Digitalization in sustainable agriculture supply chain: how digital literacy and support affect attitudes and adoption intentions

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Abstract

Purpose – This study aims to investigate how digital literacy and stakeholder support affect farmers' attitudes and their intention to adopt digital technologies in the context of sustainable agriculture supply chains. While prior research has recognized the importance of these factors individually, this study explores their interdependencies and the mediating role of farmers' attitudes. It also discusses the broader implications for agricultural digitalization and global value chain participation, particularly in developing economies like Indonesia.

Design/methodology/approach – A quantitative research design was employed using a structured questionnaire distributed to 580 rice farmers in Java, Indonesia. The measurement items were adapted from validated prior studies. Partial least squares structural equation modeling (PLS-SEM) was used to test the proposed conceptual model, including mediation pathways. The model's predictive accuracy was assessed through SRMR, Q^2 statistics and PLS Predict benchmarking, allowing for robust evaluation of both theoretical relationships and real-world predictive capability.

Findings – The results confirm that digital literacy and stakeholder support significantly affect farmers' attitudes and their adoption intentions. Attitude was the strongest predictor of intention and acted as a mediator in multiple relationships. Stakeholder support also indirectly influenced adoption via digital literacy. The model demonstrated strong predictive accuracy and explanatory power. These findings emphasize the role of behavioral factors in driving digital adoption and suggest that both technical capacity and attitudinal readiness must be addressed to achieve widespread adoption in sustainable agriculture.

Originality/value – This study extends the technology adoption literature by integrating behavioral (attitude) and contextual (digital literacy and stakeholder support) factors into a unified framework. Unlike previous research, it empirically tests multiple mediation mechanisms and links farmer-level behavior to broader implications for sustainable supply chains and global market integration. The context-specific analysis in Indonesia adds novel insights into digital inclusion strategies for smallholder farmers in emerging economies. The results offer valuable guidance for policymakers and stakeholders seeking to enhance technology adoption and sustainability in agriculture through targeted digital interventions.

Keywords Digital literacy, Stakeholder support, Technology adoption, Sustainable agriculture, Supply chain management

Paper type Research paper

1. Introduction

The integration of digital technologies in agriculture has increasingly been recognized as a solution to enhance efficiency, productivity, and sustainability within the agricultural supply chain. Technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) enable farmers to optimize resource usage, monitor crop conditions, and access market information more effectively (Smith *et al.*, 2018; Jones and Brown, 2019).

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Beyond improving local agricultural efficiency, digitalization plays a pivotal role in connecting smallholder farmers to Global Value Chains (GVCs), facilitating international trade and fostering sustainable development (Foster, 2024). Despite these potential benefits, the adoption of digital technologies among smallholder farmers, particularly in developing countries like Indonesia, remains limited. This presents a significant barrier to achieving a sustainable agriculture supply chain, which is critical for addressing food security and economic sustainability.

Digitalization transforms GVCs by enhancing transparency, reducing trade barriers, and improving overall trade performance. For instance, AI and big data analytics significantly improve production efficiency, reduce trade costs, and bolster technological innovation capacity, thereby strengthening the position of smallholder farmers in global markets (Liu *et al.*, 2024). Additionally, digital transformation fosters global trade flows, particularly in sectors like telecommunications and IT services, which have seen export growth of over 5% attributed to digital adoption (Zhang, 2024). In the context of agriculture, technologies such as blockchain and IoT enable greater traceability and sustainability, aligning with the growing demand for environmentally friendly practices in international trade (Mondejar *et al.*, 2021). However, many smallholder farmers lack the necessary digital literacy and stakeholder support to fully leverage these technologies, which impedes their integration into GVCs and limits their contribution to sustainable trade performance (Dilyard *et al.*, 2021; Ghrbeia and Alzubi, 2024).

The adoption of digital technologies among farmers remains low, primarily due to two interconnected factors involving digital literacy and stakeholder support (Hoang and Tran, 2023; Febrianda, 2021). Digital literacy refers to the ability to access, comprehend, and effectively use digital tools, which serves as a fundamental skill that empowers farmers to utilize technology for improving agricultural practices. In many rural areas, farmers struggle to develop digital competencies because of limited educational opportunities and restricted exposure to technological innovations (Lee *et al.*, 2020). Stakeholder support also plays an essential role in this process, as efforts such as training programs, infrastructure development, and financial support directly influence farmers' readiness to adopt new technologies. When such support is insufficient, farmers are more likely to resist technological change, which ultimately hampers the progress of sustainable agricultural practices (Wang and Zhang, 2021).

Although prior research has acknowledged the importance of digital literacy and stakeholder support, several gaps remain in the literature. First, existing studies often examine the effects of digital literacy and stakeholder support independently, failing to explore their interdependencies and combined influence on farmers' adoption behaviors. Second, many studies focus on the technical aspects of technology adoption but often overlook the important role of behavioral factors, such as farmers' attitudes, which significantly influence their adoption intentions (Ahmed and Miller, 2023). Third, there is limited empirical evidence examining these relationships in the context of sustainable agriculture supply chains, particularly in regions like Indonesia, where smallholder farmers play a crucial role in the agricultural economy. Moreover, the broader implications of digitalization on GVCs, trade performance, and sustainability have yet to be fully explored, leaving critical gaps in understanding its transformative potential.

