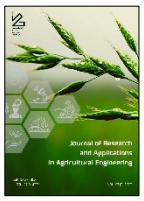
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Assessment of post-harvest losses in key staple and vegetable crops in Kano State, Nigeria

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Post-harvest losses remain a major challenge to food security, farm income, and agricultural sustainability in northern production zones like Kano State, Nigeria. The magnitude, causes, critical loss points, and economic implications of post-harvest losses among rice, maize, sorghum, millet, tomato, cabbage, and onion was assessed in Kano State. Quantitative descriptive survey design was used; data were collected between May and October 2025, covering wet and dry agricultural production seasons from 1,700 respondents across 40 Local Government Areas using a structured questionnaire administered through Computer-Assisted Personal Interviewing with the Open Data Kit platform. Respondents estimated losses at storage, transportation, processing, marketing, and consumption stages as proportions of harvested or produce handling. Data were summarized using frequencies, percentages, means, and comparative descriptive statistics in SPSS Version 25. Tomato recorded the highest average storage loss (43.7%), transportation loss (41.3%), processing loss (37.7%), and marketing loss (38.3%). Onion recorded the highest average consumption-stage loss (34.0%). Major causes included insufficient storage capacity (77.38%), inadequate pest control (76.09%), poor warehouse management (74.80%), over-supply leading to spoilage (73.20%), and inadequate market information (71.36%). Percentage revenue losses were highest for cabbage (29.33%), tomato (27.61%), and onion (26.30%). In absolute monetary terms, maize recorded the largest average revenue loss (₦438,149.9), despite its lower percentage revenue loss of 13.99%. The findings indicate that perishable vegetables face the greatest proportional losses, while high-volume cereal production can generate substantial absolute economic losses even at lower percentage loss rates. The study recommends targeted improvements in storage, transportation, handling, market information, and supply-chain coordination.

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1. Introduction

Agriculture remains one of the most important sectors of the Nigerian economy, contributing significantly to employment generation, food production, rural livelihoods, and national economic development. Kano State, located in northwestern Nigeria, is one of the country's leading agricultural production hubs

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and plays an important role in the cultivation and distribution of staple grains and vegetables (CBN, 2024; Tafida et al., 2022).

Despite the importance of agriculture to national development, post-harvest losses continue to undermine food security, reduce farmers' income, increase food prices, and weaken agricultural competitiveness. Losses occur at several points along the agricultural value chain, including harvesting, handling, transportation, processing, storage, marketing, and consumption. Food losses occur at different stages of agricultural supply chains, while food waste becomes particularly important toward retail and consumption stages (Parfitt et al., 2010). The Food and Agriculture Organization has estimated that approximately one-third of food produced globally for human consumption is lost or wasted annually (Gustavsson et al., 2011). According to Ibrahim et al. (2022), post-harvest losses are particularly important in developing-country food systems where infrastructure, storage, transportation, processing, and market systems may be inadequate.

In sub-Saharan Africa, post-harvest losses are associated with poor infrastructure, limited storage facilities, inadequate transportation systems, pest infestation, weak market systems, and insufficient access to appropriate processing technologies. Previous studies have shown that losses can be particularly severe among highly perishable crops such as tomato, onion, and cabbage (Olayemi et al., 2011).

Kano State faces additional challenges associated with high ambient temperatures, inadequate cold-chain systems, poor rural road networks, and seasonal market gluts. Studies conducted in Kano State have reported substantial physical and economic losses along tomato and onion value chains associated with poor storage, transportation damage, and inefficient marketing systems (Suleiman et al., 2024; Bello & Yakubu, 2023).

Despite previous studies, evidence integrating several staple and vegetable crops across multiple stages of the value chain in Kano State remains limited. The present study therefore provides a comparative descriptive assessment of losses across storage, transportation, processing, marketing, and consumption stages and examines the economic implications of these losses.

