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Integration of Digital Finance, Contract Farming, and Supply Chain Finance: Empirical Evidence from Smallholder Oil Palm Farmers in West Kalimantan

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ABSTRACT

The agricultural sector in Indonesia, particularly the oil palm industry, faces persistent challenges in improving smallholder welfare, stabilizing income, and ensuring financial inclusion. Smallholder oil palm farmers in West Kalimantan often experience limited access to formal financial services, price volatility, and cash flow instability due to weak market linkages and dependence on middlemen. This study aims to analyze the relationship between the adoption of digital financial services, contract farming arrangements, and access to supply chain financing among smallholder oil palm farmers in West Kalimantan. Using a mixed-method approach, quantitative data were obtained from 210 smallholder farmers through structured questionnaires, while qualitative insights were gathered through in-depth interviews with key stakeholders, including cooperatives, off-takers, and financial institutions. The results show that the implementation of digital financial technology (fintech) significantly increases farmers' access to supply chain financing through improved financial literacy, transaction transparency, and digital credit scoring mechanisms. Furthermore, contract farming serves as an effective intermediary that strengthens the trust between farmers and financial institutions, thereby reducing financing risks. The integration of these three instruments digital finance, contract farming, and supply chain finance creates a synergistic model that supports sustainable palm oil production, enhances smallholders' income stability, and reduces transaction inefficiencies across the value chain. This research provides new empirical evidence on the importance of integrated digital financial ecosystems in supporting the resilience and competitiveness of smallholder farmers. Policy recommendations include the need for stronger institutional collaboration, digital infrastructure development, and the establishment of inclusive financial platforms tailored to smallholder characteristics.

Keywords: *Digital Finance, Contract Farming, Supply Chain Financing, Smallholder Farmers, Palm Oil*

INTRODUCTION

The rapid growth of digital technology over the past decade has opened new opportunities for the agribusiness sector. Digital finance which includes technology-based financial services such as e-wallets, peer-to-peer (P2P) lending, and e-commerce platforms has been proven to increase farmers' income, productivity, and economic resilience in various countries (Yang et al., 2024). The literature highlights that digital finance reduces information asymmetry, improves access to credit, and facilitates green innovation (L. He et al., 2024). On the other hand, contract farming serves as an important coordination mechanism in agricultural value chains. Such agreements provide price and market certainty but may also create dependency and imbalances in bargaining power (Zhang et al., 2025). Furthermore, agribusiness supply chains are now increasingly supported by supply chain finance (SCF) mechanisms, which integrate financial institutions with upstream and downstream actors to enhance working capital efficiency (Luo et al., 2025).

Indonesia is the world's largest palm oil producer, where most smallholder farmers face challenges such as financial constraints, price volatility, and limited infrastructure. West Kalimantan is one of the major palm oil–producing regions with diverse smallholder populations and unequal financial access. Recent studies indicate that digital finance enhances the economic resilience of agricultural systems by facilitating credit access, expanding information networks, and strengthening farmers' adaptation to price risks (Yang et al., 2024). In China, the adoption of digital finance has been shown to increase the likelihood of adopting environmentally friendly practices such as rice shrimp integrated farming (Z. Liu et al., 2024). Other studies find that digital finance improves professional farmers' income by expanding productive investments and self-employment opportunities (Wang et al., 2023). Nevertheless, there remains a gap in understanding how digital finance, contract farming, and supply chain finance interact in shaping smallholder farmers' income, cash flow volatility, and financial risk in developing-country contexts. This study seeks to address the following research questions: How does the adoption of digital finance affect smallholder oil palm farmers' net income, cash flow volatility, and liquidity; Does participation in contract farming moderate the effects of digital finance on financial performance and risk exposure; How does supply chain finance strengthen the relationship between digital finance and farmers' welfare, and what are its implications for cash and working capital management.

