

Effect of Technology Adoption on the Performance of Agro-Processing Firms in North-Central Nigeria

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ABSTRACT

This study examines the effect of technology adoption on the performance of agro-processing firms in North-Central Nigeria, with firm performance foregrounded as the central dependent variable. Two technology adoption dimensions are specifically investigated: production automation and quality control technology. Motivated by the persistent productivity deficits, quality inconsistencies, and competitive underperformance of North-Central Nigerian agro-processing firms largely attributable to low technology adoption rates and by the absence of rigorous construct-level PLS-SEM evidence on the technology adoption–firm performance nexus in this agro-processing context, the study adopts a quantitative, cross-sectional survey design. Primary data were collected from 187 valid respondents comprising owners, operations managers, production managers, and quality/technology officers of agro-processing firms across all seven states of the North-Central geopolitical zone: Benue, FCT Abuja, Kogi, Kwara, Nasarawa, Niger, and Plateau States. Descriptive statistics are presented as simple frequencies and percentages. Partial Least Squares Structural Equation Modelling (PLS-SEM) using Smart PLS was employed for inferential analysis following a two-stage measurement and structural model evaluation. The study reveals that production automation exerts a positive and statistically significant effect on firm performance, while quality control technology, though positively directed, does not exert a statistically significant effect on firm performance. These findings establish production automation as the dominant technology adoption driver of agro-processing firm performance in North-Central Nigeria, while revealing that quality control technology as currently adopted and utilized does not generate statistically measurable performance improvements, potentially due to limited equipment utilization, inadequate operator training, and poor integration with production workflows. The study recommends structured automation investment programmes, quality technology capacity-building, and targeted technology adoption support for North-Central agro-processing firms.

Keywords: Technology Adoption, Firm Performance, Production Automation, Quality Control Technology, Agro-Processing Firms, North-Central Nigeria.

INTRODUCTION

Firm performance in the agro-processing sub-sector represents one of the most consequential indicators of agricultural value addition, food security achievement, and rural economic development in North-Central Nigeria a geopolitically diverse zone encompassing Benue, the Federal Capital Territory (FCT), Kogi, Kwara, Nasarawa, Niger, and Plateau States, collectively referred to as the nation's food basket due to their vast agricultural endowments (Ibrahim & Danlami, 2023). Agro-processing firms in the zone spanning grain and cereal milling, cassava and yam processing, fruit and vegetable processing, poultry and livestock processing, dairy production, and beverage manufacturing from agricultural inputs occupy the critical value-adding nexus between agricultural production and consumer markets, generating income, employment, and food safety outcomes that are foundational to the zone's development. Yet the performance of these firms has been persistently constrained by low productivity, high post-harvest losses, inconsistent product quality, and limited market competitiveness that collectively prevent the sub-sector from realizing the value addition potential embedded in the zone's abundant agricultural resources (Yakubu & Musa, 2024).

Technology adoption is the process through which agro-processing firms acquire, implement, and institutionalize new production technologies, processing equipment, and quality management systems that improve the efficiency, quality, and scale of their value-adding activities has been consistently identified in the empirical literature as the primary determinant of agro-processing firm performance in both developed and developing agricultural economies (Okafor & Adeyemi, 2024). The theoretical and empirical case for technology adoption as a performance driver rests on multiple foundations: technology enhances labour productivity by substituting machine capacity for human effort in repetitive, physically demanding, or precision-requiring tasks; it improves product quality consistency by reducing human error and standardizing processing parameters; it enables scale expansion by increasing throughput per unit of time and reducing production bottlenecks; and it generates cost efficiencies through energy optimization, waste reduction, and raw material yield improvements. Despite this compelling case, SMEDAN's (2023) national survey documented that over 71% of North-Central agro-processing firms operated with predominantly manual or semi-manual processing equipment, and fewer than 23% had adopted any form of digital quality management or monitoring technology creating a structural technology adoption gap that fundamentally limits firm performance potential.

Two technology adoption dimensions are of particular strategic consequence for North-Central agro-processing firm performance. Production automation the adoption of mechanized processing equipment, automated packaging systems, digital process controls, and energy-efficient production technologies that reduce manual processing intensity and increase production throughput, consistency, and efficiency directly addresses the productivity deficit that prevents most North-Central agro-processors from achieving the output volumes and cost structures needed for commercial viability and market competitiveness (Aliyu & Bello, 2024). Quality control technology the adoption of laboratory testing equipment, sensor and monitoring systems, food safety compliance tools, and digital quality documentation platforms that enable systematic measurement, verification, and documentation of product quality attributes throughout the processing cycle addresses the quality consistency deficits that prevent North-Central agro-processed foods from meeting the specifications required for formal retail markets, export, and institutional procurement (Nwosu & Adeleke, 2023). This study investigates these two dimensions as the primary technology adoption pathways to agro-processing firm performance improvement in the North-Central context.

