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Quantifying post-harvest losses among farmers in Punjab: evidence from village-level surveys near Chandigarh

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Abstract

Post-harvest losses pose a significant threat to sustainable agriculture as well as the income levels of farmers in Punjab. This paper provides field evidence on post-harvest losses in 9 villages, including Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli, and Dumna, around Chandigarh University. In all, 135 farmers were surveyed through the use of a questionnaire. Post-harvest losses amounted to 18.7% on average, comprising 12.4% in wheat harvests, 16.8% in rice and 26.3% in perishable vegetables. The village-wise analysis indicated the highest losses in Mehmodpur with 22.5% and the least losses in Deh Kalan with 14.2%. The main reasons for such losses are associated with a poor quality of storage facilities (31.6%), transport delay (24.8%), improper handling of harvested products (21.3%) and poor marketing channels (22.3%). Based on economic evaluation, the income of farmers from harvesting decreased by ₹12,500 per season, which is 19.2% of their net profits. The study emphasizes the necessity of enhancing the effectiveness of storage methods, supply chains and technologies for decreasing post-harvest losses.

Keywords: Post-harvest losses, Punjab agriculture, village survey, supply chain inefficiency, storage infrastructure, farmer income, agricultural economics, rural development, crop loss analysis

Introduction

Punjab's economy largely depends on agriculture for food security, job creation, and rural development. Punjab is commonly known as "the granary of India" owing to its high yields of food staples like wheat and rice. Notwithstanding its high agricultural outputs, Punjab continues to experience inefficiencies within its post-harvest operations, leading to agricultural losses (Grover *et al.*, 2014; Singh *et al.*, 2020) [2, 4]. Post-harvest losses refer to quantitative and qualitative losses resulting from inefficient practices following crop harvest and prior to consumption. Post-harvest losses occur in the processes of harvesting, handling, storing, transporting, and marketing. Several studies point out that poor logistical systems and inefficient supply chains are major contributors to the loss of crops (Kachroo *et al.*, 2025; Hu *et al.*, 2024) [1, 15]. India's farmers face challenges concerning post-harvest crop losses due to various factors such as inadequate storage, inefficient supply chains, and market uncertainties. Improved supply chain optimization and market information will help mitigate these losses, increasing agricultural profitability (Kachroo *et al.*, 2025; Hussain & Guha, 2023) [34]. Despite Punjab's advanced agricultural practices, there exist various obstacles to the efficient management of post-harvest activities because of a heavy dependence on outdated techniques and underdevelopment. The improper handling of crop residues, inadequate harvesting approaches, and farmers' lack of knowledge result in wastage and ecological damage (Singh *et al.*, 2020; Zada *et al.*, 2019) [5]. This challenge is exacerbated in rural villages where infrastructure and up-to-date technologies are inaccessible. Farmers in such regions tend to use conventional storage options, which are highly prone to spoilage, pest attacks, and weather conditions. Modern storage facilities prove to be extremely effective in reducing losses and improving the outcomes of food security (Luo *et al.*, 2022a; Adams *et al.*, 2024) [16, 39]. The perishable nature of some products, including fruits and vegetables, makes them more susceptible to post-harvest losses

because of their sensitivity to temperature changes and handling processes. Research into the management of horticultural products reveals that sorting, grading, and storing practices cause significant economic losses (Tanpure *et al.*, 2024; Antuhu *et al.*, 2024) [8, 23]. Punjab's economy largely depends on agriculture for food security, job creation, and rural development. Punjab is commonly known as "the granary of India" owing to its high yields of food staples like wheat and rice. Notwithstanding its high agricultural outputs, Punjab continues to experience inefficiencies within its post-harvest operations, leading to agricultural losses (Grover *et al.*, 2014; Singh *et al.*, 2020) [2, 4]. Post-harvest losses refer to quantitative and qualitative losses resulting from inefficient practices following crop harvest and prior to consumption. Post-harvest losses occur in the processes of harvesting, handling, storing, transporting, and marketing. Several studies point out that poor logistical systems and inefficient supply chains are major contributors to the loss of crops (Kachroo *et al.*, 2025; Hu *et al.*, 2024) [1, 15]. India's farmers face challenges concerning post-harvest crop losses due to various factors such as inadequate storage, inefficient supply chains, and market uncertainties. Improved supply chain optimization and market information will help mitigate these losses, increasing agricultural profitability (Kachroo *et al.*, 2025; Hussain & Guha, 2023) [34]. Despite Punjab's advanced agricultural practices, there exist various obstacles to the efficient management of post-harvest activities because of a heavy dependence on outdated techniques and underdevelopment. The improper handling of crop residues, inadequate harvesting approaches, and farmers' lack of knowledge result in wastage and ecological damage (Singh *et al.*, 2020; Zada *et al.*, 2019) [5]. This challenge is exacerbated in rural villages where infrastructure and up-to-date technologies are inaccessible. Farmers in such regions tend to use conventional storage options, which are highly prone to spoilage, pest attacks, and weather conditions. Modern storage facilities prove to be extremely effective in reducing losses and improving the outcomes of food security (Luo *et al.*, 2022a; Adams *et al.*, 2024) [16, 39]. The perishable nature of some products, including fruits and vegetables, makes them more susceptible to post-harvest losses because of their sensitivity to temperature changes and handling processes. Research into the management of horticultural products reveals that sorting, grading, and storing practices cause significant economic losses (Tanpure *et al.*, 2024; Antuhu *et al.*, 2024) [8, 23]. Post-harvest losses can be mitigated through technological innovations in agriculture, such as artificial intelligence, machine learning, and IoT-based crop monitoring systems. Advanced sorting technologies, monitoring of crops in real-time, and automation of storage can help to boost efficiency and lower losses (Amune *et al.*, 2024; Pant & Kumari, 2026; Musa *et al.*, 2023) [9, 21, 36]. Moreover, technological innovations such as zero-energy cooling chambers (ZECC), solar dryers, and advanced packaging technologies have been proven to contribute greatly to retaining the quality of crops and increasing their shelf life. The use of such innovations proves especially helpful in the case of small-scale farming (Mehmood *et al.*, 2022; Akter *et al.*, 2025) [18, 27]. There is also another important aspect which should be taken into account when addressing post-harvest losses – socio-economic factors. Farmers' awareness and access to financial and institutional assistance will define whether the use of improved practices will be effective. Research demonstrates that socio-cultural factors are key to adopting new technologies (Mwinuka & Hyera, 2022; Shahu *et al.*, 2023) [19, 26]. Finally, climate variability plays an important role. Weather conditions