This study aims to fill these gaps by examining the relationships between digital literacy, stakeholder support, farmers' attitudes, and their intentions to adopt digital technologies within the sustainable agriculture supply chain. Specifically, the research investigates how stakeholder support enhances digital literacy and influences farmers' attitudes, which in turn shape their adoption intentions. Additionally, the study links these findings to the broader impacts of digitalization on trade performance and sustainability in GVCs, offering insights into how digital tools can strengthen global market integration for smallholder farmers. By adopting a quantitative research design and analyzing data collected from 580 rice farmers in Java, Indonesia, this study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) to evaluate the proposed relationships and test the research hypotheses.

The findings of this research offer significant contributions to both theory and practice. Theoretically, the study enhances the understanding of behavioral and contextual factors influencing farmers' *intention to adopt* digital technologies in sustainable agriculture. Practically, the insights provide guidance for policymakers, agricultural organizations, and stakeholders to design targeted interventions aimed at improving digital literacy and enhancing support systems. These initiatives are crucial for accelerating the adoption of digital technologies, optimizing agricultural supply chains, and fostering economic and environmental sustainability in GVCs and international trade.

This paper is organized as follows. Section 2 provides a comprehensive review of the relevant literature and introduces the conceptual framework. Section 3 introduces the conceptual framework and outlines the hypotheses to be tested. Section 4 explains the research methodology, including the data collection process and analytical techniques. Section 5 presents the findings of the study, while Section 6 discusses the implications and limitations of the results. Finally, Section 7 concludes the study and offers recommendations for future research and practical applications.

2. Literature review

2.1 Role of digital technologies in advancing sustainable agriculture

The integration of digital technologies has become a cornerstone for achieving efficiency, productivity, and sustainability in agriculture supply chains. Technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and blockchain provide farmers with tools to optimize resource utilization, enhance decision-making processes, and improve access to markets (Smith *et al*., 2018; Jones and Brown, 2019). These advancements not only address issues of resource scarcity and market inefficiencies but also promote transparency and resilience across supply chains, aligning agricultural practices with international sustainability standards (Ebinger and Omondi, 2020; Mondejar *et al*., 2021).

Moreover, digitalization plays a critical role in supporting the Sustainable Development Goals (SDGs), particularly in ensuring food security, reducing environmental footprints, and promoting efficient resource use (Mondejar *et al*., 2021). Blockchain technologies, for instance, facilitate traceability and compliance with global trade regulations and sustainability certifications (Bunkar *et al*., 2024). In addition, AI and big data analytics significantly improve production efficiency, reduce transaction costs, and bolster technological innovation, thereby strengthening the position of smallholder farmers in supply chains (Liu *et al*., 2024).

However, despite these potential benefits, several challenges impede the widespread adoption of digital technologies, particularly in developing regions like Indonesia. Issues such as low digital literacy, inadequate infrastructure, and economic constraints hinder smallholder farmers from fully integrating into sustainable global value chains (Gao *et al*., 2021). Addressing these barriers is crucial for transforming traditional agricultural systems into sustainable, resilient, and globally connected supply chains.

2.2 Behavioral and contextual drivers of technology adoption

Digital literacy is a foundational competence that enables farmers to effectively utilize digital tools in their agricultural activities. Higher levels of digital literacy not only increase confidence in technology use but also enhance engagement with digital platforms, thereby facilitating integration into agricultural value chains (Ghrbeia and Alzubi, 2024). Digital skills allow farmers to perceive digital technologies as both useful and accessible, positively influencing their behavioral intentions toward adoption (Venkatesh *et al*., 2003; Li *et al*., 2022). For example, rice farmers with adequate digital capabilities are better able to apply IoT-based monitoring systems to optimize crop production and comply with sustainability standards (Li and Wang, 2024).

Complementary to digital literacy, stakeholder support—including training, infrastructure development, technical assistance, and financial incentives—plays a critical role in overcoming adoption barriers. Effective stakeholder interventions enhance digital literacy, reduce perceived complexity, and foster positive attitudes toward technology adoption (Ahmed and Miller, 2023; Wang and Zhang, 2021). Infrastructure investments such as broadband expansion and digital marketplace platforms further enable farmers to access broader markets and comply with international trade standards (Ebinger and Omondi, 2020).

Behavioral factors, particularly attitudes, are equally crucial in shaping technology adoption. According to the Theory of Planned Behavior (Ajzen, 1991), the intention to engage in a particular behavior emerges from a combination of personal attitudes, perceptions of social expectations, and the level of perceived control over performing the behavior. Within the agricultural context, when farmers perceive digital tools as advantageous, feel supported by their peers or community, and believe they have the capacity to use them, they are more likely to adopt such technologies (Mungkung *et al.*, 2022; Bello and Mbhele, 2024). Moreover, attitudes serve as mediators between external enablers—such as digital literacy and stakeholder support—and farmers' behavioral outcomes, emphasizing the need for both technical and behavioral interventions to facilitate widespread adoption.

