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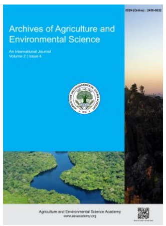

ORIGINAL RESEARCH ARTICLE

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Assessing the economic and environmental footprint of retail-level food loss: Evidence from Gauradaha Municipality, Nepal

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ABSTRACT

Food loss in vegetable markets creates economic losses and environmental pressure, especially in countries like Nepal where market infrastructure is still limited. This study examines the economic and environmental impacts of food loss in the retail vegetable market of Gauradaha Municipality, Jhapa district, Nepal. Primary data were collected from surveys of 20 vegetable vendors, supported by secondary data. The extent and causes of postharvest losses were analyzed, and economic losses were calculated using prevailing market prices. Environmental impacts were estimated using carbon and water footprint approaches based on life cycle assessment (LCA) methods. The results show that retailers experience an average economic loss of NPR 350.53 per week, representing approximately 5% of their income. Each retailer also faced an average environmental burden of 33.96 kg CO2-equivalent and a water footprint of 6,486.35 liters per week due to unsold and spoiled produce. The main causes of loss include over-ripening, loss of freshness, inadequate storage facilities, and insufficient packaging. The results suggest that practical measures such as improved storage, careful handling, and better packaging could help to reduce these losses. Reducing these inefficiencies could improve vendor income and lower environmental impacts, showing the importance of linking economic and sustainability aspects in local market systems.

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INTRODUCTION

Food Loss and Waste (FLW) refers to food that is lost, including inedible portions, along all stages of the food supply chain, from production to consumption (Adams *et al.*, 2019). In the study, food loss refers specifically to vegetables that fail to reach human consumption due to spoilage, rotting, or other forms of deterioration. After harvesting, agriculture produce passes through several stages, including transportation and storage under varying environmental conditions, before reaching retail markets. For perishable commodities such as fruits and vegetables, significant postharvest losses occur during handling, transportation, storage, and distribution, reducing per capita availability, increasing marketing costs, and causing financial losses for both farmers and traders. At the global level, food loss remains a serious issue, with about one-third of food produced for human consumption, around 1.3 billion tons, being lost or wasted annually (Gustavsson *et al.*, 2011). Fruits and vegetables are particularly susceptible to postharvest losses. These losses reduce food availability and also waste important resources such as water, land, and energy, while contributing to greenhouse gas emissions. Therefore, reducing food loss is important for achieving the Sustainable Development Goals (SDGs), particularly Goal 2 (Zero Hunger) and Goal 12 (Responsible Consumption and Production), which aim to halve per capita food waste and reduce losses across supply chains by 2030 (United Nations, 2019).

In Nepal, postharvest vegetable losses are estimated to range from 20-50%, mainly due to inadequate storage facilities, poor handling practices, and inefficient transportation systems

(Gautam & Bhattarai, 2006). These losses reduce the incomes of farmers and traders, increase food prices, and limit food availability in markets. In addition to economic impacts, food loss leads to inefficient use of natural resources such as water, land, and labor, and contributes to environmental degradation through the generation of greenhouse gases during decomposition. Vegetable markets in Nepal play a crucial role in the agricultural marketing system but are often constrained by infrastructural limitations, technological gaps, and inefficient handling practices. Improper harvesting, inadequate storage, physical damage during transportation and packaging, and microbial spoilage significantly affect product quality, leading to reduced shelf life and increased losses. While global and regional studies provide general insights into food loss, localized, quantitative assessments in developing countries, particularly at the retail level, remain limited.

However, there is still limited data on the economic and environmental impacts of vegetable loss at the retail level in Nepal, and the scale and causes of vegetable loss in local level are poorly documented. Therefore, this study aims to assess the economic and environmental impacts of food loss in the retail vegetable market of Gauradaha Municipality, Jhapa District. Study quantifies postharvest losses, estimates their economic cost, and evaluates carbon and water footprint impacts and identifies the key factors contributing to these losses.

MATERIALS AND METHODS

Study area

The study was conducted in Gauradaha Municipality, located in Jhapa District of eastern Nepal. The municipality serves as an important local agricultural market connecting farmers and consumers. However, the market is characterized by limited infrastructure, inadequate storage facilities, and inefficient handling practices, which contribute to significant postharvest vegetable losses. As a representative semi-urban market, Gauradaha provides a suitable context for analyzing food loss at the retail level.

Research design

This study used a descriptive and analytical research design to examine the economic and environmental effects of food loss in the vegetable markets. A mixed-method approach was employed, integrating quantitative survey data with qualitative insights to better understand the causes and implications of postharvest losses.

