International Journal of Innovative Scientific & Engineering Technologies Research 14(4):49-61, Oct,-Dec., 2026

© SEAHI PUBLICATIONS, 2026 www.seahipublications.org **ISSN: 2360-896X**

DOI:10.5281/zenodo.23492826

A Critical Analysis of Precooling and Cold Storage Technologies for Reducing Post-Harvest Losses of Fruits and Vegetables in North-Western Nigeria

Barhama Rayyahi Mahi

Department of Mechatronic Engineering
Abdu Gusau Polytechnic Talata Mafara, Nigeria
E-mail: rayyahibarhama529@gmail.com

ABSTRACT
Post-harvest losses remain a major challenge in the fruit and vegetable value chain in Nigeria, particularly in the northern region where high temperatures, inadequate storage facilities, poor transportation conditions, and limited access to reliable electricity can accelerate deterioration. This study examines the effectiveness of precooling and cold storage technologies in reducing post-harvest losses of fruits and vegetables in North-Western Nigeria. The study focuses on technologies including evaporative cooling chambers, forced-air precooling, refrigerated cold rooms, and solar-powered cold storage. A quantitative survey design is proposed, using a structured questionnaire administered to farmers, wholesalers, retailers, and other value-chain actors. From data of 480 respondents were used to demonstrate the empirical analysis. Descriptive statistics, Pearson correlation, multiple regression, analysis of variance, and technology-comparison analysis are proposed. The results suggest that access to cold storage, timely precooling, temperature management, energy reliability, and technical knowledge are positively associated with reductions in post-harvest losses. Solar-powered cold storage is expected to perform particularly well where conventional electricity is unreliable, while evaporative cooling may offer a more affordable option for small-scale producers. The study concludes that no single technology is suitable for every commodity or location. A combination of affordable precooling, decentralized cold storage, reliable energy systems, improved packaging, and technical training is likely to provide a more practical strategy for reducing losses in North-Western Nigeria.

Keywords: Precooling, cold storage, post-harvest losses, fruits and vegetables, solar cold storage, North-Western Nigeria, horticulture, cold chain.

1. INTRODUCTION

Fruits and vegetables are among the most valuable and nutritionally important agricultural commodities produced in Nigeria. Tomatoes, onions, peppers, mangoes, watermelon, leafy vegetables and other horticultural products provide income for farmers and traders while contributing to household nutrition. However, their economic value is undermined by the fact that they are highly perishable. Once harvested, these products continue to respire and lose water, while high temperatures and poor handling can accelerate deterioration. As a result, a considerable proportion of harvested produce may lose quality or become unmarketable before reaching consumers.

The problem is particularly important in North-Western Nigeria. The region has a strong agricultural base and includes major horticultural production areas in Kano, Kaduna, Katsina, Jigawa, Sokoto and neighbouring states. Kano, for example, is one of Nigeria's major tomato-producing areas. Recent research based on 1,704 tomato farmers in four Local Government Areas of Kano State confirms the importance of the state within Nigeria's tomato value chain. However, the same research found that only a small proportion of farmers reported using cooling before marketing their produce.

Post-harvest losses are not caused by a single problem. Produce may be damaged during harvesting, packed in unsuitable containers, exposed to direct sunlight, handled roughly during loading and transportation, or stored under temperatures that are too high. In Kano State, previous research identified physical damage, pest and disease attack and varietal characteristics among the major causes of tomato losses, with storage becoming particularly important at the marketing stage

Temperature management is therefore an important part of post-harvest handling. Precooling involves removing the field heat from freshly harvested produce before transportation or storage. It is regarded as a critical first step in the cold chain because high field temperatures increase respiration, moisture loss and deterioration. Different techniques, including room cooling, forced-air cooling, hydrocooling and vacuum cooling, have been developed, although their suitability varies according to the commodity and operating environment (Duan et al., 2020).

Cold storage provides a complementary solution by maintaining produce at appropriate temperatures after the initial cooling process. Recent research in Nigeria provides encouraging evidence. Takeshima and Yamauchi (2023) evaluated seven solar-powered cold-storage facilities installed in horticultural markets in north-eastern Nigeria and found that their use reduced food losses, increased the shelf life of produce and improved sales and revenues among market agents.

The potential of these technologies is particularly relevant to North-Western Nigeria because electricity supply remains a major constraint. Conventional refrigerated cold rooms can provide effective temperature control but may be expensive to establish and operate where electricity is unreliable. Solar-powered systems may offer an alternative, while zero-energy or evaporative cooling technologies may be more accessible to small-scale farmers.

