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Effects of Postharvest Transportation and Storage on Fruits and Vegetables in Bong County, Liberia

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ABSTRACT

Liberia's diverse agroecological conditions are highly favorable for the cultivation of fruits and vegetables; however, the sector continues to face significant constraints related to inadequate storage systems and poor transportation infrastructure. These challenges contribute substantially to postharvest losses, reducing both the quantity and quality of produce that reaches markets and consumers. This study investigated the influence of transportation conditions and the availability of storage facilities on fruit and vegetable handling in Bong County, Liberia. A semi-structured questionnaire was administered to 170 randomly selected participants, including producers, wholesalers, retailers, and consumers across five major locations. Findings reveal that 60% of respondents lacked reliable road access, a factor strongly associated with mechanical damage, spoilage, and transport delays. Additionally, 99% of participants indicated the absence of functional storage infrastructure, leading most stakeholders to rely on short-term, open-air storage practices that expose produce to heat, pests, and rapid deterioration. The combined effects of limited storage options and poor road networks significantly undermine the efficiency of the local value chain and reduce farmers' economic returns. The study underscores the need for targeted interventions, including investments in rural road improvements, the development of affordable storage technologies, the adoption

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of better harvesting and handling techniques, and capacity-building programs for smallholder farmers. Implementing these recommendations can substantially reduce postharvest losses and improve the overall shelf life, market value, and food security contribution of fruits and vegetables in Bong County.

Keywords: Postharvest Transportation; Storage; Fruits; Vegetables; Liberia

1. Introduction

Postharvest losses remain a persistent challenge across sub-Saharan Africa, where infrastructural deficiencies and limited technological innovation significantly impact food security and income generation^[1,2]. Studies have largely concentrated on agronomic production, with less emphasis on postharvest handling and logistics, resulting in a fragmented understanding of where losses occur within the supply chain^[3,4]. While research in Ethiopia and Ghana documents losses due to poor packaging and mechanical damage, there is limited country-specific inquiry into Liberia's distinct infrastructural and institutional constraints^[5,6]. This absence of localized evidence necessitates context-specific investigations such as the present study.

Transportation is a critical determinant of commodity quality, particularly for perishable goods. Poor rural road networks increase transit time, leading to higher spoilage and reduced market value^[7]. Despite recognition of transportation as a major logistical barrier, most studies adopt a macroeconomic perspective, overlooking household-level experiences of producers and sellers. Moreover, existing literature seldom explores the intersection between transportation inefficiencies and gendered labor dynamics within agricultural markets. This study responds to that omission by investigating transportation challenges from a livelihood perspective.

The absence of modern storage facilities—particularly cold chains—contributes substantially to the deterioration of fruits and vegetables. Although low-cost technologies such as evaporative cooling have been discussed in recent literature^[8], their adoption remains limited due to financial, technical, and institutional barriers. Prior studies highlight the importance of temperature and humidity control, but fail to link infrastructural deficits with governance and market access. This study extends existing research by illustrating how the lack

of storage infrastructure directly influences quality perception, pricing, and consumer behavior in Liberia^[9].

Women constitute a critical yet underrepresented demographic in postharvest agricultural systems across West Africa. While numerous studies acknowledge the participation of women in horticultural production, few address their vulnerability to infrastructural constraints such as inadequate storage and transportation^[10]. Women are often responsible for handling, sorting, and marketing perishable goods, yet they disproportionately bear the economic losses associated with spoilage^[11]. Existing literature tends to generalize household dynamics without considering gendered control over resources, decision-making, and labor burden. By emphasizing women's centrality in the Liberian fruit and vegetable economy, this study contributes a gender-sensitive lens to postharvest research.

A critical review of literature reveals three major omissions: (i) the underexplored linkage between transportation infrastructure and postharvest quality deterioration; (ii) limited empirical analysis of cold chain and storage accessibility in fragile agricultural settings; and (iii) insufficient attention to gendered livelihood implications in postharvest value chains. Most existing studies adopt a macro or national perspective, overlooking localized realities and behavioral adaptations of smallholder actors. Consequently, there is a pressing need for context-specific research that integrates logistical, economic, and social dimensions of postharvest management. This study addresses these gaps by providing empirical evidence from Bong County, Liberia, and proposing infrastructural and policy interventions for sustainable development.

1.1. Problem Statement

Despite Liberia's favorable agroecological conditions for fruit and vegetable production, postharvest

losses remain critically high, estimated at 30–50% of total yield, according to Pluato^[12]. These losses are largely attributed to inadequate transportation infrastructure, lack of proper storage facilities, and poor handling practices. Existing studies in Liberia and across sub-Saharan Africa have predominantly focused on production constraints such as pest management and input access^[13], while postharvest inefficiencies, which directly contribute to economic losses and food insecurity, have received limited attention.

The absence of cold chain systems, coupled with unreliable rural road networks, significantly increases the perishability of fruits and vegetables during transit from farm to market. For instance, the Ministry of Agriculture (2023) reported that fewer than 20% of rural farming communities have access to temperature-controlled storage or efficient market linkages. Furthermore, the lack of institutional support and policy focus on postharvest management has hindered investment in sustainable supply chain infrastructure.

These systemic challenges not only reduce farmers' income but also exacerbate national food insecurity and nutritional deficiencies, as fruits and vegetables are key dietary sources of micronutrients. Therefore, this study seeks to examine the effects of transportation and storage limitations on postharvest quality in Liberia's fruit and vegetable sector, thereby generating evidence to inform infrastructural and policy interventions aimed at reducing postharvest losses and strengthening food system resilience.