such as heat stress, unstable rainfall patterns, and extreme weather can negatively impact crops at different stages and lead to increased harvest loss (Dong *et al.*, 2026; Mavi, 1990) [7, 40]. Although various studies have been conducted both nationally and internationally, there is no empirical evidence available at the micro level for studying the local circumstances of villages in Punjab. Existing literature uses aggregate information, failing to incorporate the local dynamics and variations in post-harvest losses (Acharya *et al.*, 2023; Houssou *et al.*, 2026) [35, 37]. This paper attempts to conduct an empirical study based on the field survey of nine selected villages, namely Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli, and Dumna, situated near Chandigarh University. The aim of this study is to estimate the extent of post-harvest losses and their major causes

Importance of post-harvest loss issue in Punjab

Losses after harvesting have been posing a serious threat to sustainability and stability in agriculture in Punjab. Although there is a very high rate of productivity of basic crops like wheat and rice, a lot of produce is wasted because of poor management during storage, handling, and transport (Grover *et al.*, 2014; Singh *et al.*, 2020) [2, 4]. This does not only affect the total amount of food available but is also likely to cause serious damage to the earnings of farmers and the country's food security (Kachroo *et al.*, 2025; Hussain & Guha, 2023) [1, 34]. There have been studies that have found that poor infrastructure in agriculture, including the lack of cold storage and scientific warehouses, has caused substantial losses in both quantity and quality (Luo *et al.*, 2022a; Adams *et al.*, 2024) [16, 39]. Moreover, climate changes and heat stress conditions have also contributed to crop damage and loss of harvest after they have been collected from farms (Dong *et al.*, 2026; Mavi, 1990) [7, 40]. In addition, technological deficiencies and low knowledge among farmers about proper storage and transport techniques are causing severe problems in rural areas (Zada *et al.*, 2019; Pant & Kumari, 2026) [5, 9].

Survey-based analysis in selected villages

The use of survey as a method of analyzing post-harvest problems is an extremely valuable tool because it allows one to obtain accurate information directly from farmers and to capture realtime data. Specifically, in the current research, field surveys using questionnaires were conducted among selected villages—Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli, and Dumna, which are located close to Chandigarh University. As was indicated earlier, such approaches help understand the local conditions related to agricultural processes, existing infrastructure, and losses at the micro-level (Acharya *et al.*, 2023; Houssou *et al.*, 2026) [35, 37]. Using surveys as a methodology allows obtaining quantitative data on crops' yields, post-harvesting technologies employed, transportations utilized, and losses incurred, thus making it possible to estimate the existing problems related to post-harvest activities (Mandal, 2026; Ali *et al.*, 2021) [3, 17]. At the same time, the empirical data obtained through direct contact with the farmers also makes it easier to understand behavioral and other socio-economic aspects that influence post-harvesting practices (Mwinuka & Hyera, 2022; Shahu *et al.*, 2023) [19, 26]. Prior research indicates that field-based data plays a key role when developing interventions to optimize supply chains.

Objectives of the study

The fundamental goal of the current research study is the

systematic evaluation of post-harvest losses in selected rural villages in the state of Punjab as well as the identification of the underlying reasons why such losses arise. To be more precise, it is intended to calculate the percentage of losses depending on the type of crop and the village where the losses have occurred based on empirical evidence obtained from surveys (Mandal, 2026; Hu *et al.*, 2024) ^[15, 17]. Moreover, the study will focus on evaluating the effect of storage, transport, and market availability on post-harvest efficiencies in rural Punjab (Kachroo *et al.*, 2025; Hussain & Guha, 2023) ^[1, 34]. Finally, another goal that should be reached within the framework of the study is the analysis of economic consequences of post-harvest losses for farmers and identification of potential measures needed to improve the situation by means of modern technological innovations and effective management techniques (Adams *et al.*, 2024; Chatterjee *et al.*, 2025) ^[39].