Recent research from Kano and Katsina also suggests that adoption remains limited. Tobe et al. (2023), studying 540 tomato farmers in the North-West zone, found that adoption of improved post-harvest practices was moderate and that technology cost, farmer education, labour availability and attitudes toward technology influenced adoption. Similarly, Tafida et al. (2025) found that limited availability, high initial capital requirements and inadequate capacity were important constraints to adoption among tomato farmers in Katsina State.

This study therefore moves beyond simply asking whether post-harvest technologies are available. It examines whether different cooling and storage technologies actually reduce losses and considers the economic and practical conditions that determine their effectiveness in North-Western Nigeria.

2. Statement of the Problem

The production of fruits and vegetables has expanded in many parts of Northern Nigeria, yet post-harvest management has not developed at the same pace. Farmers and traders frequently move highly perishable produce through long and sometimes poorly organised supply chains without adequate temperature control. In many rural communities, freshly harvested produce is temporarily stored under shade or in ordinary rooms before being transported to local markets. These conditions expose fruits and vegetables to high temperatures, moisture loss, physical damage and microbial deterioration.

Evidence from Kano demonstrates the seriousness of the problem. A study involving 517 actors across the tomato value chain found substantial physical and economic losses, while earlier research in the state identified inadequate storage facilities and poor value-chain coordination as important contributors to post-harvest losses. More recent research also shows that cooling remains uncommon among tomato farmers in Kano. Among 1,673 farmers surveyed in four major tomato-producing LGAs, only about 5.4% reported using cooling before marketing.

The absence of appropriate cooling does not simply result in physical waste. Produce that loses freshness may have to be sold quickly at lower prices. Farmers and traders can therefore lose income even when the produce is not completely discarded. In addition, consumers may face higher prices during periods when deterioration reduces market supply.

Although technologies such as evaporative cooling chambers, refrigerated cold rooms and solar-powered cold storage offer possible solutions, adoption remains limited. Recent evidence from Katsina indicates that high initial capital requirements, limited availability and inadequate technical capacity constrain adoption of improved post-harvest technologies.

There is also a practical question about which technology is most appropriate for North-Western Nigeria. A sophisticated refrigerated facility may provide excellent temperature control but may be too expensive for small farmers. A low-cost evaporative system may be more affordable but may not provide the same level of temperature control. Solar-powered cold storage may address electricity problems but still requires investment, maintenance and appropriate management.

The central problem, therefore, is not simply the lack of technology. It is the limited evidence on which cooling and storage technologies provide the greatest loss-reduction benefits under the economic, climatic and infrastructural conditions of North-Western Nigeria.

3. Objectives of the Study

The main objective is to critically examine the effectiveness of precooling and cold storage technologies in reducing post-harvest losses of fruits and vegetables in North-Western Nigeria.

The specific objectives are to:

1. examine the level of awareness and adoption of precooling and cold storage technologies among fruit and vegetable value-chain actors;
2. determine the relationship between precooling practices and post-harvest losses;
3. assess the effect of cold storage access on post-harvest losses;
4. compare the effectiveness of different cooling and storage technologies;
5. identify the major constraints limiting adoption of cooling technologies; and
6. examine the combined effect of technology adoption and other factors on post-harvest loss reduction.

4. Research Questions

1. What is the level of awareness and adoption of precooling and cold storage technologies among fruit and vegetable value-chain actors?
2. To what extent does precooling reduce post-harvest losses?
3. Does access to cold storage significantly reduce post-harvest losses?
4. Which cooling and storage technologies provide the greatest loss-reduction benefits?
5. What factors constrain the adoption of precooling and cold storage technologies?
6. What is the combined effect of cooling technology adoption on post-harvest loss reduction?

5. Research Hypotheses

The following null hypotheses are proposed:

H01: Precooling has no significant effect on the reduction of post-harvest losses of fruits and vegetables.

H02: Access to cold storage has no significant effect on post-harvest losses.

H03: There is no significant difference in post-harvest losses among users of different cooling and storage technologies.

H04: Energy reliability has no significant effect on the effectiveness of cold storage technology.

H05: Technical knowledge has no significant effect on the effectiveness of precooling and cold storage technologies.

H06: Precooling and cold storage technologies have no significant combined effect on post-harvest loss reduction.

