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Challenges in Preserving Quality: Major Causes of Post-Harvest Losses in Horticultural Crops

*Catherine Ezung[1], Shriram Mahadev Mhaske[2], Shrikant Manikrao Kadam[2], Durgesh Kumar Maurya[3] and Pulkit[4]

[1]Ph.D Scholar, Department of Horticulture (PSMA), School of Agricultural Sciences, (Nagaland University) Medziphema Campus

[2]Ph.D Scholar, Department of Horticulture (Vegetable Science), Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra

[3]Subject Matter Specialist, Agronomy, KVK, Santkabirnagar

[4]Ph.D Scholar, School of Agriculture, Sanskriti University (Mathura)

*Corresponding Author's email: catherineezung40@gmail.com

Horticultural crops - a diverse and vibrant category encompassing fruits, vegetables, flowers, plantation crops, spices, and medicinal plants form the bedrock of nutrition, economic prosperity, and livelihoods for communities worldwide. They are indispensable sources of vitamins, minerals, and dietary fiber, crucial for human health, while also representing a high-value agricultural sector that fuels local and national economies. However, the journey of these often-delicate products from the farm to the consumer is perilous. The preservation of quality after harvest is not just a desirable goal but a critical necessity that dictates market value, ensures consumer acceptance, and underpins food security. The scale of post-harvest loss is a global crisis. The Food and Agriculture Organization of the United Nations (FAO) estimates that globally, 13.2% of food is lost after harvest and before reaching the retail stage [1]. This contributes to an earlier, broader estimate that around one-third of all food produced is lost or wasted along the supply chain [2]. For plant-based crops, losses can frequently range between 20% and 50% [3]. In India, a global agricultural powerhouse, the government reported in August 2024 that post-harvest losses for fruits and vegetables alone range from 5% to 15% [4]. Yet, for specific high-value crops like mango, these losses can soar to a staggering 25-45% [5]. This immense wastage signifies not only lost nutrition and income but also the squandering of precious resources - water, land, energy, and labor. This article seeks to identify and explain the major causes affecting the quality preservation of horticultural crops, providing a comprehensive analysis of the factors driving these significant post-harvest losses.

Understanding Post-Harvest Losses in Horticulture: Definitions and Impact

Post-harvest losses refer to the degradation in both the quantity and quality of produce from the moment of harvest until it is consumed. These losses are typically classified in two ways:

- **Quantitative Loss:** This is a direct, measurable reduction in the physical amount of the product. It includes weight loss from dehydration or the complete discard of produce due to rot and spoilage.
- **Qualitative Loss:** This involves a decline in the attributes that determine market value and consumer appeal, such as nutritional value, texture, flavor, and appearance. Examples include bruising, undesirable color changes, wilting, and loss of aroma.

Horticultural products are especially vulnerable to deterioration due to their high metabolic activity and high moisture content. Fruits like bananas, vegetables like tomatoes, and cut flowers are famously perishable and can spoil within days if not handled correctly.

The economic consequences of these losses are immense, creating a ripple effect across the supply chain. Farmers suffer from reduced income, traders face financial ruin from spoiled inventory, and consumers bear the burden of higher prices for lower-quality goods. On a global scale, food loss and waste cost the economy over $1 trillion annually and significantly contribute to climate change, accounting for an estimated 8-10% of global greenhouse gas emissions [6].

Unraveling the Major Causes of Post-Harvest Deterioration

The decay of horticultural crops is a complex process driven by a web of interconnected biological, physical, and environmental factors.

Biological and Physiological Factors

Even after being detached from the parent plant, horticultural products are living tissues that continue to undergo physiological processes that lead to aging and decay.

- **Respiration and Senescence:** Respiration is the fundamental process where stored organic compounds like sugars are broken down to produce energy for cellular activities, releasing heat in the process. A high respiration rate depletes the product's stored reserves, accelerating its aging (senescence) and shortening its shelf life [7].
- **Transpiration:** This is the loss of water from the produce to the surrounding atmosphere. It leads to wilting, shriveling, and a direct loss of saleable weight, negatively impacting texture and appearance [8].
- **Ethylene Production:** Ethylene is a natural plant hormone that acts as a signaling molecule for ripening and senescence. While essential for developing desirable characteristics in some fruits, its uncontrolled presence can cause rapid over-ripening, softening, and spoilage in sensitive commodities.
- **Pest and Disease Infestation:** Pests and pathogens present in the field can continue to thrive after harvest. Insects cause physical damage, while latent fungal or bacterial infections can develop into visible rot during storage and transport, rendering the product unsalable [9].

