e-ISSN 2581-0405
Asian Journal of Applied Research for Community Development and Empowerment
Journal home page: http://ajarcde-safe-network.org ISSN 2581-0405

Factors Associated with Multidimensional Agribusiness Innovation Adoption among Chili Farmers: Mixed-Methods Evidence from Sinjai, Indonesia

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ARTICLE INFO

Article History:
Received: 27 August 2026
Final Revision: 25 October 2026
Accepted:03 November 2026
Online Publication: 09 November 2026

KEYWORDS

agribusiness innovation; multidimensional adoption; chili farmers; agricultural finance; technology adoption; mixed methods

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A B S T R A C T

Chili farmers often adopt agribusiness innovations selectively because production decisions are shaped simultaneously by financial constraints, technological conditions, institutional support, and farming risks. This study examined factors associated with multidimensional agribusiness innovation adoption among chili farmers in Bongki Lengkese, Sinjai Regency, Indonesia. A cross-sectional quantitative-dominant mixed-methods design combined a structured survey of 67 purposively selected chili farmers with one focus group discussion involving 10 farmers and in-depth interviews with an agricultural extension officer and the Head of the Agricultural Extension Center. The adoption index incorporated production, farm-management, and marketing dimensions with equal conceptual weighting. Thirteen prespecified social, economic, institutional, technological, and risk-related predictors were analyzed simultaneously using multiple linear regression. Because diagnostic testing indicated potential heteroskedasticity, coefficient inference used HC3 heteroskedasticity-consistent standard errors. The model explained 38.1% of the observed variation in adoption ($R^2 = 0.381$). External or mixed financing was positively associated with adoption (B = 0.437; HC3 p = 0.040), as were technological conditions (B = 0.047; HC3 p = 0.020). Qualitative evidence supported these findings by identifying limited capital, technology costs, and uneven implementation as practical constraints, while institutional support and risk perception remained important in context. The findings suggest developing affordable technologies, appropriate financing mechanisms, and practical field-based support in an integrated manner. These findings are relevant to Sustainable Development Goals (SDGs) 2, 8, and 9 through their implications for sustainable agriculture, rural economic capacity, and agricultural innovation.

Contribution to Sustainable Development Goals (SDGs):
SDG 2: Zero Hunger
SDG 8: Decent Work and Economic Growth
SDG 9: Industry, Innovation and Infrastructure

1. INTRODUCTION

1.1. Research Background

Chili is an economically important horticultural commodity in Indonesia because of its contribution to farm income, food consumption, and price dynamics. National horticultural statistics document the continuing economic relevance of chili within Indonesia's horticultural sector [1]. At the same time, the Indonesian chili value chain is characterized by substantial price volatility and complex market relationships, exposing producers to uncertainty that extends beyond crop production alone [2]. These conditions make farmers' capacity to adopt appropriate agribusiness innovations increasingly relevant to farm adaptability and sustainability.

Agricultural innovation adoption should not be understood solely as a binary decision to adopt or reject a particular technology. Farmers often combine existing practices with selected new practices based on available resources, knowledge, perceived usefulness, compatibility with farming systems, and exposure to uncertainty [3], [4]. A broader agribusiness perspective is therefore needed because innovation can involve

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production technology, farm-management practices, and marketing arrangements that are implemented at different rates and in different combinations.

Empirical adoption studies have identified a wide range of potential correlates. A meta-analysis of studies from developing countries found that education, household characteristics, land resources, credit, tenure, extension, and organizational participation often correlate with technology adoption, although effects vary substantially across technologies and settings [5]. A recent systematic review focused on Southeast Asia similarly grouped adoption-related factors into household, institutional, economic, technological, social, and behavioral domains [6]. These findings support a context-specific analytical framework rather than assuming a universal set of determinants.

Financing is especially relevant when innovations require additional expenditure for inputs, equipment, information, or management changes. Research on chili-based agribusiness in Indonesia has shown links among microcredit, technology adoption, and farm-household prosperity [7], while a systematic review and meta-analysis from Ethiopia also identified credit access as an important mechanism for overcoming financial constraints to technology adoption [8]. A more recent meta-analysis further found a positive but highly heterogeneous relationship between microcredit access and agricultural technology adoption, indicating that the role of financing can vary substantially across technologies and farming contexts [9]. However, the empirical role of financing depends on how it is operationalized. The present study distinguishes the financing sources used by farmers from direct measures of formal credit access or borrowing constraints.

Institutional and informational environments may also shape farmers' capacity to evaluate and implement innovations. Agricultural extension can support technical learning and the acquisition of relevant information [10]. In Indonesia, mobile-phone use has been shown to facilitate access to agronomic information, markets, credit, and customers [11], while farmer field schools have demonstrated the potential of practical learning approaches for transferring agricultural technologies and improving farm performance [12]. Nevertheless, institutional support may not translate into implementation if it is poorly matched to farmers' needs.

Risk is another important consideration in chili farming. Farmers face uncertainty related to volatile prices, pests and diseases, weather, and potential production losses. Evidence from Bangladesh shows that perceived climate-related risks can shape agricultural technology adoption [13], while research involving seasonal commodity farmers in Indonesia, including chili farmers, indicates that risk tolerance is associated with experience, education, income, capital, land status, and land size [14]. Chili-specific research in Mexico further highlights the role of farmer attitudes and risk perceptions in technological innovation [15].

