had the highest adaptation mean (3.708), followed by environmental adaptation (3.672) and economic adaptation (3.588). Agribusiness system management averaged 3.730; the support system had the highest mean (3.950), whereas marketing was the lowest (3.494). Sustainability means were 3.850 for economic sustainability, 3.988 for social sustainability, and 3.856 for environmental sustainability. The pattern is noteworthy because the structurally important economic and marketing dimensions were not the highest-performing dimensions descriptively.

Table 2. Respondent characteristics and construct means (n = 100)

Variable	Mean / n	SD / %	Range / note
Age (years)	46.82	11.04	20–71
Cocoa-farming experience (years)	20.28	11.16	2–46; two missing values
Farm size (ha)	1.12	0.52	0.40–2.50
Senior high school	51	51.0%	Most common education level
Participated in cocoa revitalization	89	89.0%	4% not reported
Environmental adaptation (X1)	3.672	0.792	High
Social adaptation (X2)	3.708	0.747	High
Economic adaptation (X3)	3.588	0.532	High
Input system (M1)	3.764	0.609	High
Production & processing (M2)	3.712	0.616	High
Marketing (M3)	3.494	0.771	Lowest system dimension
Support system (M4)	3.950	0.524	Highest system dimension

Variable	Mean / n	SD / %	Range / note
Economic sustainability (Y1)	3.850	0.640	High
Social sustainability (Y2)	3.988	0.648	Highest sustainability dimension
Environmental sustainability (Y3)	3.856	0.636	High

4.2 Measurement model

The lower-order measurement model showed acceptable reliability and convergent validity after indicator evaluation. Cronbach's alpha ranged from 0.658 to 0.808, composite reliability from 0.815 to 0.873, and AVE from 0.513 to 0.624. The two alpha values below 0.70 (economic adaptation and the support system) were retained because their composite reliability exceeded 0.80 and their AVE exceeded 0.50, while the retained indicators represented necessary conceptual content.

The higher-order model also met reliability and convergent validity criteria. Farmer adaptation had CR = 0.871 and AVE = 0.693; agribusiness system management had CR = 0.886 and AVE = 0.663; and sustainability had CR = 0.945 and AVE = 0.851. Economic adaptation had the highest loading on farmer adaptation (0.908). Marketing had the highest loading on agribusiness system management (0.908), followed by production-processing (0.841), input (0.781), and support (0.713). Sustainability was strongly represented by all three dimensions: environmental (0.933), economic (0.924), and social (0.909).

Table 3. Measurement quality of lower- and higher-order constructs

Construct	Alpha	CR	AVE	Loading range / dimension loading	Assessment
X1 Environmental adaptation	0.783	0.868	0.624	0.689–0.837	Acceptable
X2 Social adaptation	0.789	0.862	0.558	0.615–0.800	Acceptable
X3 Economic adaptation	0.658	0.815	0.595	0.745–0.812	Acceptable
M1 Input system	0.755	0.848	0.583	0.695–0.838	Acceptable
M2 Production & processing	0.715	0.826	0.543	0.666–0.779	Acceptable
M3 Marketing	0.807	0.873	0.580	0.692–0.831	Acceptable
M4 Support system	0.684	0.829	0.619	0.757–0.801	Acceptable
Y1 Economic sustainability	0.808	0.867	0.568	0.684–0.830	Acceptable
Y2 Social sustainability	0.752	0.840	0.515	0.610–0.784	Acceptable
Y3 Environmental sustainability	0.760	0.840	0.513	0.628–0.792	Acceptable
X Farmer adaptation	0.776	0.871	0.693	X1=.800; X2=.784; X3=.908	Acceptable
M Agribusiness system management	0.825	0.886	0.663	M1=.781; M2=.841; M3=.908; M4=.713	Acceptable

Construct	Alpha	CR	AVE	Loading range / dimension loading	Assessment
Y Sustainability	0.912	0.945	0.851	Y1=.924; Y2=.909; Y3=.933	Acceptable

4.3 Structural model and mediation

Collinearity did not reach a critical level in the sustainability equation: the VIF values for farmer adaptation and agribusiness system management were both 2.993. The path from farmer adaptation to agribusiness system management was positive and highly significant ($\beta = 0.816$, $t = 33.656$, $p < 0.001$, 95% CI [0.769, 0.865]), supporting H1. The model explained 66.6% of the variance in agribusiness system management ($R^2 = 0.666$). The corresponding effect size was large ($f^2 = 1.993$), and $Q^2 = 0.658$ indicated substantial predictive relevance.