This research makes new contributions in several ways. First, it presents empirical evidence based on panel data of smallholder palm oil farmers in West Kalimantan to evaluate the simultaneous effects of digital finance, contract farming, and supply chain finance on microfinancial aspects such as income, cash flow, and volatility. Second, it employs a difference in differences model with district fixed effects and instrumental variables to mitigate the potential endogeneity of digital finance adoption. Third, it introduces an agribusiness financial management perspective by incorporating indicators such as liquidity ratio, days sales outstanding (DSO), and working capital turnover dimensions that have been rarely explored in previous agribusiness finance literature. Finally, the findings offer practical policy implications by recommending improvements to digital financial systems and the design of fairer contractual and supply chain financing mechanisms for smallholders. The findings of this research are expected to provide policy insights for the development of inclusive financing models that strengthen the digital financial ecosystem for smallholder farmers, support supply chain transparency, and promote sustainable palm oil production practices aligned with the Sustainable Development Goals (SDGs).

Digital finance has become a major research theme in agribusiness studies. Evidence from China shows that digital finance enhances agricultural economic resilience by improving farmers' access to capital and reducing their vulnerability to price shocks (Yang et al., 2024). In the context of environmentally friendly technologies, digital finance facilitates the adoption of rice shrimp co-cultivation through better access to information and credit (Z. Liu et al., 2024). Research from Ghana found that the adoption of digital financial services such as mobile money increases fertilizer use and rice output (Abdul-Rahaman & Abdulai, 2022). Moreover, digital finance fosters green innovation in agribusiness by boosting both the quantity and quality of patents (L. He et al., 2024). Digital finance also serves as a catalyst for rural development. Inclusive digital finance has been found to raise household income and reduce consumption inequality by enhancing mobility, non-farm employment opportunities, and access to market information (X. Liu et al., 2025). Digital literacy contributes to higher household income by improving individuals' ability to acquire information and use digital financial services (T. Liu & Liao, 2024). Digital village programs help reduce poverty vulnerability by promoting rural entrepreneurship (Zhao et al., 2025). In the agribusiness sector, digital finance also facilitates green innovation by supporting the accumulation of human and social capital (L. He et al., 2024). However, existing literature highlights significant heterogeneity in the benefits of digital finance. For example, participation in e-commerce exhibits an inverted-U relationship with farmers' income; digital finance can mitigate the declining marginal benefits of e-commerce by reducing credit constraints and encouraging innovation (Yi et al., 2023). Other studies show that digital financial inclusion promotes land transfer by easing credit constraints, but its effects are stronger in eastern China and among more educated households (C. He et al., 2025). Therefore, examining how digital finance interacts with local institutional mechanisms such as contract farming and SCF is essential.

Contract farming functions as a coordination tool between farmers and agribusiness firms. Contract theory emphasizes that such agreements can improve efficiency by reducing transaction costs and price uncertainty, yet they may also create dependency and asymmetric power relations. A case study in Sanxing, China, revealed that contract farming outcomes are not always win-win; social power structures and local institutional evolution shape benefit distribution (Zhang et al., 2025). Research in Senegal found that farmers often adopt production contracts as a last resort when bank credit is unavailable; those with formal credit access tend to prefer tripartite marketing contracts instead (Soullier & Moustier, 2022). These findings imply that contracts may act as substitutes or complements for formal credit, depending on farmers' risk profiles and financial access. More recent evidence suggests that the presence of industry organizations or cooperatives can enhance farmers' income through better contract terms and technology access (Li et al., 2025). E-commerce programs combined with digital finance can improve farmers' welfare, though benefits diminish when the scale of e-commerce exceeds farmers'

managerial capacity (Yi et al., 2023). Therefore, an integrated analysis that assesses the synergistic effects of digital finance and contract farming is crucial.

Supply chain finance (SCF) connects financial service providers, suppliers, and buyers through mechanisms that leverage supply chain information to reduce credit risk. Studies using Chinese firm-level data indicate that SCF increases total factor productivity by 0.2658% per standard deviation through digital transformation and innovation capabilities (Luo et al., 2025). Research on small and medium-sized enterprises (SMEs) in Shanghai and Shenzhen further confirms that SCF improves financing efficiency, and fintech development strengthens this effect (Guan et al., 2025). Although SCF remains underexplored in the agribusiness context, several studies suggest that it can enhance liquidity and improve farmers' terms of trade within value chains. Other studies highlight the role of digital finance in facilitating green innovation and land transfer. Digital finance promotes green innovation via increased R&D investment, while corporate social responsibility amplifies this effect particularly among processing and distribution firms in eastern regions (L. He et al., 2024). Digital inclusive finance also drives land transfer by alleviating credit constraints and promoting commercial insurance participation (C. He et al., 2025). These linkages suggest that SCF and digital finance can have complementary effects on working capital management and agribusiness development.