2.3 Research gaps and study focus

Although previous research has highlighted the importance of digital technologies in enhancing agricultural sustainability, several gaps remain unaddressed. First, many studies examine digital literacy and stakeholder support as independent factors influencing technology adoption, without exploring their potential interdependencies or collective impact on behavioral outcomes (Li *et al.*, 2022; Ghrbeia and Alzubi, 2024). Second, the dominant focus in the current literature remains on technical dimensions, while behavioral factors such as farmers' attitudes have received limited empirical investigation. This is despite the theoretical recognition of attitude as a key determinant of behavioral intention within the Theory of Planned Behavior (Ajzen, 1991). Third, there is a scarcity of research focusing specifically on smallholder farmers in developing countries, particularly within the context of sustainable agriculture supply chains in Indonesia, where technological adoption patterns may differ significantly from developed economies.

To address these gaps, this study proposes an integrated framework that examines the combined effects of digital literacy and stakeholder support on farmers' attitudes and adoption intentions. Attitude is positioned as a mediating variable, offering a comprehensive understanding of the behavioral mechanisms driving technology adoption. Additionally, by concentrating on rice farmers in Java, Indonesia, this study contributes context-specific insights to the literature on agricultural digitalization in emerging markets.

3. Conceptual framework and hypotheses

Based on the literature review mentioned in the previous section, this study proposes a conceptual framework linking digital literacy, stakeholder support, attitudes, and technology adoption intentions in sustainable agriculture supply chains. The following hypotheses are developed:

H1. Digital literacy positively influences farmers' attitudes toward adopting digital technologies.

H2. Digital literacy positively influences farmers' intentions to adopt digital technologies.

H3. Stakeholder support positively influences farmers' attitudes toward adopting digital technologies.

H4. Stakeholder support positively influences farmers' digital literacy.

H5. Stakeholder support positively influences farmers' intentions to adopt digital technologies.

H6. Farmers' attitudes positively influence their intentions to adopt digital technologies.

This framework (Figure 1) integrates the behavioral perspective (attitudes) with external factors such as digital literacy and stakeholder support, providing a holistic understanding of the drivers of technology adoption. In addition to the direct effects, this study also examines several mediation mechanisms to capture how external enablers influence farmers' adoption intentions indirectly. The following mediation hypotheses are proposed:

H7. Attitude mediates the relationship between digital literacy and the intention to adopt digital technologies.

H8. Attitude mediates the relationship between stakeholder support and the intention to adopt digital technologies.

H9. Digital literacy mediates the relationship between stakeholder support and farmers' attitudes.

H10. Digital literacy mediates the relationship between stakeholder support and the intention to adopt digital technologies.

H11. The relationship between stakeholder support and the intention to adopt digital technologies is sequentially mediated by digital literacy and attitude.

