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Beyond the Farm Gate: Evidence and a Multistakeholder Framework for Reducing Postharvest Losses in Nigeria's Perishable Value Chains

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ABSTRACT

Postharvest loss (PHL) remains a major constraint on food security, livelihoods, and the efficiency of Nigeria's perishable food systems. Although farm-level and storage losses have received substantial attention, losses during aggregation, transportation, wholesale distribution, and retailing remain unevenly documented despite their importance for highly perishable commodities. This narrative evidence synthesis examines Nigeria's tomato, leafy vegetable, plantain/banana, and fish value chains using peer-reviewed research and selected authoritative institutional evidence from the Food and Agriculture Organization of the United Nations (FAO) and the International Food Policy Research Institute (IFPRI). It evaluates where losses occur, why they occur, which interventions have demonstrated or emerging potential, and how future assessments can better integrate stakeholder perspectives. Across the evidence, handling, transport, and market-stage storage repeatedly emerge as important loss points, but reported magnitudes vary substantially with commodity, location, season, actor, and measurement method. Recurring constraints include weak cold chain coverage, poor transport infrastructure, unsuitable packaging, limited market information, restricted finance, and fragmented coordination. Recent Nigerian evidence strengthens the intervention case: reusable plastic crates are associated with lower tomato losses and higher adoption among long-distance marketers, off-grid solar cold storage preserves quality better than ambient storage under experimental conditions, and randomized evidence indicates that temperature-controlled transport can improve marketers' prices, revenues, and profits. However, systematic reviews show that the wider PHL evidence base remains disproportionately technology and farmer focused, with comparatively limited attention to traders, transporters, gender, labour, finance, policy, and environmental outcomes. The article therefore proposes a multistakeholder assessment framework that combines node-specific measurement of physical, quality, nutritional, and economic losses with analysis of infrastructure, incentives, gender, market coordination, and intervention feasibility. This systems approach can provide a stronger basis for locally appropriate and scalable PHL reduction in Nigeria.

KEYWORDS: postharvest loss; perishable value chains; Nigeria; multistakeholder assessment; cold chain; food systems

How to Cite

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1. Introduction

Reducing postharvest loss is increasingly recognized as a food systems strategy rather than merely a storage problem. Earlier global estimates suggested that roughly one third of food produced for human consumption was lost or wasted, while subsequent research has shown that loss levels vary widely by commodity, region, value chain stage, and measurement method (Food and Agriculture Organization of the United Nations [FAO], 2011, 2019; Sheahan & Barrett, 2017). Policy relevance is reinforced by Sustainable Development Goal 12.3, which calls for reductions in food losses along production and supply chains, including postharvest losses (FAO, 2024).

Nigeria is a particularly important setting because large quantities of fresh food are transported from geographically dispersed production areas to densely populated consumption centres. The transport of fresh produce is often done under ambient conditions, cold chain coverage is uneven, and the quality of roads, market information, packaging, and power supply varies considerably. Onwude et al. (2023) identified these as the major bottlenecks in Nigeria's fresh food supply chain and estimated that less than 10% of fresh food passes through a cold chain.

The impacts are not limited to the loss of food. Even when a commodity remains physically available, its quality can deteriorate and affect its grade, selling price, nutritional value, shelf life, and trader margins. The adoption of postharvest technologies by perishable commodity dealers in Nigeria improved their net returns, highlighting the direct livelihood implications of PHL management (Balana et al., 2022). This further emphasizes the importance of measuring economic and quality losses in addition to quantity loss.

The evidence base, however, is fragmented. Studies differ in commodity, geography, season, sampling unit, value chain node, and definition of loss. Systematic reviews of PHL interventions in sub-Saharan Africa and South Asia also show a persistent bias toward storage technologies and farmers, with much less evidence on traders, transporters, finance, infrastructure, gender, labour, policy, and environmental outcomes (Stathers et al., 2020, 2025). Consequently, a strong Nigerian assessment framework must move beyond isolated technologies and single actors.

This article synthesizes evidence on PHL beyond the farm gate in selected Nigerian perishable value chains. Its objectives are to: (i) characterize loss patterns across postharvest nodes; (ii) identify infrastructural, market, institutional, socioeconomic, and gender-related drivers; (iii) evaluate established and emerging mitigation options; and (iv) propose a multistakeholder framework for measurement, intervention design, and learning. The article does not claim to provide a national pooled loss estimate; instead, it emphasizes the conditions under which losses arise and the evidence needed for defensible intervention decisions. The article's principal contribution is a six-domain assessment framework that integrates physical, quality, nutritional, and economic loss measurement with stakeholder, institutional, and contextual analysis.

