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Post-Harvest Management Practices and Associated Losses in Tomato and Allied Vegetable Crops: A Review with Special Reference to Lucknow District, Uttar Pradesh

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Abstract
Post-harvest losses (PHL) remain one of the major constraints to food security, farmer income and sustainable horticultural production in India. Uttar Pradesh, particularly the Lucknow region, is an important producer of tomato and other vegetable crops; however, post-harvest handling continues to rely largely on traditional practices that contribute to quantitative and qualitative losses. This review synthesizes published literature on traditional and modern post-harvest management practices for tomato and allied vegetable crops, with emphasis on harvesting, grading, packaging, storage, transportation and marketing. Published estimates of post-harvest losses from national and regional studies were critically examinedto identify major loss points and evaluate the effectiveness of available technological interventions. The review indicates that inadequate packaging, poor storage facilities and inefficient transportation remain the principal contributors to post-harvest losses, whereas low-cost technologies such as ventilated plastic crates, evaporative cooling chambers and improved cold-chain systems have demonstrated considerable potential for minimizing these losses. Despite these advances, adoption of improved post-harvest technologies remains limited in the Lucknow region due to infrastructural, economic and awareness-related constraints. The review highlights important knowledge gaps and emphasizes the need for location-specific studies and wider dissemination of affordable post-harvest technologies to improve produce quality, reduce losses and enhance farmers' income.

Keywords
post-harvest losses; tomato; post-harvest management; coldchain; evaporative cooling; vegetable supply chain; Uttar Pradesh.

1. Introduction

Post harvest losses (PHL) represent one of the major challengest osustain ableagri cultural production and food security worldwide. Fresh fruits and vegetablesare

particularly susceptible to deterioration because of their high moisture content, rapid physiological changes and sensitivity to mechanical injury, temperature fluctuations and delayed marketing. In India, where horticultural crops contribute significantly to agricultural growth, nutritional security and farmers' livelihoods, minimizing post-harvest losses has become an important national priority.

Post-harvest loss refers to the quantitative and qualitative deterioration of agricultural produce occurring between harvesting and its final consumption. National assessments conducted by the Ministry of Food Processing Industries through **Jha et al. (2015**) and later by NABARD Consultancy Services(2022)consistently identified fruits and vegetables as the commodity group experiencing the highest proportional post-harvest losses. These studies further reported that harvesting, sorting and grading, transportation, storage and retail handling are the major stages where losses accumulate.

Uttar Pradesh is one of India's leading vegetable-producing states, and Lucknow district, together with its surrounding rural and peri-urban areas, contributes substantially to the production and marketing of tomato, okra, brinjal and other vegetables. Despite this large production base, post-harvest handling in the region continues to depend largely ontraditional practices such as open-field sorting, packaging in gunny bags or bamboo baskets, unrefrigerated transportation and ambient storage. Although these methods are inexpensive and widely adopted, they often result in mechanical damage, moisture loss, microbials poilage and reduced market value of fresh produce.

Over the past two decades, several modern post-harvest technologies have been developed and promoted by national research organizations, particularly ICAR-CIPHET and allied institutions (**Datta et al., 2023**). These include improved harvesting techniques, ventilated plastic crates, evaporative cooling chambers, pre-cooling facilities and organized cold-chain systems, all of which have demonstrated considerable potential for reducing postharvest losses. However, the adoption of these technologies among small and marginal farmers in and around Lucknow remains limited because of economic, infrastructural and awareness-related constraints.

Against this background, a comprehensive review of traditional and modern postharvest management practices is essential to understand the major sources of post-harvest losses and to identify practical interventions suitable for the Lucknow region. Such an assessment can provide useful insights for researchers, extension agencies and policymakers working towards reducing post-harvest losses and improving the efficiency of vegetable supply chains.