At the district level, the 2023 Agricultural Census provides a broader statistical context for horticultural farming in Sinjai Regency [16]. Within Sinjai Timur District, Bongki Lengkese Village was identified by local extension informants as one of the principal chili-growing areas, with substantially greater potential chili area than several neighboring villages. The study therefore uses Sinjai Regency as the broader geographical context while limiting empirical inference to surveyed farmers in Bongki Lengkese. Recent work in AJARCDE on Indonesian chili farmers also demonstrates the continuing importance of farmer readiness, extension support, and local context in agricultural technology adoption [17].

Despite the growing literature, three gaps remain relevant. First, many agricultural adoption studies focus on individual production technologies rather than innovation across the wider agribusiness system, including farm-management and marketing practices. Second, researchers often examine social, economic, institutional, technological, and risk-related factors without clearly distinguishing independent statistical associations from broader contextual conditions. Third, quantitative models alone may not sufficiently explain why farmers adopt some practices while postponing or selectively implementing others. This study addresses these gaps by operationalizing agribusiness innovation adoption as a multidimensional composite covering production, farm-management, and marketing practices, estimating the independent associations of 13 prespecified predictors, and integrating the quantitative findings with evidence from farmer focus-group discussion and institutional interviews. The study is observational and cross-sectional; it does not evaluate a training, mentoring, or technology-transfer intervention.

This study contributes by combining a multidimensional agribusiness adoption index with a simultaneous assessment of social, economic, institutional, technological, and risk-related factors, followed by mixed-methods integration to distinguish statistically associated factors from contextually important conditions.

1.2. Literature Review

1.2.1. Social, Economic, and Financing Conditions

Farmers' adoption decisions are embedded within household and farm-resource conditions. Age, education, farming experience, household responsibilities, land resources, income, training exposure, and financing capacity can influence the ability to obtain information, evaluate alternatives, and bear the costs and uncertainty associated with innovation [5], [6]. However, the direction and magnitude of these relationships vary across agricultural settings, which justifies examining multiple covariates simultaneously within the local context.

Financing deserves separate conceptual treatment because the availability of credit, actual borrowing, and the source of funds used for production are not equivalent constructs. In this study, the empirical variable records whether farmers relied exclusively on their own funds or used external or mixed financing. Accordingly, the analysis concerns financing-source use rather than formal credit accessibility. This distinction avoids interpreting a behavioral financing variable as a direct measure of credit constraints.

1.2.2. Institutional and Technological Conditions

Institutional support can influence innovation through extension, farmer organizations, government programs, access to information, and links to input or market services. Effective extension may improve farmers' knowledge and confidence, whereas farmer organizations can support collective learning and resource sharing [10], [12]. Recent evidence from Indonesian smallholders in Banten also showed positive associations between access to agricultural extension, technology adoption, and farm income [18]. Technological conditions-including availability, affordability, perceived usability, information access, and compatibility with local production systems-determine whether a practice is practically implementable [5], [6]. Recent research on digital agriculture similarly identifies farmers' economic conditions, technological infrastructure, technical knowledge, and perceived usefulness as interconnected drivers and barriers to technology adoption [19].

Technology adoption is also selective rather than uniform. Farmers may rapidly implement practices perceived as familiar, affordable, or immediately useful, while postponing capital-intensive or complex technologies. Digital information can broaden access to prices, weather information, production knowledge, and customers [11], yet the benefits of digital or physical technologies depend on farmers' ability to use them and on the broader support environment. Among smallholder farmers in Vietnam, digital technology adoption was associated with education, farm size, digital experience, knowledge exchange, access to digital information, and internet-related conditions [20]. A recent scoping review of smallholder digitalisation likewise identified connectivity, digital literacy, infrastructure, and

affordability as recurring implementation challenges [21]. This selective pattern is consistent with a multidimensional rather than binary understanding of adoption [3], [4].

1.2.3. Risk Perception and Multidimensional Adoption

Farmers make agricultural innovation decisions under uncertainty. Market-price instability, crop failure, pests and diseases, climatic variability, and dependence on particular buyers can alter farmers' willingness to commit resources to new practices [13]-[15]. Recent evidence also indicates that agricultural extension, technology adoption, and production risk can operate as interrelated dimensions of farmers' decision environments rather than as completely independent processes [22]. Risk may directly differentiate adoption decisions, but it may also operate as a widely shared contextual condition. When most farmers perceive similar levels of uncertainty, a risk measure may be substantively important without strongly distinguishing higher and lower adopters statistically.

A multidimensional approach is therefore appropriate for agribusiness innovation. A farmer may adopt improved seed yet not use drip irrigation, maintain conventional bookkeeping while changing planting-time decisions, or use digital marketing without substantially changing production technology. Production, management, and marketing represent related but distinct domains of innovation. Treating them as separate dimensions allows the analysis to capture patterns of partial and selective implementation [3], [4].

1.3. Research Objective, Question, and Hypothesis

This study aims to analyze factors associated with multidimensional agribusiness innovation adoption among chili farmers in Bongki Lengkese Village, Sinjai Regency, Indonesia. Specifically, it examines the independent associations of social characteristics, economic resources and financing conditions, institutional support, technological conditions, and risk perception with an adoption index covering production, farm-management, and marketing practices. The quantitative findings are further integrated with qualitative evidence from farmers and agricultural institutional informants to explain the contextual conditions underlying adoption and to formulate practical strategies relevant to the study area.