Agribusiness system management had a positive and significant effect on sustainability ($\beta = 0.729$, $t = 5.233$, $p < 0.001$, 95% CI [0.424, 0.973]), supporting H2. In the sustainability equation, R^2 was 0.579, indicating that farmer adaptation and agribusiness system management jointly explained 57.9% of sustainability variance. The f^2 effect of agribusiness system management was 0.422, while Q^2 for sustainability was 0.520.

The direct effect of farmer adaptation on sustainability was small and non-significant after the mediator was included ($\beta = 0.039$, $t = 0.320$, $p = 0.705$, 95% CI [−0.175, 0.307]), so H3 was not supported. By contrast, the specific indirect effect of farmer adaptation on sustainability through agribusiness system management was positive and significant ($\beta = 0.595$, $t = 5.092$, $p < 0.001$, 95% CI [0.349, 0.811]), supporting H4. The total effect of farmer adaptation on sustainability was $\beta = 0.634$ ($t = 13.058$, $p < 0.001$). Because the indirect effect was significant while the direct effect was not, the mediation pattern was classified as indirect-only mediation.

Table 4. Structural paths and mediation results

Hypothesis / effect	β	t	p	95% CI	f²	Decision
H1 X → M	0.816	33.656	<0.001	[0.769, 0.865]	1.993	Supported
H2 M → Y	0.729	5.233	<0.001	[0.424, 0.973]	0.422	Supported
H3 X → Y (direct)	0.039	0.320	0.705	[−0.175, 0.307]	0.001	Not supported
H4 X → M → Y	0.595	5.092	<0.001	[0.349, 0.811]	—	Supported
Total effect X → Y	0.634	13.058	<0.001	[0.541, 0.729]	—	Significant

Table 5. Explanatory and predictive performance

Endogenous construct	R²	Q²	Interpretation
Agribusiness system management	0.666	0.658	Moderate-to-strong explanatory power; high predictive relevance
Sustainability	0.579	0.520	Moderate explanatory power; high predictive relevance