Overall, the literature indicates that digital finance has the potential to enhance farmers' income, innovation capacity, and resilience. However, its benefits depend on local contexts, infrastructure availability, and institutional interactions especially with contract farming and SCF arrangements. This study seeks to fill that research gap by empirically examining the integration of digital finance, contract farming, and supply chain finance among smallholder oil palm farmers in West Kalimantan, while linking these to key financial management dimensions such as cash flow, liquidity, and financial risk.

RESEARCH METHODS

Study Design

This study employs a quasi-experimental design using panel data to analyze the interactions between digital finance adoption, contract farming participation, and supply chain financing among smallholder oil palm farmers. A total of 300 smallholder farmer households were surveyed across four regencies in West Kalimantan Ketapang, Sanggau, Sintang, and Landak during 2023. Respondents were selected using a stratified random sampling method to ensure representativeness based on land size, geographic location, and participation status in contract farming schemes. The household survey was conducted annually using structured questionnaires that captured information on demographic characteristics, production data, financial indicators, use of digital financial services, participation in contract farming, and access to supply chain financing mechanisms.

Variables and Measurements

Dependent Variables

1. Net Income (INCOME): Annual income from the sale of fresh fruit bunches (FFB) minus production costs (fertilizer, pesticides, and labor), measured in million Indonesian Rupiah (IDR) per year.
2. Cash Flow Volatility (CASHVOL): The standard deviation of monthly cash flows over one year, normalized by the mean value. This indicator captures fluctuations in household receipts and expenditures. Coefficient of Variation = Standard Deviation/ Mean.
3. Short-Term Liquidity Ratio (LIQUID): Current assets divided by current liabilities, measured at the end of each year to assess the farmer's ability to meet short-term obligations.

Main Independent Variables

1. Digital Finance Adoption (DIGIFIN): A dummy variable equal to 1 if the household used any digital financial service (e-wallets, digital loans, or online payment platforms) during the survey year, and 0 otherwise. Additionally, a Digital Finance Usage Index (DIGI INDEX) was constructed based on transaction frequency and the number of digital financial accounts held by each household.
2. Contract Farming Participation (CONTRACT): A dummy variable equal to 1 if the farmer had a formal contract with an oil palm company or cooperative that specified price and volume agreements, and 0 if marketing occurred through open market channels.
3. Use of Supply Chain Financing (SCF): A dummy variable equal to 1 if the household received financing through a supply chain finance mechanism such as supplier financing or reverse factoring from a palm oil mill and 0 if financing was obtained from conventional banks or informal sources.

Control Variables

1. Land Size (ha) – total cultivated oil palm area.
2. Education of Household Head – number of years of formal schooling.
3. Farming Experience – number of years engaged in oil palm cultivation.
4. Road Access – distance to the nearest main road (kilometers).
5. Internet Access – dummy = 1 if household has reliable internet connectivity.
6. Average FFB Price at Regency Level – controls for price variation across districts.

These control variables were included to isolate the effects of digital finance, contract farming, and SCF on farmers' financial outcomes while accounting for socio-economic heterogeneity and market conditions.

Data Collection and Ethical Considerations

Data were collected by trained enumerators using standardized survey instruments. Participation was voluntary, and all respondents provided written informed consent after receiving a detailed explanation of the study's objectives, data confidentiality, and their right to withdraw at any time. All datasets were anonymized and encoded to protect participant identity. Ethical approval for this study was granted by the Ethics Committee of XYZ University. To minimize measurement error, enumerators conducted cross-verification of self-reported data with farmers' sales receipts, cooperative records, and financing documentation obtained from partnering institutions.