1.1. Objectives of the study

- Quantify the magnitude of post-harvest losses across storage, transportation, processing, marketing, and consumption stages for selected staple and vegetable crops in Kano State.
- Identify critical control points and major factors contributing to post-harvest losses along the agricultural value chain.
- Examine the economic implications of post-harvest losses on farmers and market actors.
- Recommend practical strategies for reducing post-harvest losses in Kano State.

2. Methodology

2.1. Study area

The study was conducted in Kano State, located in northwestern Nigeria. Kano State lies between latitudes 10°33′N and 12°37′N and longitudes 7°34′E and 9°25′E. The state has a tropical wet-and-dry climate characterized by distinct rainy and dry seasons. Agriculture is a dominant economic activity, with major crops including rice, maize, sorghum, millet, tomato, onion, and cabbage. The study covered 40 of the 44 Local Government Areas (LGAs) in Kano State. Four LGAs were excluded because of logistical and accessibility constraints.

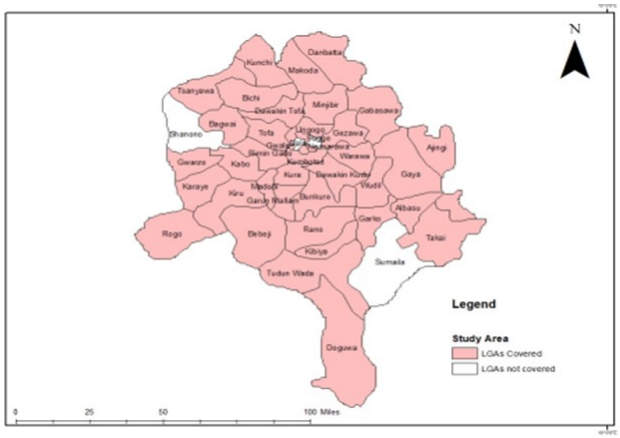


Figure 1. Map of Kano State showing the study locations (LGAs). Source: NAERLS GIS Laboratory (2026)

2.2. Research design

A quantitative descriptive survey design was adopted. The design was selected to quantify reported post-harvest losses and compare loss patterns among selected crops and stages of the agricultural value chain. The present revised manuscript reports the structured survey dataset only. Although qualitative field activities were undertaken during the broader data-collection exercise, qualitative transcripts or coded thematic outputs were not available in the materials used for this revision; therefore, no qualitative findings are presented or implied in this manuscript. This avoids attributing themes or

participant quotations that cannot be verified from the available study records.

2.3. Data collection period

Data collection was conducted between May and October 2025, covering wet and dry agricultural production seasons. The period was selected to capture variation in crop production, handling, storage, and marketing practices.

2.4. Sample size determination and sampling

A sample of 1,700 respondents was used. The Cochran's sample-size formula for large populations was applied at a 95% confidence level and 5% margin of error. The formula is $n = Z^2pq/e^2$, where n is the required sample size, Z is the standard normal deviate (1.96), p is the estimated proportion, $q = 1 - p$, and e is the acceptable margin of error (0.05). A stratified random sampling approach was used, with strata based on crop type (Table 1). Respondent allocation across the sampled Local Government Areas (LGAs) was not equal. The number of respondents selected from each LGA varied according to the relative concentration of the target agricultural population, the importance of the selected crops and value-chain activities in the LGA, and field-accessibility considerations. This approach was adopted to ensure adequate representation of the major production and post-harvest activity areas rather than imposing an equal number of respondents on all LGAs.

Table 1. Allocation of respondents by sampling stratum

Sampling stratum	Category	Number of respondents
Crop type	Rice	280
	Maize	270
	Sorghum	230
	Millet	200
	Tomato	300
	Onion	220
	Cabbage	200
Total		**1,700**

2.5. Distribution of respondents

The distribution of respondents according to occupational categories is presented in Figure 2.