The study addresses the following research question: Which social, economic, institutional, technological, and risk-related factors are independently associated with multidimensional agribusiness innovation adoption among chili farmers in Bongki Lengkese, and how does qualitative evidence help explain the observed statistical patterns?

The non-directional quantitative hypothesis was that at least one of the prespecified social, economic, institutional, technological, or risk-related predictors is independently associated with the multidimensional agribusiness innovation adoption index after simultaneous adjustment for the other predictors.

2. MATERIALS AND METHODS

2.1. Research Design and Study Area

This study employed a cross-sectional quantitative-dominant mixed-methods design with sequential data collection and integration primarily at the interpretation stage. The quantitative survey constituted the principal analytical component, while qualitative evidence was used to contextualize, explain, and triangulate the statistical findings. The authors integrated the data through narrative comparison and a joint display to identify convergence, complementarity, and divergence between quantitative and qualitative evidence [23].

The study was conducted in Bongki Lengkese Village, Sinjai Timur District, Sinjai Regency, South Sulawesi, Indonesia, during July-August 2026. Bongki Lengkese was purposively selected because local extension and Agricultural Extension Center (Balai Penyuluhan Pertanian, BPP) informants identified it as a principal chili-growing area in Sinjai Timur District. The Head of BPP estimated a potential chilli-development area of approximately 15-30 ha in Bongki Lengkese, compared with approximately 1-2 ha in each of Biroro and Lasiai. These figures were used as contextual field information rather than as population estimates.

2.2. Participants and Sampling

The quantitative component focused on chili farmers in Bongki Lengkese Village who were actively engaged in chili farming. Respondents were purposively selected based on their involvement in chili farming as an enterprise. A total of 67 farmers completed the structured survey and were included in the quantitative analysis.

The survey was conducted from 4 to 17 July 2026, shortly before the principal seasonal chili-growing period reported for the study area. Consequently, adoption indicators represented farmers' self-reported farming practices rather than contemporaneous field observations of all practices. Because participants were purposively recruited from a single village, the findings are interpreted as evidence from the study site and are not intended as statistically representative estimates for all chili farmers in Sinjai Regency.

For the qualitative component, 12 chili farmers were invited to participate in one focus group discussion (FGD) and 10 attended. In-depth interviews were also conducted with the agricultural extension officer responsible for Bongki Lengkese Village on 3 August 2026 and the Head of the Agricultural Extension Center (BPP) of Sinjai Timur District on 5 August 2026. The FGD was conducted on 7 August 2026. These participants were purposively selected for their direct knowledge of chili production, innovation practices, financing, extension services, farmer organizations, marketing, and production risks.

Because the study did not involve a controlled field trial or standardized technology-transfer intervention, soil and climatic conditions were not treated as experimental operating parameters, and no intervention-specific adoption compliance rate was defined. Instead, adoption was assessed using self-reported implementation indicators in the cross-sectional survey.

2.3. Data Collection and Predictor Measurement

We collected quantitative data through face-to-face administration of a structured questionnaire. The instrument contained respondent characteristics and measures representing social, economic, institutional, technological, risk-related, and adoption domains.

Social variables included age, education level, household dependents, years of chili-farming experience, and number of agricultural training or extension attendances during the previous year. Education was treated as an ordinal variable based on the five categories observed in the sample: no formal schooling, elementary school, junior high school, senior high school, and university/higher education. The observed education distribution consisted of 10 respondents with no formal schooling, 24 with elementary education, 13 with junior high education, 16 with senior high education, and 4 with university or higher education.

Economic variables included chili landholding size, land ownership, net chili-farming income per harvest season, source of farming finance, and the presence of other household income. Land ownership was coded 1 for owned land and 0 for rented or sharecropped land. Farm income was represented by a binary indicator distinguishing IDR 5-15 million from less than IDR 5 million per harvest because only these two income categories occurred in the observed sample.

The financing variable represented the source of funds actually used for chili farming rather than direct access to credit. Farmers relying solely on their own funds were coded 0, whereas farmers using People's Business Credit (Kredit Usaha Rakyat, KUR), cooperatives or farmer groups, traders/private lenders, or combinations of financing sources were coded 1 as external or

https://doi.org/10.29165/ajarcde.v11i1.1374

mixed financing use. Other household income was coded 1 for yes and 0 for no. The descriptive data showed that 52 farmers relied exclusively on their own funds, while the remaining 15 used one or more external or mixed financing sources.

Institutional support included six items covering extension contact and usefulness, farmer-group participation and benefits, institutional support, and access to government programs. Technological conditions consisted of five items covering smartphone or internet use for agricultural information, availability of agricultural technology, perceived capability to use technology, affordability and suitability of innovative inputs or equipment, and access to information about new technologies. Risk perception consisted of six items addressing price fluctuations, uncertainty about harvest prices, potential failure to cover production costs, pests and diseases, weather or seasonal uncertainty, and dependence on buyers. These three constructs used five-point agreement scales from 1 = strongly disagree to 5 = strongly agree.