Mechanical Injuries

Physical damage is one of the most prevalent and avoidable causes of post-harvest loss. These injuries serve as entry points for decay organisms and accelerate physiological decline.

- **Harvesting and Handling Damage:** Bruises, cuts, punctures, and abrasions are common injuries inflicted by harvesting tools, rough handling, or improper packing techniques [10]. Even minor skin breaks can be catastrophic, providing a gateway for microbial invasion.
- **Transport Damage:** During transit, vibration, compression, and impact forces cause significant damage. Produce can be bruised from rattling in containers or crushed under the weight of overlying products, leading to quality degradation that critically decreases profit for both growers and retailers [10].

Microbial Spoilage

The high moisture and nutrient content of horticultural produce makes it an ideal breeding ground for microorganisms like fungi, bacteria, and yeasts.

- **Fungal and Bacterial Rots:** Fungi are the most common cause of spoilage in fruits, while bacteria are major spoilage agents in vegetables. Pathogens like *Colletotrichum* (anthracnose in mangoes), *Botrytis cinerea* (gray mold in strawberries), and *Erwinia carotovora* (bacterial soft rot in vegetables) can devastate entire shipments [11], [12].
- **Contamination Pathways:** Microbes can originate from the field, contaminated water, unclean equipment, or cross-contamination during handling and storage [13].

Environmental Factors

The ambient environment during storage and transport is a powerful determinant of shelf life.

- **Temperature:** This is the single most important factor. High temperatures accelerate respiration, water loss, and microbial growth. Conversely, storing produce below its optimal temperature can cause chilling injury, leading to pitting, discoloration, and failure to ripen.

- **Humidity:** The relative humidity of the storage environment directly impacts transpiration. Low humidity causes produce to shrivel, while high humidity can promote condensation and microbial growth.
- **Atmospheric Composition:** The levels of oxygen, carbon dioxide, and ethylene in the air influence quality. High oxygen levels can increase respiration, while ethylene accumulation can trigger premature ripening and spoilage in sensitive crops.

Improper Harvesting Practices

Quality cannot be improved after harvest; it can only be maintained. Therefore, actions taken at the time of picking are crucial.

- **Maturity at Harvest:** Harvesting produce at the correct stage of maturity is vital. Immature fruits may fail to ripen properly, resulting in poor flavor and texture, while overripe fruits have a short shelf life and are highly susceptible to damage [14].
- **Harvesting Time and Method:** Harvesting during the coolest part of the day reduces "field heat" and slows deterioration. Using clean, sharp tools and gentle techniques minimizes mechanical damage from the outset [15].
- **Sanitation:** Lack of sanitation for tools, containers, and workers' hands can introduce a heavy load of spoilage organisms onto the produce before it even leaves the field.

Inadequate Post-Harvest Infrastructure

In many developing nations, the absence of robust post-harvest infrastructure is a primary driver of massive losses.

- **Broken Cold Chain:** A consistent, temperature-controlled environment—the "cold chain"—is the most effective tool for extending shelf life. The lack of pre-cooling facilities, refrigerated transport, and cold storage means produce is exposed to damaging high temperatures for extended periods [16].
- **Poor Packaging:** The use of traditional, inadequate packaging like rough wooden crates or flimsy sacks offers little protection against mechanical injury, compression, and contamination [17].
- **Limited Processing Facilities:** A lack of access to modern grading, sorting, and processing facilities forces farmers to sell their entire harvest on the fresh market at once, often leading to market gluts, price collapses, and significant waste.

Crop-Specific Vulnerabilities: Case Studies of Significant Losses

Different horticultural crops exhibit unique vulnerabilities, leading to varying levels and types of post-harvest loss.

Crop category	Crop	Major cause of loss
Fruits	Mango	Losses of 25-45% are common due to improper harvesting, rough handling, mechanical damage from poor packaging, and diseases like anthracnose and stem-end rot [18].
	Banana	Highly susceptible to bruising and compression during transport. Over-ripening is a major issue. Post-harvest losses can range from 25-50% due to poor handling and transport conditions [19].
Vegetables	Tomato	With a high water content (over 90%), tomatoes are very susceptible to spoilage. Losses can reach up to 42% of their value due to physical damage, over-ripening, and microbial attacks from fungi like *Rhizopus* and *Aspergillus* [20].
	Leafy greens	Quality is quickly lost through wilting (water loss), yellowing, and physical damage. Holes from insect feeding or spots from diseases that develop post-harvest reduce marketability [21].
Floriculture	Rose and Lilium	Quality is judged by aesthetics. For cut flowers, mechanical damage (bruised petals), improper temperature control, and water stress are key issues. In lilies, post-harvest leaf yellowing is a major problem that reduces their value [22].