2. Conceptual and Methodological Foundations

2.1 The Concept of Postharvest Loss and Its Value

Postharvest losses are losses of quantity and/or quality, nutritional value, safety, appearance and/or marketability of food after harvest and before consumption (FAO, 2019; Sheahan & Barrett, 2017). This definition is especially relevant for perishables because a product can still be saleable but have a considerable economic downgrade. A bruised tomato, a wilted leafy vegetable, a plantain that is not yet ripe, or a poorly chilled fish can still be sold, but at a reduced price. When only physical loss is measured, the burden on value chain actors is therefore underestimated.

FAO's food loss measurement platform includes methodologies that measure food loss at value chain levels and that explicitly incorporate quantitative and qualitative economic loss (FAO, 2024). This is especially true in Nigeria where product quality, market distance, market timing and temperature control are significant factors in realized prices. Additionally, when micronutrients or macronutrients are lost prior to food disposal, nutritional loss should be considered (Bechoff et al., 2022).

2.2 Measurement Challenges and Evidence Quality

The amount of loss measured is very dependent on the method of measurement. Farmer or trader recall can cover large samples but can be subject to recall and perception bias. Direct weighing is more physically accurate but is costly and can only sample a short period or specific nodes. Quality grading is subjective and depends on the observer and the market, and economic loss estimates are based on counterfactual prices and quality grades. As pointed out by Affognon et al. (2015) and Sheahan and Barrett (2017), it is important not to compare heterogeneous loss percentages directly. For instance, a 40% loss figure based on farmer recall in one state is not comparable to a 15% figure based on direct weighing at one market in another state.

Future studies in Nigeria should report absolute quantity and value, include the denominator for each

percentage, differentiate between observed and self-reported loss, and specify the node and time interval. It is desirable to have multiple measurements across seasons, as the conditions on the road, temperatures, supply gluts, and market prices vary considerably from season to season. New image-based methods could help standardize the process: IFPRI is now piloting an artificial intelligence (AI) based photo system to assess tomato quality at wholesale and retail markets in Nigeria, which will need to be field-tested and calibrated (IFPRI, 2026a).

2.3 Scope and Approach of This Synthesis

This article is a narrative evidence synthesis, not a systematic review or meta-analysis. Searches were conducted between January 2024 and June 2026 in Web of Science, Scopus, Google Scholar, and institutional repositories (IFPRI, FAO, CGIAR), supplemented by backward and forward citation tracking of key syntheses (Affognon et al., 2015; Sheahan & Barrett, 2017; Stathers et al., 2020, 2025).

The search string combined postharvest loss and food loss terms with Nigeria and each commodity group, plus intervention and measurement terms. An illustrative search string was: ("postharvest loss" OR "post-harvest loss" OR "food loss" OR "postharvest loss reduction") AND (Nigeria OR Nigerian) AND (tomato OR vegetable OR leafy vegetable OR plantain OR banana OR fish OR aquatic food) AND (measurement OR intervention OR adoption OR cold chain OR packaging OR transport OR market OR value chain).

Screening proceeded in three steps: title and abstract screening; full-text assessment against inclusion criteria; and final selection for synthesis. Studies were included if they were peer-reviewed Nigerian studies directly addressing PHL magnitude, determinants, measurement, technology adoption, or mitigation in perishable value chains; or high-quality regional and global syntheses used for conceptual and methodological interpretation; or recent institutional working papers supplying important emerging evidence. Studies were excluded if they addressed only on-farm production losses without a post-farm-gate component, or if loss estimates could not be attributed to a defined node or commodity.

Approximately 420 records were identified; after duplicate removal, approximately 310 records were screened at title and abstract stage; approximately 95 records were assessed at full text; and approximately 45 records were retained in the synthesis. These counts are indicative rather than exhaustive because the review was not preregistered and because backward and forward citation tracking continued iteratively during synthesis. A screening log and study-selection record were maintained throughout the review process, documenting search dates, databases, screening decisions, and reasons for exclusion at full-text stage. These records are available from the corresponding author on request. Because this is a narrative evidence synthesis rather than a preregistered systematic review, no formal PRISMA-style flow diagram is presented.

Evidence was weighted qualitatively according to study design and relevance. Randomized and experimental evidence was treated as strongest; peer-reviewed observational studies were treated as moderate; and institutional reports were treated as contextual. Evidence quality also influenced inclusion and interpretation as follows: randomized and quasi-experimental studies were weighted more heavily for intervention claims; studies with small or geographically restricted samples were not generalized nationally; highly specific percentages were treated as study-specific unless independently supported; and evidence was interpreted according to study design and purpose rather than treated as methodologically equivalent. Because the included literature is heterogeneous, no pooled national prevalence estimate was calculated.

