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Empirical Analysis of Post-Harvest Losses in Leafy Vegetables for Sustainable Livelihoods in Southwest Nigeria's Agrifood System

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Abstract

Nigeria's agrifood system supports employment, income generation, and food security, but post-harvest losses of perishable crops, especially leafy vegetables, threaten these benefits. This study examined the magnitude, profitability implications, and determinants of post-harvest losses in leafy vegetable production in Southwest Nigeria. Primary data were collected from 240 leafy vegetable producers selected through a multistage sampling procedure. Data were analysed using descriptive statistics, budgetary analysis, post-harvest loss estimation, and a two-stage least squares regression model. Respondents had a mean age of 41.8 years, average household size of 5.6 persons, and mean farming experience of 8.9 years; 68.3% were male, 66.7% married, 41.7% had secondary education, 28.3% accessed credit, and 25.0% had extension contact. Average post-harvest loss was 33.49%, with *Telfairia occidentalis* recording the highest loss at 37.78%, followed by *Amaranthus* spp. and *Corchorus olitorius*. Despite these losses, leafy vegetable production remained profitable, with return on investment ranging from 2.8 to 4.4. The 2SLS results showed that household size and storage costs significantly increased post-harvest losses, while education, farming experience, farm size, and access to credit significantly reduced them. Major constraints were price volatility, inadequate capital, poor road networks, and weak extension services. The study concludes that reducing post-harvest losses through improved preservation methods, cold chain infrastructure, access to agrifinance, and digital market linkages can enhance food availability and rural livelihoods.

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Introduction

Agriculture remains a vital sector in Nigeria's economy, contributing significantly to the national GDP and employment, particularly in rural communities (Olowo *et al.*, 2022; Olutumise *et al.,* 2023). However, one of the barriers to agricultural productivity, food security, and job creation is post-harvest loss (PHL) (Abonyi *et al.*, 2024; Aworh, 2025). These losses are severe in the horticulture subsector, where perishable crops (leafy vegetables) suffer loss from inadequate handling, transportation, and storage infrastructure. Post-harvest losses of fruits and vegetables in Nigeria are estimated at 35–45% of total production, posing a substantial threat to food availability and income security for smallholder farmers (Abonyi *et al.,* 2024). Leafy vegetables, such as *Telfairia occidentalis* (fluted pumpkin), *Amaranthus* spp., and *Corchorus olitorius* (ewedu), form an essential part of the diet in Nigeria. Thus, they provide vital micronutrients and seasonal employment, especially for women and youths in the enterprise (Aworh, 2025). However, the lack of cold storage facilities, efficient logistics, and standardised packaging practices often leads to high spoilage rates (Olanya *et al*., 2025), reducing farmers' profits and the availability of jobs in the sector.

Despite the vegetable subsector's role in the economy, post-harvest losses persist across sub-Saharan Africa. Similar studies have been reported for tomatoes and leafy vegetables in Cameroon, where poor post-harvest management practices accounted for about 35% loss at the retail stage (Asrat *et al*., 2019). South Africa has recorded sustainability implications of vegetable post-harvest inefficiencies among smallholders (Mathobo, 2023). According to Takeshima *et al*. (2023), small-scale investments in post-harvest infrastructure (e.g., solar-powered storage, mobile processing units, and cooperatively managed transportation) could cause measurable gains for vegetable farming communities. Similarly, Nnoli *et al*. (2024) argue that addressing post-harvest inefficiencies is central to tackling rural poverty and food system sustainability. Leafy vegetable farming in Nigeria is widespread, but limited access to appropriate post-harvest practices serves as a barrier to its economic benefits. According to Idris-Adeniyi *et al*. (2022), nearly 30% reduction in profit was observed due to losses due to transportation and market handling. The losses could discourage youth participation in investing in leafy vegetable enterprises. Addressing these losses will enhance food systems challenge and also serve as a good opportunity to boost employment. Therefore, this study addresses a research gap in the literature. It examines the relationship among post-harvest losses, income sustainability, and employment generation in leafy vegetable production. It is observed that several studies have worked on post-harvest challenges in agriculture (Stathers *et al*., 2020; Kaur and Watson, 2024; Khan *et al*., 2024), but few have empirically examined how the reduction of losses in leafy vegetables can contribute to job opportunities and livelihoods (Balana *et al*., 2022; Okringbo and Chukuigwe, 2023; Gebretsadik *et al*., 2025). To empirically address this gap, the study employs a two-stage least squares (2SLS) approach. This is used to account for potential endogeneity in factors influencing post-harvest losses. By integrating economic, social, and logistical determinants within a single analytical framework, this study provides new evidence on how targeted interventions in post-harvest management. In addition, it can enhance the resilience of the agrifood system and rural employment opportunities.

Post-harvest losses in vegetable value chains are largely driven by poor handling, transportation, and storage infrastructure across Sub-Saharan Africa (Kaur and Watson, 2024; Khan et al., 2024). Post-harvest losses affect smallholder farmers by reducing marketable output, food availability, and household income (Balana et al., 2022; Aworh, 2025). The problem is more severe for leafy vegetables because of their high moisture content and short shelf life, especially where farmers lack cold chains, improved packaging, and reliable market linkages. Evidence from related vegetable value chains shows that improved storage, handling, and cold-chain technologies can reduce spoilage and improve farmer welfare (Nnaemeka, 2024; Oyewole et al., 2025). However, losses remain high where storage and transport infrastructure are weak, as reported in Zambia by Mwamba

(2025). This shows the need for crop- and location-specific evidence on leafy vegetable PHLs in Southwest Nigeria. Reducing PHLs in leafy vegetables can therefore strengthen agrifood systems from production to retail. For example, Stathers *et al.* (2024) noted that improved post-harvest handling practices, such as solar drying, mobile cooling units, and local packaging centres, can generate opportunities for micro-enterprises, logistics, and processing activities. In Uganda, Elolu *et al*. (2023) demonstrate that introducing blanching and solar drying technologies for indigenous vegetables not only reduced spoilage but also increased labour demand in local processing markets. It was also reported in Nigeria that the interventions in leafy vegetable chains could support rural entrepreneurship and value addition (Okringbo and Chukuigwe, 2023).