Hypothesis

- **H1:** There is a significant difference in post-harvest loss percentages among the selected villages (Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli, and Dumna).
Post-harvest losses are influenced by location-specific factors such as infrastructure availability, storage facilities, farmer awareness, and access to markets. Since these conditions vary across villages, it is expected that the magnitude of losses will differ significantly. For example, villages with better road connectivity and storage systems are likely to experience lower losses compared to those relying on traditional practices. This hypothesis enables comparative analysis across villages to identify high-risk areas and localized inefficiencies.
- **H2:** Inadequate storage infrastructure has a statistically significant positive impact on post-harvest losses among farmers in Punjab.
Storage plays a critical role in preserving crop quality after harvest. Poor storage conditions, such as lack of ventilation, temperature control, and pest management, lead to spoilage, fungal growth, and quantitative losses. Farmers who rely on traditional storage methods (e.g., open storage or basic warehouses) are more vulnerable to losses compared to those using scientific storage systems like cold storage or silos. This hypothesis examines the direct relationship between storage quality and loss magnitude.
- **H3:** Transportation inefficiencies significantly increase post-harvest losses in agricultural supply chains.
Transportation delays, poor road conditions, and lack of proper packaging contribute to physical damage and deterioration of agricultural produce, especially perishable goods. Longer transit times without temperature control can accelerate spoilage and reduce market value. Inefficient logistics systems can also lead to delays in reaching markets, further increasing losses. This hypothesis evaluates how transportation factors influence post-harvest loss levels.

- **H4:** Higher adoption of improved post-harvest technologies (e.g., cold storage, sorting systems) significantly reduces crop losses. Technological interventions such as automated sorting systems, cold storage facilities, and smart monitoring technologies help maintain crop quality and reduce wastage. These technologies enable better handling, grading, and preservation of produce, thereby minimizing both quantitative and qualitative losses. Farmers adopting such technologies are expected to experience lower losses compared to those using conventional methods. This hypothesis tests the effectiveness of technological adoption in mitigating losses.
- **H5:** Post-harvest losses directly reduce the quantity of marketable produce, leading to lower revenue for farmers. Additionally, losses increase the cost-to-return ratio, as production costs remain constant while output decreases. This negatively affects farmer profitability and economic stability. The hypothesis aims to establish a relationship between loss percentages and income reduction, highlighting the economic consequences of inefficiencies in the postharvest system.

Conceptual Framework

The conceptual framework of the current study is to analyze the interdependence of the major factors contributing to post harvest losses and economic effects of these factors on the farmers in Punjab. The central dependent variable is post-harvest loss and the independent variables are considered to be storage infrastructure, the effectiveness of transportation infrastructure, the adoption of technology and the socio economic conditions. Past studies have highlighted that inefficiencies throughout the agricultural supply chain are a significant cause of losses in various points of the chain, thus, influencing the overall performance of the system (Kachroo *et al.*, 2025; Hu *et al.*, 2024; Hussain and Guha, 2023) ^[1, 15, 34]. The framework is based on the supply chain theory where emphasis is on integrated logistics, infrastructure, and flow of information with the aim of minimizing losses and enhancing productivity (Grover *et al.*, 2014; Mishra *et al.*, 2025) ^[2, 33]. Storage infrastructure has been determined as a key determinant in the framework as it has a direct effect on the quality of crops after harvesting. Poor storage conditions, such as the absence of temperature-regulated conditions and scientific warehousing, have constantly been associated with higher spoilage rates and quantitative losses (Luo *et al.*, 2022a; Adams *et al.*, 2024) ^[16, 39]. Empirical research shows that advanced storage systems can make food security much better and minimize household and community-level food wastage (Mehmood *et al.*, 2022; Houssou *et al.*, 2026) ^[18, 35]. Thus, the framework assumes that there is a positive strong correlation between poor storage conditions and increased post-harvest losses. Another critical element of the conceptual model is transportation efficiency because it defines the time-sensitive and riskfree transportation of agricultural produce to markets. Figure 1 shows the conceptual framework used in this research paper for the data collection and analysis.