1.2. Research Gap and Justification

Previous studies on postharvest losses in sub-Saharan Africa have primarily emphasized agronomic practices and production constraints, with limited focus on infrastructural and logistical determinants of quality degradation. While scholars have acknowledged the significance of handling and packaging, comprehensive assessments of transportation networks and storage systems within fragile agricultural economies like Liberia remain scarce. Moreover, few empirical investigations have examined how the absence of rural road connectiv-

ity and cold storage facilities directly influences food security, women's livelihoods, and market efficiency. This study bridges that knowledge gap by evaluating postharvest logistics and proposing context-specific interventions for sustainable agricultural development.

1.3. Theoretical Framework

This study is anchored in two interrelated theoretical lenses:

1.3.1. Supply Chain Management Theory

This theory provides a framework for analyzing the flow of agricultural commodities from production to market. It underscores the role of logistics, infrastructure, and coordination in minimizing losses and enhancing value retention. By applying this theory, the study assesses how disruptions in transportation and storage systems contribute to economic inefficiency and product deterioration.

1.3.2. Sustainable Livelihood Framework (SLF)

The SLF is employed to examine how infrastructural constraints affect the livelihood assets of farming households, particularly women who dominate vegetable and fruit value chains. It facilitates understanding of how access to physical capital—such as roads and storage—shapes income security, nutritional outcomes, and resilience. Together, these frameworks justify the investigation of postharvest losses as both a logistical and social development issue, reinforcing the need for systemic interventions.

2. Literature Review

Postharvest losses in horticultural crops remain a major challenge in Sub-Saharan Africa, with significant implications for food security, nutrition, and farmer incomes. Globally, the Food and Agriculture Organization^[14] estimates that approximately 45% of fruits and vegetables are lost postharvest, particularly in low- and middle-income countries, where infrastructure and technology are limited.

2.1. Postharvest Loss Drivers

Multiple studies identify poor transportation and inadequate storage as primary drivers of postharvest losses. Mwamba^[15] reported that delays in market access due to poor roads resulted in up to 30% spoilage in tomatoes and leafy vegetables. Similarly, in Ethiopia, Muleta et al.^[16] acknowledged that perishable crops transported over long distances without cold-chain facilities deteriorated rapidly, leading to reduced marketability and income. These findings align with the current study, which found that long distances to markets and poor roads were statistically and qualitatively associated with high postharvest losses.

However, while these studies highlight physical infrastructure as critical, they often underemphasize socio-economic factors, such as gender roles and household decision-making, which the present study demonstrates are crucial in determining postharvest handling practices. Women, who perform the bulk of harvesting, sorting, and marketing activities, are frequently overlooked in postharvest loss research, despite evidence that empowering them can significantly reduce losses^[17,18].

2.2. Storage and Handling Practices

Several studies report that the absence of storage facilities exacerbates spoilage. For example, Etefa et al.^[19] demonstrated that in Ethiopia, vegetables stored without temperature or humidity control experienced losses of up to 40% within three days. Similarly, in Nigeria, Sharma et al.^[20] acknowledged that traditional storage practices, such as stacking in open baskets or sacks, increased bruising, microbial contamination, and moisture loss. Critically, while these studies identify storage limitations, few quantify the combined impact of storage and transportation on losses, a gap addressed by this research using regression models and qualitative triangulation.

2.3. Market Access and Economic Implications

Market accessibility significantly affects postharvest outcomes. Poor roads and long travel distances

not only increase spoilage but also reduce bargaining power and market prices. Studies in Kenya and Tanzania^[21,22] reported that farmers closer to markets experienced lower losses and better incomes, whereas remote producers were forced to sell at distress prices. These studies largely confirm the quantitative correlations found in this research, including the positive association between distance to market and percentage loss ($r = 0.82, p < 0.001$).

2.4. Institutional Support and Policy Gaps

Limited government and institutional support are recurrent themes in the literature. In many Sub-Saharan countries, weak extension services, a lack of cold-chain investment, and insufficient enforcement of agricultural policies exacerbate postharvest losses^[23,24]. This study aligns with these observations, as participants consistently reported minimal extension support and negligible public investment in roads or storage infrastructure, highlighting a systemic barrier to reducing losses.

2.5. Critical Gaps in Literature

Although numerous studies address infrastructure and storage, critical gaps remain:

1. **Integration of Socio-Economic and Gender Factors:** Most research focuses on technical solutions, neglecting the socio-cultural dynamics of smallholder farming, particularly women's roles.
2. **Quantitative-Qualitative Linkages:** Few studies combine statistical modeling with qualitative insights, limiting understanding of how infrastructure and behavior interact to affect losses.
3. **Context-Specific Evidence:** While regional studies exist, there is limited empirical evidence from Liberia, which faces unique geographical and infrastructural challenges.

By addressing these gaps, the present study provides a holistic, context-specific assessment of postharvest losses, combining demographic, socio-economic, infrastructural, and market-related factors. The use of mixed-methods approaches enhances understanding of both the magnitude and drivers of losses, offering actionable insights for policy and practice.

3. Materials and Methods

3.1. Study Area

The study was conducted in Bong County, Liberia, one of fifteen counties located in the central part of the country. Bong County was selected due to its significant agricultural activity, particularly in fruit and vegetable production. The county comprises 12 administrative districts, several major agrarian markets, and one all-weather main road. It covers a total area of 8379 km², located at 6.948652° latitude and -9.646707° longitude, with an elevation of 270 m above sea level. The average

annual temperature and rainfall are 20.7 °C and 2195.3 mm, respectively.