PHLs undermine the environmental and economic sustainability of agrifood systems. Waste from spoiled produce reflects not just a loss of food, but also of labour, land, water, and agro-inputs invested in production. Nordhagen (2021) argues that gender-equality interventions in PHL reduction can reduce environmental pressure and empower women in agricultural supply chains, such as cooperatives or digital logistics platforms. From a broader policy perspective, Khan *et al*. (2024) stated that minimising losses is more sustainable than expanding agricultural output, especially in fragile ecological zones. Thus, investment in post-harvest systems could be a climate-smart and economically viable pathway toward food system resilience.

Figure 1 reveals the relationships between post-harvest loss (PHL) reduction and producers' livelihoods in the leafy-vegetable value chain. The framework shows that improvements in post-harvest management (better handling, preservation, storage, and logistics) directly reduce the quantity and quality of crop losses (Balana *et al.,* 2022; Aworh, 2025). The reduction in PHLs can increase economic efficiency and employment generation. This could be achieved through services (such as transportation, packaging, cold-chain management, and processing), and livelihood resilience (through more stable incomes and the inclusive participation of women and youth). The process is achieved by several factors: socio-economic characteristics (education, experience, household size), institutional support (credit access, extension services, cooperatives), and infrastructure quality (roads, market facilities, cold storage). However, higher gains/benefits will encourage farmers to reinvest in improved technologies. Therefore, it would create a feedback that will sustain income growth and food system resilience. The variable factors (education, access to finance, and market proximity) that influence post-harvest losses reported in the literature, are consistent across African studies (Nnaemeka, 2024; Mwamba, 2025). Despite the growing body of research, few studies focus specifically on leafy vegetables in Nigeria. Much of the evidence remains fragmented or generalised across broader crops.

In this regard, the broad objective of this study is to investigate the post-harvest losses in leafy vegetable production in Southwest Nigeria. The specific objectives of this study are to: assess the socio-economic characteristics of leafy vegetable farmers in the area; estimate the costs and returns from the leafy vegetable production; quantify the post-harvest losses in leafy vegetable production, and their determinants; examine the existing post-harvest handling and preservation practices in the area; and identify the main constraints affecting leafy vegetable value chains in the area.

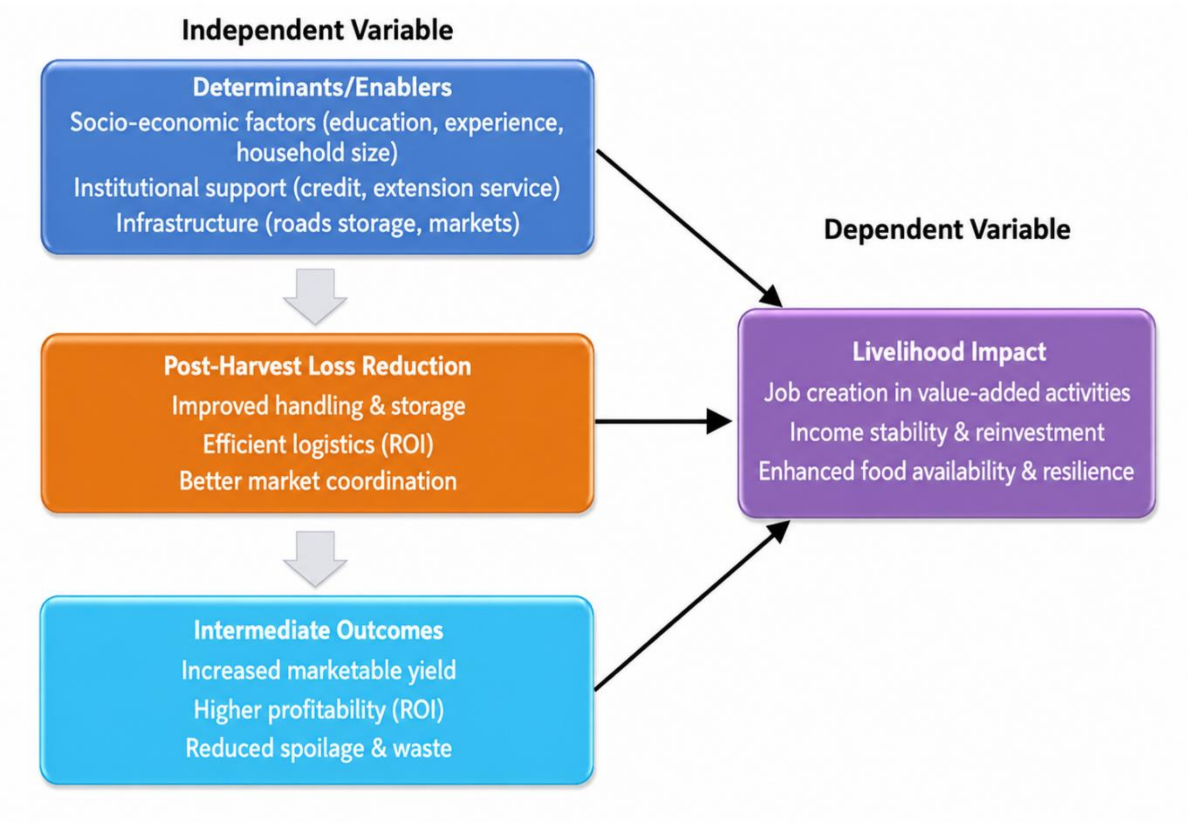

Figure 1. Conceptual Framework: Pathways Linking Post-Harvest Loss Reduction to Job and Income Sustainability in Nigeria's Agrifood System