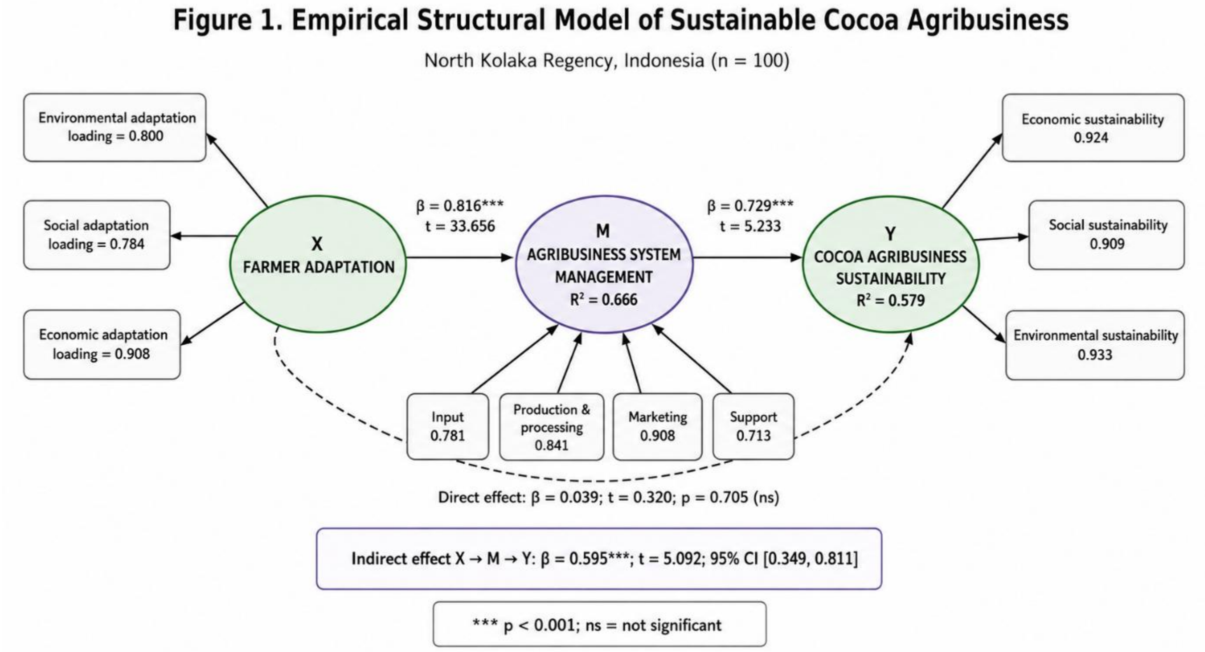

*Fig. 1. Empirical hierarchical structural model. *** $p < 0.001$; ns = not significant. Dimension loadings are shown around the three higher-order constructs.*

4.4 Farmer adaptation strongly shapes agribusiness system management

The first major finding is the strong effect of farmer adaptation on agribusiness system management ($\beta = 0.816$). This result moves the discussion of adaptation beyond the farm plot. Adaptation changes the way farmers seek inputs, schedule farm operations, learn from peers and extension agents, manage costs, invest in post-harvest quality, and respond to market signals. In other words, adaptation is not only a response to environmental stress; it is also an organizational capability that influences how farmers participate in the wider agribusiness system.

The result is consistent with cocoa adaptation studies showing that farmers' responses to climate and production risks depend on combinations of knowledge, social networks, livelihood resources, and institutional access [7, 8]. It also supports the value-chain evidence of Tennhardt et al. [10], who found that sustainable farming practice implementation is shaped by value-chain factors in addition to farm and farmer characteristics. The present study extends that argument by showing that adaptation, when modeled as an integrated environmental-social-economic capability, explains a large share of variation in the management of the agribusiness system.

A particularly important result is that economic adaptation had the highest higher-order loading (0.908) on farmer adaptation even though it had the lowest descriptive mean (3.588). This asymmetry identifies an intervention priority. Farmers were relatively strong in social participation and environmental response, but their overall adaptive capability was especially dependent on financial and market-related adjustment. Limited finance can delay replanting, constrain the purchase of quality inputs, restrict the ability to hold beans for better prices, and reduce participation in collective post-harvest systems. Evidence from smallholder cocoa systems supports the importance of credit and cooperative services for productive investment and farm performance [29].

This finding also has implications for extension design. Extension that focuses only on technical recommendations may improve knowledge but fail to change system performance when farmers cannot finance or market the recommended practices. Recent Indonesian evidence from corporate-driven cocoa certification illustrates the complementarity of capacity-building, market incentives, and implementation mechanisms: stronger intervention packages were associated with better cocoa production and income outcomes [11]. Thus, adaptation should be understood as a co-produced capability, created jointly by farmer agency and enabling institutions.

4.5 Agribusiness system management is the immediate driver of sustainability

The second major finding is that agribusiness system management strongly affects sustainability ($\beta = 0.729$). This relationship confirms the central proposition of systems agribusiness theory: sustainable outcomes emerge from coordinated flows of inputs, production decisions, post-harvest practices, market exchange, and supporting services rather than from production alone [12]. The finding is especially relevant for smallholders because fragmented access to these functions increases transaction costs and can disconnect improved practices from economic rewards.

Marketing had the highest loading (0.908) on the agribusiness system construct while recording the lowest descriptive mean (3.494). This combination makes marketing both a bottleneck and a leverage point. Farmers can improve production and bean quality, but without collective aggregation, transparent weighing, price information, differentiated quality incentives, and credible buyers, the additional value may not return to the farm household. Research on Indonesia's cocoa value chain has long identified institutional voids and weak smallholder linkages as barriers to inclusion [9]. The present results indicate that such market arrangements are not peripheral; they are central to the system mechanism through which sustainability is generated.