Objectives

- To review and document traditional post-harvest handling, storage and transportpractices followed by vegetable growers and vendors in and around Lucknow.
- To review modern post-harvest technologies promoted by research and extensionagencies and summarize their reported advantages and adoption challenges in comparable agro-climatic regions of Uttar Pradesh.
- To synthesise secondary data on stage-wise post-harvest losses in tomato and alliedvegetable crops from national and regional studies.
- To identify research gaps and future priorities for improving post-harvestmanagement practices in the Lucknow region.

2. Methodology

This narrative review was conducted using published literature retrieved from Google Scholar, Scopus, Web of Science, CAB Abstracts and ResearchGate. In addition, reports published by ICAR-CIPHET, the Ministry of Food Processing Industries, the National Horticulture Board, FAO and NABARD were consulted. Literature published between 2005 and 2025 related to post-harvest management, post-harvest losses, storage, packaging, transportationandcold-chainmanagementoftomatoandalliedvegetablecropswasincluded. Preference was given to peer-reviewed research articles, government reports and institutional publications. Duplicate records and studies lacking adequate methodological details were excluded from the review.

3. Post-Harvest Losses in India: The National and State Context

The assessment of post-harvest losses in India has received considerable attention over the past wode cades because of its implications for foods ecurity, nutritional availability and farmers' income. Among the available studies, the national assessment conducted by **Jha et al. (2015)** for the Ministry of Food Processing Industries remains one of the most comprehensive benchmarks for estimating harvest and post-harvest losses across major agriculturalcommodities.Thestudyevaluatedforty-fivecropsandcommoditiesandreported vegetable losses ranging from approximately 4.6% in tapioca to 12.4% in tomato**,** with harvesting, sorting and grading, transportation, and storage identified as the major stages contributing to these losses. At the retail level alone, tomato losses were reported to reach 18.2% under certain marketing conditions (Teshome and Loyew, 2021).

More recent evidence further confirms the magnitude of post-harvest losses in horticultural commodities. The **NABARD Consultancy Services (2022)** survey, together with the finding sre ported by **Teshomeand Loyew(2021)**,and the value-chain as sessment conducted

under the Government of India's Operation Greens programme, estimated average tomato losses of approximately 21.5%**,** accompanied by a value loss of nearly 14%. The same assessment also reported potato losses of approximately 13.7% in Uttar Pradesh (Kumar etal., 2026). Earlier investigations conducted in Himachal Pradesh similarly documented losses ranging from 19% to 28% across tomato, pea, capsicum, cauliflower and cabbage under different handling conditions. Collectively, these studies indicate that post-harvest losses in tomato under Indian conditions generally range between 12% and 22%, with storage, transportation and retail handling consistently emerging as the most critical stages.
Although national and state-level estimates are available, comparable stage-wise assessments specifically for Lucknow district remain scarce in the published literature. This lack of location-specific information limits a comprehensive understanding of the factors contributing to post-harvest losses under local production and marketing conditions. Consequently, studies conducted in other districts of Uttar Pradesh provide the most appropriate regional evidence for understanding post-harvest losses in the Lucknow region.

Tomato and Vegetable Post-Harvest Losses within Uttar Pradesh

A district-level investigation conducted in Varanasi, Uttar Pradesh, reported that tomato recorded the highest post-harvest loss (approximately 22%) among the vegetables studied, whereas cabbage exhibited the lowest losses (around 8%). The study attributed these losses primarily to inadequate grading, inappropriate packaging, poor storage facilities and inefficient transportation practices. Similarly, an economic analysis carried out in Allahabad (Prayagraj) reported an average producer-level post-harvest loss of approximately 9%, with marginal farmers experiencing relatively greater losses than larger producers. These findings suggest that farm size, access to infrastructure and the adoption of improved post-harvest practices play an important role in determining the magnitude of post-harvest losses.

An empirical investigation by **Parimi and Chakraborty (2022)** further identified transportation and distribution constraints as important determinants of post-harvest losses along fruit and vegetable supply chains in Uttar Pradesh. Likewise, **Ahmad et al. (2021)** provided statistically robustest imate sofharvest and post-harvest losses for major crops using successive sampling methodology under the national post-harvest loss assessment programme. Together, these studies provide valuable regional evidence for understanding post-harvest losses in Uttar Pradesh and serve as an important reference for interpreting the situation in Lucknow district.