References dated 2026 were available as advance online publications, working papers, or pre-publication versions at the time of writing. Their inclusion was based on their relevance and emerging evidence value. Readers should verify final published versions for any updates or revisions.

A limitation of this approach is that it cannot guarantee exhaustive retrieval in the manner of a protocol-driven systematic review. The synthesis therefore avoids claims that depend on comprehensive database coverage and treats highly specific percentages as study-specific unless independently supported. This explicit boundary improves transparency and reduces the risk of false precision.

2.4 Framework Development

The proposed framework was developed iteratively through synthesis of the reviewed evidence and adaptation of established food-loss and food-systems approaches. Six domains were retained because they address distinct questions needed for intervention decisions: where loss occurs, how much and what kind of value is lost, which actors and institutions influence it, what contextual exposures drive it, whether an intervention works and is viable, and whether benefits persist over time. The framework is proposed as an organizing and decision-support structure; it is not presented as an empirically validated instrument.

3. Evidence on Losses Across Nigerian Perishable Value Chains

3.1 Tomato and Fresh Vegetables

Tomato is one of the most studied perishables in Nigeria and is an example of the interaction of packaging, distance, market channel, temperature and coordination. Plaisier et al. (2019) used a participatory value chain approach to identify loss causes and to pilot locally identified interventions. The crate pilot showed that plastic crates led to 5% to 12% less weight loss and 16% to 20% less loss of top-grade tomatoes than did the raffia baskets, and 89% of the participants went on to buy crates, demonstrating technical and practical acceptability.

More recent evidence is used to support the adoption analysis. In line with the higher expected benefits from reduced transit damage and price premiums, Yami et al. (2025) found that farmers who sold their produce at long distances were more likely to use reusable plastic crates than farmers who sold their produce at short distances. But acquisition cost and limited availability in rural areas continued to be barriers to adoption. The results are important because they show that good technology can be poorly used if financing, distribution, and market organization are weak.

Transport and cooling are also very important. The major challenges in the fresh food value chain identified by Onwude et al. (2023) are long distances, poor roads, lack of access to cold chain and weak supply chain information. However, recent randomized evidence from Nigeria also points to the possibility that temperature-controlled transport can result in higher selling prices, revenues and profits for marketers, beyond the technical argument of preservation, to a more tangible economic one (Yamauchi et al., 2026).

3.2 Leafy Vegetables

Physiologically, leafy vegetables are vulnerable due to their high respiration and transpiration rates causing rapid wilting and loss of quality after harvest. The results from Southwest Nigeria indicate that leafy vegetable PHL is linked to storage, handling and marketing problems and that it has implications for sustainable livelihoods (Olutumise et al., 2026). The evidence from the region supports the significance of quick cooling, moisture management, packaging and reduced marketing delays. Market grade and price changes are especially significant outcome measures for this commodity group because the quality can deteriorate before the total loss. One of the important findings and research priorities in Nigeria is the relative lack of node-specific loss estimates for leafy vegetables.

3.3 Plantain and Banana

Plantains and bananas continue to ripen after harvest, and the remaining shelf life will depend on the maturity at harvest, temperature, mechanical damage and marketing speed. The study of 69 plantain and banana marketers in Lagos State showed that all the respondents had experienced PHL and the general adoption of prevention practices was low, with age, education, extension contact and income being associated with the adoption of prevention practices (Hassan et al., 2025). Akinniyi and Ejoh (2022) also report that plantain storage technology in Nigeria is still underdeveloped compared to its economic value. The results in Hassan et al. (2025) cannot be generalized due to the small sample size, but they suggest that extension contact and socioeconomic capacity are also important factors in addition to technology availability.

3.4 Fish and Aquatic Foods

Fish is different from horticultural products in that it can undergo autolytic, microbial and biochemical

degradation rapidly after harvest if it is not handled in a hygienic manner and the temperature is not controlled. According to the literature, losses are experienced at landing, transport, processing, storage and retailing stages in sub-Saharan Africa, but the methods of measuring losses are not consistent (Abelti et al., 2024). A recent study of the Nigerian sector highlights the need for investment in the cold chain, production constraints, finance, and governance as key areas of focus (Njiraini et al., 2026). National fish loss percentages should not be used unless they are based on representative, standard measurement. There is currently no nationally representative estimate of fish losses in Nigeria, which is a major evidence gap.

3.5 Selected Evidence Base and Implications

Selected verified evidence included in this synthesis is summarized in Table 1. The table is not comprehensive and only includes studies that directly contribute to the interpretation of loss patterns, intervention effectiveness and adoption conditions in the Nigerian perishable value chains.