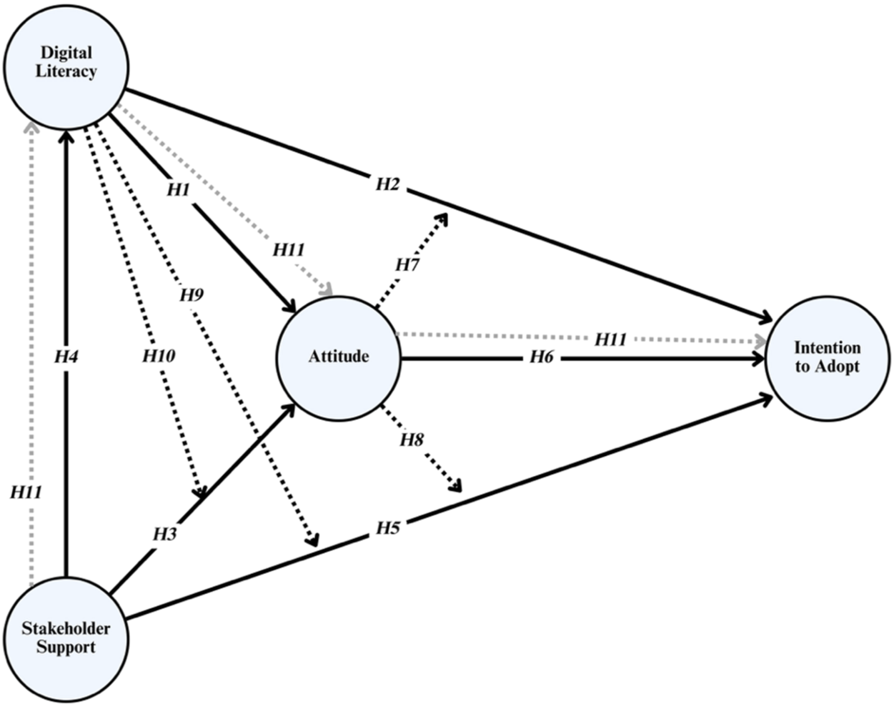

Figure 1. Conceptual framework. The authors

4. Research methodology

4.1 Research design

This study adopts a quantitative approach using a cross-sectional survey design to investigate the relationships among digital literacy, stakeholder support, attitudes, and farmers' intention to adopt digital technologies in the sustainable agriculture supply chain. A cross-sectional design was chosen due to its efficiency in capturing data at a single point in time, enabling the exploration of farmers' current perceptions, behaviors, and intentions. This approach is particularly useful for understanding technology adoption, where rapid changes in practices are influenced by external interventions and internal behavioral factors.

4.2 Samples and data collection

The target population comprises rice farmers in Java, Indonesia, who represent a critical segment in the adoption of digital tools within agriculture. A random sampling technique was employed to ensure representativeness and minimize bias. Following the guidelines suggested by Barclay *et al*. (1995), the minimum sample size was determined to be ten times the largest number of indicators pointing to any construct in the model. Based on this, a minimum threshold of 80 respondents was required. However, to enhance statistical robustness and generalizability, data were collected from 580 respondents.

The final sample reflects diversity in terms of demographic attributes, including age, gender, education level, farming experience, and land ownership. This demographic variety ensures a comprehensive understanding of technology adoption drivers across different farmer profiles.

The measurement model in this study comprises four latent constructs: digital literacy, stakeholder support, attitude, and intention to adopt. Each construct was measured using multiple items adapted from established literature. The digital literacy construct consists of seven items drawn from Raza *et al*. (2023), Yu *et al*. (2022), Kim *et al*. (2022), and Warmath and Zimmerman (2019). Example items include "I have the ability to use technology in agriculture" and "I can search for information using search engines (e.g. Google)." The stakeholder support construct also includes seven items, developed based on prior studies by Rawashdeh and Al-Namlah (2017) and Chen *et al*. (2019). Representative items are "Stakeholders provide technology assistance in the field of agriculture" and "Stakeholders provide funding assistance for using technology." To measure attitude, seven items were adapted from Raza *et al*. (2023), Wang *et al*. (2022), and Mat Dawi *et al*. (2021). Sample statements include "I believe technology will facilitate my farming activities" and "I think agricultural technology is a good idea." Finally, the intention to adopt construct was measured using seven items derived from Wang *et al*. (2019), Xie *et al*. (2021), and Alothman and Al-Meshal (2022). Illustrative examples include "I intend to use technology in farming activities in the future" and "I will recommend agricultural technology to other farmers."

4.3 Data analysis and procedure

The collected data were analyzed using SMART PLS (Partial Least Squares Structural Equation Modeling) to test the research hypotheses. PLS-SEM was chosen for its flexibility in handling non-normal data distributions and its suitability for testing complex models with latent variables. Unlike covariance-based SEM, PLS-SEM does not require strict normality assumptions, making it ideal for exploratory research. This method also allows for simultaneous testing of relationships between multiple variables, enabling the analysis of direct, indirect, and moderating effects in a single model (Hair *et al.*, 2011; Ong and Puteh, 2017).

The evaluation process followed the steps outlined by Hair *et al*. (2014) and involved two main stages: measurement model evaluation and structural model evaluation. In the first stage, confirmatory factor analysis was conducted to assess the validity and reliability of the constructs. Validity was confirmed through factor loadings, average variance extracted (AVE), and discriminant validity using the Fornell-Larcker criterion and Heterotrait-Monotrait (HTMT) ratio. Reliability was ensured by assessing Cronbach's alpha and composite reliability values. These steps established the robustness and accuracy of the measurement instruments.

In the second stage, the structural model was evaluated to test the proposed relationships between digital literacy, stakeholder support, attitudes, and farmers' intention to adopt digital technologies. Path coefficients were analyzed to determine the strength and direction of the relationships, while the significance of the hypotheses was tested using t-statistics and *p*-values. The R-squared value was used to measure the explanatory power of the model, and the Standardized Root Mean Square Residual (SRMR) was examined as an indicator of overall model fit. By employing this approach, the study was able to evaluate both the measurement and structural components of the model comprehensively.

5. Result

The structural relationships among digital literacy, stakeholder support, attitudes, and farmers' intention to adopt digital technologies were tested using PLS-SEM. The analysis proceeded in two stages: assessment of the measurement model and evaluation of the structural model. The final sample consisted of 580 rice farmers from three provinces in Java, Indonesia: East Java (57.9%), Central Java (30.8%), and Banten (11.3%). The gender distribution was balanced, with 51.4% female and 48.6% male respondents. Most participants were between the ages of 36 and 50, representing over 80% of the sample. In terms of farming experience, the majority had been engaged in rice farming for 11–25 years, indicating a high level of practical knowledge and long-term exposure to agricultural practices. Regarding educational background, 69.1% had completed senior high school, while smaller proportions had attained junior high school (15.1%), elementary school (3.6%), or higher education (12.2%, including diploma and bachelor's degree holders). Approximately 76.8% of respondents operated on land sizes ranging from 1 to 2 hectares, and nearly all (95.9%) owned the land they cultivated. Notably, the overwhelming majority (98.5%) were full-time farmers, reflecting a strong occupational commitment to agriculture.