4. Traditional Post-Harvest Practices

Traditional post-harvest management practices continue to play a dominant role in vegetable production systems across much of rural and peri-urban Uttar Pradesh. Owing to their lowcost, easy accessibility and long-standing familiarity among farmers, the sepractices remain widely adopted despite the availability of improved alternatives. However, several studies have shown that conventional methods often expose fresh produce to mechanical injury, moisture loss and microbials poilage, there by contributing significantly topost-harvest losses. The principal traditional practices reported for tomato and allied vegetable crops are discussed below.

Harvesting

Harvesting of tomato and allied vegetable crops is generally carried out manually through hand-picking, often without proper consideration of optimum maturity indices. As a result, over-ripe, under-ripe and

market-ready produce are frequently harvested together, leading to non-uniform quality and increased susceptibility to mechanical injury during subsequent handling and transportation **(Jain and Shakya, 2020).**

Sorting and Grading

Sorting and grading are commonly performed manually either at the farm or at the first point of sale. In most cases, grading is based on the visual judgement and experience of farmers or traders rather than standardized quality parameters. The absence of scientific grading often results in non-uniform market lots, reduced product quality and lower market value **(Jain and Shakya, 2020).**

Packaging

Traditional packaging primarily involves the use of jute gunny bags, bamboo baskets and wicker containers because these materials are inexpensive and readily available. However, they provide limited protection against compression and impact during transportation, resulting in bruising, crushing and accelerated deterioration of fresh produce**(Jain and Shakya, 2020**).

Storage

Storage of harvested produce is generally carried out under ambient conditions either at the farm or in unorganized market yards, with little or no control over temperature and relative humidity. Exposure to high temperatures, direct sunlight and pest infestation accelerates physiological deterioration and microbial spoilage, thereby reducing both shelf life and market quality **(Jain and Shakya, 2020).**

Transportation

Transportation is commonly undertaken using bullock carts, cycle-rickshaws or unrefrigerated tempos and trucks, often over poorly maintained roads. Repeated loading and unloading, combined with prolonged exposure to vibration and high ambient temperatures, increases mechanical bruising and quality deterioration, making transportation one of the major contributors to post-harvest losses in vegetable supply chains (**Jain and Shakya,2020**).

The traditional practices discussed above differ substantially from the improved postharvest technologies that have been developed to minimize handling losses and preserve produce quality. Figure 1 presents a schematic comparison of the traditional and modernpost-harvest management pathways adopted for tomato and allied vegetable crops.

