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Review Article

Post-harvest management to reduce fruit and vegetable losses for food sustainability: A review

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Abstract: Post-harvest loss of fruits and vegetables is a major challenge for food security and the reduction of global hunger. In some supply chains, losses can reach approximately 50%, making their prevention essential for sustainably feeding a growing population. Important loss points occur during harvesting, post-harvest handling, marketing, storage, processing, and transportation. These losses arise from interacting mechanical, physiological, pathological, microbial, and environmental factors and are intensified by inadequate infrastructure and handling practices. This review examines the principal causes of post-harvest fruit and vegetable losses and practical approaches for their reduction. Appropriate maturity assessment, careful harvesting and grading, hygienic washing, effective packaging, rapid pre-cooling, improved transport, moisture-retentive packaging, low-temperature storage, and controlled-atmosphere systems can preserve quality and extend shelf life. Affordable technologies such as crate liners, smaller packages, shaded field-packing stations, zero-energy cool chambers, and CoolBot-controlled cold rooms can provide substantial benefits to small-scale producers. Combining suitable pre-harvest practices with careful control of temperature, humidity, atmospheric composition, microbial contamination, and mechanical damage can reduce losses and support a more sustainable food system.

Keywords: cold chain; food security; fruits and vegetables; post-harvest loss; storage; sustainable food systems.

1. Introduction

Fruits and vegetables are essential components of a balanced and healthy diet (Yahaya et al., 2015). Because fresh produce consists of living tissues, it remains metabolically active after harvest and is highly perishable. These tissues must remain alive and in good physiological condition throughout harvesting, handling, storage, distribution, and marketing (Alao, 2000; Mustapha and Yahaya, 2006).

Approximately one-third of the food produced for human consumption, about 1.3 billion tonnes, is lost or wasted globally each year. At the same time, food production may need to increase substantially to meet the requirements of a growing world population (Gustavsson et al., 2011). Preventing avoidable post-harvest loss is therefore an important and resource-efficient means of improving food availability and food security.

This review describes the causes of post-harvest losses in fruits and vegetables and examines pre-harvest, handling, packaging, transport, cooling, storage, and low-cost technological interventions that can reduce those losses.

2. Post-Harvest Loss

Post-harvest loss is the deterioration in the quantity or quality of food between harvest and consumption. Quantitative loss refers to a reduction in the physical amount of produce, whereas qualitative loss includes deterioration in appearance, texture, flavour, nutritional value, marketability, or safety. Quantitative losses are particularly important in many developing-country supply chains (Kader, 2002; Kitinoja and Gorny, 2010).

Patterns of food loss vary with income and infrastructure. High-income regions tend to experience greater waste at downstream retail and consumer stages, while low-income regions experience greater losses during upstream harvesting, handling, storage, and transport (FAO, 2013). Reducing loss can be less costly and less resource-intensive than producing an equivalent additional quantity of fruits and vegetables of the same quality (Kiaya, 2014).

3. Factors Affecting Post-Harvest Loss

Fresh fruits and vegetables have short shelf lives, high water contents, and high metabolic activity. Their post-harvest losses arise from interacting mechanical, physiological, pathological, microbial, and environmental causes (Hayatu, 2000; Sani and Alao, 2006). Insects, mites, and pathogens also contribute to deterioration. Pathological rots are among the most destructive causes, followed by mechanical injury, and the interaction between tissue damage and infection can produce severe losses (Mustapha and Yahaya, 2006; FAO, 2011).

Environmental conditions such as temperature, relative humidity, oxygen, and carbon-dioxide concentration affect both physiological deterioration and pathogen development. Damage caused by these factors increases the vulnerability of produce to infection and accelerates senescence (Williams et al., 1991; Sani and Alao, 2006).

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3.1. Primary Causes

3.1.1 Microbial Activity

Fruits and vegetables are susceptible to fungi, bacteria, and yeasts. Their succulent tissues provide favourable conditions for microbial invasion, making pathogens an important cause of loss after harvest (Elias et al., 2010; Yahaya and Mardiyya, 2019). Soft-rot bacteria are estimated to account for a substantial proportion of vegetable deterioration, while fungal rots are particularly destructive in fruits. Some pathogens also produce mycotoxins that make affected produce unsafe for consumption (Naureen et al., 2009).

Sources of contamination include the field, irrigation or washing water, equipment, containers, handlers, and the storage environment. Important bacterial and fungal genera include *Erwinia*, *Pseudomonas*, *Alternaria*, *Botrytis*, *Diplodia*, *Monilinia*, *Phomopsis*, *Rhizopus*, *Penicillium*, and *Fusarium* (Opadokun, 1987; Etebu et al., 2013). *Penicillium expansum*, which causes blue mould rot, is a major pathogen of stored fruit and can produce considerable economic losses (Amin et al., 2017).

3.1.2 Environmental Factors

Temperature, humidity, and atmospheric composition have major effects on post-harvest quality. High temperature increases respiration, accelerates tissue breakdown, and encourages pathogenic microorganisms (Luengwilai et al., 2012). Continuous and appropriate temperature control from harvest to consumption is therefore one of the most effective quality-preservation measures. Cooling slows metabolism and microbial growth and provides more time for handling and marketing (Danladi, 2000).