5.1 Measurement model evaluation

The measurement model was evaluated by assessing convergent validity, discriminant validity, and reliability. As shown in Table 1, all constructs achieved Average Variance Extracted (AVE) values exceeding the recommended threshold of 0.50, with factor loadings generally above 0.70, confirming convergent validity. Reliability was established as Cronbach's alpha values and Composite Reliability (CR) values for all constructs exceeded the acceptable cut-off levels of 0.70 and 0.80, respectively.

Discriminant validity was confirmed using both the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio, with results presented in Tables 2 and 3. The square roots of the AVEs were greater than the inter-construct correlations, satisfying the Fornell-Larcker criterion (Fornell and Larcker, 1981), while all HTMT ratios were below the conservative threshold of 0.85 (Henseler *et al*., 2009). Overall, the measurement model demonstrated satisfactory convergent validity, discriminant validity, and reliability, establishing a robust foundation for subsequent structural model evaluation.

5.2 Structural model evaluation

To evaluate the proposed model, path coefficients were analyzed to determine the strength and significance of the relationships among the core constructs. Multicollinearity was first evaluated through the Variance Inflation Factor (VIF) values, all of which were below the threshold of 5.0, indicating the absence of multicollinearity concerns, as shown in Table 4. The analysis of path coefficients revealed that all proposed hypotheses were supported. Digital

Table 1. Outer model assessment

Item	Factor	Standard factor loadings	Cronbach's alpha ($\alpha > 0.6$)	Composite reliability (C.$R > 0.7$)	AVE (AVE > 0.5)
Digital Literacy (DL)	DL1	0.717	0.844	0.894	0.680
	DL2	0.705			
	DL3	0.675			
	DL4	0.765			
	DL5	0.707			
	DL6	0.552			
	DL7	0.711			
Stakeholder Support (SS)	SS1	0.671	0.808	0.864	0.559
	SS2	0.729			
	SS3	0.858			
	SS4	0.610			
	SS5	0.613			
	SS6	0.753			
	SS7	0.709			
Attitude (ATT)	ATT1	0.819	0.823	0.875	0.583
	ATT2	0.637			
	ATT3	0.634			
	ATT4	0.773			
	ATT5	0.867			
	ATT6	0.785			
	ATT7	0.454			
Intention to Adopt (ITA)	ITA1	0.515	0.831	0.886	0.661
	ITA2	0.723			
	ITA3	0.731			
	ITA4	0.597			
	ITA5	0.804			
	ITA6	0.722			
	ITA7	0.752			

Source(s): The authors

Table 2. HTMT-Heterotrait-Monotrait ratio (Discriminant validity)

	ATT	DL	ITA	SS
ATT				
DL	0.409			
ITA	0.577	0.419		
SS	0.22	0.262	0.314	

Source(s): The authors

Table 3. Fornell-Larcker criterion (Discriminant validity)

	ATT	DL	ITA	SS
ATT	0.825			
DL	0.36	0.748		
ITA	0.512	0.378	0.763	
SS	0.196	0.231	0.287	0.813

Source(s): The authors

Table 4. Inner model VIF assessment

	ATT	DL	SS	ITA
ATT				1.167
DL	1.056			1.186
SS	1.056	1		1.073
ITA				

Source(s): The authors

literacy exhibited a significant positive effect on both farmers' attitudes ($\beta = 0.333$, $t = 9.461$, $p < 0.001$) and their intention to adopt digital technologies ($\beta = 0.193$, $t = 5.391$, $p < 0.001$). Likewise, stakeholder support positively influenced attitudes ($\beta = 0.119$, $t = 3.040$, $p = 0.002$), digital literacy ($\beta = 0.231$, $t = 5.975$, $p < 0.001$), and intention to adopt ($\beta = 0.162$, $t = 4.498$, $p < 0.001$), as detailed in Table 5. Among all tested relationships, attitude demonstrated the strongest effect on farmers' intention to adopt digital technologies ($\beta = 0.410$, $t = 10.920$, $p < 0.001$).

Effect size analysis further supported these findings, where the relationship between attitude and intention to adopt indicated a medium effect size ($f^2 = 0.215$), while other paths exhibited small to medium effects, as presented in Table 5.

A visual representation of these relationships is provided in Figure 2, in which the standardized path coefficients and their statistical significance were obtained through bootstrapping analysis. In this figure, all hypothesized relationships are shown to be statistically significant. The strongest influence is observed from attitude to the intention to adopt digital technologies. The figure is intended to complement the numerical results previously discussed and to reinforce the robustness of the proposed model.