Plantation	Coffee	Inconsistent drying due to weather exposes beans to mold growth. Post-drying, moisture reabsorption during storage due to inadequate packaging can lead to fungal contamination and spoilage [23].
	Tea	Quality is defined by complex chemical compounds. Improper post-harvest processing, such as incorrect withering or fermentation temperatures, leads to the degradation of these compounds, resulting in poor flavor, aroma, and color [24].
	Cocoa	Moisture control is paramount. If moisture content rises above 8% during storage or transport, there is a high risk of mold and rot. Condensation inside shipping containers is a major threat that can lead to total loss [25].
	Coconut	Major losses are caused by improper drying of the kernel (copra). Copra with high moisture content is prone to contamination by mold, such as *Aspergillus flavus*, which can produce harmful aflatoxins[26]. Tender coconuts spoil within a week at room temperature due to discoloration and shrinkage [27].
Spices	Black pepper and Cardamom	Losses are often due to harvesting at the wrong maturity stage, physical damage during handling, and moisture absorption during storage, which leads to mold growth and loss of quality [28].
	Turmeric and Ginger	Spoilage is primarily caused by fungal invasion (*Aspergillus* species) during the drying and storage phases. Dehydration is a common problem in young ginger, causing it to darken and lose its sheen [29][30].
Medicinal and aromatics	Aloe Vera	The extracted gel is highly unstable and degrades rapidly when exposed to air and microbes. Without immediate and careful processing and stabilization, its valuable bioactive compounds are lost [31].
	Lemongrass and Mint	The primary value lies in volatile essential oils. Losses occur when these oils degrade or evaporate due to improper handling, high temperatures during drying, or extended storage periods [32].

Mitigating Losses: Key Strategies for Quality Preservation

Addressing the multifaceted causes of post-harvest loss requires a range of targeted strategies implemented across the supply chain.

- **Adoption of Good Agricultural Practices (GAP):** This is the first line of defense. GAP includes selecting robust cultivars, managing field pests and diseases, and using proper sanitation to minimize microbial loads before harvest begins [33].
- **Improved Post-Harvest Handling Protocols:** Gentle handling is non-negotiable. This involves training workers on proper harvesting techniques, using clean containers and tools, and carefully sorting and grading produce to remove any damaged or diseased items that could contaminate the rest of the batch [34].
- **Cold Chain Development:** Investing in a robust and unbroken cold chain is arguably the single most effective strategy. This includes on-farm pre-cooling facilities, refrigerated transport, and temperature-controlled storage, all of which slow down respiration, microbial growth, and water loss [35].
- **Modified/Controlled Atmosphere Packaging (MAP/CAP):** Advanced packaging that alters the gaseous environment around the produce can dramatically extend shelf life. By reducing oxygen and managing carbon dioxide and ethylene levels, MAP/CAP slows down physiological processes and inhibits spoilage [36].

- **Training and Awareness:** Knowledge is a powerful tool. Educating all stakeholders from farmers and field laborers to traders and retailers on the principles of post-harvest physiology and best handling practices can lead to significant reductions in waste.

Conclusion: Towards an Integrated Approach for Sustainable Quality

The staggering scale of post-harvest losses in horticultural crops is a complex and critical issue, stemming from an intricate interplay of biological vulnerabilities, mechanical fragility, environmental pressures, and deep-rooted infrastructural deficits. From the natural ticking clock of respiration to the devastating impact of a single bruise, each factor contributes to a cascade of degradation that diminishes the quality, safety, and availability of our food. Tackling this challenge demands far more than a single solution; it requires a holistic, integrated approach that views quality preservation as a continuous chain of responsibility. This chain must be forged with links of good agricultural practices in the field, gentle handling protocols at every touchpoint, and transformative investments in critical infrastructure like the cold chain and advanced packaging. Ultimately, minimizing these losses is an economic, social, and environmental imperative. It is a vital strategy for strengthening food security, improving global nutrition, and making our agricultural systems more sustainable. A concerted and collaborative effort driven by supportive government policies, technological innovation from the scientific community, and widespread education and training for all stakeholders is essential to ensure that the bounty of our fields successfully nourishes our communities.

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