Temperature must be selected for the commodity. Very low, non-freezing temperatures can cause chilling injury in susceptible produce. Symptoms may remain hidden during cold storage and become visible only after transfer to warmer conditions. Temperature also affects the water-holding capacity of air and therefore interacts closely with relative humidity.

High but commodity-appropriate relative humidity helps maintain nutritional value, appearance, flavour, weight, firmness, and juiciness. When relative humidity falls below the optimum level, transpiration increases and produce shrivels. Excessive humidity, however, can encourage condensation and pathogen growth (Suslow and Cantwell, 2009).

In many low-income regions, the absence of a reliable cold chain is a primary cause of large-scale food loss. Carefully maintained temperature-controlled supply chains extend shelf life and reduce contamination, but their infrastructure and energy requirements often limit adoption (Home, 2022).

3.2. Secondary Causes

Secondary causes include inadequate practices during harvesting, transport, storage, and marketing. Improper tools and rough handling create wounds that increase water loss, respiration, and microbial infection. Prolonged harvesting and grading expose produce to field heat, accelerate senescence, and shorten shelf life (Yahaya, 2005).

Mechanical harvesting can create more cracking and bruising than careful hand harvesting for some commodities. Harvesting during rain encourages microbial development, while harvesting during the hottest part of the day increases field temperature, wilting, and shrivelling. Appropriate timing, tools, worker training, and field hygiene are therefore essential.

4. Pre-Harvest Precautions

Post-harvest quality is strongly influenced by pre-harvest conditions. Quality is difficult to improve after harvest, but it can be maintained through appropriate production practices. Variety selection, season, crop nutrition, irrigation, pest and disease management, and harvest maturity all affect storage life and quality (Kader, 1988; Kitinoja and Kader, 2002; Bekele, 2018).

Useful precautions include removing diseased plants and branches, controlling late and early blight and bacterial wilt, maintaining field sanitation, and harvesting commodities such as tomatoes before complete ripening when appropriate. The potential storage life differs greatly among commodities; relatively non-perishable products such as some apple cultivars can remain marketable for several weeks under suitable conditions (Kitinoja and Kader, 2003).

4.1. Cultural Operations

Good soil preparation, irrigation, mineral nutrition, weed management, and pruning can improve keeping quality. Fine, porous soil reduces forking and mechanical defects in root crops. A consistent water supply helps prevent cracking of carrots, radishes, tomatoes, onions, and watermelons, although excessive irrigation near maturity after a dry period can also cause splitting. Irrigation should be reduced appropriately before harvesting onion and garlic to improve storage performance (Cho, 2008; Bekele, 2018).

Excess nitrogen can accelerate tissue deterioration, whereas adequate potassium often improves keeping quality. Effective weed control improves access to water, nutrients, and sunlight. Correct pruning and removal of dead or diseased branches improve light penetration and support fruit colour and size development (Fischer, 2005; Bekele, 2018).

5. Post-Harvest Loss Reduction

5.1. Harvesting and Field Handling

Consumers favour fresh, mature, attractive, and pest- and disease-free produce. Harvest maturity should be selected according to the commodity and intended market. Overmature carrots and radishes can become pithy, while delayed harvesting can reduce the storage life of onion and garlic. Some fruits are harvested at physiological maturity and ripened later to meet market requirements (Ahmad and Siddiqui, 2015; Yahia, 2011).

Harvesting should be conducted during cooler parts of the day, and produce should be transferred promptly to a shaded packing area. Harvesting during hot periods increases field heat, wilting, and shrivelling. Produce should not normally be harvested during or immediately after rain because wet conditions favour microbial growth. Manual harvesting with suitable knives, clippers, or digging tools remains important for limiting mechanical damage (Alao, 2000; Hayatu, 2000).

5.2. Grading and Washing

Produce exposed to soil or agricultural chemicals should be washed with clean water when washing is appropriate for the commodity. Root and tuber crops are often washed to remove adhering soil, while clean-water washing can improve the appearance and hydration of leafy vegetables (Alao, 2000; Hayatu, 2000).

Damaged, diseased, and unnecessary plant material should be removed before marketing. Sorting and grading create uniform, attractive product classes, reduce cross-contamination, improve packaging efficiency, and allow higher-quality produce to obtain a better price.

5.3. Packaging

Effective packaging reduces mechanical injury, unwanted physiological change, water loss, and pathological deterioration. It can preserve freshness, succulence, flavour, and appearance during handling and distribution (Alao, 2000; Hayatu, 2000). Common materials include wooden boxes, corrugated-fibreboard boxes, jute bags, bamboo baskets, plastic crates, clay pots, films, and paperboard lined with polyethylene.