The finding also converges with recent international evidence on producer organizations. Krumbiegel and Tillie [22], using data from more than 1,700 cocoa producers in Côte d'Ivoire and Ghana, found that cooperative participation and certification can complement one another in promoting sustainable agricultural practices. This does not imply that cooperatives are automatically effective. Their contribution depends on whether they perform genuine economic functions-aggregating volume, managing quality, negotiating contracts, coordinating logistics, and distributing benefits transparently. In North Kolaka, the very low score of collective marketing in this study indicates that strengthening the commercial role of producer organizations should be a priority.

Post-harvest management is another crucial connection between system management and sustainability. Fermentation and drying determine whether farmers can meet quality standards and access differentiated markets. Field research in Ecuador has demonstrated substantial variation in small-farm post-harvest practices and the importance of monitoring fermentation and drying processes for cocoa quality [30]. Consequently, quality improvement programs should link training with shared fermentation facilities, drying infrastructure, grading protocols, traceability, and buyer agreements. Quality without a market premium is difficult to sustain; a premium without reliable quality is equally unstable.

The environmental dimension further illustrates why system coordination matters. Practices such as agroforestry, organic amendments, shade regulation, and integrated pest management require knowledge, labour, material inputs, and often delayed returns. Research shows that cocoa agroforestry can provide climate and biodiversity benefits, while organic management can improve soil quality and microbial diversity [19-21]. Yet these practices will be maintained only when the agribusiness system aligns ecological goals with economic incentives and service delivery. Sustainability therefore depends on managing trade-offs across the economic, social, and environmental dimensions rather than optimizing a single outcome.

4.6 Indirect-only mediation explains the adaptation-sustainability relationship

The most important theoretical result is the mediation pattern. Farmer adaptation did not have a significant direct effect on sustainability after agribusiness system management was included ($\beta = 0.039$, $p = 0.705$), whereas the indirect effect through system management was substantial and significant ($\beta = 0.595$, 95% CI [0.349, 0.811]). According to contemporary mediation logic, this is an indirect-only mediation pattern [27, 28]. The finding indicates that adaptation is a necessary capability but not a sufficient mechanism for producing sustainability.

This result provides a coherent explanation for a common development paradox. Farmers may attend training, understand recommended practices, and express strong motivation to improve productivity and quality, yet sustainable outcomes remain limited because the surrounding system does not convert knowledge into inputs, finance, facilities, market access, and incentives. In the North Kolaka data, this pattern was visible in the contrast between strong perceived government support and weak collective marketing, between strong quality orientation and weak standardized fermentation and drying, and between long farming experience and limited access to finance. These are not isolated shortcomings; they are breaks in the transmission mechanism from adaptation to sustainability.

The mediation finding extends previous work on cocoa sustainability in two directions. First, it provides an explicit meso-level mechanism connecting farm-level capability to triple-bottom-line outcomes. Studies such as Tennhardt et al. [10] show that value-chain factors influence the implementation of sustainable practices, while

Bemelmans and Maertens [11] show that the strength and combination of institutional interventions shape socioeconomic outcomes. The present model integrates these insights by treating agribusiness system management as the transformation mechanism itself. Second, the result adds structural evidence to multidimensional sustainability studies in Indonesia, which have shown that sustainability performance can differ substantially across economic, social, technological, institutional, and ecological dimensions [15].

The finding also changes how responsibility for sustainability should be allocated. If adaptation translated directly into sustainability, policy could focus primarily on changing farmer behavior. Indirect-only mediation shows that such an approach is incomplete. Farmers remain central actors, but public agencies, cooperatives, traders, processors, financial institutions, extension services, and research organizations share responsibility for creating a system in which adaptive behavior can generate durable outcomes.

4.7 Theoretical contribution

The study contributes to theory by linking three analytical levels. At the micro level, farmer adaptation represents the capability of producers to respond to ecological, social, and economic pressures. At the meso level, agribusiness system management represents the coordination architecture that organizes resources and relationships. At the outcome level, sustainability represents the integrated economic, social, and environmental performance of the cocoa system. The significant indirect pathway demonstrates that sustainability is an emergent property of the interaction between actor capability and system organization.