Table 1. Operationalization of Quantitative Predictors

Domain	Predictor	Measurement/coding
Social	Age	Years
Social	Education level	Ordinal: no formal schooling, elementary, junior high, senior high, university/higher
Social	Household dependents	Number of persons
Social	Farming experience	Years
Social	Training/extension frequency	Number of attendances in previous year
Economic	Landholding size	Hectares
Economic	Land ownership	1 = owned; 0 = rented/sharecropped
Economic	Net chili-farming income	1 = IDR 5-15 million; 0 = < IDR 5 million per harvest
Economic	Use of external/mixed financing	1 = external/mixed; 0 = own financing only
Economic	Other household income	1 = yes; 0 = no
Institutional	Institutional support	Six-item summed score
Technology	Technological conditions	Five-item summed score
Risk	Risk perception	Six-item summed score

2.4. Measurement of Multidimensional Agribusiness Innovation Adoption

The questionnaire was structured a priori to represent three dimensions of agribusiness innovation adoption: production, farm management, and marketing. Production innovation comprised five practices: use of improved chili varieties, drip irrigation, organic or biological fertilizers, integrated pest management, and optimized planting practices. Farm-management innovation comprised simple farm bookkeeping and planting-time planning based on expected prices. Marketing innovation comprised direct marketing beyond conventional intermediary channels and the use of social media or online platforms.

The nine indicators were recorded using five-point response scales that combined agreement and implementation-frequency wording. Accordingly, the scores were interpreted as indicators of self-reported implementation rather than as purely attitudinal Likert-type measures.

YProduction = mean(Y1-Y5)
YManagement = mean(Y6-Y7)
YMarketing = mean(Y8-Y9)
YAdoption = mean(YProduction, YManagement, YMarketing)

We first averaged each dimension separately, then calculated the overall adoption index as the mean of the three dimension scores. This procedure assigned equal conceptual weight to production, farm management, and marketing and prevented the larger number of production indicators from mechanically dominating the overall index.

An exploratory internal-consistency assessment across all nine indicators yielded Cronbach's alpha = 0.431. This statistic was reported descriptively and was not used to delete items or redefine the prespecified dimensions. Because the indicators represented heterogeneous agribusiness practices across three domains, the final outcome was treated as a multidimensional composite index rather than as a single unidimensional reflective scale.

2.5. Reliability of Multi-Item Predictors

Internal consistency was examined for the three multi-item predictor constructs. Cronbach's alpha was 0.836 for institutional support, 0.658 for technological conditions, and 0.775 for risk perception. The technological-conditions scale showed more modest internal consistency than the institutional-support and risk-perception measures; however, its corrected item-total correlations ranged from approximately 0.355 to 0.554, and deletion of individual items did not materially improve the scale. The prespecified multi-item predictors were therefore retained.

2.6. Quantitative Data Analysis

Quantitative data were analyzed using descriptive statistics and multiple linear regression. The multidimensional adoption index served as the dependent variable. Thirteen predictors specified a priori from the conceptual framework were entered simultaneousy using the Enter method rather than selected through stepwise procedures. The final model included age, education level, household dependents, farming experience, training/extension frequency, landholding size, land ownership, farm-income category, external/mixed financing use, other household income, institutional support, technological conditions, and risk perception.

Regression diagnostics assessed multicollinearity, heteroskedasticity, residual behavior, linear specification, and potentially influential observations. Variance inflation factors ranged from 1.194 to 2.612, indicating no severe multicollinearity.

We estimated the multiple linear regression using ordinary least squares (OLS). Because the Glejser diagnostic indicated potential heteroskedasticity for farming experience ($p = 0.031$), OLS point estimates and R^2 were retained, while coefficient-level and joint inference was based on HC3 heteroskedasticity-consistent covariance estimates [24], [25]. We evaluated statistical significance using two-sided tests at alpha = 0.05.

As a sensitivity check, we examined leave-one-out HC3 refits for predictors that were statistically significant in the primary robust model. We conducted the principal regression analyses using IBM SPSS Statistics 27, and independently verified robust diagnostic and sensitivity calculations in Python (statsmodels).

2.7. Qualitative Data Collection and Analysis

The FGD and institutional interviews explored farmers' experiences with production practices, agricultural technologies, financing, marketing, farmer groups, extension services, price uncertainty, pests and diseases, and barriers to innovation. With participants' permission, we audio-recorded the FGD and interviews and supplemented them with field notes. The

recordings and notes were reviewed and organized through thematic categorization around recurring issues involving financing, technology implementation, extension and institutions, marketing, price uncertainty, pests and diseases, and production risks.

The qualitative component was intended primarily to contextualize and triangulate the quantitative findings rather than to generate an independently exhaustive qualitative theory. Accordingly, the study does not claim qualitative saturation or a verbatim-transcript-based reflexive thematic analysis.

The study compared quantitative and qualitative evidence to identify convergence, complementarity, and divergence, integrating the findings through narrative discussion and a joint display [23].

2.8. SWOT-Based Strategic Analysis

A qualitative SWOT analysis was conducted after mixed-methods integration to translate the empirical findings into context-specific strategic directions. Internal conditions were classified as Strengths and Weaknesses, while external conditions were classified as Opportunities and Threats. These factors were combined to formulate SO, WO, ST, and WT strategies [26].

The SWOT analysis did not employ IFAS/EFAS weighting, numerical scoring, or quadrant ranking; therefore, the resulting strategies were interpreted as qualitative alternatives rather than numerically ranked priorities.

2.9. Ethical Considerations

The study followed the institutional research-permission procedures applicable to the study site. Before questionnaire administration, in-depth interviews, and the FGD, participants were informed about the purpose of the research, the voluntary nature of participation, and confidentiality of the information provided. All participants provided verbal informed consent before data collection. The researchers treated participant information confidentially and used it solely for research purposes.