Materials and Methods

Study Area

The study was conducted in Southwest Nigeria, one of the country's six geopolitical zones (Figure 2). The region comprises Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo States. It has a tropical climate, high rainfall, and fertile soils that support leafy vegetable production (Olutumise, 2023). This makes it suitable for cultivating a wide range of crops, particularly the leafy vegetables. The region is notable for its active rural–urban food markets that could facilitate both vegetable production and market. The region is suitable for this study because leafy vegetables are highly perishable and vulnerable to losses under the prevailing handling conditions. Post-harvest systems in the area range from farm-gate sorting and roadside sales to open-air markets and peri-urban commercial channels, creating diverse points where losses may occur. This makes Southwest Nigeria relevant for examining PHLs and their socio-economic implications.

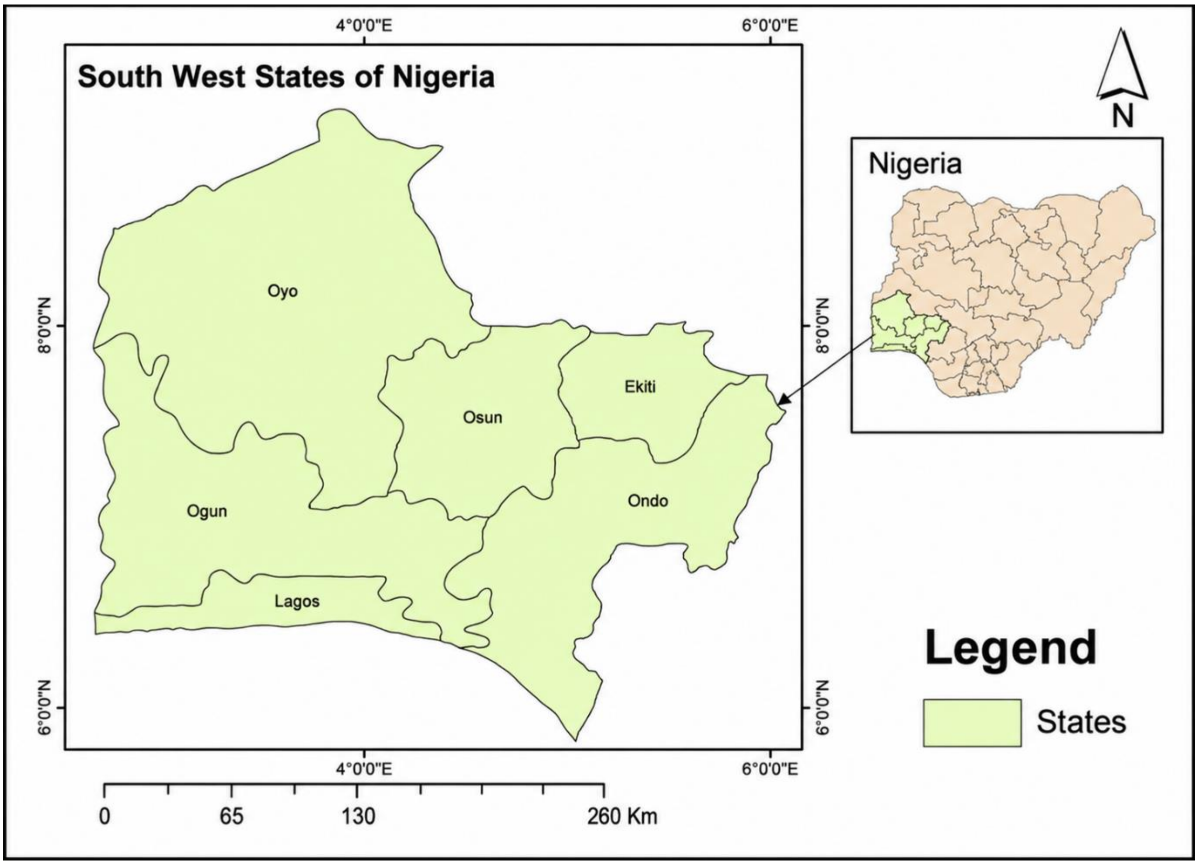

Figure 2. Map of the Study Area

Data Source and Data Collection

Primary data were collected for the study. This was carried out using a well-structured questionnaire and personal interviews. The target population was the leafy vegetable farmers, and the survey was conducted between June and September 2024. The questionnaire was pre-tested to ensure clarity and reliability before final administration in the field. Data collection was carried out by trained enumerators who were fluent in English and local languages under the close supervision of the researchers.

Sample Size and Sampling Procedure

A total of 240 leafy vegetable farmers were selected from the six states of Southwest Nigeria using a multistage sampling procedure. First stage, all six states in the zone, namely Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo, were included to ensure adequate regional coverage. In the second stage, two Local Government Areas (LGAs) were purposively selected from each state on the basis of the prominence of leafy vegetable production and market activity, giving a total of 12 LGAs. In the third stage, two major vegetable-producing communities were selected from each chosen LGA, resulting in 24 communities. In the final stage, 10 farmers actively engaged in leafy vegetable production and marketing were randomly selected from each community, yielding a total sample of 240 respondents. This sampling procedure ensured geographical representation and minimised selection bias. This is consistent with comparable empirical studies on smallholder vegetable production in Nigeria (Olowo *et al*., 2022; Sani *et al*., 2023). It is worth noting that similar approaches (Abonyi *et al.,* 2024; Mwamba, 2025) have been employed to examine post-harvest management practices across different agricultural enterprises in Nigeria.