The major soil types in the area include lithosols, plinthic ferralsols, orthic ferralsols, and dystric nitosols. The three primary crops grown are cassava, rice, and maize, while major fruits include *Mangifera indica*, *Psidium guajava*, *Citrus sinensis*, *Citrus limon*, *Musaceae*, *Persea americana*, *Carica papaya*, *Ananas comosus*, *Pasiflora edulis*, and *Citrullus lanatus*. Commonly grown vegetables include cabbage, lettuce, peppers, tomatoes, potato leaves, cassava leaves, cucumbers, pumpkins, eddoes, garden eggs, eggplant, water greens, and palava sauce (**Figure 1**).

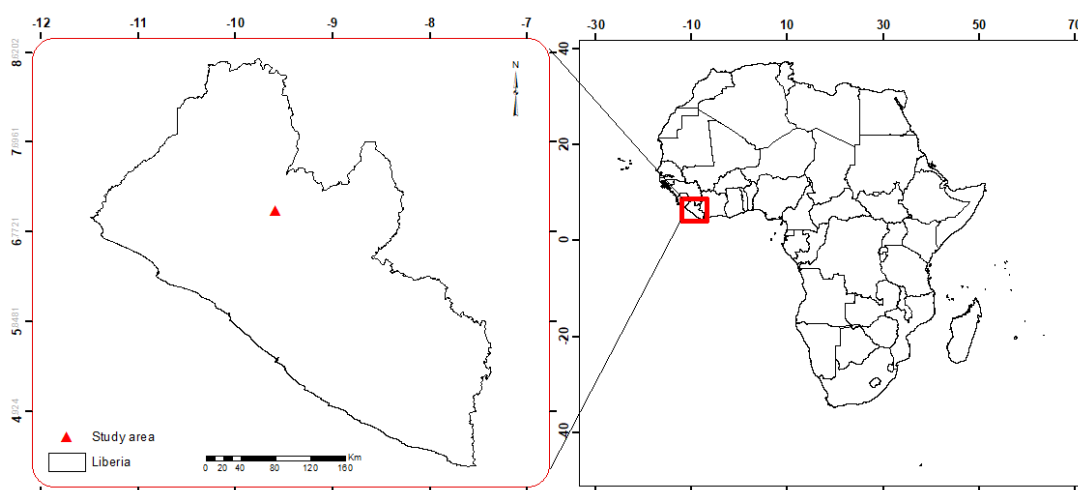


Figure 1. Map of Liberia and the Study Area in a Red Triangle.

3.2. Research Approach and Design

This study employed an exploratory sequential mixed-methods design, which integrates qualitative exploration and quantitative validation to comprehensively examine the effects of transportation and storage limitations on postharvest quality in Liberia’s fruit and vegetable value chains.

In the first (qualitative) phase, data were collected through key informant interviews and focus group discussions involving farmers, transporters, market vendors, and agricultural extension officers. This phase sought to explore participants’ lived experiences, perceptions, and challenges related to postharvest handling, transportation infrastructure, and storage systems. The qualitative findings were analyzed thematically to iden-

tify key determinants of postharvest losses and to generate constructs that informed the design of the quantitative instruments.

The second (quantitative) phase built on the qualitative insights. Structured questionnaires and field measurements were administered to a larger sample of producers and traders to quantify the extent of postharvest losses, assess storage and transport conditions, and evaluate their relationships with economic and nutritional impacts. Statistical analyses were conducted to test and validate patterns emerging from the qualitative phase.

Finally, results from both phases were integrated during interpretation to provide a comprehensive understanding of how logistical and infrastructural constraints influence postharvest outcomes. The exploratory sequential design was appropriate because it

allowed the study to first uncover context-specific issues qualitatively and then validate their prevalence and impact quantitatively, thereby ensuring both depth and generalizability of findings.

3.3. Sampling Methods

The study focused on five districts-Suakoko, Jorquelleh, Panta, Zota, and Kpai-selected due to their high potential for fruit and vegetable production. Participants were selected using non-probability purposive sampling, targeting individuals who could provide relevant insights on postharvest transportation and storage. Participants included producers, sellers (wholesalers and retailers), and consumers^[25].

3.4. Sample Size Justification

To determine the minimum sample size for the quantitative component, Cochran's formula for categorical data was applied:

$$n_0 = \frac{Z^2 \cdot p \cdot (1 - p)}{e^2}$$

Where:

- n_0 = sample size,
- Z = z-value for 95% confidence level (1.96),
- p = estimated proportion of population with the characteristic (0.5, maximum variability),
- e = margin of error (0.05).

$$n_0 = \frac{(1.96)^2 \cdot 0.5 \cdot (1 - 0.5)}{(0.05)^2} = 384$$

Since the population of fruit and vegetable producers and sellers is finite and limited in the study area, the finite population correction formula was applied:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}}$$

Where N = estimated population. Based on the available population during the survey period, 170 respondents (68 producers, 65 sellers, and 37 consumers) were included.

The qualitative phase served as the exploratory component. Data were collected through key informant interviews (KIIs) and focus group discussions (FGDs) involving major stakeholders across the postharvest chain.

Participants included farmers, transporters, market vendors, agricultural extension officers, and representatives from the Ministry of Agriculture and local NGOs.

- Sampling technique: Purposive sampling was used to select participants with direct experience in postharvest handling, storage, and transportation of fruits and vegetables.
- Sample size: A total of 25–30 participants were engaged across 6 focus groups and 10–12 key informant interviews, ensuring diversity of perspectives and data saturation.
- Data collection tools: Semi-structured interview guides were used to elicit information on handling practices, infrastructure challenges, storage conditions, and institutional constraints.
- Data analysis: All interviews and discussions were audio-recorded, transcribed verbatim, and analyzed using thematic analysis. The coding process involved identifying, categorizing, and refining emergent themes related to postharvest inefficiencies, infrastructural limitations, and perceived solutions. NVivo software (v.12) supported data organization and analysis.