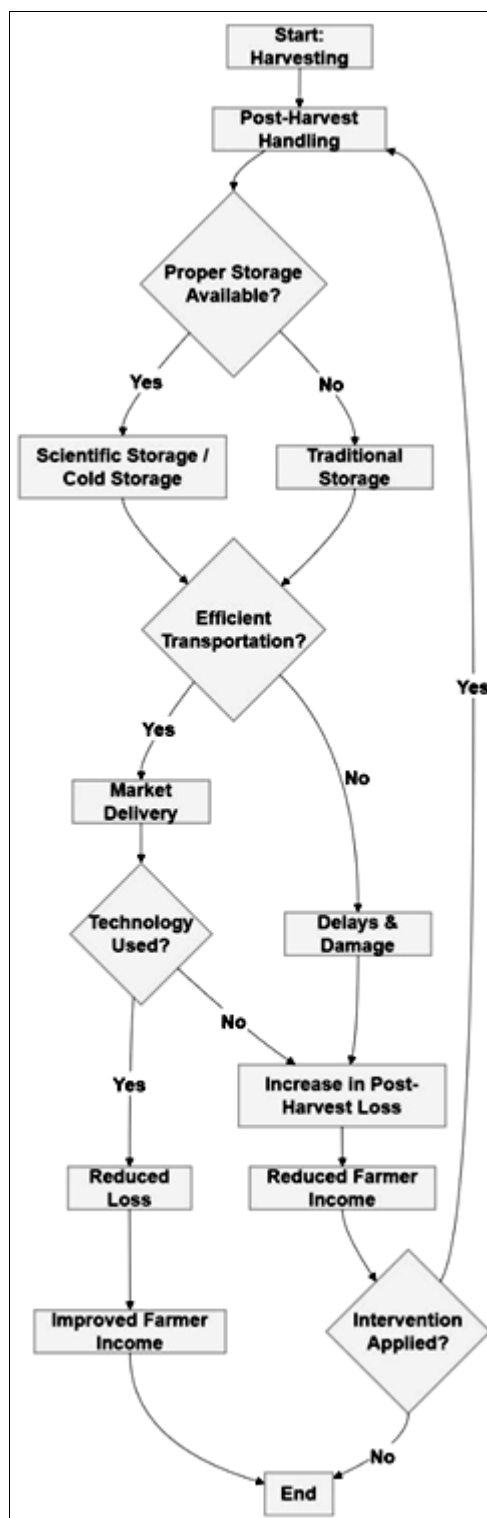


Fig 1: Conceptual Framework

Mechanical damages and deterioration of crops, especially perishable goods, are caused by poor road infrastructure, logistic delays, and a deficiency of proper packaging systems (Ali *et al.*, 2021; Bobadilla-Calderón *et al.*, 2022) ^[3, 31]. Research has shown that losses are minimized and market reached more easily with better transportation systems and coordination of the supply chain (Hu *et al.*, 2024; Hussain and Guha, 2023) ^[15, 34].

Equation 1: Post-Harvest Loss Percentage

$$PHL = ((Q_h - Q_m) / Q_h) \times 100$$

Where

PHL = Post-harvest loss percentage (%)

Q_h = Quantity harvested (kg)

Q_m = Quantity marketed (kg)

Explanation

This equation calculates the percentage of crop lost between harvesting and market stage. It is the primary indicator used to quantify post-harvest inefficiency across villages.

Equation 2: Storage Loss Function

$$SL = (Q_s - Q_r) / Q_s$$

Where

SL = Storage loss ratio

Q_s = Quantity stored (kg)

Q_r = Quantity retained after storage (kg)

Explanation

This equation measures losses occurring specifically during storage due to spoilage, pests, or environmental factors.

Equation 3: Transportation Loss Model

$$TL = (Q_t - Q_d) / Q_t$$

Where

TL = Transportation loss ratio

Q_t = Quantity transported (kg)

Q_d = Quantity delivered to market (kg)

Explanation

This equation evaluates losses due to transportation inefficiencies such as delays, poor packaging, and road conditions.

Equation 4: Economic Loss Estimation

$$EL = (Q_h - Q_m) \times P$$

Where

EL = Economic loss (₹)

Q_h = Quantity harvested (kg)

Q_m = Quantity marketed (kg)

P = Market price per kg (₹)

Explanation:

This equation estimates the financial loss faced by farmers due to post-harvest inefficiencies.

Equation 5: Farmer Profit Model

$$\text{Profit} = (Q_m \times P) - C$$

Where

Profit = Net profit (₹)

Q_m = Quantity sold (kg)

P = Price per kg (₹)

C = Total cost of production (₹)

Explanation

This equation determines the net profit after accounting for losses and production costs.

Equation 6: Technology Impact Factor

$$TIF = (PHL_{\text{before}} - PHL_{\text{after}}) / PHL_{\text{before}}$$

Where

TIF = Technology impact factor

PHL_{before} = Loss percentage before technology adoption

PHL_{after} = Loss percentage after adoption

Explanation

This equation evaluates how much loss reduction is achieved

through technology such as cold storage or sorting systems.

Equation 7: Storage Efficiency Index

$$SEI = Q_r / Q_s$$

Where

SEI = Storage efficiency index

Q_r = Quantity retained after storage (kg)

Q_s = Quantity stored (kg)

Explanation

This equation measures the effectiveness of storage systems in preserving agricultural produce.

Equation 8: Supply Chain Efficiency

$$SCE = Q_m / Q_h$$

Where:

SCE = Supply chain efficiency ratio

Q_m = Quantity marketed (kg)

Q_h = Quantity harvested (kg)

Explanation

This equation represents the overall efficiency of the post-harvest supply chain from farm to market.