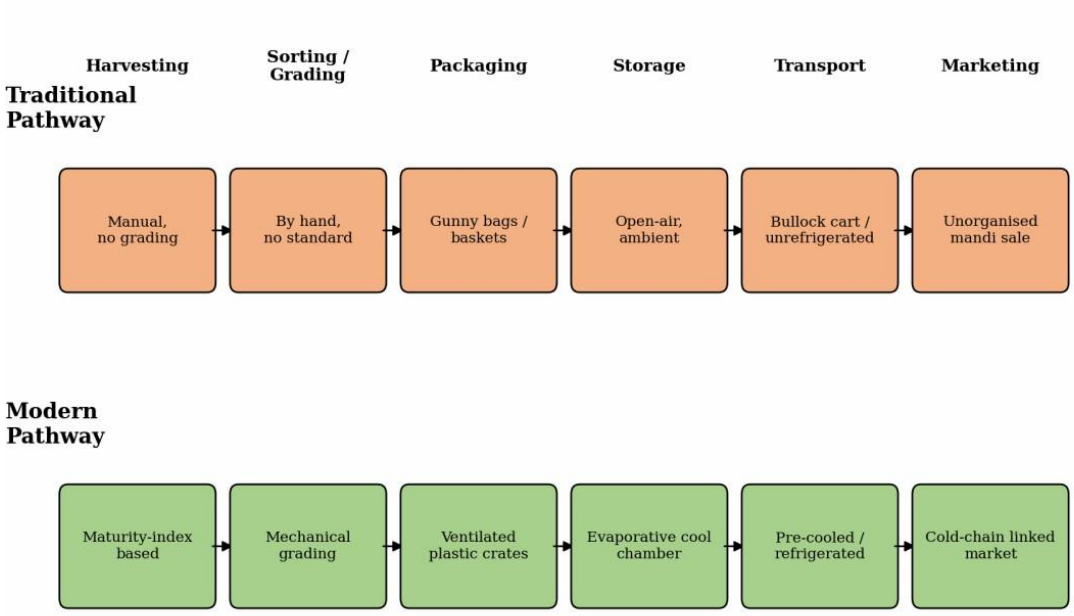

Figure1: Traditional versus modern post-harvest handling pathways for tomato and allied vegetables, stage by stage.

Figure 1 illustrates the major differences between traditional and modern post-harvest path ways from harvesting to marketing, highlighting the stages where improve dinter ventions can reduce post-harvest losses.

5. Modern Post-Harvest Practices and Technologies

In response to the substantial post-harvest losses associated with conventional handling systems, several modern post-harvest technologies have been developed and promoted by ICAR-CIPHET and other research organizations. These interventions aim to reduce physical damage, delay physiological deterioration and maintain the quality of fresh producet hroug hout the supplychain. They range from simple, low-cost technologies suitable for smallholder farmers to advanced cold-chain systems designed for commercial production and marketing.

Improved Harvesting and Grading

Scientific harvesting practices involve the use of harvesting knives or clipperstogether with maturity-index-based harvesting to minimize stem-pull injury and mechanical damage. These practices are complemented by mechanical or semi-mechanical grading systems that classify produce according to size, maturity and market quality. Standardized harvesting and grading not only improve product uniformity but also reduce losses during handling, storage and transportation.

Improved Packaging

Ventilated high-density polyethylene (HDPE) plastic crates have increasinglyreplaced traditional gunny bags and bamboo baskets in scientific post-harvest handling systems. These reusable containers improve air circulation, minimize compression injury and reduce mechanical damage during transportation. Although the initial investment is higher than that of conventional packaging materials, their longer service life and reduced produce losses make them economically advantageous over time.

Low-Cost Cool Storage

Low-cost storage technologies, particularly Zero Energy Cool Chambers (ZECC), have emerged as practical alternatives for extending the shelf life of fresh vegetables under tropical conditions. Developed initially by IARI and subsequently refined by ICAR-CIPHET and other institutions, these structures operate on the principle of evaporative cooling without requiring electricity.Studiesby **Sundaram(2016)** demonstrated that ZECC storage extended the marketable shelf life of tomato, okra, brinjal and cucumber by approximately 4–15 days compared with ambient storage, making the technology particularly suitable for smallholder farmers in North India.

Cold Chain and Pre-Cooling

Pre-cooling, refrigerated transportation and organized cold-chain systems play an important role in preserving the quality of highly perishable vegetables by slowing physiological and microbial deterioration. These technologies have been promoted under national initiatives such as Operation Greens and various State Horticulture Mission programmes. However,their adoptionre mains limited among smallholder farmers becauseof the substantial investment required and the need for organized marketing systems.

Value Addition

Value addition through drying, pulping, minimal processing and other preservation techniquesprovidesaneffectivemeansofutilizingsurplusorlower-gradeproducethatmight otherwise be wasted. In addition to reducing post-harvest losses, value-added products enhance market opportunities and improve farmers' returns. However, successful adoption depends on the availability of processing facilities, market linkages and technical support (**Parwez, 2014).**

The review demonstrates that traditional and modern post-harvest systems differ considerably in their approach to harvesting, handling, storage and transportation. While Figure 1 provides a conceptual representation of the two post-harvest pathways, a detailed comparison of the individual operations, associated limitations and potential benefits of modern interventions is presented in Table 1.