Analytical Tools

The following analytical tools were employed based on the objectives of this study:

Descriptive Statistics

Descriptive statistics were used to summarise the socio-economic characteristics of respondents, identify key production and post-harvest constraints faced by leafy vegetable farmers in the area.

Budgetary Technique

A budgetary technique was conducted to assess the profitability and economic viability of leafy vegetable farming (Objective 2) in the area. These are the computation of total revenue, total cost, net farm income (NFI), and return on investment (ROI). The mathematical equations following Onyia *et al.* (2021); Olutumise *et al.* (2023) were adopted and include:

$$\text{NFI} = \text{TR-TC}$$

Where:
NFI = Net Farm Income (Naira/ha)
TR = Total Revenue (Naira/ha)
TC = Total Cost of Production (Naira/ha)
TC = TVC+TFC
Total Cost (TC) = Total Variable Cost (TVC) + Total Fixed Cost (TFC)
TVC = (e.g., costs of seed, fertilizer, labour, agrochemicals)
TFC = (e.g., costs of renting land, hoe, wheelbarrow, rake)

$$\text{ROI} = \frac{\text{TR}}{\text{TC}}$$

Estimation of Post-Harvest Losses

The post-harvest losses (PHLs) were estimated using the weight-loss method commonly applied in post-harvest studies (Kitinoja and Kader, 2015):

$$PHL(\%) = \frac{\text{W}_0 - \text{W}_1}{\text{W}_0} \times 100$$

Where:
PHL = Post-harvest loss percentage;
Wo = Initial weight (or volume) of harvested vegetables (kg);
W_1 = Weight of vegetables suitable for market or consumption (kg).

This measurement helped assess the extent of physical and economic losses. Again, this method was adopted from the FAO (2020) post-harvest loss assessment framework and has been applied in similar studies (Stathers *et al*., 2020).

Econometric Strategy: Two-Stage Least Squares (2SLS) Regression Approach

The Ordinary Least Squares (OLS) technique provides biased and inconsistent results when explanatory variables are endogenous. That is, a situation in which the error term is correlated (Olutumise *et al*., 2023; Soneye, 2024). The main socio-economic factors (farm size, access to credit, and storage costs) may be endogenous in the study area. The effects violate the OLS assumption of zero correlation between regressors and the error term. To address this issue, the study employs a 2SLS regression model that provides consistent estimates in the presence of endogeneity. The 2SLS framework allows isolating exogenous variation in potentially endogenous regressors using valid instruments. The 2SLS estimation technique was chosen for three main reasons: (1) OLS estimation may suffer from simultaneity bias or measurement error. The 2SLS corrects for this by using instruments that are correlated with the endogenous regressors but uncorrelated with the error term; (ii). 2SLS supports a stronger causal interpretation of relationships between farmers' characteristics and post-harvest loss outcomes; and (iii). Similar agricultural studies addressing productivity, technology adoption, and income effects in Nigeria have used 2SLS to mitigate endogeneity bias (Mukaila *et al*., 2022; Soneye, 2024).

Model Specification: The empirical model estimated the determinants of post-harvest losses (PHL) among leafy vegetable farmers while correcting for endogeneity in selected explanatory variables using the two-stage least squares (2SLS) approach (Gujarati and Porter, 2009; Wooldridge, 2010). The model is specified as:

$$\mathrm{PHL}_i = \beta_0 + \beta_1\mathrm{AGE}_i + \beta_2\mathrm{HHSIZE}_i + \beta_3\mathrm{EDUC}_i + \beta_4\mathrm{EXP}_i + \beta_5\widehat{\mathrm{FARMSZ}}_i + \beta_6\widehat{\mathrm{STORCOST}}_i + \beta_7\mathrm{OTHCOST}_i + \beta_8\widehat{\mathrm{CREDIT}}_i + \varepsilon_i$$

Where:

PHL_i= Post-harvest loss rate (%) for farmer i

$\widehat{\mathrm{FARMSZ}}$, $\widehat{\mathrm{STORCOST}}$, $\widehat{\mathrm{CREDIT}}$= Predicted (instrumented) values of the endogenous variables

ε_i= Random disturbance term

First Stage Equations (Instrumental Regressions):

Following the two-stage least squares (2SLS) procedure, each potentially endogenous variable was first regressed on the selected instrumental variables and other exogenous covariates to obtain predicted values for the second-stage estimation (Gujarati and Porter, 2009; Wooldridge, 2010). The first-stage equations are specified as:

$$\mathrm{FARMSZ}_i = \pi_0 + \pi_1\mathrm{LANDTENURE}_i + \pi_2\mathrm{COOPMEMB}_i + \pi_3\mathrm{EXTSERV}_i + \pi_4\mathrm{AGE}_i + \pi_5\mathrm{EDUC}_i + u_{1i}$$

$$\mathrm{STORCOST}_i = \rho_0 + \rho_1\mathrm{DISTMKT}_i + \rho_2\mathrm{ROADCND}_i + \rho_3\mathrm{COOPMEMB}_i + \rho_4\mathrm{INCOME}_i + u_{2i}$$

$$\mathrm{CREDIT}_i = \gamma_0 + \gamma_1\mathrm{COOPMEMB}_i + \gamma_2\mathrm{EXTSERV}_i + \gamma_3\mathrm{AGE}_i + \gamma_4\mathrm{EDUC}_i + u_{3i}$$

The predicted values from these first-stage regressions are then substituted into the main (second-stage) equation to yield consistent estimates of the determinants of post-harvest losses.