Table 1. Selected verified evidence used to strengthen interpretation. Percentages and effects remain study-specific unless otherwise stated.

Source	Commodity/ context	Design/evidence	Key contribution	Implication
Plaisier et al. (2019)	Tomato, Nigeria	Participatory value chain intervention	Crates reduced weight and grade losses relative to baskets; strong post-pilot uptake	Pair technology testing with stakeholder ownership
Balana et al. (2022)	Perishable commodity dealers, Nigeria	Econometric impact analysis	PHT adoption increased net returns	Evaluate livelihood and economic outcomes, not only tonnes saved
Onwude et al. (2023)	Fresh food supply chain, Nigeria	Supply chain bottleneck analysis	Long distances, weak cold chain, roads, and information constrain logistics	Treat infrastructure and information as interacting constraints
Yami et al. (2025)	1,704 tomato farmers, Nigeria	Recursive bivariate probit	Long-distance sellers more likely to adopt RPCs; cost and rural availability constrain uptake	Technology access and market channel jointly shape adoption
Stathers et al. (2025)	SSA and South Asia	Systematic scoping review update; 457 studies, 2,187 interventions	Evidence remains technology and farmer dominated; gaps for traders, transporters, gender, and non-technology interventions	Broaden actors and outcome domains
Salaudeen et al. (2026)	Tomato, orange, carrot; Nigeria	Controlled storage experiment	Solar-powered cold storage outperformed evaporative and ambient storage on quality indicators	Off-grid cooling is promising but requires field and business validation
Yamauchi et al. (2026)	Vegetable marketing, Nigeria	Randomized controlled trial	Cool transportation improved economic outcomes for marketers	Cold chain evaluation should include prices, revenues, and profits

IFPRI (2026a)	Tomato markets, Nigeria	AI measurement development and pilot	Photo-based quality assessment aims to quantify quality distribution and spoilage	Digital measurement may improve scalability after validation

Note. PHL = postharvest loss; PHT = postharvest technology; RPC = reusable plastic crate; SSA = sub-Saharan Africa; AI = artificial intelligence. Table is illustrative rather than exhaustive; studies were selected because they provide Nigeria-specific evidence on major commodity groups or intervention pathways and because their design permits interpretation of reported findings.

4. Crosscutting Drivers of Postharvest Loss

4.1 The Cold Chain and Transport Infrastructure

Temperature management is a crosscutting determinant for horticultural products as well as for fish. The low penetration of cold chain in Nigeria is also associated with the distance of the markets and the poor state of the road network which can result in cooling failure (Onwude et al., 2023). The unit of intervention is thus a series of interdependent units, from pre-cooling (if applicable) to storage, transport, power, handling and market access, not a single cold room.

Laboratory proof of concept in Nigeria. Salaudeen et al. (2026) evaluated the performance of solar powered cold storage, metal-in-wall evaporative cooling and ambient storage for tomato, orange and carrot. Solar-powered cold storage proved to be the most successful in terms of several quality measures and reduced mass and nutrient losses amongst the other options. But there is a need for experimental evidence to be validated at commercial scale. The use of the equipment, operating cost, maintenance, throughput and willingness to pay have not yet been assessed in the field.

4.2 Packaging, Handling, and Standards

Packaging affects compression, impact, ventilation, stacking and handling efficiency. Reusable plastic crates have been found to be an alternative to raffia baskets for tomatoes and other fresh produce in Nigeria (Olayemi et al., 2020; Plaisier et al., 2019; Yami et al., 2025). But packaging improvement is a system intervention: crate ownership, cleaning, deposits or rental, reverse logistics, standard fill weights, and transporter incentives all have an impact on whether the technology can be used at scale. Crate systems can break down if crates are not returned, diverted or cleaned properly between trips.

4.3 Market Information, Coordination, and Processing

A lack of information can make a manageable logistics problem a loss event. Actors need up-to-date price, demand, congestion, buyer needs, transport availability and alternative outlets information. Seasonal surpluses can be stored in the form of processed and dried products, provided the quality is acceptable, market demand exists, food safety is guaranteed, and energy, labour and raw material coordination is possible. In Nigeria, for instance, the study of solar drying reflects the increasing interest in the preservation options of horticultural commodities (Balana et al., 2024).

4.4 Finance and Business Models

The high initial investment is always mentioned as a challenge to the use of PHL technology. This is evident for reusable plastic crates and is likely to be even more important for cooling and refrigerated transport. Financial models should thus be considered along with engineering performance. Rental, pay per use, cooperative ownership, aggregation centre and service-based cold chains can lower the capital costs, but transaction costs and utilization rates of these models need to be tested empirically. Balana et al. (2022) and Yamauchi et al. (2026) offer economic evidence that profitability and income effects should be considered primary rather than secondary outcomes.