Table1.ComparisonofTraditionalandModernPost-HarvestManagementPractices for Tomato

Operation	Traditional practice	Modern intervention	Limitation	Expected benefit
Packaging	Gunny bags	HDPE crates	Compression injury	Reducedmechanical damage
Storage	Ambient storage	ZECC	High temperatureand moisture loss	Longer shelf life
Transport	Open vehicles	Refrigerated transport	Bruising and heat exposure	Lower spoilage

The comparison presented in Figure 1 and Table 1 indicates that improvements in packaging, storage and transportation represent the major opportunities for reducing postharvest losses. The magnitude of these losses reported in different studies is summarized in the following section.

6. Reported Post-Harvest Losses in Tomato and Allied Vegetable Crops

Published studies conducted at national and regional levels provide valuable evidence on the magnitude of post-harvest losses in tomato and allied vegetable crops under different production and marketing systems. Although reported estimates vary depending on geographical location, crop type and assessment methodology, they collectively identify the major stages of loss within the post-harvest supply chain. Table 2 summarizes the reported post-harvest losses compiled from the reviewed literature, while Figure 2 provides agraphical representation of these findings to facilitate comparison among different studies.

Table2.Reportedpost-harvestlossesintomatoandalliedvegetablecropsfrom published Indian studies

Crop	Reported PHL (%)	Region	Study / Source
Tomato	12.44 (national avg.);up to 18.20 at retaillevel	All-India	**Jha et al.,2015**
Tomato	21.51 ± 1.00	Gujarat,Maharashtra ,Uttar Pradesh	**Kumar et al., 2026 (Operation Greens)**
Tomato	22.01 (highest of 5vegetables studied)	Varanasi, Uttar Pradesh	**Kumar et al., 2015**
Vegetables (producer-level,all crops)	8.92 (avg.); up to 10.24 for marginal farmers	Allahabad, Uttar Pradesh	**Barker et al,2017**
Potato	13.67 ± 0.59	Uttar Pradesh	**Kumar et al.,2026 Kumar et al., 2026 (Operation Greens)**
Onion	12.59 ± 0.51	Maharashtra	**Kumar et al.,2026 Kumar et al., 2026 (Operation Greens)**
Tomato,Capsi cum,Cauliflo wer, Cabbage Pea,	18.98 – 28.25	Himachal Pradesh	**Singh and Vaidya,2005**
Vegetables (multi-crop range)	4.58(Tapioca)– 12.44(Tomato)	All-India	**Jha et al.,2015**
FruitsVegetab & les (aggregate)	~49.9MMTannualloss(ho rticulture)	All-India	**ICAR-CIPHETnationalestimate**