2.6. Data collection instrument and procedures

Primary quantitative data were collected using Computer-Assisted Personal Interviewing (CAPI) implemented through the Open Data Kit (ODK) platform. The questionnaire covered socioeconomic characteristics, harvesting practices, transportation practices, storage practices, marketing and processing losses, and revenue losses and mitigation strategies. Respondents estimated percentage losses based on the proportion of produce lost relative to total harvested or handled quantities during the production season.

The questionnaire was pilot-tested among 50 respondents in two non-sampled LGAs to assess clarity, consistency, and appropriateness. Feedback from the pilot exercise was used to modify ambiguous questions and restructure response categories.

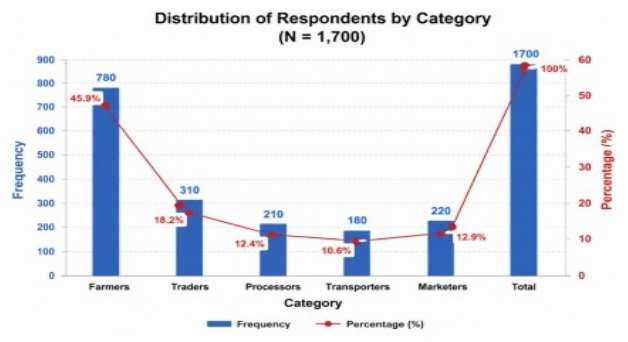


Figure 2. Distribution of respondents according to occupational categories

2.7. Data analysis

Data were analyzed using SPSS Version 25. Means, percentages, frequency distributions, and comparative descriptive statistics were used to summarize loss levels, causes, and revenue implications across crops and value-chain stages. The study therefore does not make statistical significance claims.

2.8. Ethical considerations

Participation was voluntary. Respondents were informed about the objectives of the study and verbal consent was obtained before data collection.

3. Results

3.1. Magnitude of post-harvest losses

Post-harvest losses were observed across storage, transportation, processing, marketing, and consumption stages (Tables 2-7). The results below are descriptive and interpreted as reported loss estimates rather than statistically tested differences.

3.1.1. Storage losses

Tomato recorded the highest average storage loss (43.7%), followed by onion (40.3%) and cabbage (39.3%). Maize recorded the lowest average storage loss (19.7%). The reported loss components indicate important roles for pest and rodent damage, poor ventilation, and improper packaging.

Table 2. Post-harvest losses (%) at the storage stage improper packaging.

Storage losses	Cabbage	Rice	Maize	Millet	Onion	Sorghum	Tomato
Storage pest and rodent damage	39	24	19	29	38	23	42
Storage poor ventilation	34	22	21	32	43	28	44
Storage improper packaging	45	21	19	39	40	27	45
Average storage losses	**39.3**	**22.3**	**19.7**	**33.3**	**40.3**	**26.0**	**43.7**

3.1.2. Processing losses

Tomato recorded the highest average processing loss (37.7%), followed by cabbage (34.7%) and onion (32.3%). Millet and sorghum recorded the lowest average processing losses (20.3% each). The major reported processing-loss components were packaging, peeling and milling; over-processing; and leakages and breakages.

Table 3. Post-harvest losses (%) at the processing stage

Processing losses	Cabbage	Rice	Maize	Millet	Onion	Sorghum	Tomato
Packaging, peeling and milling	37	25	27	21	31	20	42
Over-processing	31	27	29	19	36	19	33
Leakages and breakages	36	21	20	21	30	22	38
Average processing losses	**34.7**	**24.3**	**25.3**	**20.3**	**32.3**	**20.3**	**37.7**

3.1.3. Marketing losses

Tomato recorded the highest average marketing loss (38.3%), followed by onion (37.3%) and cabbage (35.8%). The cereal crops recorded lower average marketing losses, with millet at 21.0%, sorghum at 22.8%, maize at 24.0%, and rice at 25.0%.