Packages must provide adequate protection and ventilation. Materials that are excessively impermeable to water vapour, oxygen, and carbon dioxide can create undesirable atmospheres and off-flavours. Produce should be packed without compression, bruising, or abrasion. Flexible films are useful for retaining moisture, particularly at low temperatures, while rigid containers provide stacking strength (Anwar et al., 2008; Hofman et al., 2013).

5.4. Pre-Cooling

Pre-cooling removes field heat and slows ripening, respiration, senescence, water loss, and microbial growth. It is particularly important when harvesting occurs in hot weather and for vegetables that deteriorate rapidly during storage (Williams et al., 1991).

Methods include forced-air cooling in refrigerated vehicles or rooms, package icing, hydro-cooling by immersion or chilled-water spray, and vacuum cooling. The appropriate method depends on commodity tolerance, package design, cost, water availability, and scale of operation.

5.5. Transportation

Transport is one of the most hazardous stages for perishable produce in many developing-country supply chains. Delays, vibration, compression, poor roads, inadequate ventilation, and uncontrolled temperature and humidity cause major mechanical and physiological losses (Alao, 2000; Opadokun, 1987). Rapid transport, suitable infrastructure, careful stacking, and strong, ventilated packages are necessary to maintain quality (Yahaya and Mardiyya, 2019).

5.6. Minimizing Moisture Loss

Moisture-retentive consumer packaging can reduce weight loss, particularly in leafy vegetables and root crops. Packaged produce generally maintains quality longer than unpackaged produce in refrigerated retail displays, provided that condensation and microbial growth are controlled (Suslow and Cantwell, 2009; Bekele, 2018).

5.7. Low-Temperature and Cold Storage

Storage extends the marketing life of fruits and vegetables by slowing respiration, transpiration, ripening, biochemical change, and disease development. Temperature, relative humidity, and atmospheric composition must be controlled according to the commodity (Danladi, 2000; Hayatu, 2000).

The optimum cold-storage temperature is generally the lowest temperature that does not cause chilling injury. Respiration and microbial multiplication increase with temperature, but temperature and humidity requirements differ among commodities and varieties (Alao, 2000; Ahmad and Siddiqui, 2015).

Controlled-atmosphere storage combines refrigeration with reduced oxygen and elevated carbon dioxide. It can slow respiration, yellowing, softening, and other quality changes. Successful use requires a gas-tight storage barrier and maintenance of oxygen and carbon-dioxide concentrations within commodity-specific tolerance limits (Williams et al., 1991; Yahaya, 2005).

6. Low-Cost Mitigation Technologies

A review of field trials and cost-benefit analyses identified small-scale technologies capable of reducing post-harvest losses and improving farmer returns. Technologies that were simple, inexpensive, and compatible with existing value chains generally achieved the highest adoption rates (Ridolfi et al., 2018).

6.1. Crate Liners

A field trial in India evaluated inexpensive corrugated-fibreboard liners for plastic crates. The liners reduced guava bruising by more than 60%. Fifty liner sets cost approximately US$7.40, while the additional profit from transporting a one-tonne load of guava was estimated at about US$40. The liners could also be reused and recycled (Ridolfi et al., 2018).

6.2. Smaller Packages

In Ghana, cabbage sacks holding approximately 30 kg were compared with conventional sacks holding up to 70 kg. About 77% of the cabbage transported in the smaller sacks remained saleable, compared with 68% in the larger sacks. Reducing package size limited compression and handling damage.

6.3. Shaded Field-Packing Stations

A field trial near Kigali, Rwanda, used a thatched-roof packing station with a concrete floor. Tomatoes were sorted, graded, and packed in plastic crates under shade. Shading reduced water loss, while grading and sorting allowed farmers to sell higher-quality tomatoes at improved prices (Ridolfi et al., 2018).

6.4. Zero-Energy Cool Chambers

Zero-energy cool chambers are constructed from bricks and sand and kept wet to provide evaporative cooling. In Indian field trials, chambers holding approximately 100 kg of mixed vegetables reduced weight loss by about 20% and increased shelf life from one day to five or six days. A trial in Ghana increased the proportion of produce available for sale from 42% without cooling to 62% with the chamber (Ridolfi et al., 2018).

6.5. CoolBot-Controlled Cold Rooms

CoolBot systems use conventional air-conditioning units with a control device to maintain low temperatures and high humidity in insulated rooms. A Ghanaian onion trial reduced storage loss from 30% in traditional sheds to 5% in the CoolBot room. The value of stored onions increased substantially during the off-season, allowing the investment to be recovered within several years when a reliable power source was available (Ridolfi et al., 2018).

7. Conclusion

Inadequate practices throughout the fresh-produce marketing chain cause substantial post-harvest losses, particularly during harvesting, storage, and transportation. Product quality is influenced by respiration, ethylene production, metabolic activity, biochemical reactions, microbial growth, relative humidity, temperature, and atmospheric gas composition.

Careful management of these endogenous and environmental factors, combined with suitable harvesting, washing, grading, packaging, cooling, storage, and transport practices, can extend shelf life and reduce loss. Affordable technologies adapted to local infrastructure and marketing conditions can make these benefits accessible to small-scale farmers and contribute directly to food security and sustainability.

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