3. RESULTS AND DISCUSSION

3.1. Respondent Characteristics

The quantitative analysis included 67 chili farmers. Respondents had a mean age of 43.13 years (SD = 7.855; range = 28-60) and an average of 9.10 years of chili-farming experience (SD = 5.511). Participation in agricultural training or extension averaged 13.45 times during the previous year, while mean chili landholding size was 0.187 ha, indicating that the sample predominantly consisted of small-scale producers.

Table 2. Characteristics of Surveyed Chili Farmers (N = 67)

Characteristic	Category/statistic	Value
Age (years)	Mean +/- SD	43.13 +/- 7.855
	Range	28-60
Household dependents	Mean +/- SD	2.88 +/- 0.879
Farming experience (years)	Mean +/- SD	9.10 +/- 5.511
Training/extension frequency	Mean +/- SD	13.45 +/- 6.255
Landholding size (ha)	Mean +/- SD	0.187 +/- 0.159
Education	No formal schooling	10 (14.9%)
	Elementary school	24 (35.8%)
	Junior high school	13 (19.4%)
	Senior high school	16 (23.9%)
	University/higher	4 (6.0%)
Land status	Owned	55 (82.1%)
	Rented	8 (11.9%)
	Sharecropped	4 (6.0%)
Net chili-farming income per harvest	< IDR 5 million	53 (79.1%)
	IDR 5-15 million	14 (20.9%)
Farming finance	Own financing only	52 (77.6%)
	External/mixed financing	15 (22.4%)
Other household income	Yes	53 (79.1%)
	No	14 (20.9%)

The educational profile was concentrated in the lower formal-education categories, with 50.7% of respondents having either no formal schooling or only elementary-school education. Most respondents cultivated their own land (82.1%), while 79.1% reported net chili-farming income below IDR 5 million per harvest. A particularly relevant economic feature was the strong reliance on self-financing: 77.6% used only their own funds, whereas 22.4% used external or mixed financing sources. These percentages describe the economic and financing characteristics of the surveyed farmers rather than intervention-related performance indicators.

3.2. Descriptive Statistics and Multidimensional Adoption Patterns

The multidimensional agribusiness innovation adoption index had a mean of 3.269 (SD = 0.420), with observed values ranging from 2.43 to 4.43. Institutional support averaged 26.06 out of 30, technological conditions averaged 20.22 out of 25, and risk perception averaged 27.93 out of 30.

To make the multidimensional character of adoption more explicit, the three prespecified adoption domains were also summarized separately. Production adoption had the highest descriptive mean (3.875 +/- 0.483), followed by marketing adoption (3.619 +/- 0.708), whereas farm-management adoption showed a lower mean (2.313 +/- 0.783). These values are descriptive and should not be interpreted as evidence of statistically significant differences among domains.

 https://doi.org/10.29165/ajarcde.v11i1.1374

Table 3. Descriptive Statistics of Principal Measures and Adoption Dimensions

Variable	Items	Observed range	Mean +/- SD	Cronbach alpha
Institutional support	6	19-30	26.06 +/- 3.152	0.836
Technological conditions	5	14-25	20.22 +/- 3.209	0.658
Risk perception	6	21-30	27.93 +/- 2.127	0.775
Production adoption	5	2.80-4.80	3.875 +/- 0.483	-
Farm-management adoption	2	1.00-4.50	2.313 +/- 0.783	-
Marketing adoption	2	1.00-5.00	3.619 +/- 0.708	-
Overall multidimensional adoption	9 indicators	2.43-4.43	3.269 +/- 0.420	-

Note: The exploratory Cronbach's alpha across all nine adoption indicators was 0.431. Because the indicators represent heterogeneous practices across production, farm-management, and marketing domains, the overall outcome was treated as an equally weighted multidimensional composite rather than as a unidimensional reflective scale.

The domain-level results further support treating adoption as multidimensional rather than binary. Farmers could report relatively high implementation in production practices while displaying lower implementation of farm-management practices, and marketing adoption could develop separately from both. This pattern is conceptually consistent with research emphasizing that agricultural adoption is often selective, adaptive, and dependent on the compatibility and feasibility of individual practices [3], [4].

Risk perception was also concentrated toward the upper end of the scale. The mean of 27.93 out of 30, with an SD of only 2.127, indicates limited between-farmer variation in risk perceptions. This provides a plausible contextual explanation for why perceived risk may remain substantively important while showing limited statistical differentiation between higher and lower levels of adoption.

Figure 1 provides a descriptive comparison of the mean adoption scores across the three domains. Error bars represent standard deviations, and no inferential comparison among domain means is implied.

3.3. Regression Results and Robust Inference

The 13-predictor OLS model yielded R = 0.617, R^2 = 0.381, adjusted R^2 = 0.229, and F(13,53) = 2.507 (p = 0.009). Thus, the predictors in the fitted model accounted for 38.1% of the observed variation in the multidimensional adoption index. The remaining variation is more appropriately described as variation not accounted for by the fitted model rather than automatically attributed to unspecified causal factors.

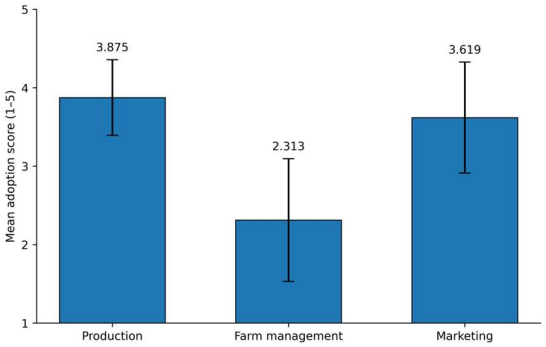


Fig. 1. Mean Scores of Multidimensional Agribusiness Innovation Adoption by Domain

Note: Error bars represent +/- SD.