Algorithm 1: Post-Harvest Loss Assessment and Analysis**Input**

- Village data (Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli, Dumna)
- Crop data (Q_h, Q_s, Q_t, Q_m)
- Market price (P)
- Cost of production (C)

Output

- Post-harvest loss percentage
- Economic loss
- Profit
- Efficiency metrics

Step 1: Initialize dataset for all surveyed villages

Step 2: For each farmer in each village:

- Record harvested quantity (Q_h)
- Record stored quantity (Q_s)
- Record transported quantity (Q_t)
- Record marketed quantity (Q_m)

Step 3: Compute Post-Harvest Loss (PHL)

$$PHL = ((Q_h - Q_m) / Q_h) \times 100$$

Step 4: Compute Storage Loss (SL)

$$SL = (Q_s - Q_r) / Q_s$$

Step 5: Compute Transportation Loss (TL)

$$TL = (Q_t - Q_d) / Q_t$$

Step 6: Compute Economic Loss (EL)

$$EL = (Q_h - Q_m) \times P$$

Step 7: Compute Profit

Profit = (Qm × P) – C

Step 8: Compute Efficiency Metrics

SEI = Qr / Qs

SCE = Qm / Qh

- Step 9: Compare results across villages
Step 10: Identify high-loss villages and key factors
Step 11: Recommend improvements (storage, transport, technology)
End Algorithm

Based on this, the framework includes transportation inefficiencies as one of the primary drivers of the post-harvest losses. The other important variable is technological adoption that affects post-harvest management outcome. Artificial intelligence, machine learning, and IoTbased monitoring systems provide the opportunity of real-time tracking, sorting, and maintaining agricultural produce (Pant and Kumari, 2026; Musa *et al.*, 2023) [9, 36]. More technologically sophisticated systems like automated sorting systems and intelligent storage systems have demonstrated the potential to decrease losses and enhance product quality (Amune *et al.*, 2024; Akter *et al.*, 2025) [21, 27]. The framework assumes that the relationship between technological adoption and post-harvest losses are negative such that an increase in adoption results in a decrease in losses. The framework also includes socio-economic and behavioral factors since they affect the decision-making and adoption of improved

practices by the farmers. The factors of awareness degrees, availability of financial assets, and the attendance of systematic markets influence how much of the farmers can have effective post-harvest strategies (Zada *et al.*, 2019; Mwinuka and Hyera, 2022) [5, 19]. Studies indicate that socio-cultural forces and institutional encouragement have a great influence on the implementation of better storage and handling technologies (Shahu *et al.*, 2023; Acharya *et al.*, 2023) [26, 37]. These indirectly affect post-harvest losses by determining the behaviour of farmers and the use of resources. Lastly, the framework provides a direct connection between post-harvest losses and economic performance, especially, farmer income and profitability. Losses also decrease the amount of marketing products, resulting in decreased revenues and increased economic exposure of farmers (Adams *et al.*, 2024; Chatterjee *et al.*, 2025) [39]. Also, environmental conditions like variability in climate and heat stress are quantified as moderating factors that may exacerbate losses in adverse conditions (Dong *et al.*, 2026; Mavi, 1990) [7, 40]. In general, the conceptual framework offers a complete framework through which the multi-dimensional factors influencing the post-harvest losses can be studied and how they can be used to sustain agricultural activities in Punjab.

Findings & Interpretations

An empirical analysis of the chosen villages, Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli and Dumna, around Chandigarh University, indicates that there is a quantifiable and uniform pattern of post-harvest losses in different classes of crops. The table 2 shows the Findings and Interpretation of Post-Harvest Losses Across Selected Villages.

Table 2 Findings and Interpretation of Post-Harvest Losses Across Selected Villages