Instrument Selection and Validity: The following instruments (Table 1) were selected based on theoretical relevance and empirical validity. While the selected instruments satisfy statistical tests of validity, the possibility of unobserved location-specific factors influencing both credit access and loss outcomes cannot be ruled out entirely.

Table 1. Instrumental variable (IV) selection and validation

Endogenous Variable	Instruments Used	Rationale
Farm Size	Land tenure status, cooperative membership.	Access to land and cooperatives influence farm size, but not direct loss outcomes.
Storage Cost	Distance to market, road condition, and income level.	Affects the cost of storage/logistics but not spoilage directly.
Credit Access	Cooperative membership, extension service contact.	Determines access to finance, but not the spoilage rate directly.

Instrument relevance was verified using the F-statistic (>10) from the first-stage regression. At the same time, validity was tested using the Sargan-Hansen overidentification test, which ensured that the instruments were uncorrelated with the error term. All statistical analyses were conducted using Stata software (Version 17).

Diagnostic and Model Evaluation

To validate the robustness of the 2SLS model, the following diagnostics were performed:

i. Endogeneity Test (Durbin–Wu–Hausman): To confirm whether OLS estimates are inconsistent due to endogeneity.

ii. Instrument Relevance Test (First-stage F-statistics): Ensures instruments are sufficiently correlated with the endogenous variables.

iii. Overidentification Test (Sargan-Hansen): Confirms the instruments are exogenous.

iv. Heteroskedasticity Test (Breusch–Pagan): To verify the homoscedasticity assumption.
v. Normality Test (Jarque–Bera): To check the distribution of residuals.

Ethics Statement

The study protocol was reviewed and approved by the Faculty of Agriculture Research Ethics Committee (FAREC), Adekunle Ajasin University, Akungba-Akoko (AAUA), Ondo State, Nigeria. Informed consent was obtained from all participants prior to data collection.

Results and Discussion

Socioeconomic Characteristics of the Respondents

The results for socio-economic characteristics in Table 2 are presented for the leafy vegetable farmers in the study area. The majority (50%) of producers fall within the productive age range of 31–50 years, with a mean age of 42 years. This result aligns with studies by Bamiwuye *et al.* (2024), who found that economically active individuals formed the majority in the leafy vegetable enterprise. The age distribution suggests that most respondents were within the economically active population, which supports sustained participation in leafy vegetable production. This is an indication that the sector is not ageing out, as observed in other agricultural practices. It is also an indication that younger farmers are more adaptable to improved post-harvest and marketing practices. The dominance of male respondents (68.3%) and the lower proportion of women (31.7%) suggest unequal engagement in leafy vegetable production. This may reflect gender-based differences in access to land, capital, and other productive assets. Although men appear more involved in production, women remain important actors in vegetable value chains, especially in processing, packaging, and retailing (Vercillo *et al.,* 2023). Therefore, in many horticultural value chains, men tend to dominate land access and primary production, while women are more visible in processing, packaging, and retail activities (Gebretsadik *et al*., 2025).

The results of marital status showed that 66.7% of the respondents were married, 21.7% were single, and 11.6% were widowed. The household size distribution shows that most respondents (60.0%) had between 4 and 6 household members, while the mean household size was 5.6 persons. This relatively moderate household size may provide access to family labour for farm and post-harvest operations. The educational profile reveals that the producers were fairly literate. While 15.0% had no formal education and another 15.0% had only primary education, 41.7% had secondary education and 28.3% had tertiary education. Thus, about 70.0% of the respondents had at least secondary education. This level of education may enhance farmers' ability to understand and adopt improved post-harvest handling, storage, and marketing practices. Related studies have similarly reported that education is important in shaping post-harvest management decisions among vegetable farmers (Bada *et al.,* 2023).

Monthly income was generally low to moderate. Nearly half of the respondents (48.4%) earned between ₦20,000 and ₦39,999 per month, 30.8% earned between ₦40,000 and ₦59,999, and 20.8% earned between ₦60,000 and ₦79,999. The mean monthly income was ₦46,389, indicating that there is still room for improvement, especially in value addition and technology.

Furthermore, only 28.3% had access to credit, which could be a challenge that prevents smallholders from investing in cold storage or transport logistics that could reduce PHLs. With an average household size of 6, many farmers have access to family labour. This could support production without direct labour costs. Onyia *et al*. (2021) argue that leafy vegetable farming, if adequately supported, can transition from subsistence to employment-generating micro-enterprises. Manual harvesting (80%) formed the majority, with less than 2% using mechanised tools. This is an indication of low level of mechanisation, which contributes to high labour intensity. Sani *et al*. (2023) stated that while mechanisation can reduce drudgery and increase efficiency, adoption depends heavily on income levels and credit access of the producers. Thus, as emphasised by

Fadairo *et al*. (2020), enhancing resilience and productivity in vegetable value chains is essential for achieving inclusive rural transformation.