This contribution is relevant to adaptation theory because it emphasizes institutional translation. Classical adaptation perspectives explain how people modify technology and social organization in response to environmental change [16, 17]. In contemporary commodity systems, however, the necessary organizational structures extend beyond the community to include markets, finance, quality standards, logistics, processing, and formal support institutions. Agribusiness system management is therefore not merely a control variable; it is the organizational space in which adaptation becomes economically, socially, and environmentally consequential.

The model also contributes to the triple bottom line literature by showing why economic, social, and environmental sustainability should not be treated as independent checklists. All three dimensions loaded strongly on the higher-order sustainability construct. This supports the conceptual argument that sustainability is weakened when one dimension is pursued at the expense of others [13, 14]. For smallholder cocoa, the practical implication is clear: ecological practice adoption is more durable when farmer income and institutional participation are simultaneously strengthened.

4.8 Policy and managerial implications

The findings suggest five priorities for cocoa development in North Kolaka and comparable smallholder regions. First, collective marketing should be strengthened through producer organizations that perform business functions rather than only administrative or project functions. Key services include volume aggregation, transparent weighing, quality grading, price information, sales contracts, and traceable transaction records.

Second, post-harvest quality systems should be organized at group or cluster level. Shared fermentation units, drying facilities, standard operating procedures, quality testing, and differentiated purchasing arrangements can connect farmers' quality orientation with actual price rewards. This is important because post-harvest quality is a system function: individual adoption is difficult when market volumes and infrastructure need coordination.

Third, finance should be aligned with the cocoa production cycle. Seasonal credit, group-based guarantees, input financing, and cash-flow-oriented lending can help farmers invest in rehabilitation, soil fertility, pruning, pest management, and post-harvest improvement. Financial inclusion should be combined with financial literacy and transparent repayment arrangements so that credit increases adaptive capacity without increasing vulnerability.

Fourth, extension should integrate technical, organizational, and market learning. Field schools can combine climate-adaptive farm management with cost recording, quality management, cooperative governance, and market negotiation. This recommendation is consistent with the finding that effective capacity-building has stronger impacts when combined with incentives and implementation mechanisms [11].

Fifth, sustainability governance should be multi-stakeholder. A district-level cocoa platform could coordinate government agencies, extension services, producer organizations, banks, research institutions, traders, and processors around measurable indicators for farm resilience, quality, collective sales, income, participation, and environmental management. Such coordination would reduce fragmented projects and help ensure that interventions strengthen the mediation pathway identified by the model.

4.9 Limitations and future research

The study has several limitations. First, the cross-sectional design supports predictive and associational interpretation but cannot establish temporal causality. Panel data would be valuable for testing whether changes in farmer adaptation precede changes in agribusiness system management and sustainability. Second, most indicators are based on farmer perceptions and self-reported practices. Future studies should integrate objective farm measures such as yield, net income, bean quality, soil indicators, shade-tree diversity, and verified marketing records.

Third, the study covers three districts in one regency. The structural mechanism is theoretically transferable, but coefficient magnitudes may differ across cocoa regions with different market structures, infrastructure, certification coverage, and ecological conditions. Multi-region studies could test measurement invariance and compare the strength of the mediation pathway. Fourth, future models may examine moderators such as farm size, age of cocoa trees, participation in cooperatives, access to credit, extension intensity, certification, or buyer relationships. These variables could explain when and for whom agribusiness system management most effectively converts adaptation into sustainability.

V. CONCLUSION

This study shows that sustainable cocoa agribusiness is not produced by farmer adaptation alone. Farmer adaptation strongly improved agribusiness system management, and agribusiness system management strongly improved sustainability. Once the system mechanism was included, the direct adaptation-sustainability relationship disappeared, while the indirect effect remained strong and significant. The result therefore supports an indirect-only mediation model.

The substantive implication is that farmer capability must be translated into coordinated agribusiness functions. Environmental, social, and economic adaptation become sustainable outcomes when farmers can access suitable inputs, apply production and post-harvest practices, participate in effective marketing, and receive institutional, financial, and extension support. For North Kolaka, the most strategic leverage points are collective marketing, inclusive finance, standardized fermentation and drying, stronger producer organizations, climate-adaptive farm management, and coordinated multi-stakeholder governance.