These results collectively confirm the robustness of the hypothesized model and underscore the pivotal roles of digital literacy, stakeholder support, and attitudes in facilitating digital technology adoption within sustainable agriculture supply chains.

5.3 Model fit and predictive accuracy

The evaluation of model fit and predictive accuracy was conducted to validate the structural model's overall performance. This includes assessing the standardized root mean square residual (SRMR) and the predictive power using PLS Predict. The SRMR value of 0.074 indicates a good model fit, being below the commonly accepted threshold of 0.08. This suggests that the discrepancy between the observed and predicted correlations is minimal.

The model's out-of-sample predictive power was further evaluated through the PLS Predict analysis. As presented in, the majority of Q^2_predict values for the indicators were greater than

Table 5. Pathway assessment

Hypotheses	Pathway	Pathway coefficient	*t*-stats	*p*-value	*F* square	Results
H1	Digital Literacy → Attitude	0.333	9.461	0.000	0.122	*Accepted*
H2	Digital Literacy → Intention to Adopt	0.193	5.391	0.000	0.047	*Accepted*
H3	Support → Attitude	0.119	3.04	0.002	0.016	*Accepted*
H4	Support → Digital Literacy	0.231	5.975	0.000	0.056	*Accepted*
H5	Support → Intention to Adopt	0.162	4.498	0.000	0.036	*Accepted*
H6	Attitude → Intention to Adopt	0.410	10.92	0.000	0.215	*Accepted*

Source(s): The authors

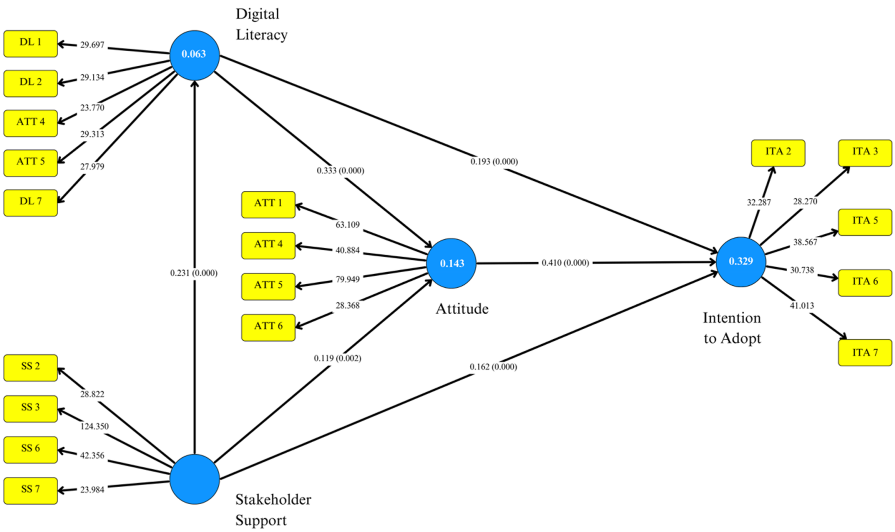

Figure 2. Bootstrapping results. Note: Indirect(meditated) paths are not shown in this figure. The authors

zero, indicating predictive relevance. Furthermore, the Root Mean Squared Error (RMSE) values for the PLS-SEM model were consistently lower than those for the linear benchmark model, suggesting that the PLS-SEM model offers superior predictive accuracy. These results confirm that the proposed model possesses strong predictive capabilities, which are crucial for practical application in sustainable agriculture supply chain contexts. Table 6 presents the model fit indices, indicating an acceptable fit with an SRMR value of 0.074, which is below the commonly accepted threshold of 0.08. Table 7 summarizes the results of the PLS Predict analysis, demonstrating that the PLS-SEM model outperforms the linear benchmark model in terms of predictive accuracy, as reflected by consistently lower RMSE and MAE values.

5.4 Mediation analysis

The mediation effects of attitude were tested to assess its role in linking digital literacy and stakeholder support to the intention to adopt digital technologies. The analysis revealed that attitude significantly mediated both pathways. The indirect effect of digital literacy on intention through attitude was statistically significant and positive ($\beta = 0.137$, $t = 7.387$, $p < 0.001$). Likewise, stakeholder support had a significant indirect effect on intention via attitude ($\beta = 0.049$, $t = 2.663$, $p = 0.008$). These results suggest that both digital competence and institutional support influence adoption decisions through the development of favorable attitudes. The full mediation outcomes are presented in Table 8.