4.5 Gender, Labour, and Equity

Gender is more than just a demographic variable. Studies on food loss in Africa show that women and men may have different roles in postharvest, different transport and time constraints, different decision-

making power, and different access to processing technologies and finance (FAO, IFAD, & WFP, 2022). The scoping review update in 2025 showed that gender, labour, food security, economic and environmental outcomes are still under-researched in PHL intervention studies (Stathers et al., 2025). In Nigeria, data should thus be collected in a sex-disaggregated way on roles, asset ownership, labour time, access to technology, decision making, income effects and unintended burdens.

5. Intervention Options and Strength of Evidence

5.1 Reusable Plastic Crates and Improved Handling

Among the interventions considered here, reusable plastic crates have one of the clearest Nigeria-specific evidence chains: participatory testing shows reduced damage relative to baskets; stakeholder studies document practical benefits; and large-sample adoption research identifies the market and access conditions associated with uptake (Olayemi et al., 2020; Plaisier et al., 2019; Yami et al., 2025). Future work should compare rental, ownership, and deposit systems and should measure crate losses, cleaning requirements, durability, and return logistics.

5.2 Cooling and Temperature-Controlled Transport

Cooling has strong biological plausibility and growing Nigerian evidence. Controlled storage experiments support solar-powered cold storage (Salaudeen et al., 2026), while randomized evidence on cool transportation supports economic benefits for marketers (Yamauchi et al., 2026). These findings justify larger commercial evaluations that integrate technical performance with utilization, energy reliability, operating cost, willingness to pay, and distributional effects across actors. A key equity question remains: who benefits from cool transport, and who is excluded by cost or geography?

5.3 Drying and Processing

Solar drying and other preservation methods can increase shelf life and alternative markets where fresh market is in short supply. Nigerian baseline data and experience offers a starting point for designing interventions (Balana et al., 2024). More robust data are required on product quality, consumer acceptability, food safety, profitability, labour, and whether the processing really decreases loss throughout the system or just transfers it to another actor. Food safety (e.g., during the drying process) needs explicit consideration.

5.4 Digital Measurement and Decision Support

Digital solutions can enhance measurement, market intelligence, traceability and logistics coordination, but similar assertions should be proportionate to the evidence at hand. The quality work by IFPRI to date using AI on tomatoes is best characterized as an emergent measurement innovation, not a validated loss-reduction intervention. Just as sensors and digital platforms are only useful when data have actionable operational implications, trials of the future should generate evidence on how much information affects behaviour and results, rather than just the fact that the device captures data. Digital solutions also risk stacking the digital divide against poorer actors.

6. Proposed Multistakeholder Assessment Framework

The proposed framework integrates six domains: value chain mapping, multidimensional loss measurement, stakeholder and institutional analysis, contextual exposure measurement, intervention evaluation, and monitoring, evaluation, and learning. Its purpose is to identify not only where food is lost but where value is destroyed, why the loss occurs, who has the capacity and incentive to act, and whether the proposed response is technically, economically, socially, and institutionally sustainable.

Table 2. Operational multistakeholder framework for future Nigerian PHL studies and programmes.

Framework domain	Core variables	Preferred methods	Decision use
1. Chain mapping	Actors, flows, distances, timing, ownership, product and price information	Process mapping; stakeholder workshops; observation	Locate nodes and upstream/downstream dependencies
2. Loss measurement	Weight and count loss, grade, price discount, nutrients, rejection, shelf life	Direct weighing; standardized grading; price records; validated sensors and images	Quantify physical, quality, nutritional, and economic loss
3. Stakeholders and institutions	Roles, incentives, contracts, finance, associations, gender, decision authority	Surveys; key informant interviews (KIIs); focus group discussions (FGDs); sex-disaggregated analysis	Explain behaviour, adoption barriers, and distributional effects
4. Context and exposure	Road quality, journey time, temperature, relative humidity (RH), packaging, handling, season, power and water	Route logs; environmental monitoring; structured observation	Identify causal exposure pathways and seasonal risk
5. Intervention evaluation	Effect size, cost, profit, adoption, usability, equity, environmental effects	Randomized controlled trials (RCTs) or quasi-experiments where feasible; cost-benefit analysis (CBA); mixed methods	Select scalable interventions and business models
6. MEL cycle	Persistence, maintenance, utilization, unintended effects, stakeholder feedback	Repeated follow-up; dashboards; participatory review	Adapt interventions and support policy learning

Note. PHL = postharvest loss; MEL = monitoring, evaluation, and learning; KII = key informant interview; FGD = focus group discussion; RH = relative humidity; RCT = randomized controlled trial; CBA = cost-benefit analysis.