More broadly, the study offers an adaptive-systemic perspective for smallholder commodity development. Sustainability should be treated as a property of the system linking capable farmers with functioning institutions and markets. Policies that strengthen only one side of this relationship are likely to generate incomplete results; durable cocoa sustainability requires both adaptive farmers and an agribusiness system capable of converting adaptation into economic, social, and environmental value.

REFERENCES

[1] J.E. Kongor, M. Owusu, and C. Oduro-Yeboah, Cocoa production in the 2020s: Challenges and solutions, *CABI Agriculture and Bioscience, 5,* 2024, 102. https://doi.org/10.1186/s43170-024-00310-6

[2] P. Läderach, A. Martinez-Valle, G. Schroth, and N. Castro, Predicting the future climatic suitability for cocoa farming of the world's leading producer countries, *Climatic Change, 119,* 2013, 841-854. https://doi.org/10.1007/s10584-013-0774-8

[3] G. Schroth, P. Läderach, A.I. Martinez-Valle, C. Bunn, and L. Jassogne, Vulnerability to climate change of cocoa in West Africa: Patterns, opportunities and limits to adaptation, *Science of the Total Environment, 556,* 2016, 231-241. https://doi.org/10.1016/j.scitotenv.2016.03.024

[4] M. Wessel and P.M.F. Quist-Wessel, Cocoa production in West Africa: A review and analysis of recent developments, *NJAS: Wageningen Journal of Life Sciences, 74-75,* 2015, 1-7. https://doi.org/10.1016/j.njas.2015.09.001

[5] BPS-Statistics Indonesia, *Indonesian cocoa statistics 2023* (Jakarta: BPS-Statistics Indonesia, 2024).

[6] BPS-Statistics of North Kolaka Regency, *North Kolaka Regency in figures 2025* (Lasusua: BPS-Statistics of North Kolaka Regency, 2025).

[7] P. Antwi-Agyei, A.J. Dougill, L. Connolly-Boutin, and L.C. Stringer, Climate change adaptation choices among smallholder cocoa farmers in Ghana, *Climate Change Economics, 11(2),* 2020, 2040007. https://doi.org/10.1142/S2010007820400076

[8] F.A. Asante, A.A. Boakye, and I.S. Egyir, Climate change adaptation strategies of cocoa farmers in the Wassa East District of Ghana, *Climate Services, 22,* 2021, 100232. https://doi.org/10.1016/j.cliser.2021.100232

[9] D. de Boer, G. Limpens, A. Rifin, and N. Kusnadi, Inclusive productive value chains, an overview of Indonesia's cocoa industry, *Journal of Agribusiness in Developing and Emerging Economies, 9(5),* 2019, 439-456. https://doi.org/10.1108/JADEE-09-2018-0131

[10] L.M. Tennhardt, E.F. Lambin, M. Curran, and C. Schader, Implementation of sustainable farming practices by cocoa farmers in Ecuador and Uganda: The influence of value chain factors, *Frontiers in Sustainable Food Systems, 7,* 2023, 1167683. https://doi.org/10.3389/fsufs.2023.1167683

[11] J. Bemelmans and M. Maertens, Implementation and effectiveness of corporate-driven smallholder cocoa certification schemes in Indonesia, *Agricultural and Food Economics, 13,* 2025, Article 30. https://doi.org/10.1186/s40100-025-00375-5

[12] W.D. Downey and S.P. Erickson, *Agribusiness management, 2nd ed.* (New York: McGraw-Hill, 1987).

[13] J. Elkington, *Cannibals with forks: The triple bottom line of 21st century business* (Oxford: Capstone, 1997).