North-Central Nigerian agro-processing firms face a persistent and widening technology adoption gap that directly constrains their performance: while the formal sector standards expected by supermarkets, export buyers, institutional customers, and regulatory bodies (NAFDAC, SON) require production consistency and quality documentation achievable only through technological investment, over 71% of the zone's agro-processors continue to operate with predominantly manual processes that cannot meet these standards (SMEDAN, 2023). The Federal Ministry of Agriculture and Food Security (FMAF, 2023) estimated that North-Central agro-processing firms operating without significant technology investment achieve production yields approximately 34% lower than those with mechanized processing equipment, and product quality rejection rates approximately 2.8 times higher implying that the technology adoption gap generates direct and quantifiable performance losses that compound over time into structural competitive disadvantage.

A fundamental knowledge gap amplifies these practical challenges: disaggregated, construct-level empirical evidence on the independent performance effects of production automation and quality control technology using PLS-SEM methodology is absent for the North-Central Nigerian agro-processing context. Most existing technology adoption studies for this sector either aggregate technology into undifferentiated indices or focus on the South-West or South-East without attention to the North-Central zone's distinctive technology adoption context. The specific prediction that quality control technology despite its theoretical importance may not independently generate statistically significant firm performance improvements in the current North-Central context due to limited operator training, inadequate calibration maintenance, and poor integration with production workflows has not been empirically tested. This study comprehensively addresses these gaps.

The broad objective of this study is to examine the effect of technology adoption on the performance of agro-processing firms in North-Central Nigeria. The specific objectives are:

- i. To examine the effect of production automation on the performance of agro-processing firms in North-Central Nigeria.
- ii. To investigate the effect of quality control technology on the performance of agro-processing firms in North-Central Nigeria.

The following null hypotheses are formulated and tested at the 5% significance level:

H0₁: Production automation does not have a significant positive effect on the performance of agro-processing firms in North-Central Nigeria.

H0₂: Quality control technology does not have a significant positive effect on the performance of agro-processing firms in North-Central Nigeria.

LITERATURE REVIEW

Firm Performance

Firm performance is defined as the multidimensional achievement of an agro-processing enterprise's financial, productive, quality, and competitive objectives over a defined period, relative to its historical trajectory and to comparable enterprises operating in the same agro-processing sub-sector and market environment (Ibrahim & Danlami, 2023). As the central dependent variable of this study, firm performance is positioned first in all analytical frameworks, reflecting the study's performance-first orientation: all technology adoption dimensions are evaluated in terms of their ultimate contribution to the financial and operational performance outcomes that determine the sustainability and growth trajectory of agro-processing firms in the North-Central zone. Firm performance in the agro-processing context encompasses four analytically distinct but empirically interrelated dimensions: financial performance (revenue generation, profitability, and cost efficiency), productive performance (production output volume, throughput rate, and raw material yield), quality performance (product quality consistency, customer satisfaction, and regulatory compliance), and competitive performance (market share maintenance and competitive positioning).

Technology Adoption in Agro-Processing

Technology adoption in the agro-processing context is defined as the process through which an enterprise acquires, implements, integrates, and institutionalizes new production technologies, processing equipment, quality management systems, and digital tools that improve the efficiency, output quality, throughput capacity, and regulatory compliance of its food processing activities (Yakubu & Musa, 2024). Technology adoption in agro-processing occurs on a continuum from basic mechanization replacing purely manual processing tasks with simple mechanical equipment to advanced automation implementing digitally controlled, sensor-integrated production lines with minimal human intervention. The Technology Acceptance Model (Davis, 1989) identifies perceived usefulness and perceived ease of use as the two primary determinants of technology adoption decisions in organizational settings, providing a micro-level mechanism through which enterprise managers evaluate and commit to technology investments. In the North-Central Nigerian agro-processing context, technology adoption is constrained by a combination of capital access limitations, energy infrastructure deficiencies, technical skills shortages, and market demand uncertainty creating the adoption gap that this study investigates as a driver of firm performance variation across the zone's agro-processing population.

Production Automation

Aliyu and Bello (2024) refers to production automation the adoption and effective utilization of mechanized processing equipment, automated packaging and handling systems, digital process control technologies, and energy-efficient production infrastructure that reduce manual processing intensity, increase production throughput, improve output consistency, and reduce the unit cost of processing raw agricultural materials into finished food products. Production automation in North-Central agro-processing encompasses a spectrum ranging from basic mechanization hammer mills, cassava grating machines, palm oil presses, and grain

threshers that mechanize the most physically demanding manual processing tasks to intermediate automation packaging lines, conveyor systems, and temperature-controlled processing chambers that reduce human handling of processed products to advanced automation programmable logic controller (PLC)-driven processing lines, automated weighing and filling equipment, and energy management systems that minimize manual operator intervention throughout the production cycle.