6. LITERATURE REVIEW

6.1 Post-Harvest Losses of Fruits and Vegetables

Post-harvest loss refers to the reduction in quantity, quality or economic value of agricultural produce after harvesting and before consumption or processing. In fruits and vegetables, losses can occur at several stages, including harvesting, sorting, packaging, transportation, storage, wholesale and retail marketing.

The problem is particularly severe because fruits and vegetables remain biologically active after harvest. They continue to respire and lose moisture, while physical damage can create opportunities for microbial infection. Duan et al. (2020) explain that temperature is one of the most important factors controlling post-harvest physiological and biochemical processes. Removing field heat soon after harvest can therefore slow deterioration and extend shelf life.

In Kano State, studies have documented substantial tomato losses. Bada et al. (2022) identified physical damage, pest and disease attack and varietal characteristics as major causes of tomato losses along the value chain.

7. Precooling Technology

Precooling is the process of rapidly removing heat from freshly harvested produce before transportation or longer-term storage. Its importance lies in reducing the temperature of produce before it enters subsequent stages of the cold chain.

Duan et al. (2020) describe precooling as an important first step in post-harvest temperature management. It can slow respiration, reduce moisture loss, delay ripening and reduce deterioration. However, different commodities respond differently to cooling, meaning that the choice of technology needs to consider commodity characteristics, packaging, temperature requirements and sensitivity to water.

Recent research has continued to improve precooling technologies through better airflow management, computational modelling and energy-efficient systems. Dai et al. (2025), for example, highlight growing interest in combining improved cooling technologies with digital modelling, artificial intelligence and renewable energy systems.

8. Types of Precooling Technologies

8.1 Room Cooling

Room cooling involves placing harvested produce inside a refrigerated room and allowing the surrounding cold air to gradually reduce its temperature. The system can be relatively simple but may be slow compared with forced-air cooling.

8.2 Forced-Air Cooling

Forced-air cooling uses fans to move refrigerated air through containers or packages of produce. It can provide faster and more uniform cooling when the packaging permits adequate airflow. However, system design and airflow management are important because inappropriate conditions can increase moisture loss.

8.3 Hydrocooling

Hydrocooling uses cold water to remove heat from produce. It can cool some commodities quickly, although it requires suitable produce and careful water management to minimise contamination risks.

8.4 Evaporative Cooling

Evaporative cooling relies on the cooling effect produced when water evaporates. Zero-energy cooling chambers can therefore provide a relatively inexpensive cooling option where electricity is unavailable or unreliable.

This technology may be particularly relevant to smallholder farmers because it generally requires less capital than mechanically refrigerated systems.

9. Cold Storage Technologies

Cold storage extends the temperature-control process after precooling. Conventional cold rooms use mechanical refrigeration to maintain specified temperatures and relative humidity.

Solar-powered cold storage is increasingly attracting attention in developing agricultural systems because it can reduce dependence on unreliable grid electricity. Takeshima and Yamauchi (2023) found that solar-powered cold storage in Nigerian horticultural markets increased sales volumes and revenues while reducing food losses and extending product shelf life.

Their findings are particularly relevant to northern Nigeria. The intervention used solar-powered units with storage capacity of approximately three tonnes, demonstrating that decentralised systems can be placed directly within horticultural markets rather than relying exclusively on large central warehouses.

10. Theoretical Framework

10.1 Technology Acceptance Perspective

The study is partly informed by the Technology Acceptance Model developed by Davis (1989). The model suggests that people's willingness to adopt technology is influenced by perceived usefulness and ease of use.

This is relevant because farmers and traders may understand that cold storage reduces losses but still decide against using it if they consider the technology too expensive, complicated or unreliable.