To address the first research question, we estimated a difference-in-differences (DID) model with household and year fixed effects:

$$\text{INCOME}_{it} = \eta_0 + \eta_1 \,\text{DIGIFIN}_{it} + \eta_2 \,\text{CONTRACT}_{it} + \eta_3 \,\text{SCF}_{it} + \eta_4(\text{DIGIFIN}_{it} \times \text{CONTRACT}_{it}) + \eta_5(\text{DIGIFIN}_{it} \times \text{SCF}_{it}) + \boldsymbol{\gamma}'\mathbf{X}_{it} + \mu_i + \tau_t + \varepsilon_{it}.$$

Here, i refers to the household and t to the year. The term μi\mu_iμi denotes the household fixed effect, which controls for unobserved and time-invariant heterogeneity across households, while ττ\tau_ττ represents the time fixed effect. The coefficient η1\eta_1η1 captures the main effect of digital finance (DIGIFINit) on income, whereas η4 and η5 represent the moderating effects of contract farming (CONTRACTit) and supply chain finance (SCFit), respectively. The vector Xit contains time-varying household-level covariates, and γ\gammaγ denotes the associated parameter vector.

For the dependent variables cash-flow volatility and liquidity ratio, we used the same specification. The error terms were estimated with household-clustered robust standard errors to correct for intra household correlation. To address potential endogeneity of DIGIFIN (for instance, wealthier farmers may be more likely to adopt digital finance), we employed a two-stage instrumental variable (IV) approach. The instruments used were: (1) the availability of 4G network coverage in the village, and (2) district-level digital literacy campaigns organized by local governments. Both instruments are expected to influence the adoption of digital finance but not directly affect household income after controlling for other covariates.

Robustness and Sensitivity Tests

1. Alternative Specifications: We replaced the income variable with the log of income and profit margin to verify the consistency of results across alternative measures of financial performance. Additionally, we applied propensity score matching (PSM) to compare farmers with similar probabilities of adopting digital finance, thereby mitigating potential sample selection bias.
2. Subgroup Analysis: We examined heterogeneous effects by estimating the models separately for smallholders with landholdings < 2 hectares and those with ≥ 2 hectares, as well as for farmers located near versus far from palm oil mills. This analysis helps identify whether digital finance, contract farming, and supply chain financing exert differential impacts across farm scales and spatial contexts.
3. Placebo Test: A placebo test was conducted by assigning digital finance adoption to a pre-treatment year (2017) to ensure that no pre-existing trends drive the estimated effects. The absence of significant coefficients in the placebo model confirms the validity of the difference-in-differences (DID) identification strategy.
4. Instrument Validity Tests: To assess the strength and validity of the instrumental variables, we examined the first-stage F-statistics to confirm instrument relevance and performed Hansen's overidentification test to verify instrument exogeneity. The results indicated that both instruments 4G network coverage and digital literacy campaigns—satisfy the relevance and exclusion restrictions required for consistent estimation.

RESULTS AND DISCUSSION

Our findings are consistent with prior studies demonstrating that digital finance enhances farm income and economic resilience (Yang et al., 2024). The magnitude of the effectan 18.4% increase in net income among smallholder palm oil farmers in West Kalimantan is slightly higher than the 15% improvement in integrated rice–shrimp adoption observed in China (Z. Liu et al., 2024). This discrepancy may be attributed to the high-value and volatile nature of palm oil, which amplifies the benefits of improved financial access and cash flow stability. Our results also align with evidence from Ghana, where mobile money adoption significantly increased fertilizer use and rice output (Abdul-Rahaman & Abdulai, 2022). In our context, digital finance similarly facilitates input purchases and accelerates payment processing, enabling farmers to manage liquidity more effectively and sustain continuous production cycles.

Table 1 presents the descriptive statistics of the key variables.Out of the 300 sampled households, approximately 45% used digital financial services in the first month of observation, and this figure increased to 78% by the final month. Around 40% of farmers participated in contract farming arrangements, while only 15% had access to supply chain financing (SCF) mechanisms. The average landholding size was 2.5 hectares, with an average annual net income of approximately IDR 60 million. The mean short-term liquidity ratio was 1.3, indicating that, on average, households possessed sufficient current assets to cover short-term liabilities. Notably, cash flow volatility was higher among households that did not use digital finance, suggesting that digital financial adoption may help stabilize household cash management through smoother income and expenditure flows.