Table 2. Socio-economic Characteristics of Leafy Vegetable Producers

Variable	**Category**	**Frequency (n = 240)**	**Percentage (%)**	**Mean**
Age (Years)	≤ 30	48	20.0	
	31–40	72	30.0	
	41–50	64	26.7	
	51–60	36	15.0	
	61 and above	20	8.3	42
Sex	Male	164	68.3	
	Female	76	31.7	
Marital Status	Single	52	21.7	
	Married	160	66.7	
	Widow	28	11.6	
Household Size	1–3 members	24	10.0	
	4–6 members	144	60.0	
	7–9 members	60	25.0	
	>9 members	12	5.0	6
Educational Attainment	No formal education	36	15.0	
	Primary school	36	15.0	
	Secondary school	100	41.7	
	Tertiary education	68	28.3	
Monthly Income (₦)	₦20,000–₦39,999	116	48.4	
	₦40,000–₦59,999	74	30.8	
	₦60,000–₦79,999	50	20.8	₦46,389
Cooperative Association Member	Yes	108	45.0	
	No	132	55.0	
Access to Extension Services	Yes	60	25.0	
	No	180	75.0	
Access to Credit	Yes	68	28.3	
	No	172	71.7	
Harvesting Method	Hand	192	80.0	
	Hand tools	44	18.3	
	Machinery	4	1.7	
Years of Farming Experience	1–5	92	38.4	
	6–10	80	33.3	
	11–15	48	20.0	
	16–20	8	3.3	
	>25	12	5.0	8.9

Source: Field survey (2025).

Costs and Returns Analysis

The profitability analysis presented in Table 3 shows the economic viability of leafy vegetable production. Four major leafy vegetables were assessed, which are: Ugwu (*Telfairia occidentalis*), *Amaranthus spp*., African Spinach (*Amaranthus hybridus*), and Ewedu (*Corchorus olitorius*). The result shows that the variable costs had the highest cost structure, especially for labour, transportation, storage, and water. This aligns with the study by *Sani et al.* (2023). Storage costs were higher for African Spinach (₦5,674) and Ewedu (₦6,543), which could indicate greater post-harvest loss. This finding supports the argument of Olowo *et al*. (2022). The authors stated that without affordable cold-chain solutions, leafy vegetables may be sold quickly at low prices or avoid the risk of spoilage. Transportation costs (averaging ₦2,300 across crops) further reduce net gains. Furthermore, Ugwu recorded the highest total revenue (₦133,456) and net farm income (₦103,253), reflecting its higher market demand and return on investment (ROI) of 4.4. An ROI of 4.4 means that for every ₦1.00 invested in leafy vegetable production, the farmer earned ₦4.40 as return. Economically, this indicates that the enterprise is highly profitable, even after accounting for post-harvest losses.This is consistent with findings by Wuyep *et al.* (2022), who reported that Ugwu dominates urban markets. The net income of Amaranthus and African Spinach were close at ₦82,987 and ₦71,848, and ROIs of 3.4 and 2.9, respectively. Although these vegetables were less profitable than Ugwu, their lower production costs still make them economically viable enterprises. Ewedu had the lowest returns (₦58,366 net income) and ROI (2.8), mainly due to higher post-harvest handling costs and perishability, as also noted by Onyia *et al*. (2021). Thus, all four vegetables had positive gross margins, ranging from ₦70,161 to ₦116,545. These results corroborate Fadairo *et al.* (2020) assertion that leafy vegetable production remains a profitable agrifood livelihood. However, the margin differentials across vegetables also highlight the need for product-specific interventions.

Table 3. Cost and Returns Structure of Leafy Vegetable Production (₦)

Cost/Return Components	**Ugwu**	**Amaranthus**	**African Spinach**	**Ewedu**
A. Variable Costs				
Labour	7,700	9,800	12,000	6,700
Agrochemicals	1,750	1,670	1,720	1,750
Stake	750	–	–	–
Manure	–	1,500	1,450	1,456
Storage	3,280	4,545	5,674	6,543
Water	1,340	1,230	1,250	1,234
Transportation to Market	2,091	2,400	2,350	2,356
Total Variable Cost (TVC)	16,911	21,145	24,444	20,039
B. Fixed Costs				
Land Rent	9,292	7,654	7,865	7,654
Cutlass	500	450	498	560
Shovel	1,200	1,340	1,345	1,234

Wheelbarrow	2,300	2,450	2,345	2,347
Total Fixed Cost (TFC)	13,292	11,894	12,053	11,795
C. Total Cost (TC = TVC + TFC)	30,203	34,269	36,497	31,834
D. Total Revenue (TR)	133,456	117,256	108,345	90,200
E. Net Farm Income (NFI = TR − TC)	103,253	82,987	71,848	58,366
F. Gross Margin (GM = TR − TVC)	116,545	94,881	83,901	70,161
G. Return on Investment (ROI = TR ÷ TC)	4.4	3.4	2.9	2.8

Note: US$ equivalents were calculated using an exchange rate of ₦1,370 = US$1.00.
Source: Field survey (2025).

Post-Harvest Losses of Leafy Vegetables and Their Determinants

This section presents the post-harvest losses (PHL) among leafy vegetable farmers in the study area (Table 4). The mean value (33.5%) of PHL is higher than the average range (20–30%) commonly reported for fresh produce in sub-Saharan Africa (FAO, 2020). This confirms inadequacies in the post-harvest sub-sector of the agrifood system (Stathers *et al*., 2020). However, the result was higher than the value (30–35%) observed in Zambia (Mwamba, 2025) due to transport delays and poor handling. Among the leafy vegetables studied, *Telfairia occidentalis* (Ugwu) recorded the highest losses, followed by *Corchorus olitorius* (Ewedu), *Amaranthus spp.*, and then the *Amaranthus hybridus* (African spinach). The relatively higher losses in *T. Occidentalis* may be attributed to its broad leaves and thick stems. According to Olowo *et al*. (2022), it leads to wilting and microbial spoilage in the absence of cooling facilities, also reported that high ambient temperatures, poor road networks, and distribution delays increase perishability. Similarly, vegetables with larger leaf areas tend to deteriorate faster due to higher rates of post-harvest respiration and transpiration (Kitinoja, 2016). The findings also support Fadairo *et al*. (2020), who reported that post-harvest losses weaken rural farmers. The results reaffirm that reducing post-harvest losses is not only a technical priority but also a way to boost income and create jobs in the area.