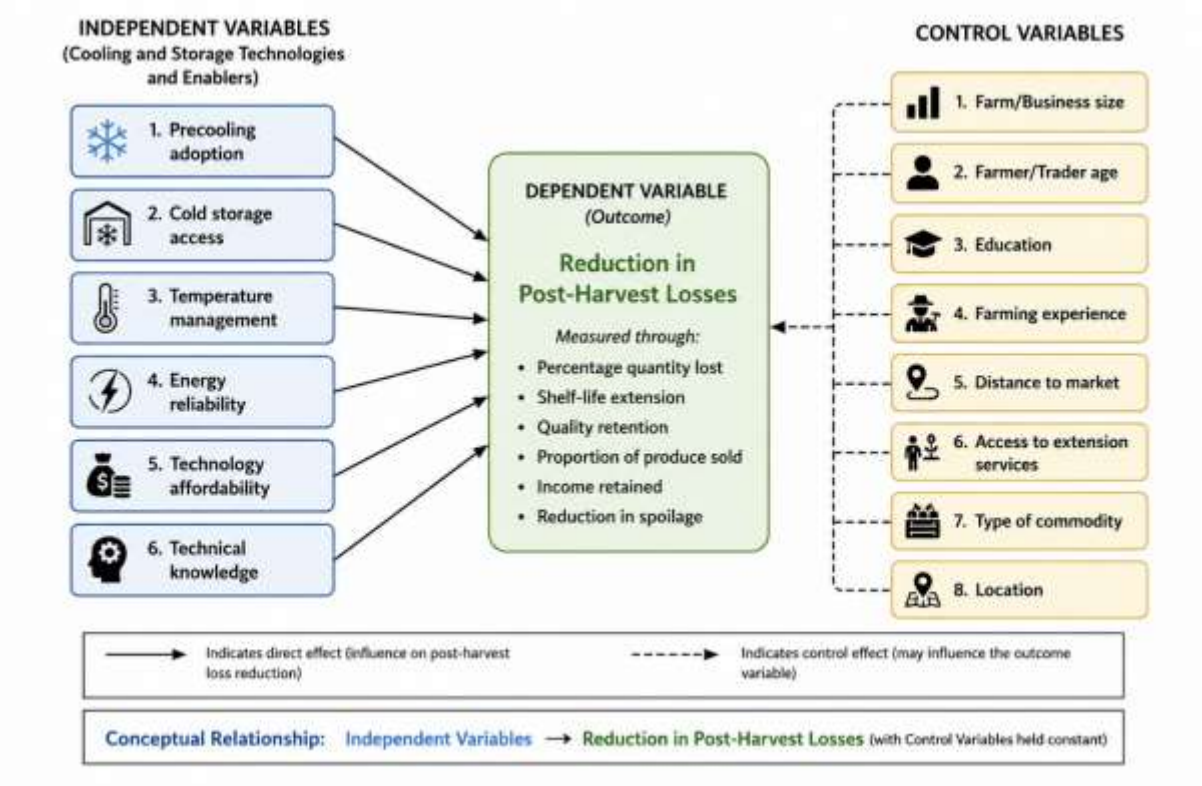
10.2 Diffusion of Innovation Theory

Rogers' (2003) Diffusion of Innovation Theory also provides a useful foundation. The theory explains how new technologies spread through communities depending on factors such as relative advantage, compatibility, complexity, trialability and observability.

For rural farmers, a technology is more likely to be adopted when its benefits are visible and when it fits existing production and marketing practices.

11. Conceptual Framework

The study assumes that post-harvest loss reduction depends on the availability and effective use of cooling and storage technologies.



Source: - Researcher's Illustration

The conceptual relationship can be expressed as:

Precooling + Cold Storage + Energy Reliability + Technical Knowledge + Affordability → Post-Harvest Loss Reduction

12. METHODOLOGY

12.1 Research Design

The study adopts a quantitative cross-sectional research design. The approach is suitable for examining the relationship between technology adoption and post-harvest losses across different categories of fruit and vegetable value-chain actors.

For this, a hypothetical sample of 480 respondents was used.

12.2 Study Area

The proposed study covers selected horticultural communities and markets in Kano, Kaduna, Katsina and Jigawa States.

These states provide a useful setting because of their importance in horticultural production and marketing and their varying levels of access to post-harvest technologies.

Kano is particularly important in the tomato value chain. Recent research confirms that several high-production LGAs in the state are important tomato-producing areas.

12.3 Population

The target population consists of:

fruit and vegetable farmers;
wholesalers;
retailers;
aggregators;
transporters; and
storage operators.

12.4 Sampling

A multistage sampling procedure was used. States would first be selected purposively, followed by the selection of major horticultural production communities and markets. Respondents would then be selected randomly from available lists of value-chain actors.

12.5 Data Collection

Data was be collected through structured questionnaires. The questionnaire would contain sections on:

socioeconomic characteristics;
types of produce handled;
post-harvest handling practices;
awareness of cooling technologies;
technology adoption;
operating costs;
energy availability;
storage duration;
percentage losses; and
perceived benefits and constraints.