Table 4. Post-harvest losses (%) at the marketing and retail stages

Marketing	Cabbage	Rice	Maize	Millet	Onion	Sorghum	Tomato
Rejection due to appearance	37	24	25	19	31	19	34
Market and retail spoilage	31	24	19	20	41	22	39
Market and retail: poor storage at retail	33	27	28	24	39	22	42
Market and retail contamination	42	25	24	21	38	28	38
Average marketing and retail losses	**35.8**	**25.0**	**24.0**	**21.0**	**37.3**	**22.8**	**38.3**

3.1.4. Transportation loses

Tomato recorded the highest average transportation loss (41.3%), followed by cabbage (37.0%) and onion (34.5%). Millet recorded the lowest average transportation loss (20.8%). Tomato had the highest reported spoilage from delays (44%) and leakage/spillage (43%), while cabbage had the highest physical-damage component (40%).

Table 5. Transportation losses (%)

Storage losses	Cabbage	Rice	Maize	Millet	Onion	Sorghum	Tomato
Transportation physical damage	40	21	19	19	37	19	39
Transportation spoilage from delays	37	19	20	20	33	25	44
Transportation temperature fluctuations	38	23	22	21	37	29	39
Transportation leakage and spillage	33	27	24	23	31	27	43
Average transport losses	**37**	**22.5**	**21.3**	**20.8**	**34.5**	**25**	**41.3**

3.1.5. Consumption-stage losses

Onion recorded the highest average consumption-stage loss (34.0%), followed by cabbage (32.3%) and tomato (31.7%). This result is important because the highest loss at the consumption stage was not recorded by tomato, despite tomato having the highest losses at storage, transportation, processing, and marketing. Onion recorded the highest over-purchasing and wastage component (37%) and the highest overcooking component (37%). Tomato recorded the highest poor-food-preservation component (34%).

Table 6. Post-harvest losses (%) at the consumption stage

Consumption losses	Cabbage	Rice	Maize	Millet	Onion	Sorghum	Tomato
Over-purchasing and wastage	30	22	19	20	37	24	32
Poor food preservation	31	26	20	27	32	19	34
Consumption misinterpretation	33	19	23	25	31	24	30
Consumption cooking losses	32	20	24	19	34	19	31
Consumption over-purchasing	33	19	25	22	33	21	30
Consumption overcooking	35	21	27	19	37	22	33
Average consumption losses	**32.3**	**21.2**	**23.0**	**22.0**	**34.0**	**21.5**	**31.7**

3.2. Revenue losses

The economic results show an important distinction between proportional and absolute losses. Cabbage recorded the highest percentage revenue loss (29.33%), followed by tomato (27.61%) and onion (26.30%). However, maize recorded the largest average monetary loss, ₦438,149.9, despite a lower percentage revenue loss of 13.99%. This reflects the much larger average revenue base associated with maize in the survey.

Table 7. Estimated revenue losses due to post-harvest losses

Crop	Average revenue generated (N)	Average revenue loss due to PHL (N)	Percentage revenue loss
Cabbage	904,235.7	176,841.1	29.33
Maize	10,955,495	438,149.9	13.99
Millet	1,471,908	218,215.8	13.35
Onion	1,669,055	105,227.7	26.30
Rice	2,124,690	179,277.8	18.44
Sorghum	1,782,369	96,454	15.41
Tomato	675,231.7	186,464.4	27.61

3.3. Reported causes of post-harvest losses

Storage-related constraints dominated the reported causes of post-harvest losses. Insufficient storage capacity was reported by 77.38% of respondents, followed by inadequate pest and rodent control (76.09%), use of substandard storage materials (74.92%), poor warehouse management practices (74.80%), and lack of temperature and humidity regulation (74.06%). Other important reported constraints included over-supply leading to spoilage (73.20%), inadequate market information (71.36%), overloading (65.83%), inadequate road infrastructure (65.46%), and delays in selling produce (65.83%).

The concentration of the highest responses around storage and market constraints indicates that the most prominent reported problems are associated with the ability to preserve produce, control deterioration, and match supply with market demand.