5.5 Explanatory power and predictive relevance

The explanatory power of the structural model was assessed using the coefficient of determination (R^2) values. As shown in Table 9, the R^2 value for digital literacy was 0.053,

Table 6. Fit indices for the measurement model

Description	Value	Baseline value	Reference
SRMR	0.074 (acceptable fit)	<0.10 (acceptable fit)	Schermelleh-Engel *et al.* (2003)

Note(s): SRMR: standardized root mean square residual
Source(s): The authors

Table 7. PLS predict

	PLS RMSE	MAE	LM RMSE	MAE
DL 1	0.788	0.674	*0.790*	0.675
DL 2	*0.796*	0.683	0.795	0.680
DL 4	*0.460*	0.347	0.458	0.343
DL 5	0.839	0.715	*0.842*	0.716
SS 1	0.765	0.660	*0.766*	0.656
SS 4	0.420	0.233	*0.422*	0.238
SS 5	*0.438*	0.256	0.437	0.264
SS 6	0.464	0.268	*0.466*	0.267
ITA 2	0.656	0.525	*0.660*	0.528
ITA 3	*0.562*	0.495	0.559	0.495
ITA 5	*0.431*	0.291	0.414	0.296
ITA 6	*0.502*	0.331	0.498	0.338
ITA 7	*0.486*	0.319	0.484	0.316

Source(s): The authors

Table 8. Mediation

Pathway	Pathway coefficient	*t*-stats	*p*-value	Results
Stakeholder Support → Digital Literacy → Attitude	0.077	5.049	0.000	*Accepted*
Digital Literacy → Attitude → Intention to Adopt	0.137	6.509	0.000	*Accepted*
Stakeholder Support → Digital Literacy → Attitude → Intention to Adopt	0.032	4.384	0.000	*Accepted*
Stakeholder Support → Attitude → Intention to Adopt	0.049	3.069	0.002	*Accepted*
Support → Digital Literacy → Intention to Adopt	0.045	3.915	0.000	*Accepted*

Source(s): The authors

Table 9. Structural model assessment

Endogenous variables	*R*-square	Q-square
Attitude	0.143	0.092
Digital Literacy	0.053	0.029
Intention to Adopt	0.329	0.180

Source(s): The authors

indicating a small proportion of variance explained by stakeholder support. The R^2 value for attitude was 0.143, suggesting a modest explanatory power of digital literacy and stakeholder support combined. Meanwhile, the R^2 value for intention to adopt digital technologies was 0.329, reflecting a substantial level of variance explained by digital literacy, stakeholder support, and attitude.

The predictive relevance of the model was further evaluated using Stone-Geisser's Q^2 values obtained through blindfolding procedures. All Q^2 values were greater than zero, as reported in Table 9, indicating that the model has adequate predictive relevance for the endogenous constructs. These findings collectively demonstrate that the proposed structural model possesses acceptable explanatory and predictive capabilities, thereby supporting its application in the context of sustainable agriculture supply chains.

6. Discussion

The findings provide critical insights into the factors influencing the adoption of technology within sustainable agricultural supply chains. Specifically, the analysis demonstrates that digital literacy exerts a significant positive effect on both farmers' attitudes ($\beta = 0.333$, $t = 9.461$, $p < 0.001$) and their intention to adopt digital technologies ($\beta = 0.193$, $t = 5.391$, $p < 0.001$). These results underscore the importance of digital competencies in enabling farmers to better understand and engage with technological tools. These results align with the Technology Acceptance Model (TAM), which suggests that individuals' behavioral intentions are influenced by how easy a technology is to use and how beneficial it is perceived to be (Venkatesh *et al.*, 2003). In practice, higher digital literacy appears to reduce technical hesitation while enhancing farmers' confidence in applying precision agriculture approaches that contribute to improved efficiency and sustainability (Lee *et al.*, 2020).

Digital literacy also facilitates farmers' integration into Global Value Chains (GVCs) by enabling compliance with international sustainability standards. For example, technologies such as blockchain and IoT require a certain level of digital competence to ensure traceability and transparency, which are essential for building trust and competitiveness in global markets (Mondejar *et al.*, 2021; Ebinger and Omondi, 2020).

Stakeholder support was shown to have both direct and indirect effects on farmers' intentions to adopt digital technologies. By directly influencing digital literacy ($\beta = 0.231$, $p < 0.05$) and attitudes ($\beta = 0.119$, $p < 0.05$), stakeholder support addresses key adoption barriers such as limited infrastructure, lack of training, and financial constraints. This finding corroborates previous research by Wang and Zhang (2021), which emphasized the role of external interventions in overcoming systemic barriers to technology adoption.

Stakeholder initiatives, including financial incentives, infrastructure investments, and training programs, not only build farmers' capacity for adopting digital tools but also strengthen their ability to participate in GVCs. These interventions promote sustainability by facilitating the adoption of eco-friendly technologies while simultaneously improving trade competitiveness by reducing inefficiencies and fostering compliance with global trade standards (Ahmed and Miller, 2023).

The results also highlight the mediating effect of farmers' attitudes, which emerged as the most influential factor directly shaping their intention to adopt digital technologies ($\beta = 0.410$, $t = 10.92$, $p < 0.001$). This supports the framework proposed in the Theory of Planned Behavior (Ajzen, 1991), which emphasizes that an individual's positive evaluation of a behavior is instrumental in forming the intention to act. Farmers who perceive digital tools as reliable, accessible, and beneficial are significantly more likely to adopt them. Moreover, attitudes mediated the relationships between digital literacy and adoption intention (indirect effect $\beta = 0.137$, $p < 0.05$) and between stakeholder support and adoption intention. This mediating role underscores the importance of fostering positive attitudes through targeted interventions. For instance, well-designed training programs and supportive policies can help farmers perceive digital technologies as practical and advantageous, thereby encouraging their widespread adoption. Positive attitudes not only drive individual behavior but also contribute to the collective transformation of supply chains into sustainable and trade-competitive systems.