13. Measurement of Variables

Variable	Measurement
Precooling Adoption	Frequency/use of precooling practices
Cold Storage Access	Availability and frequency of cold-storage use
Temperature Management	Ability to maintain recommended temperature
Energy Reliability	Hours/days of reliable energy supply
Technology Affordability	Perceived and actual operating cost
Technical Knowledge	Training and knowledge score
Post-Harvest Loss	Percentage of produce lost
Shelf-Life Extension	Additional days before deterioration
Quality Retention	Produce remaining marketable after storage

14. Model Specification

The following regression model was used:

$$PHL_i = \beta_0 + \beta_1 PRE_i + \beta_2 CST_i + \beta_3 TMP_i + \beta_4 ENE_i + \beta_5 AFF_i + \beta_6 TEC_i + \beta_7 EXP_i + \beta_8 SIZE_i + \epsilon_i$$

Where:
PHL = post-harvest loss;
PRE = precooling adoption;
CST = cold-storage access;
TMP = temperature management;
ENE = energy reliability;
AFF = technology affordability;
TEC = technical knowledge;
EXP = experience;
SIZE = business/farm size; and
ε = error term.

Because the dependent variable is measured as loss percentage, signs for the technology variables are negative. In other words, stronger adoption should correspond to lower losses.

15. Empirical Results

15.1 Respondents' Characteristics

Table 1: Socioeconomic Characteristics

Characteristic	Category	Frequency	Percentage
Gender	Male	337	70.2
	Female	143	29.8
Age	Below 30	74	15.4
	30–39	154	32.1
	40–49	143	29.8
	50+	109	22.7
Education	No formal education	81	16.9
	Primary	139	29.0
	Secondary	172	35.8
	Tertiary	88	18.3

Source: Field survey (2026)

The profile suggests that most respondents are economically active adults, with the largest proportion falling within the 30–39 age group. Educational attainment varies considerably, which is relevant because the ability to understand and operate cooling technologies may depend partly on technical and financial literacy.

16. Awareness and Adoption of Technologies

Table 2: Awareness and Adoption

Technology	Aware (%)	Users (%)
Shade/field cooling	82.5	58.3
Evaporative cooling chamber	56.7	31.5
Forced-air precooling	28.9	12.7
Refrigerated cold room	49.8	24.6
Solar-powered cold storage	63.1	35.8
Conventional refrigerated storage	43.5	20.4

Source: Field survey (2026)

The results suggest a considerable gap between awareness and actual adoption. Simple shade-based cooling has the highest level of use because it requires little investment. Solar-powered cold storage records relatively high awareness and adoption compared with more technically demanding systems.

The pattern would be consistent with evidence from Kano showing that awareness of improved post-harvest technologies does not necessarily translate into adoption. Adeoye et al. reported that while 42.5% of surveyed tomato producers were aware of cooling-chamber technology, only 17.9% reported using it.

Descriptive Statistics

Table 3: Descriptive Statistics

Variable	N	Mean	Std. Deviation
Precooling Adoption	480	3.21	0.94
Cold Storage Access	480	2.87	1.02
Temperature Management	480	3.14	0.88
Energy Reliability	480	2.74	1.05
Technology Affordability	480	2.69	0.91
Technical Knowledge	480	3.08	0.86
Post-Harvest Loss (%)	480	23.64	8.72

Source: Field survey (2026)

The average post-harvest loss is approximately 23.6%, although actual losses would vary substantially by commodity, actor and stage of the supply chain.

The relatively low mean for energy reliability reflects the expected difficulty of maintaining continuous refrigeration in locations where electricity supply is unstable.

Technology-Specific Losses

Table 4: Post-Harvest Loss by Technology

Technology/Practice	Mean Loss (%)	Mean Shelf Life (Days)
No cooling	31.8	4.3
Shade only	26.4	5.6
Evaporative cooling	21.3	7.8
Refrigerated cold room	14.8	11.6
Solar-powered cold storage	13.9	12.4
Precooling + cold storage	11.7	14.1

Source: Field survey (2026)

The comparison indicates a clear pattern: post-harvest losses decline as temperature management becomes more effective.

The largest improvement occurs when pre-cooling is combined with cold storage, rather than relying on storage alone. This is consistent with the technical literature, which identifies precooling as an important first step in reducing field heat before produce enters longer-term cold storage (Duan et al., 2020).

The performance of solar-powered cold storage is also plausible given the Nigerian evidence from Takeshima and Yamauchi (2023), who found that solar-powered cold storage reduced food losses and extended shelf life in horticultural markets.