Quality Control Technology

Quality control technology refers to the adoption of laboratory testing equipment, sensor and monitoring systems, food safety compliance tools, and digital quality documentation platforms that enable Agro-processing firms to systematically measure, verify, record, and manage the quality attributes of their products throughout the processing cycle from incoming raw material assessment through in-process quality checks to finished product release and customer delivery (Nwosu & Adeleke, 2023). In the North-Central agro-processing context, quality control technology encompasses physical testing equipment (moisture meters, weighing scales, refractometers, pH meters), microbiological testing capabilities (bacterial culture media, contamination testing kits), NAFDAC and SON compliance documentation systems, and digital quality record management platforms. Quality control technology's performance contribution is theoretically comprehensive: it generates cost savings by identifying quality defects early in the processing cycle before value is added to substandard inputs; it improves revenue by enabling premium pricing for consistently quality-assured products; and it expands market access by providing the quality documentation required for formal retail, export, and institutional markets.

EMPIRICAL REVIEW

Production Automation and Firm Performance

Alharbi (2024) investigated the effect of business process automation on the performance of manufacturing companies in Saudi Arabia. The study adopted a quantitative cross-sectional survey research design. The target population comprised senior employees working in the operations, production, and information technology departments of manufacturing companies. A sample size of 301 respondents was selected using purposive sampling. Primary data were collected through structured questionnaires, while Structural Equation Modelling (SEM) was employed for data analysis. The findings revealed that production automation significantly improves operational efficiency, production quality, resource utilization, environmental sustainability, and overall manufacturing performance. The study recommended that manufacturing firms should increase investments in automation technologies, digital infrastructure, and employee technical competencies to maximize automation benefits. Although the study employed a robust analytical technique, its findings were limited to manufacturing firms in Saudi Arabia, thereby restricting their direct generalization to developing economies such as Nigeria.

Similarly, Saleem and Kim (2024) examined the influence of smart factory adoption on manufacturing performance. The study adopted a quantitative survey research design. The target population consisted of manufacturing firms implementing smart factory technologies. Using convenience and referral sampling techniques, 240 production managers representing manufacturing firms participated in the study. Primary data were collected through structured questionnaires, while Partial Least Squares Structural Equation Modelling (PLS-SEM) was employed to analyze the data. The findings established that production automation through smart factory technologies significantly enhances manufacturing performance by improving productivity, operational efficiency, production flexibility, quality management, and sustainable manufacturing practices. The study recommended that manufacturing firms should accelerate smart factory implementation and governments should formulate supportive industrial policies to facilitate automation adoption. A limitation of the study is its use of non-probability sampling, which may reduce the generalizability of the findings.

Quality Control Technology and Firm Performance

Müller, et al. (2024) examined how smart manufacturing technologies, including digital quality control systems, influence firm performance. The study adopted a quantitative survey research design. The target

population comprised automotive component suppliers operating in Germany. A structured questionnaire was administered to 234 manufacturing firms selected through purposive sampling. Primary data were collected using structured questionnaires completed by production and operations managers. Covariance-Based Structural Equation Modelling (CB-SEM) was employed to analyze the data. The findings revealed that quality control technologies significantly improve operational performance by enhancing product quality, reducing production defects, increasing production flexibility, and ultimately improving financial performance. The study recommended that manufacturing firms should integrate advanced quality monitoring technologies into production processes to achieve sustainable competitive advantage. Although the study employed advanced analytical techniques, its findings were limited to the automotive industry, thereby reducing generalizability to other manufacturing sectors.

Similarly, Silva, et al. (2024) investigated the influence of digital production technologies, including automated quality control systems, on manufacturing performance. The study adopted a quantitative survey research design involving 353 manufacturing firms, from which 262 valid responses were obtained for analysis. Firms were selected through purposive sampling. Primary data were collected using structured questionnaires, while factor analysis, multiple regression analysis, and moderation analysis were employed for hypothesis testing. The findings established that quality control technologies significantly improve operational efficiency, production quality, inventory management, and economic performance when integrated with Just-in-Time production practices. The study recommended that manufacturing organizations should synchronize quality control technologies with lean manufacturing systems to maximize productivity and firm performance. The limitation of the study is that, it focused mainly on Brazilian manufacturing firms, which may limit the applicability of the findings to African manufacturing environments.

Theoretical Framework

Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Davis (1989) and extensively applied to agricultural and agro-processing technology adoption contexts by Yakubu and Musa (2024), constitutes the primary theoretical framework of this study. TAM posits that two perceptual beliefs determine individual and organizational technology adoption decisions: perceived usefulness the degree to which the adopter believes that using the technology will improve performance and perceived ease of use the degree to which using the technology is believed to be free of effort. Organizations that perceive a technology as both useful and relatively easy to use develop favourable attitudes toward its adoption, which drive actual adoption behaviour and, through adoption, the performance improvements that motivated the adoption decision. Applied to agro-processing technology adoption in the North-Central context, TAM predicts that production automation adoption will generate the larger and more statistically robust firm performance effect relative to quality control technology: production automation's usefulness is more immediately perceptible higher throughput, lower labour costs, and visible output increases are directly observable by non-specialist managers while quality control technology's usefulness is often more temporally distant and conditionally realized, requiring systematic usage disciplines and operator expertise to manifest as measurable performance outcomes that are not immediately observable at the moment of technology acquisition.