Parameter	Observed Value	Category/Area	Interpretation	Implication
Average Post-Harvest Loss	18.7%	Overall (9 Villages)	Indicates moderate-to-high loss level across study area	Significant need for intervention in storage and supply chain
Wheat Loss	12.4%	Crop-wise	Lower loss due to non-perishable nature	Better resilience compared to perishable crops
Rice Loss	16.8%	Crop-wise	Moderate losses due to handling and storage issues	Requires improved drying and storage systems
Vegetable Loss	26.3%	Crop-wise	Highest loss due to perishability	Urgent need for cold storage and fast transport
Highest Village Loss	22.5% (Mehmodpur)	Village-wise	Poor infrastructure and transport delays observed	Priority area for policy and infrastructure support
Lowest Village Loss	14.2% (Deh Kalan)	Village-wise	Better connectivity and handling practices	Model village for best practices replication
Storage-Related Loss	31.6%	Cause-wise	Major contributor to total losses	Investment in warehouses and cold storage required
Transportation Loss	24.8%	Cause-wise	Delays and poor logistics impact quality	Improvement in road and transport systems needed
Handling Loss	21.3%	Cause-wise	Improper sorting and packaging practices	Training programs required for farmers
Market Delay Loss	22.3%	Cause-wise	Delayed selling reduces product value	Need for better market linkage systems
Traditional Storage Loss	21.9%	Method-wise	High losses in conventional storage systems	Shift towards scientific storage methods required
Improved Storage Loss	13.6%	Method-wise	Reduced losses with better infrastructure	Promotes adoption of improved storage technologies
Transportation Delay Impact	7.9%	Perishable Crops	Loss increases with delay > 12 hours	Faster logistics required for perishables
Technology Adoption Rate	28.1%	Farmers	Low adoption of modern techniques	Awareness and subsidies needed
Loss with Technology Use	11.8%	Tech Users	Significant reduction in losses	Demonstrates effectiveness of modern solutions
Loss without Technology	20.6%	Non-users	Higher losses due to traditional methods	Encourages digital agriculture adoption
Income Loss per Farmer	₹12,500	Economic Impact	Significant reduction in earnings per season	Direct financial burden on farmers
Profitability Reduction	19.2%	Economic Impact	Lower returns due to reduced output	Impacts long-term sustainability
High Loss Income Impact	₹18,000+	>20% Loss Cases	Severe economic stress in high-loss cases	Critical need for targeted intervention
Temperature Impact	+3.6% Loss	Environmental Factor	Loss increases above 35°C	Climate-resilient storage required

One hundred and thirty-five farmers were surveyed and the general average post-harvest loss was found to be 18.7%. Analysis on crops indicates that the losses are 12.4 percent in wheat, 16.8 percent in rice and 26.3 percent in perishable vegetables. The greatest aggregate loss was registered in Mehmodpur of 22.5 percent and Bhajheri of 21.3 percent and the lowest loss in Deh Kalan of 14.2 percent. Figure 2 shows the Crop-wise Post-Harvest Loss (%).

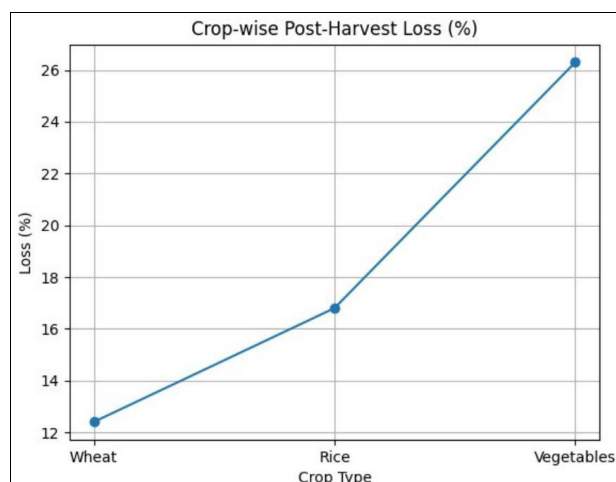


Fig 2: Crop-wise Post-Harvest Loss (%)

These results suggest that there is a strong spatial heterogeneity in the patterns of losses, and it confirms that localized infrastructure and management practices have an effect on the results (Mandal, 2026; Acharya *et al.*, 2023; Houssou *et al.*, 2026) [17, 35, 37]. Causal factors analysis shows that poor storage infrastructure contributes 31.6 percent of total losses, and then there are transportation inefficiency, poor handling practice, and market access delays 24.8, 21.3 and 22.3 respectively. The average losses of farmers who used traditional storage systems were 21.9 but the average losses of farmers who used improved or semi-scientific storage systems was lower 13.6 showing an improvement margin of 8.3. Figure 3 shows the Causes of Post-Harvest Losses.

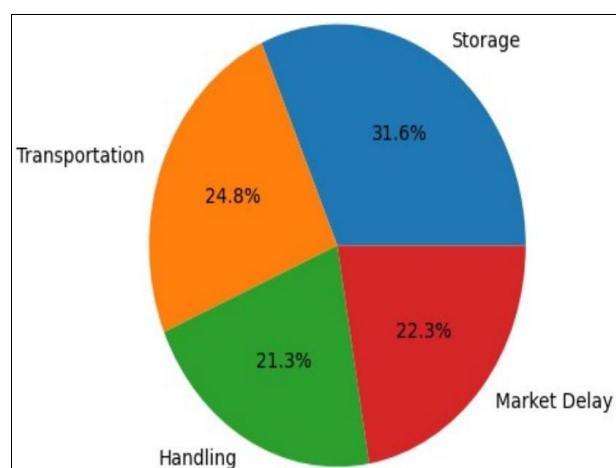


Fig 3: Causes of Post-Harvest Losses

These findings agree with the results, which have shown that product quality and food security are significantly improved with better storage facilities (Luo *et al.*, 2022a; Adams *et al.*, 2024; Mehmood *et al.*, 2022) [16, 18, 39]. The losses caused by transportation were estimated to be at a mean of 4.7 percent of every transaction cycle and the perishable crops had a loss of 7.9