Table 4. Post-Harvest Losses of Leafy Vegetables by Types

Leafy Vegetable	**Average Quantity Harvested (kg)**	**Quantity Lost Post-Harvest (kg)**	**Post-Harvest Loss (%)**
Ugwu (*T. occidentalis*)	180	68	37.78%
Amaranthus spp.	165	55	33.33%
African Spinach	160	44	27.50%
Ewedu (*C. olitorius*)	150	53	35.33%
Average	—	—	33.49%

Source: Field Survey (2025).

Factors Influencing the Post-Harvest Losses among Leafy Vegetable Farmers

According to Table 5, a Two-Stage Least Squares (2SLS) regression model was used to examine the determinants of PHL. The 2SLS corrects for potential endogeneity that might arise in the model. The variables may have biased the OLS estimates when run with the PHL. The first-stage regressions confirmed that the selected instruments (land tenure, cooperative membership, road condition, and distance to market) were strongly correlated with the endogenous variables but not with the error term in the structural equation. Thus, the instruments satisfied the relevance and exogeneity conditions. The first-stage F-statistics (>10) confirm instrument strength, while the Sargan–Hansen test ($p = 0.292$) indicates that the instruments are valid and uncorrelated with the error term. The Durbin–Wu–Hausman test ($p = 0.017$) further validates the use of 2SLS over OLS by confirming endogeneity among the identified regressors. The model's explanatory power is high, with an Adjusted R^2 of 0.64, indicating that approximately 64% of the variation in post-harvest losses is explained by the independent variables. See Appendix Tables A1 and A2 for the results that confirms the robustness, validity, and consistency of the model.

From the Table 5, it was shown that farm size coefficient was negative but statistically significant at the 1% level. It can be interpreted that a one-hectare increase in farm size reduces losses by 8.6%, *ceteris paribus*. The result could suggest that better investment capacity with economies of scale and the adoption of improved post-harvest technologies contribute to enhanced efficiency. This finding corroborates Balana *et al*. (2022), who reported that an increase in farm size increases technology adoption and thereby minimises loss in vegetable value chains.

The coefficient of credit access is negative and significant at the 1% level. It implies that farmers with access to credit can reduce losses. It can be deduced that farmers can finance improved packaging, transportation, and preservation practices that could effectively reduce losses (Aworh, 2025). This supports the findings of Mukaila *et al*. (2022), who found that liquidity and financial inclusion enhance farmers' capacity to reduce post-harvest losses. Nnaemeka (2024) opined that access to credit and training on post-harvest technologies significantly reduced losses and improved welfare status of tomato farmers in Kaduna, Nigeria. The positive and significant coefficient for storage cost ($p < 0.01$) indicates that higher storage costs are associated with greater losses. This is contrary to the *apriori* expectations as the relationship may reflect inefficient storage investments observed in the study area. For instance, farmers spend more on low-quality facilities or rent space under poor conditions. This finding was also noted by Olowo *et al*. (2022). The authors stated that poorly designed post-harvest facilities often increase losses. Asrat *et al.* (2019) similarly linked high vegetable losses in Cameroon to poor post-harvest handling and dependence on informal storage systems. Based on related findings, Oyewole *et al.* (2025) recommended digital and sensor-based cooling innovations to reduce losses in Nigeria.

Education significantly reduces post-harvest losses ($p < 0.05$). Each additional year of schooling is associated with reduced losses. Education encourages better adoption of preservation techniques and more efficient marketing decisions (Olutumise *et al*., 2023). This finding also aligns with Sani *et al*. (2023), who reported the role of human capital in agricultural efficiency and food quality control. Furthermore, the coefficient on farming experience is negative and significant at 5% level. It is an indication that experienced farmers had knowledge over time that reduces post-harvest losses. The findings show that experience complements education in reducing losses. Age is negatively associated at 5% level with post-harvest losses, suggesting that older farmers incur less loss. The probable reason may be the practical experience gained over the years and greater caution in handling highly perishable crops. However, household size is positively and significantly associated with post-harvest losses. Within large households, untrained or younger members may not follow best practices for handling, which could be a possible reason for the result. Fadairo *et al.* (2020) shared the same view that linked family labour to post-harvest inefficiencies.

Table 5. Two-Stage Least Squares (2SLS) Regression Estimates for Determinants of Post-Harvest Losses

Variable	Coefficient	Std. Error	t-Statistic	p-Value
Constant	1.243	0.512	2.43	0.016
Age	-0.017**	0.008	-2.10	0.037
Household Size	0.024**	0.010	2.40	0.018
Education	-0.029**	0.013	-2.23	0.027
Farming Experience	-0.014**	0.007	-2.00	0.046
Farm Size	-0.086***	0.025	-3.44	0.001
Storage Cost	0.058***	0.020	2.90	0.004
Other Costs	0.015	0.070	0.21	0.340
Access to Credit	-0.121***	0.044	-2.75	0.006
Extension Contact	-0.071	0.380	-0.19	0.650
Model Statistics				
R-squared (2SLS)	0.682			
Adjusted R-squared	0.641			
F-statistic (first stage)	12.47 (Prob. > F = 0.000)			
Durbin–Wu–Hausman Test	$\chi^2 = 8.12$ (P = 0.017)			
Sargan-Hansen Test	$\chi^2 = 2.46$ (P = 0.292)			

Dependent variable: Post-harvest loss rate (%).
Number of observations: 240.
Note: ***p < 0.01; **p < 0.05; *p < 0.10.