The proposed framework integrates six domains (Table 2) and is presented visually in Figure 1. Panel A maps the flow of perishable commodities from farm gate to consumer, identifying where losses intensify. Panel B shows the six assessment domains and their interrelationships, including the feedback loop from monitoring and evaluation back to chain mapping.

Figure 1. Postharvest Loss Flow and Multistakeholder Assessment Framework for Nigerian Perishable Value Chains



6.1 Positioning Relative to Existing Approaches

The framework builds on and extends existing assessment approaches. FAO's food loss analysis methodology provides a foundation for node-level measurement (FAO, 2024), while the scoping review framework developed by Stathers et al. (2020, 2025) offers a structure for evaluating intervention evidence. The present framework differs in three respects. First, it integrates physical, quality, nutritional, and economic loss measurement within a single protocol rather than treating them as separate exercises. Second, it treats stakeholder and institutional analysis as a core domain rather than a contextual afterthought. Third, it embeds monitoring, evaluation, and learning as a feedback mechanism rather than a terminal step. The framework is resource-intensive and may not be feasible for all research teams or contexts; it is intended to be adapted rather than applied rigidly.

6.2 Illustrative Application: Long-Distance Tomato Transport from Northern Nigeria to Lagos

The framework can be illustrated through a hypothetical application to a long-distance tomato supply corridor linking production areas in northern Nigeria with wholesale markets in Lagos. This example is illustrative rather than an empirical description of a specific corridor; journey duration, temperatures, numbers of intermediaries, handling events, and incentive structures would need to be measured during fieldwork.

Domain 1 — Chain mapping. Process mapping would identify farmers, aggregators, loaders, transporters, wholesalers, retailers, service providers, market associations, and other relevant actors, together with product, financial, and information flows.

Domain 2 — Loss measurement. Consignments would be weighed and graded at predefined points. Price observations would distinguish physical loss from economic loss caused by quality downgrading; nutritional indicators could be assessed in a justified subsample. A worked operationalization for Domain 2 would specify the following indicators and data sources: weight loss (%), measured with calibrated scales at farm gate, aggregation, loading, transport, wholesale, and retail; grade reduction (%), assessed through standardized grading protocols at each node; price discount (%), calculated from wholesale and retail price records; shelf-life reduction (days), estimated through validated sensors or image-based quality assessment; and nutritional retention (%), assessed through subsample analysis where justified. These indicators would be used to identify where physical and economic losses concentrate, to quantify the gap between physical loss and economic loss, and to inform targeting of packaging, cooling, or handling interventions.

Domain 3 — Stakeholders and institutions. Surveys, interviews, and focus groups would examine allocation of risk, financing, contracts, access to crates and cooling, bargaining power, and incentives for quality preservation, with sex-disaggregated data where relevant.

Domain 4 — Context and exposure. Temperature and humidity sensors, route logs, and structured observation would quantify journey duration, delays, environmental exposure, road-related shocks, stacking, loading, and unloading.

Domain 5 — Intervention evaluation. Reusable crates, improved loading, temperature-controlled transport, or combinations could be compared with prevailing practice using experimental or robust quasi-experimental designs where feasible.

Domain 6 — MEL cycle. Follow-up would determine whether technologies remain in use, maintenance and reverse logistics function, benefits persist, and unintended effects emerge.

6.3 Retrospective Application of the Framework to Published Evidence

Selected studies were retrospectively mapped against the six domains to examine analytical usefulness without claiming empirical validation. The mapping is qualitative and illustrative. Coding rules were as follows: **substantial coverage (●)** indicates that the study design or reported findings directly and explicitly address the domain, with domain-relevant data or analysis constituting a core component of the study; **partial coverage (●)** indicates that the domain is addressed implicitly, indirectly, or as a secondary component, or is touched on in discussion without dedicated data collection or analysis; and **little or no explicit coverage (○)** indicates that the domain is not addressed in the study design, methods, or reported findings, or is mentioned only in passing. Coding was performed by two authors independently, with disagreements resolved by discussion. The mapping is based on a purposive subset and structured qualitative judgement; it demonstrates potential analytical utility but does not validate the framework.

Table 3. Retrospective mapping of selected studies to framework domains.