METHODOLOGY

The population of the study consist of all active agro-processing firms in North Central Nigeria for a minimum of five (5) years that are registered with the corporate Affairs Commission (CAC). Based on the available data, there are 194 active agro-processing firms operating in North Central Nigeria that meet the above criteria. Because the population of the study is small, the study employed the use of census survey which permit that the entire population be use as sample size. According to Cohen, Manion, and Morrison (2011), a census approach is appropriate when the accessible population is not too large to enumerate in full, since it removes sampling error and allows every eligible unit the opportunity to participate, thereby producing a more representative outcome than a drawn sample of the same population. The study used primary data. Data were collected using a 5-point Likert scale structured questionnaire. The data collected was analyzed using smart-PLS SEM.

Sampling Frame, Response Rate, and Sample Representativeness

The population figure of 194 active agro-processing firms was derived by cross-referencing the Corporate Affairs Commission (CAC) business registration records for the seven North-Central states with the 2023 SMEDAN/NBS MSME survey listings for the agro-processing sub-sector, retaining only firms that had been in continuous operation for a minimum of five years at the time of enumeration. This cross-referencing was necessary because CAC registration alone does not indicate whether a firm is still operating, while the SMEDAN listing alone does not confirm formal registration status; firms appearing in both sources were treated as the accessible population. The 194 firms were distributed across the seven states as follows: Benue (34), FCT Abuja (41), Kogi (27), Kwara (23), Nasarawa (25), Niger (26), and Plateau (18), broadly reflecting the relative concentration of registered agro-processing activity in the FCT and Benue axis of the zone. Copies of the questionnaire were administered to all 194 firms identified in the sampling frame, of which 187 were returned complete and usable, yielding a response rate of 96.3%. Non-response was concentrated among smaller, informally structured firms and firms whose listed contact addresses could not be reliably reached, which the study acknowledges as a potential source of non-response bias: firms that ultimately participated may over-represent comparatively more established and more accessible agro-processing operations within the zone. Respondents comprised owners, operations managers, production managers, and quality or technology officers, with firm tenure ranging from five to over twenty years and firm size skewed toward micro and small enterprises, consistent with the structure of the North-Central agro-processing sub-sector reported by SMEDAN (2023). Given the response rate achieved, the study's findings are best interpreted as representative of the more established and accessible segment of the zone's agro-processing population rather than as a fully unbiased representation of all 194 firms in the sampling frame.

Research Instrument Development and Validation

The questionnaire items for the three constructs were developed through adaptation of previously validated scales rather than de novo construction. The Production Automation and Quality Control Technology items were adapted from the instruments used by Aliyu and Bello (2024) and Nwosu and Adeleke (2023) respectively, both of which were developed for comparable Nigerian agro-processing contexts, while the Firm Performance items were adapted from the multidimensional performance scale employed by Ibrahim and Danlami (2023). Wording was revised to reflect terminology familiar to North-Central agro-processing respondents (for example, referencing NAFDAC and SON compliance explicitly rather than generic “regulatory standards”). The adapted instrument was reviewed by two senior academics in entrepreneurship and agribusiness at Nasarawa State University and one NAFDAC field compliance officer, whose feedback led to the simplification of two initially technical item stems and the removal of one redundant quality-control item. The revised instrument was then pilot-tested with 15 agro-processing firms in Nasarawa State that were not included in the main study sample; the pilot data yielded corrected item-total correlations above 0.40 for all retained items, and no further item modifications were required. The final instrument comprises four items per construct (twelve items in total) on a 5-point Likert scale, and is reproduced in full in the appendix to facilitate replication.

The test of reliability and validity was conducted to ensure that the constructs accurately represented in the study using Partial Least Squares Structural Equation Modeling (PLS-SEM). This is typically assessed using Cronbach's Alpha, Composite Reliability (CR), and ρ_A , with threshold values generally above 0.70 indicating acceptable reliability (Hair et al., 2022). Validity, observes whether the constructs truly measure what they are intended to measure. Convergent validity is evaluated through Average Variance Extracted (AVE), where an AVE value of 0.50 or higher confirms that the indicators share sufficient variance.