Evaluate Existing Post-Harvest Handling and Preservation Practices

The frequency and percentage of post-harvest handling practices in the area are shown in Table 6. It was observed that most producers depend on low-cost and traditional methods to minimise spoilage and also maintain market quality. About 72% of the farmers spread leafy vegetables under shade immediately after harvest to minimise heat exposure. This practice is consistent with FAO recommendations to slow respiration and prevent wilting (FAO, 2020). Woven baskets (66%) and water sprinkling (62%) were used for preservation, which help maintain turgidity during transit. Nearly 58% of the farmers harvest early morning when lower temperatures and higher humidity minimise physiological stress. It was reported that it extends shelf life. This is in line with the observation of Kitinoja and Kader (2015) on optimal harvest timing for perishable vegetables. Few (8%) of the farmers use cold water or refrigeration, while only 13% apply chemical preservatives. About 47% rely on local packaging materials (jute sacks and raffia bags). The method causes poor ventilation and often leads to bruising and contamination. Some (31%) farmers adopt night-time transportation to avoid daytime heat. The use of improved sorting and trimming (28%), and delayed harvesting (40%) were low on the list. These results indicate that while farmers have developed local coping strategies, access to modern technologies is still a constraint. The crude methods commonly used by the farmers in the area require targeted investments like cold chain infrastructure, mobile cooling units, and cooperative-based storage systems.

Table 6. The Results of Post-Harvest Handling/Preservation Practices

Handling/Preservation Practice	Frequency	Percentage (%)	Remarks
a. Delayed harvesting	97	40.4	6th
b. Woven baskets	158	65.8	2nd
c. Sorting and trimming	68	28.3	8th
d. Water sprinkling	149	62.1	3rd
e. Early morning harvesting	140	58.3	4th
f. Jute sacks or raffia bags	113	47.1	5th
g. Sold immediately	34	14.2	11th
h. Night-time transportation	74	30.8	7th
i. Spreading under the shade	172	71.7	1st
j. Chemicals for preservatives	31	12.9	9th
k. Cooling technologies	19	7.9	10th

Constraints to Post-Harvest Loss Reduction in Leafy Vegetable Production

The result in Table 7 showed the constraints to post-harvest loss reduction in leafy vegetable production in the study area. Price fluctuation ranked first, with 95% of respondents identifying it as the most severe challenge. This could reveal high market uncertainty among farmers (Ojo and Apata, 2023). Sudden price drops always cause the farmers to delay sales and extend storage time. This aligns with the findings of Ojo and Apata (2023), who found that vegetable price volatility leads to inefficiencies in urban–peri-urban supply chains. Inadequate funds (91.7%) ranked second, showing financial barriers to investment in preservative facilities. Olagunju *et al.* (2021) reported that liquidity constraints negatively affect the value chain. Poor road networks (90%) and long distances to markets (75%) significantly prolong transit times. It has been argued in the literature that sustainable vegetable production depends on integrating post-harvest technologies with financial and institutional support (Mathobo, 2023). The World Bank (2022) notes that such infrastructural gaps increase rural–urban disparities and reduce supply chain efficiency. Inadequate market information (83.3%) and low extension visitation (81.7%) were also reported as constraints. Kitinoja and Kader (2015) stated that technical advisory services and capacity-building are essential for reducing losses among small-scale farmers. High labour costs (80.8%), labour shortages (70.8%), and unavailability of input (78.3%) further hinder timely harvesting and effective handling. Although high taxation (39.2%) was less frequently cited, it still affects producers' operations.

Table 7. Constraints to Post-Harvest Loss Reduction in Leafy Vegetable Production in the Area

Constraint	Frequency	Percentage (%)	Rank
i. Market information	200	83.3	4th
ii. Price fluctuations	228	95.0	1st
iii. Distance to market	180	75.0	8th
iv. Inadequate funds	220	91.7	2nd
v. Availability of inputs	188	78.3	7th
vi. Road network	216	90.0	3rd
vii. Extension visitation	196	81.7	5th
viii. Government charges	94	39.2	10th
ix. Cost of labour	194	80.8	6th
x. Labour shortage	170	70.8	9th

Conclusions

The study concludes that leafy vegetable farming is profitable, with *Telfairia occidentalis* (Ugwu) recording the highest return on investment. However, profitability is reduced by post-harvest losses and constraints such as price fluctuations, inadequate funds, poor road networks, labour shortages, and weak extension support. Manual handling and traditional preservation methods also increase spoilage and loss of income. Therefore, reducing post-harvest losses is both an economic and policy priority for improving farmers' livelihoods and strengthening the agrifood system in the study area. Based on the findings, interventions should target the key factors driving post-harvest losses. Farmers should be supported with affordable credit to invest in improved storage, packaging, and handling facilities. Extension services should provide practical training on sorting, grading, shade drying, and low-cost preservation methods. Since poor roads and price fluctuations were major constraints, rural road improvement, market information systems, and contract marketing should be promoted to reduce transit losses and distress sales. Women and youth should also be supported to participate in packaging, logistics, processing, and vegetable marketing. These measures will reduce losses, improve income, and strengthen the leafy vegetable value chain in the study area.

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Conflict of interests

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Author Contribution

A. I. Olutumise and A. Adegoroye wrote the original draft of the manuscript. O. O. Ajayi and A. A. A. Afyare reviewed, edited, and finalized the manuscript. All authors read and agree to the submission of the manuscript to the journal.

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