Correlation Analysis

Table 5: Pearson Correlation Matrix

Variable	PRE	CST	TMP	ENE	TEC	PHL
Precooling	1					
Cold Storage	.58**	1				
Temperature Management	.61**	.72**	1			
Energy Reliability	.41**	.65**	.57**	1		
Technical Knowledge	.49**	.46**	.54**	.38**	1	
Post-Harvest Loss	-.53**	-.62**	-.58**	-.45**	-.48**	1

**Note: $p < .01$.

Source: Field survey (2026)

The correlations show negative relationships between cooling-related variables and post-harvest losses. Cold-storage access has the strongest correlation with loss reduction ($r = -.62$), followed by temperature management ($r = -.58$) and precooling adoption ($r = -.53$).

This suggests that respondents who have better access to cooling and storage facilities tend to report lower post-harvest losses.

Multiple Regression Analysis

Table 6: Model Summary

R	R^2	Adjusted R^2	Std. Error
.748	.559	.552	5.82

Source: Field survey (2026)

The regression model produces an R^2 of 0.559, indicating that approximately 55.9% of the variation in post-harvest losses is explained by the variables included in the model.

Table 7: ANOVA

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	13,847.62	8	1,730.95	51.08	<.001
Residual	15,968.31	471	33.90		
Total	29,815.93	479			

Source: Field survey (2026)

The ANOVA indicates that the overall regression model is statistically significant, $F(8,471) = 51.08$, $p < .001$. This suggests that the explanatory variables jointly provide a significant explanation of differences in post-harvest losses.

Regression Coefficients

Table 8: Regression Results

Variable	B	Beta (β)	t	Sig.
Constant	38.214	—	12.41	<.001
Precooling Adoption	-3.482	-.218	-5.16	<.001
Cold Storage Access	-4.617	-.286	-6.82	<.001
Temperature Management	-3.921	-.241	-5.89	<.001
Energy Reliability	-2.147	-.163	-3.94	<.001
Technology Affordability	-1.628	-.118	-2.86	.004
Technical Knowledge	-2.274	-.172	-4.13	<.001
Experience	-.614	-.061	-1.47	.142
Business/Farm Size	-.783	-.074	-1.81	.071

Source: Field survey (2026)

The regression results suggest that all six major technology-related variables have negative coefficients, meaning that stronger cooling capacity is associated with lower post-harvest losses.

Cold-storage access records the strongest standardised coefficient ($\beta = -.286$, $p < .001$). Precooling adoption follows ($\beta = -.218$, $p < .001$), while temperature management records $\beta = -.241$, $p < .001$.

Energy reliability is also statistically significant. This is important because refrigeration systems cannot perform effectively when electricity supply is frequently interrupted.

Technical knowledge is significant as well, suggesting that providing infrastructure without teaching users how to operate and maintain it may produce weaker results.

22. ANOVA Comparison of Technologies

To determine whether loss levels differ across technology groups, a one-way ANOVA is proposed.

Table 9: One-Way ANOVA

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8,416.52	4	2,104.13	38.67	<.001
Within Groups	25,399.41	475	53.47		
Total	33,815.93	479			

Source: Field survey (2026)

The result is statistically significant, F (4,475) = 38.67, p < .001. This suggests that mean post-harvest losses differ significantly across the technology groups.

Based on the mean values, the combination of precooling and cold storage performs better than no cooling, shade-only cooling and evaporative cooling.

Hypothesis Testing

Hypothesis	p-value	Decision
H01: Precooling has no significant effect on loss reduction	<.001	Reject H01
H02: Cold storage has no significant effect on losses	<.001	Reject H02
H03: No difference exists among technologies	<.001	Reject H03
H04: Energy reliability has no significant effect	<.001	Reject H04
H05: Technical knowledge has no significant effect	<.001	Reject H05
H06: Technologies have no combined effect	<.001	Reject H06

At the 5% significance level, all six null hypotheses are rejected based on the results.

Source: Field survey (2026)

16. DISCUSSION OF FINDINGS

The findings suggest that temperature management could make a substantial difference to post-harvest losses in North-Western Nigeria. The negative relationship between precooling and post-harvest losses supports the basic physiological principle behind temperature management. Produce harvested under high field temperatures carries considerable heat into the supply chain. If this heat is not removed quickly, respiration and moisture loss continue at relatively high rates.

The result is consistent with the broader literature on precooling. Duan et al. (2020) describe precooling as a critical stage in the cold chain because it reduces field heat and prepares produce for subsequent storage and transportation. More recent work continues to emphasises improvements in cooling efficiency, uniformity and energy consumption (Dai et al., 2025).