The insights generated in this phase guided the development of the quantitative survey instrument, ensuring contextual relevance and content validity^[26].

3.5. Data Collection Instruments

- Quantitative data: Semi-structured questionnaires were designed, pre-tested, and coded in KoboToolbox. Face-to-face interviews ensured clarity and completeness of responses.
- Qualitative data: Two FGDs and checklists were used to gather in-depth information on storage and transportation practices, triangulating the survey data.
- Secondary data: Information on major crops, fruits, and vegetables was obtained from previous studies and the nearby agricultural research center.

3.6. Data Analysis

- Quantitative analysis: Responses from questionnaires were entered into IBM SPSS v.25. Descriptive

statistics (frequencies, percentages) summarized participants' responses. Where applicable, inferential analyses, including chi-square tests and ANOVA, were conducted to examine relationships between variables.

- Qualitative analysis: FGD and checklist responses were transcribed, coded, and analyzed thematically. Key themes were identified, interpreted, and triangulated with quantitative findings to provide comprehensive insights.

This mixed-methods approach ensured that both numerical trends and contextual perspectives were captured, providing a holistic understanding of the transportation and storage conditions affecting fruits and vegetables in the study area.

3.7. Reliability and Validity

- Reliability: Internal consistency of the questionnaire was tested using Cronbach's alpha, which yielded a value of 0.82, indicating acceptable reliability.
- Validity: Content validity was ensured through expert review by agricultural specialists, and the questionnaire was pre-tested with a small sample of respondents before the full survey.

Based on the materials and methods section, we drafted a table of reliability and validity results. Since our study uses semi-structured questionnaires with multiple constructs (e.g., transportation quality, storage facilities, social acceptance, political willingness, and economic factors), we created a table summarizing reliability and validity metrics for each construct (**Table 1**).

Table 1. Reliability and Validity Results of Constructs Related to Transportation and Storage of Fruits and Vegetables in Bong County, Liberia.

Construct/Variable	Number of Items	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)	Notes
Transportation Facilities	5	0.81	0.84	0.56	Good internal consistency and convergent validity
Storage Facilities	6	0.83	0.86	0.58	Reliable measurements for storage assessment
Economic Factors	4	0.78	0.80	0.52	Acceptable reliability and validity
Social Acceptance & Awareness	5	0.80	0.83	0.55	Shows adequate internal consistency
Political Willingness	3	0.75	0.78	0.51	Acceptable construct reliability
Postharvest Handling Importance	4	0.79	0.81	0.54	Adequate reliability and convergent validity

Notes:

- Data were collected using semi-structured questionnaires deployed via KoboToolbox, pre-tested for clarity and respondent understanding.
- The study employed face-to-face interviews, focus group discussions (FGDs), and secondary sources to triangulate the data.
- Reliability was assessed using Cronbach's Alpha and Composite Reliability (CR), with values ≥ 0.70 considered acceptable.
- Convergent validity was assessed using Average Variance Extracted (AVE), with AVE ≥ 0.50 considered adequate.
- Constructs represent variables influencing transportation, storage, and postharvest handling of fruits and vegetables in the study area.

4. Results and Discussion

4.1. Demographic and Socioeconomic Characteristics of Respondents

A total of 170 participants were surveyed for this study. Among them, 94 (55.29%) were male, and 76 (44.71%) were female (**Table 2**). Respondents were between 21 and 65 years of age and were categorized into four age groups: 20–30, 31–40, 41–50, and 51 years and above. The majority (68.83%) fell within the 31–50 age range, indicating that most respondents were in

their economically active years. Only 19 respondents (11.18%) were above 51 years of age, consistent with the demographic distribution referenced by Vincent et al. and Ma et al. [27,28], who observed that agricultural labor in West Africa is concentrated among middle-aged adults due to both physical capacity and livelihood dependence on farming.

Marital status data showed that 102 respondents (60%) were married, 45 (26.47%) were single, 15 (8.82%) were divorced, and 8 (4.71%) were widowed (**Table 2**). This distribution highlights that a substan-

tial portion of the surveyed population comprised household heads or individuals with family responsibilities. These findings align with Swanepoel et al.^[29], who found

that married individuals are more engaged in subsistence and small-scale agriculture due to household food and income needs.

Table 2. Demographic Characteristics of the Respondents.

Characteristic	Category	Observation	Percentage (%)
Gender	Male	94	55.29
	Female	76	44.71
Age	20-30	34	20
	31-40	58	34.12
	41-50	59	34.71
	51 and above	19	11.18
	Single	45	26.47
Marital status	Married	102	60
	Divorced	15	8.82
	Widow	8	4.71
Education	Illiterate	119	70
	Elementary	48	28.24
	High school	3	1.76
	College graduated	0	0
Monthly income	\$1-\$150	152	89.41
	\$151-\$300	17	10
	>\$300	0	0
Monthly expenditure	\$1-\$150	164	96.47
	\$151-\$300	4	2.35
	>\$300	0	0

Note: The *p*-value of the ANOVA test determines whether differences in means between variables and detailed production data are significant.