Because the Glejser diagnostic indicated possible heteroskedasticity, we based inferential conclusions on HC3 heteroskedasticity-consistent standard errors. The robust joint test remained statistically significant, F(13,53) = 2.067, p = 0.032. Under coefficient-level HC3 inference, only external or mixed financing and technological conditions reached the prespecified 5% significance threshold.

Table 4. HC3 Robust Regression Estimates for Multidimensional Agribusiness Innovation Adoption

Predictor	B (HC3 SE)	p	95% CI
Intercept	1.138 (1.004)	.262	-0.876. 3.153
Age	.009 (.007)	.192	-0.005. .023
Education level	.019 (.052)	.721	-0.086. .124
Household dependents	-.007 (.067)	.915	-0.141. .126
Farming experience	.017 (.012)	.159	-0.007. .042
Training/extension frequency	.003 (.009)	.759	-0.016. .022
Landholding size	-.292 (.358)	.417	-1.010. .425
Owned land	<.001 (.163)	1.000	-0.328. .328
Net income IDR 5-15 million	-.014 (.150)	.928	-0.314. .286
External/mixed financing	.437 (.208)	.040	.021. .854
Other household income	.437 (.229)	.062	-.022. .897
Institutional support	-.028 (.017)	.105	-.063. .006
Technological conditions	.047 (.020)	.020	.008. .087
Risk perception	.033 (.032)	.310	-.031. .096

Note: B = unstandardized coefficient; SE = HC3 heteroskedasticity-consistent standard error; CI = 95% confidence interval. Reference categories were own financing only, rented/sharecropped land, and net chili-farming income < IDR 5 million.

Conditional on the other predictors, farmers using external or mixed financing had predicted adoption-index scores 0.437 points higher than farmers relying exclusively on their own financing (HC3 p = 0.040). This estimate describes an association with financing-source use and should not be interpreted as evidence that borrowing or credit access causally increased adoption.

Technological conditions were also positively associated with adoption. Each one-point increase in the technological-condition score was associated with an estimated 0.047-point increase in the multidimensional adoption index (HC3 p = 0.020).

Other household income showed a positive coefficient but did not meet the 5% threshold under HC3 robust inference (p = 0.062). Institutional support (p = 0.105), risk perception (p = 0.310), and the remaining social and economic variables likewise did not demonstrate clear independent statistical associations after simultaneous adjustment. Nonsignificance should not be

interpreted as evidence that these factors are unimportant in farmers' decision environments.

Leave-one-out HC3 sensitivity analyses provided an additional qualification. The technological-condition coefficient remained positive and statistically significant in all 67 refitted models, with B approximately 0.041-0.055. The financing coefficient remained positive in all refits, but its statistical significance was more sensitive to individual-case omission; 58 of 67 refits remained significant at $p < 0.05$. Thus, the technological association was more stable, whereas the financing association warrants more cautious interpretation.

3.4. Financing and Technological Conditions as Key Associated Factors

Use of external or mixed financing was positively associated with multidimensional innovation adoption. This finding is broadly consistent with evidence that financial resources can facilitate agricultural innovation by reducing liquidity constraints related to inputs, equipment, and implementation costs [5], [7]-[9]. Recent meta-analytic evidence similarly found a positive relationship between microcredit access and agricultural technology adoption but also substantial heterogeneity across studies and technology types [9]. This heterogeneity reinforces the need to interpret financing within specific farming and institutional contexts rather than assuming a uniform effect. Nevertheless, this variable reflects the source of financing actually used, rather than a direct measure of credit accessibility or borrowing constraints. The result should therefore not be interpreted as a causal effect of credit availability.

The qualitative evidence provides a practical explanation for the observed association. FGD participants explicitly identified capital and equipment costs as barriers to implementing new technologies. They reported widespread use of improved seed and some use of organic fertilizer, whereas drip irrigation had not been implemented and pest or disease management continued to rely heavily on pesticide spraying.

Institutional interviews complemented these findings. The extension officer reported that farmers predominantly relied on their own capital although some used KUR. The Head of BPP similarly explained that farmers had previously been encouraged to access KUR but often preferred self-financing because chili farming was perceived as uncertain. These observations suggest that financing decisions take place within a broader environment of production and price uncertainty.

Technological conditions demonstrated a particularly stable positive association with adoption. This is consistent with broader evidence that availability, affordability, compatibility, information access, and farmers' ability to use agricultural technologies influence implementation [5], [6]. A recent analysis of digital-agriculture adoption similarly identified economic capacity, technological infrastructure, technical knowledge, and perceived usefulness as interconnected conditions shaping adoption [19]. Evidence from Indonesia also indicates that mobile-phone use can facilitate access to agricultural information, markets, credit, and customers [11], while farmer field schools illustrate the importance of practical learning in agricultural technology implementation [12].

The qualitative findings further show why technological adoption should not be treated as a single binary decision. Some relatively familiar practices had already been incorporated, while more costly or operationally demanding technologies were implemented unevenly. Comparable evidence from smallholder farmers in Vietnam shows that digital adoption depends on a combination of digital experience, knowledge exchange, access to information, farm characteristics, and internet-related conditions [20]. Broader review evidence also indicates that limited connectivity, digital literacy, infrastructure, and affordability can constrain the practical use of digital agricultural technologies among smallholders [21]. These findings reinforce an understanding of adoption as a process of selective adaptation rather than uniform acceptance of all available innovations [3], [4].