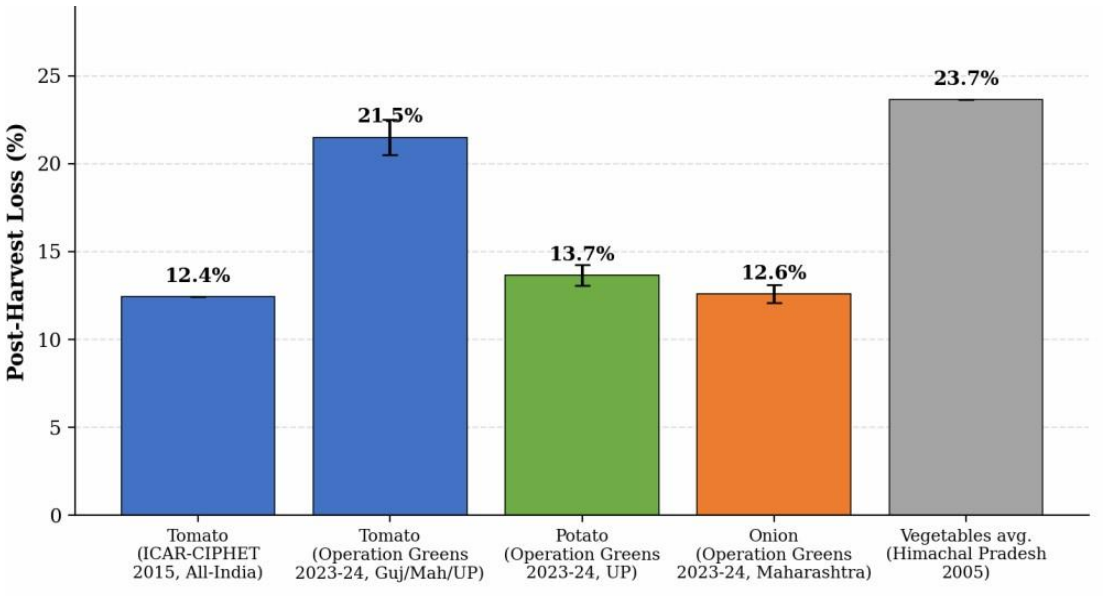

Figure2.Comparativepost-harvestlosspercentagesfortomatoandalliedvegetablecrops

The published literature reveals three consistent patterns regarding post-harvest losses in tomato and allied vegetable crops. First**,** reported losses in tomato generally range from 12% to 22% under Indian conditions, although the magnitude varies with production environment, post-harvest handling practices and methods of estimation (**Tadesse et al., 2022)**. Studies conducted in Uttar Pradesh, particularly in Varanasi and Allahabad, reported loss estimates comparable to national assessments, suggesting that these values provide a useful regional reference for understanding post-harvest losses in the Lucknow region.

Second, storage, transportation and retail handling consistently emerge as the stages contributing the highest proportion of total post-harvest losses. Inadequate packaging, prolonged storage under ambient conditions and repeated handling during transportation accele rate physical damageandphy siologi cald eterioration, thereby reducing both marke table quality and shelf life (**Sidhu et al., 2024).**

Third, the reviewed studies indicate that access to post-harvest infrastructure isclosely associated with the magnitude of losses. Small and marginal farmers generally experience higher post-harvest losses because of limited access to scientific grading, improved packaging, cold storage and organized marketing facilities (**Akhter et al., 2024).** These observations emphasize the importance of affordable post-harvest technologies and improved supply-chain infrastructure for minimizing losses in vegetable production systems.

Overall, there view edliteraturede monstratest hat post-harvest losses into ma to are not attributable to as ing leoperation butarise from the cumulative effect so fharvesting,

handling, packaging, storage, transportation a nd marketing practices. Although modern postharvest technologies have shown considerable potential for reducing these losses, their adoption continues to be constrained by economic, infrastructural and knowledge-relatedfactors.

7. Discussion

The reviewed literature consistently indicates that post-harvest losses in tomatoremain a significant challenge in India despite considerable advances in post-harvest management technologies. Although the reported magnitude of losses varies among studies because of differences in geographical location, production systems and assessment methodologies, there is broad agreement that losses occur throughout the supply chain andare strongly influenced by harvesting practices, packaging methods, storage conditions and transportation facilities (**Spiker et al.,2023**; **Jha et al., 2015; NABARD Consultancy Services, 2022; Kumar et al., 2026**). Collectively, the available evidence further suggests that substantial reduction in these losses can be achieved through the adoption of appropriate post-harvest technologies.

Traditional post-harvest practices continue to dominate

Published evidence further indicates that vegetable growers, particularly small and marginal farmers, continue to rely largely on traditional post-harvest practices including manual harvesting, visual grading, packaging in gunny bags or bamboo baskets, ambient storage and transportation through unrefrigerated vehicles (**Jain and Shakya, 2020**). These practices require minimal investment and are easily accessible under rural conditions; however, they expose produce to mechanical injury, moisture loss and microbial spoilage. Similar observations have been reported in district-level studies from Uttar Pradesh, where inadequate grading, poor packaging and lack of scientific storage facilities contributed significantly to physical and economic losses among vegetable growers (**Kumar et al., 2015; Barker et al., 2017).**