[14] B. Purvis, Y. Mao, and D. Robinson, Three pillars of sustainability: In search of conceptual origins, *Sustainability Science, 14,* 2019, 681-695. https://doi.org/10.1007/s11625-018-0627-5

[15] M. Hidayanto and Y. Fiana, Sustainability evaluation of a smallholder cocoa plantation on the Sebatik Island, Indonesia, using a multidimensional scaling approach, *Journal of Water and Land Development, 60,* 2024, 167-176. https://doi.org/10.24425/jwld.2024.149118

[16] J.H. Steward, *Theory of culture change: The methodology of multilinear evolution* (Urbana, IL: University of Illinois Press, 1955).

[17] E.F. Moran, *People and nature: An introduction to human ecological relations* (Malden, MA: Blackwell Publishing, 2006).

[18] J.M. Cohen and N.T. Uphoff, *Rural development participation: Concepts and measures for project design, implementation and evaluation* (Ithaca, NY: Cornell University, 1977).

[19] W.J. Blaser, J. Oppong, S.P. Hart, J. Landolt, E. Yeboah, and J. Six, Climate-smart sustainable agriculture in low-to-intermediate shade agroforests, *Nature Sustainability, 1(5),* 2018, 234-239. https://doi.org/10.1038/s41893-018-0062-8

[20] M. Lori, L. Armengot, M. Schneider, U. Schneidewind, N. Bodenhausen, P. Mäder, and H.-M. Krause, Organic management enhances soil quality and drives microbial community diversity in cocoa production systems, *Science of the Total Environment, 834,* 2022, 155223. https://doi.org/10.1016/j.scitotenv.2022.155223

[21] W. Niether, J. Jacobi, W.J. Blaser, C. Andres, and L. Armengot, Cocoa agroforestry systems versus monocultures: A multi-dimensional meta-analysis, *Environmental Research Letters, 15(10),* 2020, 104085. https://doi.org/10.1088/1748-9326/abb053

[22] K. Krumbiegel and P. Tillie, Sustainable practices in cocoa production: The role of certification schemes and farmer cooperatives, *Ecological Economics, 222,* 2024, 108211. https://doi.org/10.1016/j.ecolecon.2024.108211

[23] J.F. Hair, J.J. Risher, M. Sarstedt, and C.M. Ringle, When to use and how to report the results of PLS-SEM, *European Business Review, 31(1),* 2019, 2-24. https://doi.org/10.1108/EBR-11-2018-0203

[24] J.F. Hair, G.T.M. Hult, C.M. Ringle, and M. Sarstedt, *A primer on partial least squares structural equation modeling (PLS-SEM), 3rd ed.* (Thousand Oaks, CA: SAGE, 2022).

[25] N. Kock and P. Hadaya, Minimum sample size estimation in PLS-SEM: The inverse square root and gamma-exponential methods, *Information Systems Journal, 28(1),* 2018, 227-261. https://doi.org/10.1111/isj.12131

[26] M. Sarstedt, J.F. Hair, J.-H. Cheah, J.-M. Becker, and C.M. Ringle, How to specify, estimate, and validate higher-order constructs in PLS-SEM, *Australasian Marketing Journal, 27(3),* 2019, 197-211. https://doi.org/10.1016/j.ausmj.2019.05.003

[27] C. Nitzl, J.L. Roldán, and G. Cepeda, Mediation analysis in partial least squares path modeling: Helping researchers discuss more sophisticated models, *Industrial Management & Data Systems, 116(9),* 2016, 1849-1864. https://doi.org/10.1108/IMDS-07-2015-0302

[28] X. Zhao, J.G. Lynch Jr., and Q. Chen, Reconsidering Baron and Kenny: Myths and truths about mediation analysis, *Journal of Consumer Research, 37(2),* 2010, 197-206. https://doi.org/10.1086/651257

[29] A.D. Kehinde and A.A. Ogundeji, The simultaneous impact of access to credit and cooperative services on cocoa productivity in South-western Nigeria, *Agriculture & Food Security, 11,* 2022, Article 11. https://doi.org/10.1186/s40066-021-00351-4

[30] S. Streule, S. Freimüller Leischtfeld, M. Galler, and S. Miescher Schwenninger, Monitoring of cocoa post-harvest process practices on a small-farm level at five locations in Ecuador, *Heliyon, 8(6),* 2022, e09628. https://doi.org/10.1016/j.heliyon.2022.e09628