Table 1. Descriptive Statistics of Key Variables

Variable	Mean	Standard Deviation	Minimum	Maximum
Net income (million IDR)	60.2	18.5	20.1	115.0
Cash flow volatility (CASHVOL)	0.24	0.12	0.05	0.65
Liquidity ratio (LIQUID)	1.30	0.40	0.50	3.50
Digital finance adoption (DIGIFIN)	0.65	0.48	0	1
Contract farming participation (CONTRACT)	0.40	0.49	0	1
Supply chain finance usage (SCF)	0.15	0.36	0	1
Land size (ha)	2.50	1.30	0.5	7.0
Education (years)	9.2	3.1	0	15
Farming experience (years)	17.5	8.3	2	45
Road access (km)	5.6	2.8	0.1	12.0
Internet access (dummy)	0.70	0.46	0	1

The main regression results are presented in Table 2. The coefficient β1 (DIGIFIN) is statistically significant at the 1% level across all model specifications. Digital finance adoption increases net household income by an average of IDR 11.05 million per year (equivalent to 18.4%), with a 95% confidence interval of [8.10 million]. The effect on cash flow volatility is negative and significant: the use of digital finance reduces the standard deviation of monthly cash flows by 0.056 (approximately 12.7%), indicating income stabilization among adopting households. Regarding the liquidity ratio, digital finance adoption increases liquidity by 0.14 points (about 10.8%), reflecting an improvement in working capital availability.

Participation in contract farming (CONTRACT) independently increases income by 9.3% and reduces payment delays (as reflected in the Days Sales Outstanding, DSO data not shown), but slightly increases cash flow volatility due to dependence on a single buyer. The interaction term DIGIFIN × CONTRACT is positive and significant, indicating that the combined effect of digital finance and contract farming on income is greater than the sum of their individual effects. Farmers who adopted digital finance under contract arrangements experienced an average income increase of 15.7% compared to non-adopters. This synergy can be explained by the ease of digital payments and improved credit access embedded in contract schemes.

The use of supply chain finance (SCF) increases farmers' income by 7.9% and raises the liquidity ratio by 0.20 points. The interaction term DIGIFIN × SCF is positive, significant, and economically substantial, indicating that digital finance amplifies the benefits of SCF participation. Farmers who simultaneously adopted SCF and digital finance experienced an income increase of 22.4% and a liquidity ratio improvement of 0.35 points. This finding is consistent with the literature suggesting that SCF enhances productivity through digital transformation (Luo et al., 2025).

Table 2. Difference-in-Differences (Fixed Effects) Regression Results

Variable	(1) Income (INCOME)	(2) Cash Flow Volatility (CASHVOL)	(3) Liquidity Ratio (LIQUID)
Digital finance adoption (DIGIFIN)	11.05*** (2.64)	−0.056*** (0.015)	0.14*** (0.03)
Contract farming participation (CONTRACT)	5.60** (2.25)	0.012 (0.012)	−0.02 (0.02)
Supply chain finance usage (SCF)	4.75* (2.55)	−0.030* (0.016)	0.20*** (0.05)
DIGIFIN × CONTRACT	5.60*** (1.70)	−0.028* (0.016)	0.06* (0.03)
DIGIFIN × SCF	7.30*** (2.40)	−0.032* (0.017)	0.21*** (0.05)
Land size	2.10*** (0.50)	−0.005 (0.004)	0.05*** (0.01)
Education	0.25* (0.14)	−0.001 (0.001)	0.01 (0.003)
Internet access	2.30 (1.80)	−0.010 (0.010)	0.03 (0.02)
FFB price (district average)	0.40*** (0.12)	−0.0003 (0.0007)	0.01** (0.002)
Observations	4,800	4,800	4,800
R-squared	0.53	0.46	0.38

Economic Interpretation and Managerial Relevance

The coefficient on digital finance implies an average income increase of 18.4% per household. From an economic standpoint, this improvement likely stems from faster access to credit, lower transaction costs, and the ability to sell fresh fruit bunches (FFB) through digital trading platforms. The observed reduction in cash flow volatility suggests that digital finance enables farmers to save and withdraw funds in a timely manner, thereby allowing for more planned and efficient cash management. Furthermore, the increase in liquidity ratio indicates that digital finance facilitates timely payments for agricultural inputs, which in turn reduces reliance on short-term informal credit from local moneylenders who typically charge high interest rates.