Data collection and data types

Both primary and secondary data were used in this study. Pre assessment was conducted to identify the retail stores. From the assessment, 20 stores involved in fresh vegetable and fruit trade were recognized. Data were collected during April 2025 using a structured questionnaire. Purposive sampling was used to select retailers actively engaged in vegetable trading. The survey captured information on types of vegetables sold, quantity of spoilage, frequency of losses, and prevailing retail prices. Secondary data were obtained from municipal reports, the Ministry of Agriculture and Livestock Development (MoALD), FAO publications, and ISO guidelines.

Data analysis

Garrett's ranking method was applied to prioritize the causes of food loss (Garrett, 1969), as it helps convert respondents' rankings into meaningful priority scores to identify the most important causes of food loss. The Kruskal-Wallis rank sum test, a non-parametric statistical test, was used to examine differences in food loss across categories such as packaging type, education level, and storage methods (Kruskal & Wallis, 1952), as it is suitable for small sample sizes and non-normally distributed or ordinal data. All local measurement units were converted into standard scientific units for analysis.

Economic and environmental evaluation of food loss

Economic analysis

For economic valuation, the retail prices of fruits and vegetables in the Gauradaha market were collected for the specific study week to determine the weekly economic value (EV) of loss using the formula:

$$\text{EV} = \text{Quantity lost per week (kg)} \times \text{Retail price per kg (NPR)}$$

Environmental analysis

The environmental impact of food loss was assessed using carbon and water footprint approaches based on life cycle assessment (LCA) following ISO 14040 guidelines (ISO, 2006). The carbon footprint was expressed as Global Warming Potential (GWP) in kg CO_2-equivalent per kg of food lost, using emission factors from published LCA databases and literature. Water footprint values were estimated using standard LCA-based coefficients, representing freshwater use associated with vegetable production and supply chains FAO, 2013).

Integrated EN–EC footprint index

To evaluate the combined economic and environmental impact, this study applied a normalized index termed the EN–EC Footprint Index (Bahramian *et al.*, 2025), which integrates both dimensions as follows:

$$\text{EN} - \text{EC Footprint Index} = \sum[(\text{WFP} + \text{GWP}) + \log_{10}\text{W})]$$

In this model, WFP represents the water footprint, GWP denotes the greenhouse gas emissions (kg CO_2-eq), and W is the total weight of lost products (kg). The logarithmic transformation was applied to normalize weight variation across observations.

RESULTS AND DISCUSSION

Food loss impact by category

Table 1 presents the estimation of economic and environmental impacts due to vegetable loss. The results indicate higher economic losses for fruits compared to vegetables. This disparity is mainly attributed to the higher unit value and faster perishability of fruits at the retail stage. In addition, a considerable amount of loss may remain unrecorded, particularly for fresh produce. This finding is consistent with Eriksson *et al.* (2012), who reported that recording gaps are common in retail environments, particularly for highly perishable products. Similar recent studies also confirm that fruits generally experience higher postharvest losses due to faster physiological deterioration and weak cold chain systems (Kasso & Bekele, 2020; Kitinoja & Kader, 2021).

Impact of food loss on retailers

Retailers experienced an average weekly economic loss of NPR 350.53, accounting for 5% of their weekly income (Table 2). Although this percentage is lower than the 20–50% farm-to-fork losses reported by Gautam & Bhattarai (2006), it represents a significant loss of embedded value since retail produce has already incurred transport, handling, and marketing costs. Environmentally, the loss of 33.96 kg CO_2-eq and 6,486.35 liters of water per retailer per week indicates substantial wastage of embedded natural resources from upstream production. In Nepal's context of increasing climate vulnerability, this level of irrigation water loss highlights the importance of improving postharvest efficiency at the retail level. Recent FAO assessments further emphasize that food losses at retail stage significantly increase the carbon and water footprint of food systems in developing countries (FAO, 2021).

Transportation, packing, and storage information

Modes of transportation

The majority of vegetable retailers (55%) used auto/rickshaws for transportation, followed by pick-up vehicles (20%), while a smaller proportion relied on walking or bicycles (10%). Auto/rickshaws were the most commonly used mode due to their convenience and cost-effectiveness under local market conditions.

Packaging practices

Plastic crates were the most commonly used packaging materials (40%), followed by plastic sacks (30%), jute sacks (25%), and wooden crates (20%) (Table 3). The preference for plastic crates may be due to their durability and reusability, which reduces mechanical damage during transport. The Kruskal-Wallis test indicated no statistically significant difference in total vegetable waste across packaging types ($p > 0.05$). This may be due to the dominance of temperature-related spoilage rather than mechanical damage. Packaging improvements alone have limited impact on reducing postharvest losses in perishable supply chains without adequate temperature control and handling systems (Arah *et al.*, 2016).