Taken together, the mixed-methods evidence suggests that financing and technological conditions may be practically interconnected rather than competing explanations of innovation adoption. Farmers may perceive a technology as useful but postpone implementation when equipment or operating costs exceed available financial capacity or appear risky relative to expected returns. The findings therefore support integrated attention to financing feasibility and technological appropriateness rather than designating one factor as a single dominant determinant.

3.5. Institutional Support and Risk as Contextual Factors

Institutional support did not independently reach the prespecified 5% significance threshold under HC3 inference ($B = -0.028$; $p = 0.105$). This should not be interpreted as evidence that extension, farmer groups, or government programs were irrelevant to farmers' decision environments. The institutional-support score was generally high, averaging 26.06 out of 30, which may have reduced differences between farmers.

More importantly, the qualitative evidence revealed a divergence between institutional presence and perceived practical usefulness. The extension informant reported frequent field visits and described farmers as receptive to new information. The Head of BPP also characterized farmer-group cooperation positively. In contrast, FGD participants reported that although farmer groups met and extension activities occurred, they wanted more practical field demonstrations and direct problem-solving, particularly for pest and disease management. Some farmers perceived existing activities as overly oriented toward theory and documentation.

This divergence suggests that the frequency or presence of institutional support does not necessarily match its perceived practical utility. Previous evidence emphasizes the importance of effective extension and field-based learning rather than institutional contact alone [10], [12]. The present finding differs from evidence from smallholder farmers in Banten, Indonesia, where access to agricultural extension showed positive effects on technology adoption and farm income [18]. This contrast may partly reflect the distinction between having access to extension services and farmers' perceptions of whether the support received is sufficiently practical and responsive to their immediate production problems.

Farmers' requests for more direct demonstrations and problem-oriented assistance are also consistent with recent guidance emphasizing that farmer participation should be matched to the readiness, intended use, and local relevance of agricultural innovations [27]. Such an approach may help ensure that institutional support extends beyond information delivery toward technologies and practices that farmers can realistically test and adapt.

Risk perception also did not show a statistically significant independent association with the adoption index ($B = 0.033$; $p = 0.310$), despite being prominent in both descriptive and qualitative evidence. Risk scores averaged 27.93 out of 30 with limited dispersion, indicating that uncertainty was widely perceived across the sample.

FGD participants described episodes in which chili prices fell to approximately IDR 2,000/kg. The Head of BPP likewise characterized market-price fluctuation as an important challenge and reported substantial changes in chili prices across periods. Pest and disease problems were also repeatedly identified as important constraints.

These results suggest that risk may operate primarily as a shared contextual condition rather than a variable that strongly differentiates adoption levels among farmers in this particular sample. Previous studies indicate that risk perceptions can shape agricultural technology decisions while interacting with farmers' resources and implementation capacity [13], [14]. Recent

https://doi.org/10.29165/ajarcde.v11i1.1374

evidence from Bangladesh further shows that extension services, technology adoption, and production risk can be empirically interconnected [22]. In the present study, however, institutional support and risk perception did not independently differentiate adoption scores after simultaneous adjustment, suggesting that their statistical roles may depend on local conditions, measurement, and the degree of variation observed within a farmer population.

3.6. Mixed-Methods Integration

The mixed-methods analysis provides a more nuanced interpretation than the regression results alone. Financing and technological conditions showed convergence between quantitative and qualitative evidence, while institutional support and risk perception demonstrated complementarity or divergence. Table 5 distinguishes statistically associated factors from factors that remained contextually important.

Table 5. Joint Display of Quantitative and Qualitative Findings

Factor	Quantitative evidence	Integrated qualitative interpretation
External/mixed financing	B = .437; p = .040	Convergence: own financing predominated; farmers identified capital and equipment costs as barriers; KUR existed but was used selectively.
Technological conditions	B = .047; p = .020	Strong convergence: selected innovations were implemented, whereas higher-cost practices remained uneven; the technology coefficient was stable in sensitivity analyses.
Institutional support	B = -.028; p = .105	Divergence/complementarity: institutional actors described active support, while farmers requested more practical, field-based assistance.
Risk perception	B = .033; p = .310; mean = 27.93/30	Complementarity: risk did not statistically differentiate adoption but was widely perceived through price volatility, pests, diseases, and production uncertainty.
Social characteristics	No social predictor reached p < .05	Complementarity: institutional informants perceived younger farmers as faster in using technology, but age showed no independent adjusted association.

The joint display demonstrates why statistical nonsignificance should not automatically be interpreted as substantive irrelevance. Institutional support may matter through its quality and practical usefulness rather than solely through frequency or presence. Similarly, risk may affect nearly all farmers and therefore show limited capacity to statistically discriminate between adoption levels. By contrast, financing and technology demonstrated both adjusted statistical associations and direct qualitative evidence of implementation constraints.

3.7. SWOT-Based Strategic Implications and SDG Relevance

The integrated findings were translated into a qualitative SWOT framework [26]. Internal strengths included farmers' use of selected innovations, receptiveness to information, farming experience, farmer-group structures, and established marketing experience. Internal weaknesses included heavy reliance on self-financing, uneven implementation of more advanced technologies, limited translation of some extension activities into practice, and limited control over wider marketing channels.