4. Discussion

The descriptive results show a clear contrast between perishable vegetables and cereal crops. Tomato recorded the highest average losses at storage, transportation, processing, and marketing stages. This pattern is consistent with the greater perishability and sensitivity of tomato to handling, temperature, packaging, and delays. The finding agrees with previous work in Kano State that identified poor storage, packaging weaknesses, and transportation delays as important contributors to tomato losses (Suleiman et al., 2024; Olayemi et al., 2011). More broadly, recent Nigerian evidence indicates that post-harvest losses vary substantially across commodities and are associated with handling practices, inadequate storage, poor infrastructure, and other constraints affecting agricultural value chains (Olanrewaju et al., 2026).

Storage constraints were prominent in the present study, with insufficient storage capacity, inadequate pest and rodent control, substandard storage materials, poor warehouse management, and lack of temperature and humidity regulation all reported by more than 74% of respondents. These results suggest that storage is a major control point for reducing losses, especially for crops that remain in the value chain for extended periods. The finding is consistent with evidence that inadequate storage facilities and pest infestation contribute substantially to post-harvest losses among Nigerian crops (Falola et al., 2023). For cereal crops, Ibrahim et al. (2022) reported post-harvest losses in maize, millet, and sorghum in Katsina State, with losses occurring at different stages including drying, threshing, and storage. Similarly, Adeola et al. (2024) identified storage and associated problems, including rodent attack, as important sources of rice losses in Kurfi Local Government Area of Katsina State. Recent national evidence also identifies inadequate storage facilities among the leading factors associated with post-harvest losses in Nigerian agricultural commodities (Olanrewaju et al., 2026).

Transportation losses were also substantial for the perishable vegetables. Tomato recorded a 41.3% average transportation loss, while cabbage and onion recorded 37.0% and 34.5%, respectively. Physical damage, delays, temperature fluctuations, and leakage or

spillage were reported as important components. Poor packaging and road conditions can increase mechanical damage and extend the time produce is exposed to unfavorable environmental conditions. Previous studies have similarly identified transportation infrastructure and packaging as important loss points in Nigerian vegetable value chains (Abubakar & El-Okene, 2015; Plaisier et al., 2019). Evidence from onion production in Kano State also demonstrates the economic consequences of post-harvest losses among onion producers (Bello & Yakubu, 2023). Similarly, Gounga et al. (2023) identified harvesting, packaging, storage, transportation, and preliminary processing as important stages at which losses occur in cabbage and other market-garden products in Niger. These findings support the importance of improving transportation, packaging, and handling systems for highly perishable vegetables.

The consumption-stage result for onion deserves particular attention. Onion recorded the highest average consumption loss at 34.0%, exceeding cabbage (32.3%) and tomato (31.7%). The largest onion components were over-purchasing and wastage and overcooking, each at 37%, while poor food preservation accounted for 32%. This indicates that post-harvest loss does not end when produce reaches the household or final consumer. Loss-reduction strategies should therefore extend beyond production, storage, and marketing to include household purchase planning, preservation, preparation, and food-use practices. The importance of addressing losses across the entire value chain is also reflected in research on onion in Kano State (Bello & Yakubu, 2023) and in the wider Nigerian post-harvest literature (Olanrewaju et al., 2026).

The revenue results demonstrate why percentage loss alone is insufficient for assessing the economic burden of post-harvest losses. Cabbage had the highest percentage revenue loss at 29.33%, while tomato and onion also recorded high proportional losses. In contrast, maize recorded the highest absolute average monetary loss, ₦438,149.9, even though its percentage revenue loss was only 13.99%. The maize result reflects the larger revenue base associated with the crop in the survey. Consequently, interventions should consider both proportional loss and absolute financial exposure when prioritizing commodities. The evidence from Katsina on maize, millet, and sorghum further demonstrates the importance of considering post-harvest losses in relation to food security and the economic value of major cereal crops (Ibrahim et al., 2022). Recent national evidence similarly shows that post-harvest losses can have important economic implications for Nigerian farmers and agricultural value chains (Olanrewaju et al., 2026).