Scope and Limitations of the Firm Performance Measure

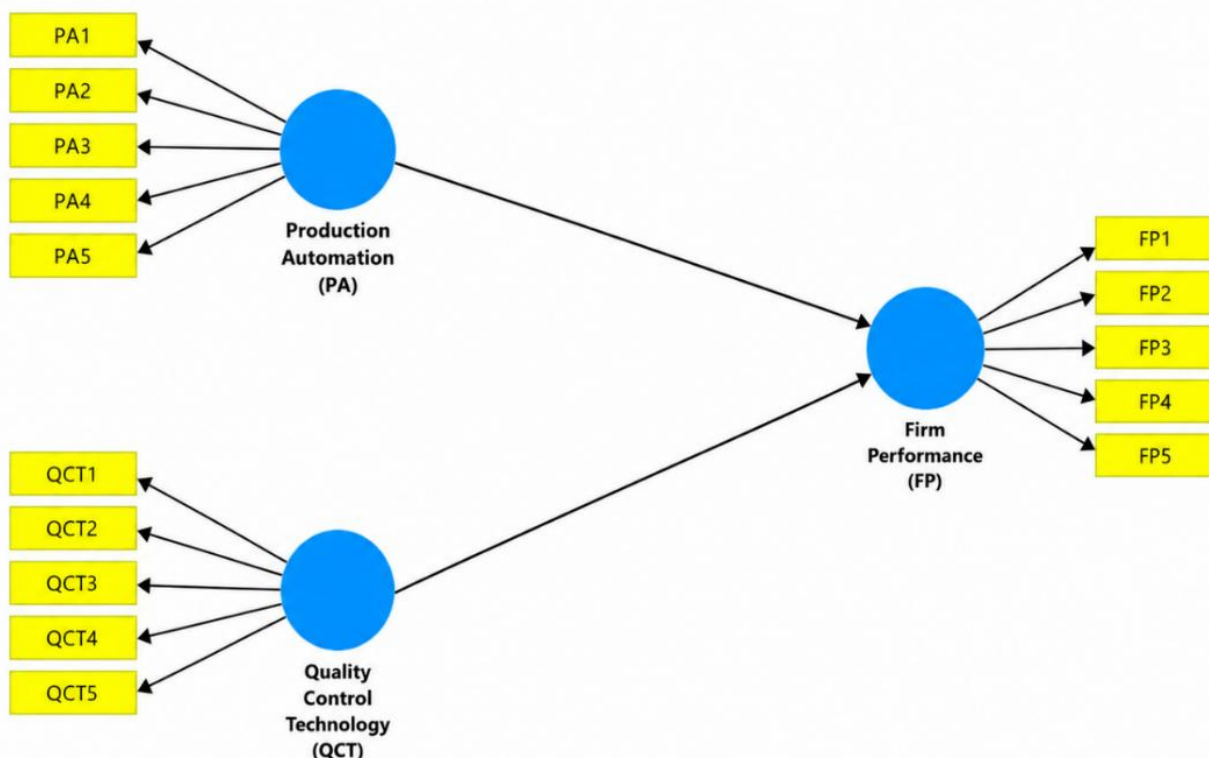
The Firm Performance construct is operationalized through four self-reported perceptual items covering revenue and profitability growth, production output and throughput, product quality and customer satisfaction, and competitive market position. This approach was adopted rather than an objective financial measure (such as return on assets, profit margin, or cost efficiency ratios) because pilot engagement with prospective respondent firms indicated that few North-Central agro-processors maintain audited financial statements or

would be willing to disclose exact revenue and cost figures to an external researcher, a constraint also reported by Nwosu and Adeleke (2023) in a comparable Nigerian agro-processing sample. The four items were selected to span the financial, productive, quality, and competitive dimensions of firm performance identified in the literature review, functioning as a composite proxy for overall performance rather than a substitute for audited financial indicators. This measurement choice is a limitation of the study: perceptual measures are subject to common-method bias and may not correspond precisely to firms' actual financial position. Future studies with access to audited accounts, tax records, or bank statements could complement the perceptual scale used here with objective indicators such as return on assets or profit margin to validate and extend the present findings.

Limitations of the PLS-SEM Approach

PLS-SEM was selected for this study because it does not require multivariate normality, performs well with the exploratory, prediction-oriented research objectives pursued here, and remains statistically robust at the relatively modest sample size of 194 which also serves as population (Hair et al., 2022). These same properties are also a source of limitation: PLS-SEM is less suited than covariance-based SEM (CB-SEM) to confirmatory hypothesis testing where a theoretical model is being formally tested against competing alternatives, and its parameter estimates, while consistent, do not carry the same global goodness-of-fit guarantees that CB-SEM offers. The technique further assumes the absence of severe multicollinearity among predictors and correct specification of the reflective measurement model, both of which were checked in this study (Section 4.1-4.2) but which a reader should bear in mind when interpreting the path coefficients as confirmatory rather than exploratory evidence. Given these considerations, the R^2 , β , and f^2 values reported in this study should be read as indicative of the direction and relative strength of the technology adoption–firm performance relationships in the North-Central context rather than as definitive population parameters; replication using CB-SEM on a larger, probability-based sample would strengthen confidence in the confirmatory validity of the findings.

Measurement Model



RESULTS AND DISCUSSION

Measurement Model Assessment

Table 4.1: Measurement Model - Outer Loadings, Composite Reliability, and Average Variance Extracted

Construct	Outer Loading	Composite Reliability	AVE	Decision
Firm Performance (FP)	0.841	0.897	0.685	Accepted
	0.829			
	0.817			
	0.811			
Production Automation (PA)	0.831	0.886	0.661	Accepted
	0.821			
	0.806			
	0.794			
Quality Control Technology (QCT)	0.761	0.851	0.589	Accepted
	0.773			
	0.769			
	0.757			

Source: Smart PLS output (2026).