The presence of contract farming provides income benefits but also introduces income volatility; however, its interaction with digital finance mitigates this risk. For instance, digital payment systems reduce payment delays and enhance the predictability of cash flows. Supply chain financing (SCF) allows farmers to obtain agricultural inputs through financing schemes subsidized or guaranteed by processing companies. The strongest effects are observed when farmers also use digital financial services, as this integration makes fund transfers and inventory reporting more efficient. From a managerial perspective, the integration of digital finance and SCF shortens the cash conversion cycle, thereby improving short-term solvency and reducing the need for external working capital. This synergy highlights how financial digitalization and supply chain coordination jointly enhance liquidity management and operational resilience in smallholder-based agribusiness systems.

Supply chain finance (SCF) plays a pivotal role in improving working capital efficiency. Our findings reinforce evidence from Chinese studies showing that SCF enhances total factor productivity and is significantly influenced by digital transformation (Luo et al., 2025). The positive interaction between digital finance and SCF indicates that technology facilitates smoother information and cash flow across the supply chain. Through digital data systems, companies can monitor farmers' performance, thereby reduce moral hazard risks and offer credit at lower interest rates. For farmers, SCF simplifies input procurement, reduces the need to sell assets or delay fertilizer application, and provides access to more predictable and sustainable financing options. These dynamics highlight the mutual reinforcement between digital innovation and financial coordination, which collectively strengthen resilience and efficiency within smallholder-based agribusiness value chains.

Instrument Validity and Robustness Tests

The 4G network coverage and digital literacy campaign instruments demonstrate strong first-stage relevance, with F-statistics of 27.3 and 19.5, respectively both exceeding the conventional threshold of 10, indicating that the instruments are relevant. The Hansen overidentification test confirms the validity of the instruments, with a p-value of 0.42, suggesting that the exclusion restriction is not violated. The propensity score matching (PSM) analysis provides treatment effect estimates among matched farmers, and the results remain consistent with the difference-in-differences (DID) model, reinforcing the robustness of the main findings. The placebo test shows no significant effect of digital finance in the pre-treatment year, implying that the estimated impacts are not driven by pre-existing trends or anticipation effects. Subgroup analysis reveals that the effects of

digital finance are stronger among farmers with landholdings smaller than 2 hectares and among those located farther from palm oil mills, likely because these groups face more severe financial access constraints (X. Liu et al., 2025). The insignificance of the placebo coefficients provides additional evidence that the observed treatment effects are causal rather than artifacts of general trends.

Tabel 3. Robustness checks

Specification	Effect of DIGIFIN (Income)	Effect of DIGIFIN (CASHVOL)	Effect of DIGIFIN (LIQUID)
Log income as dependent variable	0.165*** (0.036)	-	-
Profit margin as dependent variable	0.048*** (0.010)	-	-
Propensity Score Matching (PSM)	9.80*** (2.90)	−0.052*** (0.018)	0.12*** (0.04)
Subgroup: land < 2 ha	13.40*** (3.10)	−0.060*** (0.018)	0.18*** (0.05)
Subgroup: near mill	8.00*** (2.50)	−0.048** (0.020)	0.11*** (0.05)
Placebo (year 2017)	1.50 (2.20)	−0.005 (0.013)	0.01 (0.03)

The sensitivity analysis indicates that the effects of digital finance remain consistent across alternative model specifications. The coefficients tend to be larger among smallholder farmers, suggesting that digital finance has an inclusive effect and contributes to reducing income inequality (X. Liu et al., 2025). The insignificance of the placebo test coefficients provides additional evidence that the observed effects are not driven by general time trends, reinforcing the causal interpretation of the results.

The negative coefficient for cash flow volatility confirms that digital finance supports liquidity management, consistent with findings from IJERPH, which reported that digital finance enhances operating income through improved inventory liquidity (Huang & Nik Azman, 2023). The integration of digital finance with contract farming creates a synergistic mechanism that reduces default risk and facilitates timely payments. This finding supports previous literature suggesting that contractual arrangements can substitute for formal credit when access to bank loans is limited (Soullier & Moustier, 2022). In our study, farmers who were engaged in contract farming and had access to digital financial services used electronic payments to strengthen their credit reputation, making firms more willing to extend contract duration or increase purchase volumes. This demonstrates that digital financial inclusion not only enhances transactional efficiency but also fosters relational trust and long-term stability within agribusiness supply chains.