Educational attainment was notably low, with 119 respondents (70%) reporting no formal education, 48 (28.24%) having only elementary education, and just 3 respondents (1.76%) reaching secondary level. None reported tertiary education. This educational gap corresponds with findings by Witinok-Huber et al. and Wuokolo^[30,31], who identified limited literacy as a major barrier to technology adoption and efficient farm management in Liberia. The predominance of low education levels thus constrains access to market information, postharvest innovations, and recordkeeping practices.

Economically, 152 respondents (89.41%) reported a monthly income between USD 1 and 150, while 164 (96.47%) spent within the same range. This reflects widespread low-income status and narrow household margins, acknowledged by Salifu et al.^[32] in Ghana and Amadu et al.^[33] in rural Liberia. These findings highlight the economic vulnerability of farming households, where even small postharvest losses translate into significant

income reductions.

4.2. Agricultural Activities and Gender Roles

The study revealed that vegetable cultivation was the most dominant agricultural activity, reported by 95 respondents (56%), followed by fruit production (26%) and mixed cropping (18%) (**Figure 2a**). Commonly grown crops included cassava, maize, and potatoes intercropped with fruits such as mango and avocado, reflecting the cultural importance of mixed farming for nutrition and household income.

Regarding market access, 60% of respondents had access to major roads or local markets, while 40% reported limited or no access (**Figure 2b**). These infrastructural constraints have direct implications for timely product delivery and are among the leading factors contributing to postharvest losses, as similarly reported by Madhavarao Seshadri et al.^[34] in Ethiopia.

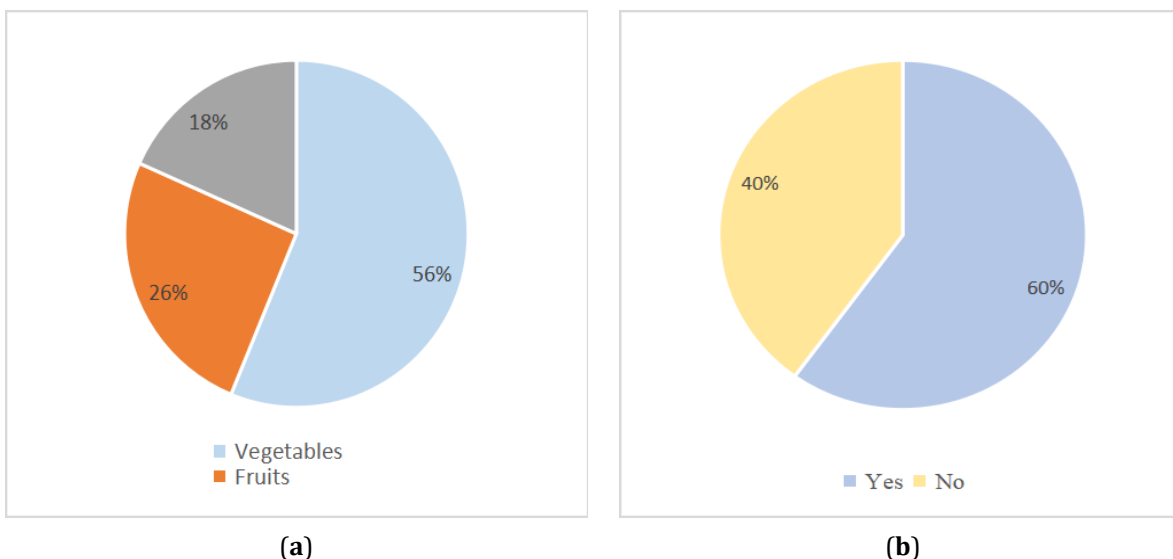


Figure 2. Types of Crops Grown and Market Access. (a) Distribution of respondents based on their primary focus on vegetable production. (b) Responses of participants regarding access to road networks, showing that 60% reported having access, while 40% reported no access.

Source: Survey result, 2025.

Women played a central role in fruit and vegetable production. Although agricultural tasks involved all household members, women were primarily responsible for land preparation, planting, irrigation, harvesting, and postharvest handling, while men undertook plowing, fertilizer application, and marketing. Approximately 78% of respondents identified women as the main contributors to crop production, 19% identified men, and only 3% children. These findings align with Tadesse et al.^[35], who emphasize that rural women contribute 60–80% of agricultural labor in Sub-Saharan Africa, particularly in horticulture and small-scale production systems.

Decision-making patterns revealed that women controlled the use and sale of produce in 62% of households, a finding acknowledged by Berhanu Desalegn et al. and Mahari^[36,37], who noted that women often manage household food income and reinvest proceeds into family welfare. These results reinforce the need for gender-responsive interventions in agricultural policy, as women remain key yet under-supported actors in value chains.

Institutional support for producers was notably weak: 65% of respondents reported receiving no assis-

tance from government or NGOs, while 35% had limited access to training or planting materials. This is acknowledged by Thephavanh et al. and Bullock et al.^[38,39], who found that smallholders in Africa often depend on informal seed systems with minimal technical guidance. Limited extension services in the study area have consequently hindered knowledge transfer on improved postharvest management.

4.3. Infrastructure and Transportation Constraints

Transportation infrastructure plays a vital role in market accessibility. In the study area, motorbikes and small vehicles were the predominant means of transportation, while animal-drawn or mechanized systems were rare (Figures 3 and 4).

Poor road conditions were widely cited as a major challenge affecting the movement of produce. Field data show that traveling approximately 50 km from remote villages to all-weather roads required 4–5 h by truck, with an additional one-hour waiting period-making a round trip a full day's task (Figure 5).



Figure 3. Means of transportation by: (a) Motorbike; (b) Small car.