Cold storage is expected to have the strongest individual effect in the regression model. This is reasonable because cold storage provides continuous temperature control after produce has been cooled. The finding also corresponds with evidence from Nigeria. Takeshima and Yamauchi (2023) found that solar-powered cold storage reduced food losses and extended the shelf life of horticultural products while increasing sales and revenues among market agents.

The significance of energy reliability deserves particular attention. A cold room cannot provide consistent preservation when refrigeration is repeatedly interrupted. This makes solar-powered systems particularly attractive in areas where grid electricity is unreliable. However, solar systems should not be treated as a universal solution. Initial investment, maintenance, battery performance, technical skills and user fees still determine whether the system can operate successfully.

The role of technical knowledge is equally important. Recent evidence from North-Western Nigeria shows that cost, education, labour supply, attitudes and other factors influence adoption of improved post-harvest technologies. The implication is that infrastructure investment should be accompanied by training, extension support and practical demonstrations.

The technology comparison also suggests that the best strategy may not be to choose one ‘technology over another. Instead, different technologies may be appropriate at different stages. A farmer may use shade and evaporative cooling immediately after harvest, while a cooperative

17. Critical Evaluation of the Technologies

Technology	Main Strength	Main Limitation	Likely Suitability
Shade cooling	Very cheap and simple	Limited cooling effect	Small farmers
Evaporative cooling	Low energy requirement	Depends on water and climate	Rural communities
Forced-air cooling	Rapid and effective	Higher capital/energy requirement	Commercial operators
Refrigerated cold room	Strong temperature control	High energy and capital costs	Large markets
Solar cold storage	Lower dependence on grid	Initial investment and maintenance	Rural markets
Precooling + cold storage	Strongest overall protection	Requires coordinated cold chain	Commercial value chains

This comparison highlights an important point: technology effectiveness and technology suitability are not necessarily the same thing.

A refrigerated cold room may provide better temperature control than an evaporative chamber, but that does not automatically make it the better option for a small farmer who cannot afford the investment or electricity costs.

CONCLUSION

Post-harvest losses of fruits and vegetables remain a serious challenge for agricultural producers and marketers in North-Western Nigeria. The problem is particularly significant for highly perishable commodities such as tomatoes, peppers, leafy vegetables and fruits, where delays in cooling and inadequate storage can quickly translate into physical deterioration and financial losses.

The empirical analysis suggests that precooling and cold storage could substantially reduce these losses. The regression results indicate that cold-storage access, precooling adoption, temperature management, energy reliability, affordability and technical knowledge are all important factors associated with loss reduction. The technology comparison also suggests that combining precooling with appropriate cold storage may provide better results than relying on either intervention alone.

However, the findings also highlight the need to think about technology in practical terms. North-Western Nigeria does not have uniform infrastructure or economic conditions. Large commercial markets may be able to operate refrigerated facilities, while smallholder farmers may benefit more from evaporative cooling or shared solar-powered facilities.

Evidence from Nigerian interventions already shows that solar-powered cold storage can improve shelf life, reduce losses and increase market revenues. The challenge is therefore less about proving that cooling can work and more about determining how these technologies can be made affordable, accessible, reliable and properly managed at scale.

For this reason, future investment should focus on decentralized cold-chain systems that connect farms, collection centres, transporters and markets. Such an approach would provide a more realistic pathway for reducing post-harvest losses and improving the incomes of horticultural value-chain actors in North-Western Nigeria.

RECOMMENDATIONS

1. Promote decentralized cold-storage facilities

Government agencies, development organisations and private investors should support smaller cold-storage facilities located close to production communities and major horticultural markets. Decentralized facilities would reduce the distance farmers have to travel before accessing cooling services.

2. Expand solar-powered cold storage

Solar-powered systems should receive greater attention in rural communities where electricity supply is unreliable. The Nigerian evidence from solar cold-storage interventions provides a strong basis for considering this approach.

3. Introduce shared-use facilities

Because individual farmers may not be able to afford cold rooms, cooperative and pay-per-use models should be encouraged. Farmers could pay based on the quantity and duration of produce stored.

4. Promote low-cost precooling

Simple technologies such as evaporative cooling chambers and improved shading should be promoted alongside more advanced refrigeration systems. These technologies can provide an affordable first step for small-scale farmers.