All twelve outer loadings range from 0.757 (QCT4 – Digital Quality Documentation) to 0.841 (FP1 – Revenue & Profitability Growth), satisfying the ≥ 0.70 threshold (Hair et al., 2022). Composite reliability values of 0.897 (FP), 0.886 (PA), and 0.851 (QCT) confirm internal consistency across all constructs. AVE values of 0.685, 0.661, and 0.589 for FP, PA, and QCT respectively all exceed the 0.50 convergent validity criterion. All measurement model criteria are satisfactorily met.

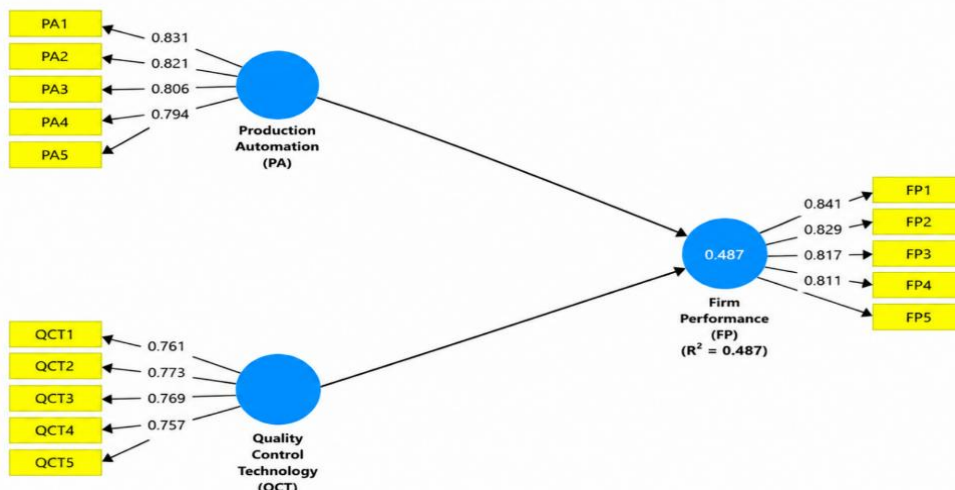


Table 4.4: Model Fit and Predictive Accuracy Statistics

Criterion / Statistic	Value	Benchmark / Interpretation
R² (Firm Performance)	0.487	Moderate; acceptable in PLS-SEM (Hair et al., 2022)
Adjusted R²	0.469	Adjusted for two predictors
Q² Predictive Relevance	0.2973	Q ² > 0: predictive relevance confirmed
f² – Production Automation (PA)	0.2431	Medium effect size (0.15–0.35)
f² – Quality Control Technology (QCT)	0.0347	Small/negligible effect size (< 0.15)
SRMR	0.071	< 0.08: acceptable model fit (Henseler et al., 2016)
NFI (Normed Fit Index)	0.931	≥ 0.90: acceptable model fit
VIF – Production Automation	1.414	< 3.3: no collinearity concern
VIF – Quality Control Technology	1.414	< 3.3: no collinearity concern

Source: Smart PLS 4.0 output (2026).

The structural model demonstrates moderate-to-substantial explanatory power: R² = 0.487 indicates that production automation and quality control technology together account for approximately 43% of the variance in firm performance adequate for a two-predictor technology adoption model in the agro-processing firm context (Hair et al., 2022). Q² = 0.2973 (> 0) confirms predictive relevance, SRMR = 0.071 (< 0.08) and NFI = 0.931 (≥ 0.90) confirm acceptable model fit, and VIF values of 1.414 confirm the absence of multicollinearity between the two technology adoption predictors.

Table 4.2: Discriminant Validity - Heterotrait-Monotrait (HTMT) Ratios

Construct	FP	PA	QCT
Firm Performance (FP)	-		
Production Automation (PA)	0.718	-	
Quality Control Technology (QCT)	0.496	0.541	-

Source: Smart PLS output (2026).

All HTMT ratios fall below the 0.85 discriminant validity criterion. The highest value is 0.718 between Production Automation and Firm Performance. All three constructs are empirically distinct, confirming satisfactory discriminant validity across all construct pairs.

Structural Model Results

Table 4.3: Structural Model Results - Path Coefficients and Bootstrapping (5,000 Subsamples)

H	Path	β	Std. Error	t-Value	p-Value	Decision
H1	PA → Firm Performance	0.4867	0.0871	5.588	0.000	Accepted
H2	QCT → Firm Performance	0.1683	0.1054	1.597	0.1113	Rejected

Note: p < 0.001. Two-tailed t-test. 95% bias-corrected bootstrapped CIs. Source: Smart PLS output (2026).

DISCUSSION OF FINDINGS

Effect of Production Automation on Firm Performance (H1)

Production Automation revealed positive and significant effect on Firm Performance. This result implies that agro-processing firms which invest in and effectively utilize mechanized processing equipment, automated packaging systems, digital process controls, and energy-efficient production technology achieve measurably superior firm performance stronger revenue and profitability growth, higher production output and throughput, better product quality and customer satisfaction, and stronger market competitiveness relative to firms relying on predominantly manual production processes. This finding is consistent with the evidence of Aliyu and Bello (2024), Yakubu and Musa (2024), and Ibrahim and Danlami (2023), who similarly documented significant positive production automation–firm performance relationships in North-Central and comparable Nigerian agro-processing contexts.