Table 1. Economic and environmental cost of food loss by category in Gauradaha.

Food category	Economic value per annum (NPR)	Environment	
		CO_2 (kg/kg food production)	Water (liter/ kg)
Fruits	33963.33	167.87	38675.23
Vegetable	17564	511.67	91051.80
Total	51527.33	679.54	129727

Table 2. Average food loss and its economic and environmental effects.

Factor	Economic value per week (NPR)	Economic value per year (NPR)	Environment		EC/EN footprint index	Percentage of income (%)
			CO_2-eq (kg CO_2-eq/ kg food production/ week)	Water (liter/ kg food production/ week)		
Avg. Food loss per retailer	350.53	18227.36	33.96	6486.35	0.09	5

Table 3. Relationship between packaging practices and food loss among vegetable retailers.

Variables	Sub category	Frequency	Relation with food wastage (*p-value*)
Packaging type	Wooden crates	4(20)	0.13
	Plastic sacks	6(30)	
	Plastic crates	8(40)	
	Jute sacks	5(25)	
	Cardboard boxes	2(10)	

Table 4. Storage techniques in relation to food loss among vegetable retailers.

Variables	Sub category	Frequency	Relation with food wastage (*p-value*)
Method to storage	Spraying water	15(75)	0.06
	Well-ventilated baskets or crates	2(10)	
	Cool storage	2(10)	
	Sacks or cloth covers	1(5)	

Note: Figures in parentheses indicate the percentage.

Table 5. Garrett ranking of food loss factors.

Causes	Garrett value	Rank
Overripe or damaged produce	1255	I
Dehydration or loss of freshness	1255	II
Inadequate storage practices	1200	III
Limited access to modern packaging technology	1190	IV
Lack of efficient sorting and grading facilities	1170	V

Post-harvest storage methods

Most respondents (75%) used water spraying to maintain vegetable freshness. A smaller proportion used well-ventilated containers (10%) and cool storage facilities (10%), while only 5% used sacks or cloth covers. This reflects reliance on traditional, low-cost preservation methods due to limited access to improved storage infrastructure. The Kruskal-Wallis test indicated weak statistical evidence of variation in total vegetable waste across storage methods (Table 4), suggesting that storage practices alone do not significantly influence overall postharvest losses ($p > 0.05$). This indicates that other factors, particularly temperature conditions and handling practices, play a more decisive role. This finding is consistent with evidence that, in the absence of cold chain infrastructure, traditional storage methods have limited effectiveness for perishable commodities (Kitinoja & Kader, 2021).

Ranking of major causes of food loss

The Garrett ranking identified over-ripening and dehydration as the primary causes of food loss (Table 5). This aligns with the widespread use of water spraying (75%) to control moisture loss. However, such practices may also increase microbial spoilage under humid conditions in the absence of temperature control. These findings are consistent with regional evidence indicating that inadequate postharvest infrastructure is a major driver of fruit and vegetable losses in South Asia (FAO, 2021), reinforcing that infrastructural constraints are the dominant factors of food loss in the study area rather than individual retailer practices alone.

Conclusion

Food loss in the vegetable market of Gauradaha Municipality mainly occurred due to over-ripening, loss of freshness, and poor storage and handling practices. These factors resulted in financial losses for local retailers, reducing their income and affecting overall market efficiency. Reducing food loss at the retail level is important for improving vendor livelihoods, strengthening food security, and reducing environmental impacts associated with wasted resources. Improved postharvest handling, better packaging, and improved transportation systems can help reduce losses and extend product shelf life. The study is limited by underreporting and incomplete record-keeping, a relatively small sample size, and its focus on a single municipality. In addition, the short observation period may not adequately capture seasonal variations in food loss patterns. Overall, reducing food loss at the market level is essential for improving efficiency, support sustainability, and contributing to food security within Nepal's agri-food system.

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DECLARATIONS

Authors contribution

Conceptualization: P.K., R.B., and B.T.; Methodology: P.K. and B.T.; Software and validation: P.K., R.B., and B.T.; Investigation: P.K., R.B., and B.T.; Data curation: P.K. and R.B.; Writing-original draft preparation: P.K.; Writing-review and editing: P.K. and B.T.; Supervision: B.T. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare no conflict of interest.

Ethics approval: This study involved survey data from retailers; however, no personal or sensitive information was collected, and ethical approval was not required.

Consent for publication: All co-authors gave their consent to publish.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: No supplementary data is available for the paper.

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