External opportunities included government assistance, BPP and extension services, KUR and other financing mechanisms, potential collective financing, wider buyer networks, and opportunities for value-added chili processing. Threats included price volatility, pest and disease pressure, technology and equipment costs, dependence on intermediaries, and uncertainty about the continuity of external assistance.

Table 6. Qualitative SWOT Strategies for Strengthening Agribusiness Innovation Adoption

Strategy	Strategic formulation
SO	Use farmers' receptiveness to innovation, existing groups, and marketing experience to expand practical technology dissemination, collective marketing, and value-added chili development through available institutional support.
WO	Link appropriate financing mechanisms with affordable technologies, collective equipment arrangements, farmer-group financing, and practical field-based extension to address financial and technological constraints.
ST	Use farmer networks, marketing experience, and willingness to learn to diversify buyers, strengthen market-information exchange, and improve pest and disease management.
WT	Promote gradual and financially prudent technology adoption, strengthen collective marketing and buyer diversification, and reduce exposure to high-cost investments under volatile prices and production uncertainty.

Because the SWOT analysis did not use IFAS/EFAS weighting, numerical scoring, or quadrant ranking, interpret these strategies as context-specific strategic alternatives rather than quantitatively ranked priorities.

The combined evidence points to a particularly relevant applied direction: link financing mechanisms with affordable, context-appropriate technologies and practical, field-based assistance. Financing alone may have limited value if technologies remain costly or difficult to implement; conversely, technology promotion may have limited uptake if farmers lack feasible financing or practical technical support. Future innovation-support initiatives in the study area may also benefit from involving farmers more directly in selecting, demonstrating, testing, and adapting technologies to local production constraints, consistent with recent guidance on farmer participation in agricultural innovation processes [27].

The findings are relevant to SDG 2 (Zero Hunger) through their implications for sustainable agricultural innovation, SDG 8 (Decent Work and Economic Growth) through farm financing and rural economic capacity, and SDG 9 (Industry, Innovation and Infrastructure) through the accessibility and implementation of agricultural technology. However, this study did not measure changes in formal SDG target indicators, intervention-attributable agricultural productivity, household-income changes over time, or other baseline-endline outcomes. The SDG relevance should therefore be interpreted as an implication of the observed findings rather than as evidence of intervention-induced SDG achievement.

4. CONCLUSION

This study shows that agribusiness innovation adoption among surveyed chili farmers in Bongki Lengkese is a multidimensional process encompassing production, farm-management, and marketing practices. The fitted model accounted for 38.1% of the observed variation in the multidimensional adoption index. Under

HC3 robust inference, use of external or mixed financing (B = 0.437; p = 0.040) and technological conditions (B = 0.047; p = 0.020) were positively associated with adoption. The technological association remained particularly stable in leave-one-out sensitivity analyses, whereas the financing association remained positive but was more sensitive to individual observations.

The qualitative findings provided important context for these statistical results. Farmers identified limited financial capacity and technology costs as practical constraints, while implementation differed across individual innovations. Institutional support and risk perception did not independently reach the 5% significance threshold, but both remained contextually important. Farmers emphasized the need for more practical field-based assistance, particularly for pest and disease management, while price volatility and production uncertainty were widely perceived across the study setting.

Taken together, the findings suggest that efforts to strengthen agribusiness innovation adoption should integrate context-appropriate financing with affordable technologies, practical extension support, farmer-group mechanisms, and broader marketing opportunities rather than promoting financing or technology in isolation. For longer-term continuity, collaboration among farmer groups, extension institutions, financing providers, and market actors may help sustain access to technical support, appropriate financing, and locally relevant innovation. These implications are relevant to SDGs 2, 8, and 9, although the study did not measure changes in formal SDG indicators or intervention-induced outcomes.

Interpret the findings within the boundaries of the study design. The quantitative analysis involved 67 purposively selected farmers from one village and 13 predictors, limiting statistical generalizability and the precision of some estimates. The cross-sectional design supports associational rather than causal interpretation, and adoption was measured using self-reported implementation indicators collected shortly before the principal chili-growing period. The qualitative component was intended primarily to contextualize and triangulate the survey findings rather than to represent all stakeholder perspectives exhaustively. Future research should involve larger probability-based samples across multiple chili-producing locations, repeated or longitudinal observations, and complementary objective measures of innovation implementation and farm performance.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Directorate of Research and Community Service (DPPM), Directorate General of Research and Development, Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, for supporting this research through the Penelitian Dosen Pemula (PDP) scheme. The authors also thank the chili farmers of Bongki Lengkese Village, the agricultural extension officer, and the Agricultural Extension Center (BPP) of Sinjai Timur District for their participation and support during data collection.

FUNDING

This research was funded by the Directorate of Research and Community Service (DPPM), Directorate General of Research and Development, Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, through the Penelitian Dosen Pemula (PDP) research scheme administered via BIMA, under Contract No. 093/II.3.AU./LPPM/UMSi/2026.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

The de-identified data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to participant confidentiality and applicable research-permission requirements.

GENERATIVE AI DISCLOSURE

ChatGPT (OpenAI) was used to support language refinement, manuscript organization, and supplementary checking of statistical reporting and diagnostics. The authors reviewed and verified all research data, statistical analyses, references, interpretations, and final manuscript content. The authors remain fully responsible for the accuracy, integrity, and conclusions of the manuscript.

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