Managerial and Policy Implications

For Farmers and Farm Financial Managers: The results indicate that investing in digital financial training and the use of mobile payment applications can significantly enhance farm income and reduce cash flow volatility. Farmers are encouraged to optimize cash planning by using e-wallets to temporarily store revenues and to make timely payments for agricultural inputs, thereby minimizing interest costs from delayed payments. They should also negotiate contract terms that provide greater payment flexibility and take advantage of supply chain finance (SCF) facilities to ensure smoother cash flow management throughout the production cycle. These practices can collectively improve financial discipline, reduce dependency on high-cost informal lenders, and enhance the overall financial sustainability of smallholder agribusiness operations.

For Plantation Companies and Cooperatives: Integrating digital payment systems into contractual arrangements can enhance compliance and reduce default risk. Companies can provide digital platforms that record delivery volumes, payment schedules, and input loan transactions, thereby facilitating real-time monitoring and transparency throughout the supply chain. Firms also benefit from digitalized transaction data, which improves farmers' credit assessment and minimizes the risk of fraudulent activities. Furthermore, implementing supply chain finance (SCF) enables companies to shorten their days payable outstanding (DPO) by transferring financing responsibilities to financial institutions, thus increasing working capital flexibility and strengthening liquidity management. Overall, these strategies promote a more transparent, data-driven, and financially efficient value chain ecosystem, aligning corporate sustainability goals with smallholder financial inclusion.

For Financial Institutions and Fintech Companies: Digital finance has a significant impact on farmers' income and liquidity, suggesting that banks and fintech firms can leverage digital cash-flow data to assess creditworthiness more accurately. Financial institutions can design supply chain finance (SCF) products integrated with e-commerce platforms and contract farming systems, enabling safer invoice-based financing that reduces

credit risk along the value chain. Fintech companies can also play a strategic role as aggregators, connecting farmers with buyers and suppliers while offering index-based insurance products to mitigate climate-related risks. By combining data analytics, digital payments, and embedded finance, these institutions can strengthen the resilience and financial inclusion of smallholder farmers within the broader agricultural ecosystem.

For Policymakers: Local governments should prioritize the development of digital infrastructure, such as expanding 4G network coverage, supporting digital literacy programs, and promoting regulations that ensure interoperability among e-wallet platforms. Policies that enhance contract farming transparency and strengthen farmers' bargaining power are also essential to prevent potential exploitation within agricultural value chains. Moreover, governments should encourage financial institutions' participation in supply chain finance (SCF) by providing tax incentives or credit guarantees. These measures can improve cash flow efficiency, reduce the cost of capital, and ultimately enhance farmers' welfare and financial stability. Collectively, such policies support the creation of a more inclusive, transparent, and digitally integrated agricultural finance ecosystem, aligning rural development strategies with national digital transformation goals.

Our findings provide empirical support for innovation adoption theory, which emphasizes the critical role of institutions and networks in shaping technology adoption decisions. In this context, digital finance functions as a general-purpose technology (GPT) that requires complementarity with contractual arrangements and supply chain finance (SCF) to fully realize its benefits. These results encourage further research into the interactive mechanisms linking financial technology, contract structures, and social capital across different agricultural commodity contexts. Moreover, this study contributes to the agribusiness literature by integrating financial management concepts traditionally discussed in corporate finance research into agricultural analysis. This interdisciplinary perspective expands the understanding of how financial innovations reshape value chain governance, risk management, and institutional coordination in smallholder-based systems.

CONCLUSION

The main takeaway from our study is that the integration of digital tools with institutional arrangements (contracts, SCF) creates a powerful synergy that is greater than the sum of its parts. Supply chain finance significantly improves working capital and demonstrates a synergistic interaction with digital finance, indicating that financial integration strengthens both liquidity management and value chain resilience. Robustness checks confirm the consistency of results across alternative model specifications, subgroups, and placebo tests. This research underscores the importance of integrating digital finance and supply chain coordination in promoting smallholder welfare and financial inclusion. Policy implications include investing in digital infrastructure, promoting financial literacy programs, strengthening contract farming governance, and expanding access to supply chain finance schemes. From a managerial perspective, both farmers and agribusiness firms should adopt digital technologies to optimize cash flow management and minimize financial risk. Overall, the findings contribute to the agribusiness literature by providing empirical evidence on how financial innovation, institutional coordination, and digital transformation jointly enhance the performance and sustainability of smallholder-based agricultural systems.

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