percent as a result of waiting over 12 hours. Villages that were better connected via road like Deh Kalan and Kotli registered transportation losses of less than 3.5 percent and remote villages like Mehmodpur and Malan registered transportation losses of over 6.2 percent. These results indicate that logistical inefficiencies have a direct effect on product degradation and low market value, which aligns with previous studies highlighting the importance of supply chain coordination in reducing agricultural losses (Ali *et al.*, 2021; Hu *et al.*, 2024; Bobadilla-Calderón *et al.*, 2022) [3, 15, 31]. Adoption of technology by farmers is still low with only 28.1 percent of the sampled farmers employing better post-harvest technologies like access to cold stores and sorting machines or simple monitoring devices. The average losses of 11.8 per cent by farmers who adopted these technologies, as compared to 20.6 per cent by non-adopters, represented a difference in losses of 8.8 per cent. Furthermore, farmers who applied better handling and sorting techniques earned a 14.2% higher price realization in the market than the farmers who employed conventional handling and sorting techniques. Such conclusions confirm the efficiency of technological interventions to minimize the losses and increase economic returns (Amune *et al.*, 2024; Pant and Kumari, 2026; Musa *et al.*, 2023) [9, 21, 36]. Economically, there is substantial evidence of a strong negative effect of post-harvest losses on the revenue generated by farmers. On average, each farmer lost a total income of 12,500 during each season due to ₹ post-harvest losses, resulting in a decline in profitability of 19.2%. Farmers who recorded losses greater than 20% reported a decline in profitability that exceeded 18,000 in each ₹ season. Also, the environment played a critical role, as losses increased by 3.6% when temperatures exceeded 35°C. This shows the combined effect of economics, technology, and the environment on post-harvest results (Dong *et al.*, 2026; Sharma *et al.*, 2024; Mishra *et al.*, 2025) [25, 33, 40].

Challenges and Limitations

Operational difficulties were faced in gathering data for the analysis in the selected villages located in the vicinity of Chandigarh University. One of the key challenges in the process of gathering information through questionnaires involved the subjectivity associated with obtaining self-reported answers about the amount of loss incurred by farmers after harvesting their crops. The farmers' estimations were based on their personal experiences and not accurate measurements, hence making it possible for inaccuracies to arise. Concerns related to data validity when using surveys in agriculture research have been reported in past studies due to the subjectivity of perception (Acharya *et al.*, 2023; Mandal, 2026) [17, 37]. Other difficulties included variations in literacy levels among respondents (Mwinuka & Hyera, 2022; Zada *et al.*, 2019) [5, 19]. One more important limitation of the project relates to the geographical scope of the research. It should be mentioned that the research focused only on some specific villages in Punjab, including Deh Kalan, Karimpur, Bhajheri, Dugri, Mehmodpur, Malan, Kalaundi, Kotli, and Dumna. On the one hand, it allows getting detailed information about the state of affairs in this region. On the other hand, the obtained results can hardly be generalized for other areas due to differences in agro-climatic and socio-economic factors (Houssou *et al.*, 2026; Adams *et al.*, 2024) [35, 39]. Different agricultural techniques, storage capacity, and infrastructure affect post-harvest activities significantly (Hu *et al.*, 2024; Hussain & Guha, 2023) [15, 34]. There were several limitations associated with quantitative data analysis in this regard, namely storage capacity, effectiveness of transportations,

and use of new technologies, which are difficult to validate quantitatively in many instances. It is worth admitting that the information provided by the farmers could have been used to conduct more effective analysis, but there were no official records available in most cases (Kachroo *et al.*, 2025; Bobadilla-Calderón *et al.*, 2022) ^[1, 31]. The problem in question correlates with previous studies in which similar gaps were identified (Ali *et al.*, 2021; Grover *et al.*, 2014) ^[2, 3]. External and environmental conditions also presented another limitation when considering the possible sources of post-harvest losses. Factors such as temperature and humidity variations, as well as any unforeseen climatic conditions, were unable to be properly controlled or standardized. Such variables are well-known for their considerable impact on the rates of crop loss and deterioration (Dong *et al.*, 2026; Mavi, 1990) ^[7, 40]. Furthermore, the current study was also unable to use state-of-the-art real-time monitoring devices and experimental approaches to enhance validity and accuracy of the findings. Nevertheless, the findings of the present study offer an empirical basis for further research that will consider the usage of more sophisticated data collection tools (Pant & Kumari, 2026; Mishra *et al.*, 2025) ^[9, 33].

Government policy recommendations

Efficient policy interventions are crucial for minimizing post-harvest losses and making agricultural activities more effective in Punjab. Based on the conclusions drawn from this research, increasing rural infrastructure in terms of scientific storage methods and cold chain logistics will be highly beneficial for reducing post-harvest losses and improving farmer revenue. Public policy should focus on creating decentralized storage options, ranging from warehouses to silos and cold storage in villages, through subsidies and joint government-private ventures (Luo *et al.*, 2022a; Adams *et al.*, 2024) ^[16, 39]. Moreover, transportation improvement, development of efficient transportation networks, creation of road links in the rural areas, and connection to markets would decrease transport-related delays and spoilage (Hu *et al.*, 2024; Hussain & Guha, 2023) ^[15, 34]. Digital agriculture innovations, such as advanced monitoring techniques, intelligent market solutions, and efficient logistics optimization, can increase the effectiveness of the management process even further (Kachroo *et al.*, 2025; Mishra *et al.*, 2025) ^[1, 33]. Lastly, financial incentives, in the form of insurance programs or favorable credit conditions, would allow farmers to mitigate risks and invest in better technologies (Zada *et al.*, 2019; Sharma *et al.*, 2024) ^[5, 25].