Study	D1	D2	D3	D4	D5	D6
Plaisier et al. (2019)	●	●	●	●	●	○
Balana et al. (2022)	●	●	●	○	●	○
Onwude et al. (2023)	●	○	●	●	●	○
Yami et al. (2025)	●	●	●	●	●	○
Stathers et al. (2025)	○	●	●	○	●	●
Salaudeen et al. (2026)	○	●	○	●	●	○
Yamauchi et al. (2026)	●	●	●	●	●	○
IFPRI (2026a)	●	●	○	○	●	○
Hassan et al. (2025)	●	●	○	●	●	○
Abelti et al. (2024)	●	●	○	●	●	○
Akinniyi & Ejoh (2022)	●	●	○	○	●	○
Olutumise et al. (2026)	●	●	●	●	●	○

Note. D1 = chain mapping; D2 = loss measurement; D3 = stakeholders and institutions; D4 = context and exposure; D5 = intervention evaluation; D6 = MEL cycle. ● = substantial coverage; ● = partial coverage; ○ = little or no explicit coverage. See Section 6.3 for coding protocol.

Three broad patterns emerge. First, loss measurement and intervention evaluation are comparatively prominent. Second, stakeholder/institutional analysis and direct measurement of contextual exposures are less consistent. Third, longitudinal monitoring and learning remain particularly weak. These observations are consistent with the broader synthesis of Stathers et al. (2025). Because the mapping is based on a purposive subset and structured qualitative judgement, it demonstrates potential analytical utility but does not validate the framework.

6.4 Protocol for Field Testing and Empirical Refinement

The appropriate next step is field testing and empirical refinement rather than claiming prior validation. A longitudinal mixed-methods study could follow tomato consignments from selected northern Nigerian aggregation locations to destination wholesale markets over contrasting marketing periods. Sampling should be determined after preliminary chain mapping and should represent farmers, aggregators, transporters, wholesalers, retailers, market associations, and service providers. Sample sizes should be based on the primary quantitative outcome and clustering structure rather than fixed arbitrarily.

Field instruments should include standardized consignment-level weighing and quality grading; stakeholder questionnaires covering incentives, finance, contracts, technology access, and decision authority; semi-structured interviews; route and handling logs; calibrated temperature and humidity sensors; price and transaction records; intervention cost and profitability templates; and follow-up instruments for utilization and maintenance.

Framework evaluation should assess: (i) feasibility through completion rates, time, cost, missingness, and operational burden; (ii) reliability through agreement between trained assessors; (iii) construct coherence; (iv) added informational value beyond quantity-loss measurement alone; (v) decision utility to value-chain actors and policymakers; and (vi) sensitivity to differences across commodities, seasons, routes, and market settings.

7. Research Gaps and Priorities

First, comparable longitudinal datasets are scarce. Future studies should follow the same consignments or actor cohorts across successive nodes and seasons, allowing upstream conditions to be linked to downstream outcomes. This is preferable to combining unrelated loss percentages from separate studies. This priority links most directly to Domain 1 (chain mapping) and Domain 4 (context and exposure) of the framework in Table 2.

Second, quality and economic downgrading require much greater attention. Physical disappearance is only one component of loss; grade reduction, price discounts, shortened shelf life, nutrient deterioration, and distress sales can impose substantial hidden costs. FAO and IFPRI measurement approaches provide a useful foundation for multidimensional measurement. This priority links to Domain 2 (loss measurement).

Third, intervention evidence should move beyond technical efficacy. The updated scoping review by Stathers et al. (2025) shows that PHL research remains heavily technology oriented. Nigerian trials should routinely report profitability, financing, labour, gender, adoption persistence, environmental effects, and consequences for traders and transporters as well as farmers. This priority links to Domain 5 (intervention evaluation).

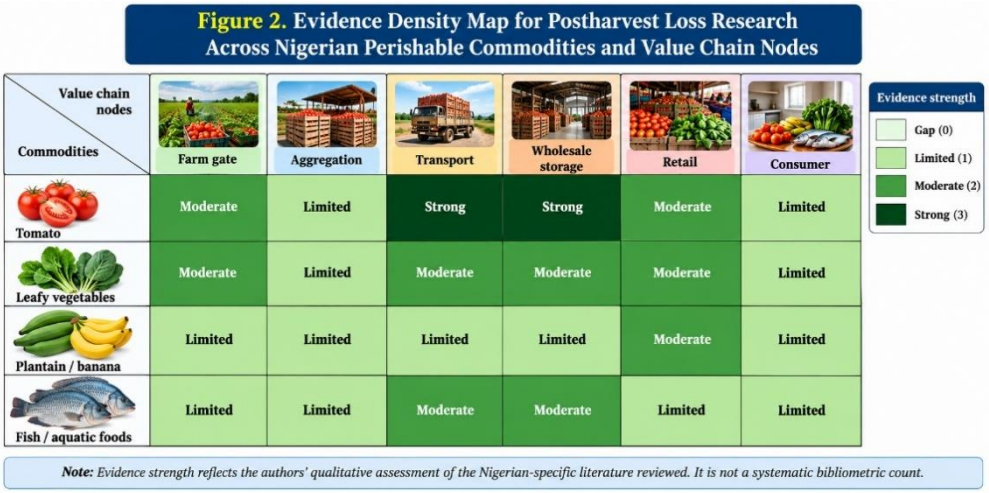
Fourth, cooling research needs a stronger bridge from laboratory or pilot performance to commercial scale. Solar cold rooms and cool transport should be tested under realistic utilization, maintenance, route, power, and willingness-to-pay conditions, with transparent comparison against existing practices. This priority links to Domain 5 (intervention evaluation) and Domain 4 (context and exposure).