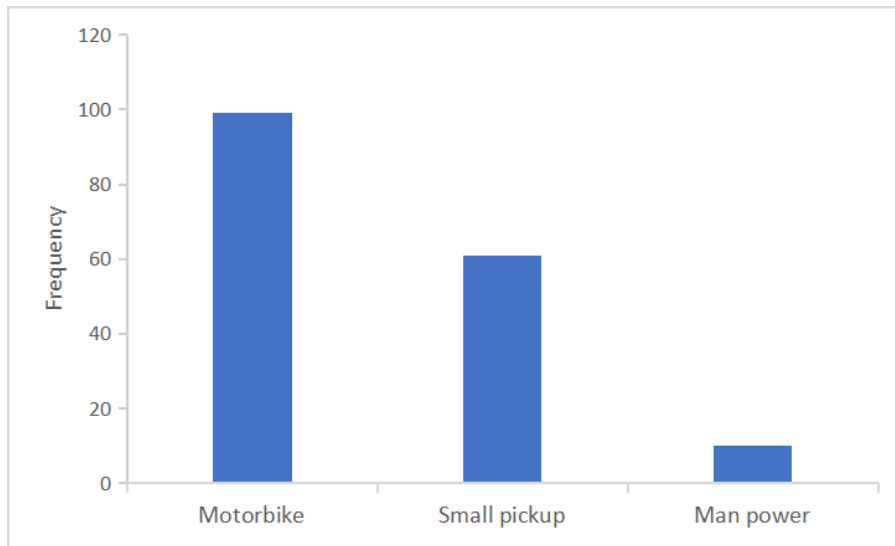


Figure 4. Predominant Transportation Methods.



Figure 5. Poor Road Conditions and Travel Challenges.

These findings are referenced by Juayire et al. and Abbey^[40,41], who emphasized that inadequate rural roads severely impede agricultural productivity and increase postharvest losses. Similarly, Ibrionke et al.^[42] reported that transportation inefficiencies account for 40–50% of vegetable losses in Nigeria. Poor roads not only prolong transit times but also subject produce to mechanical shocks and temperature fluctuations, accelerating spoilage.

Comparative literature suggests that improving rural roads could significantly reduce postharvest losses and stabilize market prices^[43,44]. Both advocate that investment in feeder roads directly correlates with higher farmgate prices and lower transaction costs.

The regression and chi-square analyses further substantiate these observations. There was a strong statistical relationship between road condition and postharvest loss ($\chi^2(2) = 165.73, p < 0.001$), consistent with quantitative evidence acknowledged by Githumbi et al. and Qange et al.^[45,46]. Regression results showed that poor road conditions, lack of storage, and longer distances were significantly associated with higher losses,

together explaining 90.1% of the variance in postharvest loss levels ($R^2 = 0.901$).

4.4. Storage Facilities and Postharvest Handling

Storage emerged as a major constraint in the study area. Almost all respondents (99%) lacked access to formal storage facilities (**Figure 6a**). Given Liberia’s average temperature (~30 °C) and high relative humidity (78–82%), the absence of cold or dry storage greatly increases perishability. These findings are acknowledged by Rutta and Yengnone^[47,48], who identified poor postharvest infrastructure as a key factor behind 15–35% produce losses in tropical regions.

Respondents indicated a strong preference (88%) for privately owned storage over cooperative systems (**Figure 6b**). Similar tendencies have been reported by van Klingeren et al.^[49], who attributed individual storage preferences to trust and control issues. However, studies from Rwanda and Tanzania^[50] show that cooperative storage models can enhance collective bargaining and reduce individual costs.

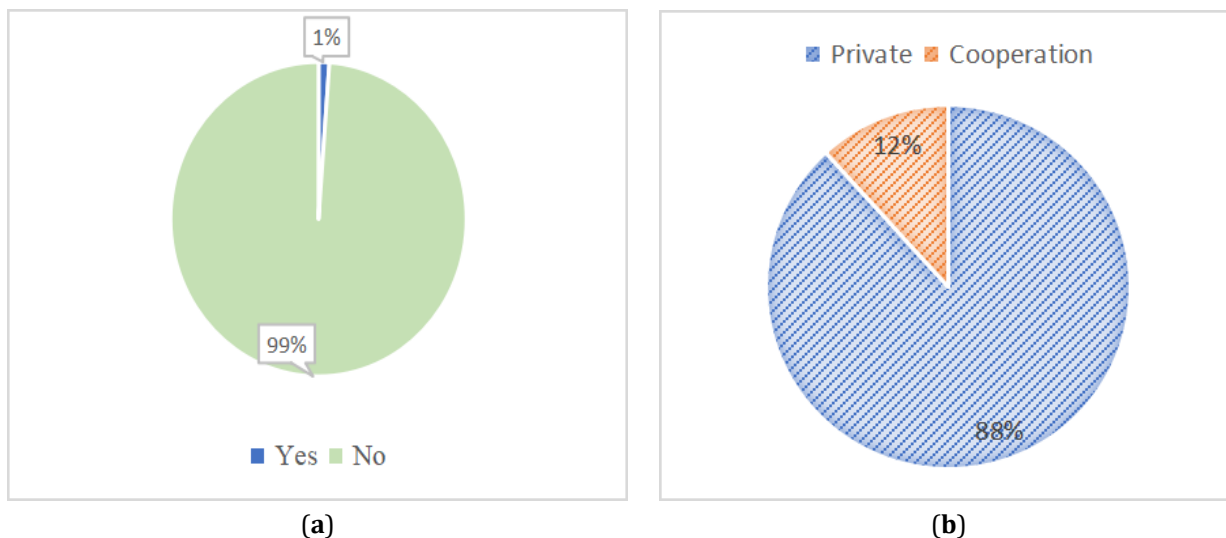


Figure 6. Access to and Preference for Storage Facilities. (a) Proportion of respondents with access to adequate storage facilities in the study area. (b) Distribution of private ownership types.