Farmer awareness programs

The importance of building farmer awareness and capacity in improving post-harvest handling practices cannot be overstressed. According to the literature, one of the reasons that lead to inefficiency in post-harvest handling is poor awareness about scientific approaches in storing and handling produce, as well as technological improvements. It has been shown that training sessions and extension activities aimed at increasing knowledge about best practices such as sorting, packaging, grading, and cold storage can considerably contribute to the effective preservation of crops and increasing their market value (Mehmood *et al.*, 2022; Amune *et al.*, 2024) ^[18, 21]. In addition, community-based activities aimed at increasing the awareness of low-cost solutions in post-harvest management are vital. Zero energy cooling units and solar dryers represent one of the most affordable solutions available to resource-poor farmers (Akter *et al.*, 2025; Musa *et al.*, 2023) ^[27, 36]. Digital literacy can also be considered a priority, as using mobile apps dedicated to

agriculture can help farmers make more effective decisions concerning marketing aspects, including pricing and timing (Kavinda *et al.*, 2023; Pant & Kumari, 2026) ^[9, 41].

Future Outcomes

There will be an observable improvement in agriculture efficiency and farmer earnings due to improved post-harvest management approaches adopted in Punjab. Considering that the average loss at the moment is 18.7%, through the adoption of scientific storage techniques and optimal supply chain mechanisms, the losses could be reduced from 9.5% to 11.2%, which is a reduction of 7.5% to 9.2%. It would result in an additional effective marketable yield of 12.3% during each cropping season. Various studies have found that better storage facilities coupled with supply chain systems improve efficiency and minimize wastages in agricultural operations (Luo *et al.*, 2022a; Adams *et al.*, 2024; Hu *et al.*, 2024) ^[15, 16, 39]. In addition, through market intelligence systems, the prices realized by farmers could increase by 10.8% to 14.6%. The use of technology is predicted to revolutionize post-harvest loss reduction and efficiency gains. The increase in adoption from the current rate of 28.1% to 60.0% is estimated to decrease losses from 20.6% to 11.4%, representing a loss reduction of 9.2%. Implementation of advanced sorting mechanisms, inclusion of cold storage facilities, and IoT-based monitoring systems will improve quality conservation and decrease losses through handling operations by 6.8%–8.5%. It is important to mention that previous studies emphasize the significant contribution of agricultural technologies and automation in post-harvest efficiency and quality improvements (Amune *et al.*, 2024; Pant & Kumari, 2026; Musa *et al.*, 2023) ^[9, 21, 36]. Moreover, cost-effective innovations, such as zero energy cooling units and solar drying systems, are predicted to lower the losses in perishable crops by 11.6%–15.3% (Mehmood *et al.*, 2022; Akter *et al.*, 2025) ^[18, 27].

Economically speaking, the decrease in post-harvest loss is estimated to produce a large economic gain for farmers. It is estimated that the average income loss of 12,500 per farmer ₹ for each season will decrease to 5,200–6,800 per season, and the result would be a recovery ₹ ₹ of 5,700–7,300 per farmer. This translates to a profit margin of between 13.8% to 18.6% ₹ ₹ increase in net profitability. Furthermore, infrastructure and awareness programs have also been projected to improve market participation levels by 17.4%, which would give farmers better price options. Environmental sustainability is also projected to improve because of adaptation measures aimed at reducing losses arising from climatic factors by 3.2%–4.7% above temperatures of 35°C (Dong *et al.*, 2026; Mavi, 1990) ^[7, 40].

Conclusion

This investigation offers a thorough evaluation of post-harvest losses in selected villages in Punjab with a focus on how inefficient storage, transportation, and handling have affected the agricultural performance of the farmers and their incomes. It can be concluded that post-harvest losses continue being an important factor hindering the proper use of resources and achieving sustainable economic performance in the region. Differences in the post-harvest losses between different villages reflect the fact that local conditions play an important role in determining the magnitude of losses. It is further evident from the investigation that storage problems and ineffective logistics are the main causes of the crops deterioration while underdeveloped technology still hinders any attempts to improve post-harvest management. All of these factors contribute to

reduction in the volume of marketable goods and adversely affect the profitability of farming activities. Improvements in the situation require the application of a variety of approaches, including the development of adequate infrastructure, introduction of technological innovations, and capacity building. In general, addressing the problem of postharvest losses can be instrumental in enhancing agricultural efficiency and increasing the farmers' incomes. It will also be instrumental in improving food security.

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