Fifth, emerging digital approaches require validation against objective reference measurements. AI-assisted grading, sensors, and digital market tools should be evaluated for accuracy, usability, behavioural response, and cost-effectiveness before claims of system-wide loss reduction are made. This priority links to Domain 2 (loss measurement) and Domain 6 (MEL cycle).

Figure 2 maps the density of Nigerian-specific evidence across commodities and value chain nodes. Dark shading indicates a strong evidence base; light or absent shading indicates a gap. The figure shows that

tomato transport and wholesale storage are comparatively well studied, whereas aggregation-stage losses across all commodities and fish value chain losses beyond transport remain under-researched.

Figure 2. Evidence Density Map for Postharvest Loss Research Across Nigerian Perishable Commodities and Value Chain Nodes



Among these five priorities, the first and second are the most urgent. Without comparable longitudinal data and multidimensional loss measurement, intervention evaluations will continue to produce results that cannot be compared across studies or generalized beyond their immediate context.

8. Policy and Practice Implications

The evidence is in favour of a portfolio policy instead of a single-technology policy. Enabling infrastructure such as roads, reliable energy, market facilities, aggregation, water and sanitation should be prioritised for public investment. Complementary to this, private and cooperative models can offer crates, cooling, transport, processing and information services. Enforcement of standards for packaging, grading and handling can enhance interoperability but must be accompanied by training and access to affordable technologies that meet the standards.

Policy should also differentiate between technologies that save food and business models that enable these technologies. A low utilization cold room, or a crate system with no reverse logistics, can be technically correct but economically unfeasible. Utilization, cost recovery, user composition, loss reduction, income effects and equity outcomes should thus be monitored in public programmes.

Relevant instruments are already in place in the Nigerian policy environment. The National Agricultural Technology and Innovation Policy (Federal Ministry of Agriculture and Rural Development [FMARD], 2022) prioritizes postharvest management and market access, while the Agricultural Promotion Policy (FMARD, 2016) has as one of its objectives the reduction of postharvest losses. However, implementation is widely reported to face constraints including inter-agency coordination challenges between federal and state agencies, insufficient budgets, and weak monitoring systems (FMARD, 2016, 2022; Onwude et al., 2023). These constraints are inferred from policy documents and the broader literature rather than demonstrated by the intervention studies reviewed here, and they warrant systematic empirical verification. The structure outlined in this article could facilitate more systematic implementation and assessment of these policy commitments.

Lastly, Nigeria needs a standardised PHL measurement system for the main perishables. Comparability between states and programmes would be enhanced by standard definitions, denominators, node labels, quality grades and economic valuation rules. This would also ensure that national investment priorities are more evidence-based.

9. Conclusion

Postharvest loss in Nigeria's perishable value chains is a systems problem created by the interaction of commodity physiology, handling, infrastructure, markets, finance, information, and institutions. The expanded evidence base supports several practical interventions, particularly improved packaging, cooling, temperature-controlled transport, and preservation, but it also shows that technical performance alone is insufficient. Adoption and impact depend on who pays, who benefits, how assets circulate, whether markets reward quality, and whether supporting infrastructure functions.

The strongest direction for future research is therefore integrated and multistakeholder. Studies should measure physical, quality, nutritional, and economic loss at clearly defined nodes; track exposures such as time, temperature, packaging, and handling; analyse gender and institutional constraints; and evaluate interventions using technical, financial, behavioural, equity, and environmental outcomes. The six-domain framework proposed in this article offers a structured approach for such research and can be adapted to specific commodities, corridors, and policy contexts. It replaces broad national loss claims with decision-relevant evidence and provides a more credible foundation for reducing preventable loss while improving food availability, livelihoods, and value chain efficiency.

This synthesis has limitations. As a narrative review, it cannot guarantee exhaustive retrieval, and the evidence base is uneven across commodities and nodes. The framework has not been empirically tested in a Nigerian field setting. Future research should prioritize longitudinal, multidimensional, and multistakeholder assessments that can validate and refine the framework proposed here.

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