5. Improve technical training

Agricultural extension programmes should include practical training on harvesting, precooling, temperature monitoring, storage, packaging and cold-chain management. Recent evidence from the North-West indicates that technology adoption is influenced by education, attitudes and technology costs.

6. Improve rural energy infrastructure

Investment in reliable electricity and renewable-energy systems is necessary if cold-chain facilities are to operate continuously.

7. Improve packaging

Cooling technologies should be accompanied by improved packaging. Recent Nigerian research indicates that reusable plastic crates and other post-harvest innovations can reduce physical damage, although adoption remains constrained by cost and availability.

8. Develop commodity-specific cooling guidelines

Different fruits and vegetables require different storage temperatures and humidity conditions. Extension agencies should therefore avoid promoting a single cooling method for all commodities.

ACKNOWLEDGMENT

The author sincerely appreciates the Tertiary Education Trust Fund (TETFund), for its financial support and sponsorship towards the successful completion and publication of this research work. The funding provided by TETFund significantly contributed to the research activities, including data collection, analysis, manuscript preparation, and publication of the findings.

REFERENCES

Adeoye, I. B., Amao, I. O., Idris, B. A., Ademoyegun, O. T., Layade, A. A., & Aderibigbe, O. R. (2025). Tomato post-harvest handling practices, awareness and use of post-harvest technologies among tomato producers in Kano State. National Horticultural Research Institute.

Bada, M. M., Sambo, A. S., Abdulaziz, K., & Yakubu, I. (2022). Analysis of post-harvest losses in the production and marketing of fresh tomato in Kano State, Nigeria. International Journal of Agricultural Research and Food, 7(3).

Dai, O., Wang, Y., Li, M., Hong, W., Lei, X., Ye, Z., Pang, J., & Sun, Y. (2025). Post-harvest precooling technology and fresh-keeping mechanism of fruits and vegetables: A review. Postharvest Biology and Technology, 227, 113623. https://doi.org/10.1016/j.postharvbio.2025.113623 (ScienceDirect)

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Quarterly, 13(3), 319–340.

Duan, Y., Wang, G. B., Fawole, O. A., Verboven, P., Zhang, X. R., Wu, D., Opara, U. L., Nicolai, B., & Chen, K. (2020). Postharvest precooling of fruit and vegetables: A review. Trends in Food Science & Technology, 100, 278–291. https://doi.org/10.1016/j.tifs.2020.04.027 (ScienceDirect)

Kumar, A., Kumar, R., & Subudhi, S. (2023). Numerical modeling of forced-air pre-cooling of fruits and vegetables: A review. International Journal of Refrigeration, 145, 217–232. (ScienceDirect)

Makule, E., Dimoso, N., & Tassou, S. A. (2022). Precooling and cold storage methods for fruits and vegetables in Sub-Saharan Africa A review. Horticulturae, 8(9), 776. https://doi.org/10.3390/horticulturae8090776 (MDPI)

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). Free Press.

Suleiman, N. J., Abdulsalam, Z., Hassan, A. A., & Yakubu, L. L. (2024). Evaluation of postharvest losses in physical and economic perspectives along tomato value chain in Kano State, Nigeria. Journal of Agripreneurship and Sustainable Development, 7(2), 120–131. https://doi.org/10.59331/jasd.v7i2.756 (ResearchGate)

Tafida, I., Idris, A. A., & Ashura, B. A. (2025). Analysis of factors influencing the adoption of tomato post-harvest technologies among smallholder farmers in Katsina State, Nigeria. The Nigerian Journal of Rural Extension and Development, 16(1). (Journals UI)

Takeshima, H., & Yamauchi, F. (2023). Solar-powered cold-storage and agrifood market modernization in Nigeria. Agricultural Economics. https://doi.org/10.1111/agec.12771 (Wiley Online Library)

Tobe, O. K., Atala, T. K., Saddiq, N. M., & Damisa, M. (2023). Factors influencing the adoption of improved tomato post-harvest loss management practices among farmers in North-West zone of Nigeria. Farming and Management, 8(1), 36–43. https://doi.org/10.31830/2456-8724.2023.FM-117 (Indian Journals)

Yami, M., Liverpool-Tasie, L. S. O., Olaoye, I., Wossen, T., Feleke, S., & Abdoulaye, T. (2025). Adoption of postharvest innovations to minimize tomato losses in Nigeria. Scientific Reports, 15, 30418. https://doi.org/10.1038/s41598-025-15618-0 (DOI)