The findings have underscored broader implications for enhancing the efficiency and resilience of GVCs. Supported by improved digital literacy and stakeholder initiatives, digital technologies have been shown to facilitate traceability and transparency within supply chains. These advancements have proven particularly critical for agricultural products like rice, where compliance with sustainability certifications and trade requirements is essential for global market access (Rachman *et al.*, 2022). Furthermore, technologies such as AI and blockchain have been identified as tools that enable supply chains to adapt to disruptions caused by climate change or geopolitical uncertainties, thereby strengthening resilience (Liu *et al.*, 2024).

This study has extended the existing body of knowledge by integrating the roles of digital literacy, stakeholder support, and attitudes into a unified framework. While previous research has examined these factors individually, their interdependencies and collective impact on adoption intentions have been demonstrated in this study. Unlike the work of Lee *et al*. (2020), which primarily focused on the direct effects of digital literacy, this research has revealed its indirect effects through attitudes. Similarly, stakeholder support has been identified as having a dual role: directly influencing adoption intentions and indirectly enhancing digital literacy and attitudes, thus offering a more holistic understanding of technology adoption mechanisms (Li *et al.*, 2022).

The results of this study have important implications for countries like Indonesia, where agriculture plays a central role in rural livelihoods and national food security. The strong effect of digital literacy on both attitude and intention to adopt technology suggests that farmer-oriented digital education should be prioritized in development planning. Training programs need to be practical, tailored to the local context, and supported by accessible tools to increase their relevance and effectiveness. The findings also highlight the significance of stakeholder support, including consistent access to infrastructure, trusted extension services, and active institutional involvement. These forms of support create an enabling environment that helps bridge the gap between awareness and actual adoption. Furthermore, the mediating role of attitude indicates that farmers' willingness to engage with technology cannot be assumed and must be actively nurtured. For policy and program design, this means addressing not only technical barriers but also cognitive and motivational factors that shape adoption behavior in practice.

7. Conclusion

This study investigates the role of digital literacy, stakeholder support, and attitudes in influencing farmers' intention to adopt digital technologies in the context of sustainable agriculture supply chains. The findings demonstrate that digital literacy significantly enhances farmers' attitudes and directly contributes to their adoption intentions. Stakeholder support further strengthens this relationship by providing essential resources, including training, infrastructure, and financial assistance, while simultaneously enhancing farmers' digital literacy and fostering positive perceptions of technology. Additionally, the mediating role of attitudes has been highlighted, demonstrating their critical function in linking external enablers to behavioral intentions.

From a theoretical perspective, this research integrates the Technology Acceptance Model (TAM) and the Theory of Planned Behavior (TPB) to provide a comprehensive framework that explains the interplay between behavioral factors and external interventions in driving adoption intentions. By focusing on intention to adopt as a precursor to actual technology adoption, this study addresses an often-overlooked area in previous research. Furthermore, the findings contribute to the literature by providing a nuanced understanding of how digital literacy and stakeholder support collectively shape behavioral outcomes, offering a holistic view of the mechanisms driving technology adoption in sustainable agriculture.

The practical implications of these findings are significant for stakeholders aiming to promote sustainability and trade competitiveness in agriculture. Efforts to improve farmers' digital literacy through targeted training programs, practical workshops, and user-friendly digital tools are essential. Policymakers and agricultural organizations must address systemic barriers by investing in digital infrastructure, providing financial incentives, and implementing capacity-building initiatives. Additionally, fostering positive attitudes through awareness campaigns, demonstration projects, and success stories can reshape farmers' perceptions and increase their willingness to adopt digital technologies. Such interventions not only enhance farmers' readiness for digital transformation but also strengthen their integration into Global Value Chains (GVCs), promoting sustainability and improving trade performance.

Despite its contributions, this study has certain limitations. First, the cross-sectional design only captures relationships at a single point in time, limiting the ability to observe how adoption intentions evolve over time. Second, the research focuses specifically on rice farmers in Java, Indonesia, which may limit the generalizability of the findings to other regions or agricultural sectors. Future research could address these limitations by employing longitudinal designs to examine changes in adoption behavior over time, expanding the scope to diverse geographical contexts and farming types, and incorporating mixed-method approaches to gain deeper insights into the factors influencing technology adoption.

By addressing these limitations and building on the insights provided, future studies can further advance understanding of how digitalization contributes to sustainable agriculture and trade development. Such efforts will be essential for designing interventions that enhance efficiency, resilience, and competitiveness in agriculture supply chains, ensuring that smallholder farmers are empowered to participate effectively in global markets.

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