Storage and transportation represent the major points of post-harvest loss

A consistent finding emerging from the reviewed literature is that the greatest proportion of post-harvest losses occurs after harvesting, particularly during storage, transportation and marketing. National estimates by **Jha et al. (2015**) identified harvesting, sorting and grading, transportation and storage as the major contributors to losses in horticultural commodities (**Mohan et al, 2023**). Similar trends have also been reported in more recent value-chain assessments under Operation Greens, where tomato losses remained highdespiteimprovementsinproductionpractices(**Kumaretal.,2026**).Studies from Uttar Pradesh and other vegetable-producing regions similarly indicate that repeated handling, inadequate packaging materials, long transportation distances and exposure to high ambient temperatures accelerate deterioration of tomato fruits (**Parimi and Chakraborty, 2022; Ahmad et al., 2021**). These findings collectively suggest that interventions targeting storage and transportation are likely to produce greater reductions in post-harvest losses than improvements in harvesting practices alone.

Modern technologies provide practical opportunities for reducing losses

The reviewed studies consistently indicate that several modern post-harvest technologies have demonstrated considerable potential to reduce quantitative and qualitative losses. Ventilated plastic crates minimize compression damage during transport, while evaporative cooling structures such as zero-energy cool chambers effectively extend the shelf life of tomatoes and other vegetables under

tropical conditions without requiring electricity (**Sundaram, 2016**). Similarly, pre-cooling, organised cold-chain systems and value-addition strategies have been shown to improve produce quality and reduce spoilage during marketing (**Thakur and Naan, 2026**; **Parwez, 2014)**. Despite these demonstrated benefits, adoption remains limited, particularly among smallholder farmers, because of financial constraints, limited awareness, fragmented marketing systems and inadequate infrastructure(**Senguptaet al., 2024; Chen et al., 2017; Villacis et al., 2024)**. Therefore, increasing accessibility and affordability of these technologies remains an important priority for reducing post-harvestlosses.

Knowledge gaps in the Lucknow region

Althoughconsiderableinformationisavailablefromnationalstudiesandfromseveral states of India, the review reveals a distinct lack of published, district-specific information on stage-wise post-harvest losses in tomato cultivation in and around Lucknow. Consequently, much of the available understanding is derived from studies conducted in comparable agro-climatic regions such as Varanasi and Prayagraj within Uttar Pradesh (**Kumar et al., 2015; Barker et al., 2017**). While these studies provide a useful baseline, differences in production systems, marketing channels and infrastructure suggest that their findings cannot be directly extrapolated to Lucknow without further validation. These findings highlight the need for systematic field-based studies to quantify post-harvest losses under local conditions and evaluate the suitability of affordable post-harvest technologies for the Lucknow region.

Implications for future research and extension

The collective evidence reviewed in this paper indicates that reducing post-harvest loss esrequires both technological and institutional in terventions. Future research should prioritize the generation of reliable district-level estimates using standardized methodologies while simultaneously evaluating thee conomic feasibility flow-costtechnologiesunderlocal farming conditions. Extension programmes should focus on promoting scientific harvesting, grading, improved packaging, evaporative cooling structures and better market linkages among vegetable growers. Strengthening post-harvest infrastructure through coordinated efforts involving research institutions, extension agencies and government programmes could substantially improve produce quality, reduce losses and enhance farmers' income in the Lucknow region.

8. Conclusion

Post-harvestlossesintomatoandalliedvegetablecropsremainasignificantchallenge to sustainable horticultural production and farmers' income in India. The literature reviewed indicates that losses occur throughout the post-harvest supply chain, with inadequate packaging, storage and transportation emerging as the major contributing factors. Although several modern technologies, including ventilated plastic crates, zero-energy cool chambers, pre-cooling and cold-chain systems, haved emonstrated considerable potentiall forminimizing these losses, their adoption remains limited, particularly among smallholder farmers.

The review also highlights the scarcity of district-specific information on post-harvest losses in Lucknow, emphasizing the need for location-specific studies to support evidence-based interventions. Overall, reducing post-harvest losses will require an integrated approach involving improved post-harvest technologies, effective extension services and strengthened market infrastructure. The findings

of this review provide a useful reference for researchers, extension personnel and policymakers working to improve post-harvest management and enhance the sustainability of tomato and allied vegetable production systems.

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