The findings also show that loss reduction requires attention to multiple points along the value chain. Storage infrastructure can reduce deterioration; improved packaging and transportation can reduce mechanical damage; better market information can reduce delays and market gluts; and improved handling and preservation can reduce losses at processing and consumption stages. Crop-specific evidence supports this value-chain approach. Ibrahim et al. (2022) identified drying, threshing, and storage as important loss stages for maize, millet, and sorghum, while Adeola et al. (2024) highlighted storage-related losses in rice. Bello and Yakubu (2023) demonstrated the economic consequences of post-harvest losses in onion production in Kano State, while Gounga et al. (2023) identified several loss points affecting cabbage and other market-garden products. At the national level, Olanrewaju et al. (2026) also identified inadequate storage, poor road networks, poor electricity supply, and security concerns among factors associated with post-harvest losses in Nigeria. These findings are consistent with the broader literature on post-harvest loss reduction in developing-country food systems (Affognon et al., 2015; Kitinoja et al., 2011).

5. Study limitations

The study has several limitations. First, post-harvest loss estimates relied partly on self-reported responses and may therefore be affected by recall or reporting bias. Second, the study covered a defined data-collection period and may not fully represent all seasonal and inter-annual variation. Third, differences in market prices and climatic conditions across locations may have influenced estimated economic losses.

6. Conclusion

The study demonstrates substantial post-harvest losses across major staple and vegetable crops in Kano State, with the most pronounced proportional losses occurring among perishable vegetables. Tomato recorded the highest average losses at storage (43.7%), transportation (41.3%), processing (37.7%), and marketing (38.3%) stages, while onion recorded the highest consumption-stage loss (34.0%). Storage constraints were the most prominent reported causes, led by insufficient storage capacity (77.38%), inadequate pest and rodent control (76.09%), substandard storage materials (74.92%), and poor warehouse management (74.80%).

The economic findings reveal an important distinction between proportional and absolute losses. Cabbage had the highest percentage revenue loss (29.33%), followed by tomato (27.61%) and onion

(26.30%). However, maize recorded the highest average absolute monetary loss (₦438,149.9), despite its lower percentage revenue loss of 13.99%. Thus, prioritization of post-harvest interventions should consider both the proportion of output or revenue lost and the absolute economic value at risk.

Overall, the evidence supports targeted investment in climate-appropriate storage, pest management, improved packaging and transportation, rural feeder roads, market information systems, and better post-harvest handling and preservation practices. The results are descriptive and do not support statistical significance claims. Future studies with respondent-level data should undertake inferential modelling to determine whether the observed crop and infrastructure differences remain significant after controlling for relevant socioeconomic and location factors.

6. Recommendations

- The Kano State Government and relevant development partners should invest in climate-smart storage facilities and appropriate cold-chain systems for highly perishable crops such as tomato, onion, and cabbage.
- Rural feeder roads should be rehabilitated and transport logistics improved to reduce delays, physical damage, and exposure to adverse temperatures.
- Farmers, traders, processors, and transporters should receive practical training on harvesting maturity, packaging, handling, loading, and transportation practices.
- Market information systems should be strengthened to improve demand and price information, reduce avoidable delays, and help producers respond to periods of market glut.
- Agricultural cooperatives should be supported to establish community-based storage, aggregation, and processing facilities.
- Government and development agencies should promote suitable storage technologies, pest-management practices, and improved warehouse management.
- Household-level awareness should be strengthened on purchase planning, food preservation, appropriate preparation, and reduction of avoidable food waste.
- Future research should use respondent-level longitudinal or repeated-season data and report inferential tests where hypotheses about crop differences and determinants of loss are explicitly specified.

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