Source: Survey result, 2025.

High temperature and humidity create conditions conducive to microbial growth and tissue softening, accelerating deterioration^[51,52]. The widespread use of sacks and open-air storage further increases damage due to

compression and poor aeration. Similar practices have been observed by Okparavero et al.^[53] in Ghana and Nigeria, linking such methods to 20–30% quality losses.

Respondents’ sensory-based assessment of fresh-

ness-using color, texture, and taste-reflects a lack of objective grading systems or laboratory facilities, a trend acknowledged by Adegbola and Singbo^[54]. Consequently, price determination becomes subjective, re-

ducing farmers' bargaining power. **Table 3** shows that 44% perceived no significant price difference between fresh and stored produce, implying an underdeveloped quality-based pricing mechanism.

Table 3. Market Availability, Price Perception, and Consumption Frequency.

Item	Frequency	Percentage (%)
Mostly available fruits and vegetables in the market		
Fruits and vegetables are mostly kept for a little while in an open environment	69	40.59
Fruits and vegetables are partially damaged during transportation	31	18.24
Fruits and vegetables are usually kept in a refrigerator	6	3.53
Market price of fruits and vegetables		
Fruits and vegetables are sold for a comparable price	75	44.12
It depends on the demand and supply in the market	51	30.00
Fruits and vegetables are less expensive	28	16.47
Fruits and vegetables are more expensive	16	9.41
Vegetables and fruits consumption frequency by the respondents		
Everyday	44	25.88
Twice a week	79	46.47
3-4 times a week	47	27.65

Note: The *p*-value of the ANOVA test determines whether differences in means between variables and detailed production data are significant.

4.5. Qualitative Insights: Thematic Analysis of Interviews and FGDs

Thematic analysis identified four dominant themes: **transportation barriers, storage constraints, eco-**

nomic impact, and institutional support (Table 4). Participants consistently linked poor roads and high transport costs to rapid deterioration and income loss^[55,56]. Storage limitations and weak extension services were equally cited as critical drivers of loss.

Table 4. Postharvest Challenges: Themes, Sub-Themes, and Participant Quotes.

Theme	Sub-Theme	Illustrative Participant Quotes (Anonymized)
1. Transportation barriers	Poor road conditions	"During the rainy season, trucks cannot pass; the produce stays in the field and rots." (P3, Interview)
	Lack of reliable transport	"We often wait 2-3 days to get a vehicle; fruit is gone by then." (P7, FGD2)
	High transport costs	"Even when transport is available, fees double in rainy months and farmers cannot afford it." (P11, Interview)
2. Storage constraints	Inadequate formal storage	"There is no cold room or even a dry store in the district; we stack items under tarpaulins." (P1, FGD1)
	Poor on-farm handling	"We harvest in bulk but have no crates; fruits bruised on the way." (P5, Interview)
	Short storage duration	"We have at most 2-3 days before quality drops; that's not enough when markets are far." (P8, FGD3)
3. Economic impact	Income loss	"We lose up to half of the harvest-sometimes no profit at all." (P14, Interview)
	Market bargaining weakness	"Buyers exploit farmers when produce is near spoilage, reducing income." (P4, FGD2)
4. Institutional & government support	Weak extension services	"No one comes to show us improved storage or transport practices." (P2, Interview)
	Lack of investment	"Local government promises roads, but nothing happens; nothing changes." (P8, FGD1)

Note: Qualitative data were collected through 6 focus group discussions (FGDs; n ≈ 6-8 participants per FGD) and 20 key informant interviews with farmers, transporters, and market managers. Transcripts were coded using open, axial, and selective coding; themes and sub-themes below are presented with anonymized participant quotes (P = interview participant; FGD = focus group).

Participants' narratives complement the quantitative findings: poor road conditions significantly correlated with high loss levels ($r = 0.82, p < 0.001$). The combination of poor transport, long market distances, and a lack of cold storage causes both physical and financial losses. These insights are referenced from Kitinoja et al.^[57], who emphasized that infrastructural deficiencies, rather than solely poor handling practices, are the primary determinants of postharvest inefficiency in Africa.

4.6. Statistical Analysis of Postharvest Loss Factors

A chi-square test indicated a highly significant relationship between road condition and postharvest loss ($\chi^2(2) = 165.73, p < 0.001$), confirming that respondents reporting poor road conditions experienced higher losses (>25%). Pearson correlation analysis also showed a strong positive association between distance to market and percent loss ($r = 0.82, p < 0.001$). The multiple regression model ($F(3,166) = 504.2, p < 0.001, R^2 = 0.901$) revealed that poor roads, lack of storage, and longer distances significantly increased postharvest losses. These results mirror findings by Barrett et al.^[58], who reported similar correlations between distance and spoilage in Ethiopia, and by Marion et al.^[59] in Madagascar, who linked improved road access to reduced losses and higher farmer income.

4.7. Integration of Findings

Overall, the findings situate Liberia's postharvest challenges within broader regional trends. Infrastructural deficits, limited institutional support, and gendered labor dynamics collectively undermine the efficiency of horticultural value chains. The evidence supports calls by Flores Rojas et al.^[60] for integrated rural development policies that emphasize road rehabilitation, investment in cold storage, and gender-responsive capacity building. Strengthening cooperative models, improving access to market information, and adopting climate-resilient transport and storage technologies could significantly reduce postharvest losses and enhance livelihoods in Liberia's agricultural communities.