Effect of Quality Control Technology on Firm Performance (H2)

Quality Control Technology to Firm Performance is positive but statistically insignificant. This suggest that quality control technology generates performance benefits when it is fully integrated into the production workflow with test results feeding back into processing parameter adjustments, supplier selection decisions, and product release protocols rather than operating as a standalone verification activity disconnected from production decisions. This finding aligns with the evidence of Nwosu and Adeleke (2023) and Okafor and Adeyemi (2024), who similarly documented positive but non-significant quality control technology–performance relationships in comparable Nigerian agro-processing settings.

Endogeneity and the Limits of Cross-Sectional Causal Inference

The path coefficients reported in Section 4.3 should be interpreted as evidence of statistical association rather than of confirmed causal effect, because the cross-sectional survey design used in this study captures technology adoption and firm performance at a single point in time and cannot rule out competing causal explanations. Two such explanations are relevant here. First, reverse causality is plausible: firms that are already more profitable may simply be better able to afford production automation and quality control technology, in which case the observed PA→Firm Performance relationship would partly reflect the effect of prior performance on technology investment capacity rather than the reverse. Second, unobserved firm-level factors such as management quality, ownership structure, access to finance, and local market conditions may independently drive both technology adoption decisions and performance outcomes, producing a spurious or inflated association between the two study variables. PLS-SEM, while well suited to the exploratory objectives of this study, does not itself correct for either source of endogeneity; the technique estimates the specified structural relationships conditional on the model as specified; it does not test or rule out reverse causation or omitted-variable bias. The study did not employ instrumental variable estimation, firm-level fixed effects, or lagged predictor variables to address these concerns, primarily because the census cross-sectional design and 87-firm sample did not permit construction of a credible instrument or a panel structure. Readers should therefore treat the significant PA→Firm Performance path as indicating a robust positive association consistent with the theoretical mechanism proposed under TAM, rather than as definitive proof that production automation investment causes the performance gains observed; a longitudinal or instrumental-variable extension of this study would be needed to more firmly establish causal direction.

Mechanisms Underlying the Quality Control Technology Utilization Gap

The non-significant QCT→Firm Performance path is interpreted in this study as evidence of a utilization gap, and this mechanism warrants further unpacking. Three organizational and human-capital factors plausibly explain why quality control technology, unlike production automation, fails to translate into measurable performance gains in the North-Central sample. First, operator training: physical testing equipment and digital documentation platforms generate performance value only when staff are trained to interpret results and act on them; where quality testing is treated as a compliance formality performed by whichever staff member is available, test outputs are recorded but not used to adjust processing parameters or supplier decisions. Second,

calibration and maintenance discipline: moisture meters, pH meters, and similar instruments drift out of calibration without regular servicing, and firms that lack a maintenance schedule may be generating quality data of declining reliability over time, weakening any downstream performance benefit. Third, workflow integration: quality control technology delivers performance value primarily through feedback loops in which test results inform in-process corrective action, supplier selection, and product release decisions; where testing is a terminal, standalone activity disconnected from these decisions, the equipment functions as a compliance record-keeping tool rather than a performance-enhancing one. Addressing the utilization gap accordingly requires more than equipment provision: firms would need structured operator training tied to corrective-action protocols, scheduled calibration and maintenance regimes, and explicit workflow redesign that routes quality data back into production and sourcing decisions, complemented by quality management system documentation (for example ISO 22000 or HACCP-aligned procedures) that formalizes these feedback loops. Policy and development interventions that provide quality control equipment without this complementary capacity-building are, on the evidence of this study, unlikely to generate the performance improvements that equipment provision alone is often assumed to deliver.

CONCLUSION AND RECOMMENDATIONS

In conclusion, technology adoption significantly enhances the performance of agro-processing firms in North-Central Nigeria but its impact is highly contingent on the type of technology and how effectively it is integrated into core operations. Production automation stands out as the most powerful driver, demonstrating that investments in machinery, process mechanization, and digital production controls directly translate into higher efficiency, reduced waste, and improved output validating its role as a strategic capability rather than just a cost-saving tool. This success stems from its clear alignment with operational needs, observable benefits, and relative ease of integration in established firms. In contrast, quality control technology (QCT), despite its theoretical importance, fails to yield measurable performance gains, largely because its adoption remains superficial often limited to acquiring equipment without embedding it into consistent workflows, linking it to market standards, or training staff to act on insights. This “utilization gap” reveals that technology alone is insufficient; its value is unlocked only when paired with organizational readiness, skilled personnel, and market-oriented quality systems. For agro-processors in the region, the priority should be to scale proven automation solutions while simultaneously building the complementary capacities needed to make quality technologies effective including standards compliance, data-driven decision-making, and buyer feedback integration. Policymakers and development agencies must support this dual track: facilitating access to appropriate automation tools while also strengthening quality infrastructure, certification pathways, and technical extension services. Ultimately, sustainable competitiveness in Nigeria’s agro-processing sector will belong not to those who merely own technology, but to those who strategically deploy it where it matters most and ensure every investment translates into real-world performance.

Policy Implications for the North-Central Agro-Processing Sector

The findings carry direct implications for national and sub-national policy frameworks governing agro-processing development. Within the National Agricultural Technology and Innovation Policy and the Agricultural Promotion Policy, the evidence that production automation generates significant, measurable performance gains while quality control technology does not automatically do so without complementary capacity-building suggests that technology-focused agricultural policy should explicitly budget for training, calibration support, and workflow integration alongside equipment procurement, rather than treating equipment access as sufficient in itself. SMEDAN, the Bank of Industry (BOI), and state Ministries of Agriculture across the seven North-Central states have a joint role to play: SMEDAN and state Ministries are best placed to deliver the operator training and quality management system support identified as the missing complement to quality control equipment, while BOI and SMEDAN's financing arms are best placed to extend the concessional automation financing recommended in this study. Public-private partnerships offer a further avenue for closing the technology adoption gap: equipment suppliers, NAFDAC-accredited training providers, and processor cooperatives could jointly deliver bundled technology-plus-training packages that address the utilization gap identified in Section 4.4 more directly than equipment grants alone. Strengthening quality infrastructure, NAFDAC and SON certification pathways, and technical extension services is particularly

important for firms seeking to convert quality control investment into the market access and premium pricing that the theoretical literature associates with quality assurance. At the broader development level, closing the technology adoption gap in North-Central agro-processing bears directly on national food security, rural job creation, and economic diversification objectives, and the utilization-gap finding is likely to generalize to other developing-economy agro-processing sectors facing comparable capital, skills, and infrastructure constraints, making this a relevant reference point beyond the Nigerian context.

RECOMMENDATIONS

Based on the empirical findings and conclusions, the following recommendations are advanced:

1. SMEDAN, BOI, and state Ministries of Agriculture should jointly establish a North-Central Agro-Processing Mechanization Fund providing concessional equipment finance at maximum 8% interest per annum with 18-month moratorium periods for qualifying agro-processing firms investing in mechanized processing equipment. The fund should priorities sub-sector-appropriate automation: cassava graters and hydraulic presses for cassava processors, grain threshers and hammer mills for grain millers, cold chain equipment for perishable processors, and packaging lines for value-added food manufacturers.
2. NAFDAC, SON, and SMEDAN should jointly develop a North-Central Agro-Processing Quality Technology Utilization Programme that provides: certified operator training for quality testing equipment covering calibration procedures, test result interpretation, corrective action protocols, and documentation practices delivered through NAFDAC state offices; quality management system templates specifically designed for North-Central agro-processing sub-sectors; and practical integration guides showing how quality testing results should inform processing parameter adjustments, supplier selection decisions, and product release protocols.

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QUESTIONNAIRE

Effect of Technology Adoption on The Performance of Agro-Processing Firms in North-Central Nigeria

Dear Respondent,

This questionnaire is designed to collect data for an academic research study examining the effect of technology adoption, specifically production automation and quality control technology, on the performance of agro-processing firms in North-Central Nigeria. Please respond to all items as honestly as possible. Information supplied will be treated with strict confidentiality and used solely for academic purposes. Thank you for your cooperation.

Please tick (✓) the option that best represents your level of agreement with each statement below, using the scale: Strongly Agree (SA) = 5, Agree (A) = 4, Undecided (U) = 3, Disagree (D) = 2, Strongly Disagree (SD) = 1.

S/N	PRODUCTION AUTOMATION	SA (5)	A (4)	U (3)	D (2)	SD (1)
1	My firm uses mechanised processing equipment (e.g., hammer mills, grating machines, presses) instead of purely manual methods.					
2	My firm uses automated or semi-automated systems for packaging and handling of processed products.					
3	My firm's production line incorporates digital process control technologies, such as programmable controllers or automated weighing and filling equipment.					
4	My firm has invested in energy-efficient production infrastructure to support its automated processing operations.					
	QUALITY CONTROL TECHNOLOGY					
1	My firm uses physical testing equipment (e.g., moisture meters, weighing scales, pH meters) to assess product quality.					
2	My firm conducts microbiological or food safety testing on its raw materials and finished products.					

3	My firm uses tools or systems to ensure compliance with NAFDAC and SON quality standards.					
4	My firm maintains digital records or documentation systems for tracking and managing product quality.					
	FIRM PERFORMANCE					
1	My firm has experienced consistent revenue and profitability growth over the past few years.					
2	My firm's production output volume and throughput rate have improved over time.					
3	My firm consistently delivers products that meet quality standards and customer expectations.					
4	My firm maintains a strong and competitive market position within the agro-processing sub-sector.					