5. Conclusion and Recommendations

5.1. Conclusion

This study investigated the demographic, socioeconomic, and infrastructural factors influencing agricultural productivity and postharvest losses among smallholder farmers in the study area. The findings revealed that vegetable and fruit production constitute the primary agricultural activities, dominated largely by women. Despite their pivotal role, women's contributions remain underrecognized and under-supported, with limited access to training, credit facilities, and improved technologies. Most respondents were middle-aged, married, and had little or no formal education, reflecting a largely subsistence-oriented agricultural structure.

The study further established that poor transportation infrastructure, inadequate storage facilities, and long distances to markets are the major determinants of postharvest losses. Quantitative analyses confirmed strong correlations between these factors and the magnitude of produce deterioration. Regression results ($R^2 = 0.901$) demonstrated that road conditions, market distance, and lack of storage jointly accounted for over 90% of the variance in postharvest loss, highlighting infrastructural inefficiencies as a critical constraint.

Qualitative evidence complemented these findings: farmers' narratives emphasized that high transportation costs, delayed market access, and the absence of cold storage collectively contribute to significant physical and financial losses. Thematic insights further underscored the economic vulnerability of farmers, who often absorb losses without institutional compensation or technical assistance.

Overall, the study concludes that Liberia's postharvest management challenges stem not merely from individual practices but from systemic weaknesses in infrastructure, extension service delivery, and rural investment. Addressing these interrelated factors is essential to improving the resilience and profitability of agricultural value chains, enhancing food security, and promoting rural livelihoods.

5.2. Recommendations

Based on the study's findings, the following recommendations are proposed to policymakers, agricultural stakeholders, and development agencies:

1. **Rehabilitation of Rural Infrastructure:** Immediate investment is required to rehabilitate rural feeder roads and develop alternative transport systems that facilitate the timely movement of perishable produce. Improved infrastructure will significantly reduce spoilage and lower transaction costs for farmers.
2. **Establishment of Community-Based Storage Facilities:** Public-private partnerships should be encouraged to construct affordable, decentralized cold storage and warehouse facilities. Cooperative-based storage systems can enhance collective bargaining, ensure consistent product quality, and reduce postharvest losses.
3. **Strengthening Agricultural Extension Services:** The government and NGOs should expand agricultural extension coverage to provide training on improved harvesting, handling, and storage techniques. Gender-responsive approaches are particularly important to reach women farmers who dominate horticultural production.
4. **Promoting Access to Finance and Market Information:** Microfinance institutions and agricultural cooperatives should provide accessible credit schemes for smallholders. Digital market information platforms can help farmers make informed selling decisions and minimize losses due to market delays.
5. **Encouraging Research and Innovation in Postharvest Technologies:** Investment in research and locally adaptable postharvest technologies as solar-powered cold rooms, improved packaging materials, and mobile processing units-can enhance produce shelf life and quality.
6. **Gender Mainstreaming in Agricultural Policy:** Agricultural policies should explicitly address women's roles and constraints in postharvest management. Ensuring equitable access to resources, training, and decision-making will strengthen household

food security and income stability.

7. **Institutional Coordination and Policy Implementation:** The Ministry of Agriculture, local authorities, and development partners must coordinate interventions across the agricultural value chain. Integrated rural development strategies should align infrastructure development, market systems, and climate adaptation measures.

5.3. Recommendations for Future Research

1. **Comparative Regional Studies:** Future studies should compare postharvest management systems across different regions of Liberia to identify context-specific challenges and scalable best practices.
2. **Gender Dynamics and Decision-Making:** In-depth qualitative research is needed to explore intra-household gender dynamics, particularly how women's control over production and marketing decisions affects postharvest outcomes.
3. **Economic Impact Modelling:** Further quantitative research should estimate the direct and indirect economic costs of postharvest losses to national food security and GDP contribution.
4. **Technology Adoption and Behavioral Change:** Longitudinal studies examining farmers' willingness to adopt improved postharvest technologies, including solar drying, cold storage, and packaging innovations, would provide valuable policy insights.
5. **Climate Change and Postharvest Systems:** Given Liberia's vulnerability to climate variability, research should also focus on how temperature and rainfall patterns influence spoilage rates and the performance of existing storage systems.

Author Contributions

Conceptualization, methodology, software, validation, and formal analysis: F.G. and Z.P.; investigation, resources, data curation, writing—original draft preparation, writing—review, and editing: D.P.T.; visualization and supervision: O.I. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Ethical review and approval were waived for this study by the Central Agricultural Research Institute (CARI), Liberia, Institutional Review Board, because the research participants received verbal explanations. All procedures were limited to plant materials and managed under standard agronomic and laboratory conditions, which are exempt from IRB review.

Informed Consent Statement

Participants received verbal explanations of the study in their preferred local language. Participation was voluntary, with the option to withdraw at any time. Verbal consent procedures were approved by the Institutional Review Board of the Central Agricultural Research Institute (CARI), Liberia.

Data Availability Statement

All data and materials, as well as software applications or custom code, support our published claims and comply with field standards.

The data supporting the findings of this study are available upon reasonable request from the corresponding author. No publicly archived dataset was created due to the nature of the experimental work, which involved locally generated field and laboratory observations at the Central Agricultural Research Institute (CARI), Liberia. All raw measurements, processed data tables, and analytical files can be provided upon request, as there are no privacy or ethical restrictions preventing data sharing.

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Conflicts of Interest

The authors have no competing interest to declare that are relevant to the content of this article.

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