Chapter
10

ADVANCES IN POST-HARVEST SYSTEMS AND VALUE ADDITION FOR FRUITS AND VEGETABLES

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Abstract
Post-harvest losses in horticulture crops remain a serious concern, influencing food quality, marketability, and economic returns, particularly in developing nations. This chapter addresses the numerous sources of post-harvest losses, including incorrect harvesting procedures, inadequate storage infrastructure, inefficient transportation systems, inappropriate packing, consumer-level waste, and poor communication across supply chains. Inadequate traceability procedures, a lack of availability to high-quality seeds, and the existence of several middlemen are further contributing factors that make managing the product more difficult. The chapter also highlights innovative post-harvest technologies and management strategies, including drying, canning, freezing, controlled and modified atmospheric storage, ethylene action inhibitors, and the integration of logistics and cold chain advances. Modern packaging methods that assist in preserving product freshness and increasing shelf life, like active, intelligent, and modified atmosphere packaging, are emphasized. Collectively, these observations underline the need to implement improved post-harvest techniques and technology to boost food security, reduce economic losses, and strengthen horticulture value chains.
Keywords: *Post-harvest management, cold chain, value addition, packaging, horticultural crops, physiological loss, storage, processing, food safety.*

Introduction

Post-harvest loss is described as a "measurable quantitative and qualitative loss of a given product at any point along the postharvest chain" (De Lucia and Assennato, 2006) and covers the change in the availability, edibility and wholesomeness of the food that keeps it from being eaten (FAO, 1989). Postharvest management of fruits and vegetables comprises pre- and post-harvest techniques, their harvesting, handling, packaging, storage, distribution, marketing, etc. (Yadav et al., 2014). The demand for high-quality fruits and vegetables is rising daily and is crucial to a balanced diet. Most of the fresh are highly perishable in nature because to the presence of high moisture content (75-95%) and high equilibrium relative humidity (95%) (Norman et al., 1984).

It is estimated that around one-third of the fresh produce cultivated worldwide is wasted at some stage between harvest and consumption (Bisht and Singh, 2024). Fruits and vegetables, as we all know, are living things that can breathe even after being harvested and can only stay fresh as long as their regular metabolites continue. Fresh fruits and vegetables have a shorter shelf life in such conditions because they are more vulnerable to deterioration from bacteria, yeasts, and mold (Devon, 2018). These losses can be decreased to a large extent with the timely and safe management of post-harvest food. Post-harvest losses for fresh fruits and vegetables have been estimated to be between 20 and 30%, and in unfavorable circumstances, they may surpass 50%, according to a number of studies. According to reports, losses were from 20 to 30% for apples, 15 to 20% for citrus, 10 to 15% for tomatoes, and 10 to 15% for cauliflower (Adhikari, 2006). Inappropriate maturity stages, direct packing and shipment without removing field heat, inadequate grading and sorting, poor transportation and handling, and inadequate storage facilities are the main causes of post-harvest losses in fruits and vegetables. Transportation from the yard to the collecting center and then to the wholesale market and retail locations, however, accounts for the majority of losses (Adhikari and Arati, 2021).

Reason for Losses

Harvesting

The timing of harvest has a significant impact on the quality and shelf life of fruits and vegetables. Financial considerations can lead to premature harvesting, which can produce immature, flavorless food that is more prone to harm. Ripe fruits, on the other hand, have a shorter shelf life. Fruits that are overripe or underripe are more likely to create physiological problems. Early harvesting reduces crops' nutritional and economic value. Unripe or overripe vegetables can often result in the loss of entire batches (Azabagaoglu, 2018). Harvesting techniques may also lead to losses (Liu, 2014).

When farmers don't have the right cold storage or storage containers, these losses might grow multiple times during or after the collection procedure. The quality of fresh vegetables and horticulture items declined as a result.

"Inadequate cultural practices" takes the place of "inadequate implementation of cultural practices." "Including a variety of factors" is substituted for "including pre-harvest irrigation, fertilization, pruning, infections, physiological disorders, hail, drought, excessive rainfall, and plant nutrition." Additionally, losses ranging from 4% to 12% are caused by "improper harvesting techniques, and inaccurate harvest timing" being substituted for "inaccuracies in determining the appropriate harvest time, harvesting at the wrong moment, improper use of harvesting techniques, and failure to pre-cool crops like cherries during the harvest season" (Bisht and Singh, 2024).

Storehouse

Storage technologies offer chances to improve marketing campaigns, increase value, and get beyond quarantine restrictions. They are also essential to the development and internationalization of the horticultural industries. The fundamental technology of many storage systems is temperature, and efficient temperature control is still necessary. Controlling relative humidity, adjusting the storage environment, using chemical treatments, and applying appropriate packing can all be coordinated with cold storage, even though other storage technologies can increase its impact (Watkins and Ekman, 2004). Temperature has a complex effect on ethylene metabolism.

Increased ethylene generation during refrigerated storage may be a sign of damage to perishable goods that are susceptible to cold. Although volatile fragrance components are essential to the flavor of strawberries, the effects of low-temperature storage on these compounds have not gotten as much attention as other aspects of quality. Strawberries release a wide variety of volatile chemicals after harvest. The temperature affects the specific compounds that are produced, even if this emission continues during cold storage (Forney et al, 2000).

Transportation

A vital component of business, especially for newly made items, is the transfer of goods from producers to consumers. An effective strategy is direct delivery from manufacturers to consumers. Consumer pricing is greatly impacted by transportation expenses, particularly in intricate distribution networks that cater to both remote and urban cities. In certain instances, these transportation expenses can even surpass the cost of the components required to manufacture the goods (Condratchi and Movileanu, 2012). Perishable food preservation is difficult in less developed nations because of poor road conditions, inadequate transit, and poor logistics management. Additionally, people with low literacy and skill levels frequently perform loading and unloading duties in many countries, which results in negligent handling of items and subsequent mechanical damage to agricultural products (Azabagaoglu, 2018).

Inappropriate Packaging

Appropriate packaging is crucial to minimize losses and extend the freshness of fresh fruit and vegetables. Top post-harvest losses are largely caused by inadequate packaging methods and the use of inappropriate packing materials. When inferior packaging materials are used, fresh produce can deteriorate more quickly due to inadequate damage protection. Unfortunately, using cheap but inferior packing materials is a widespread practice worldwide, particularly in poor and underdeveloped countries (Kitinoja and AlHassan, 2010).

Waste from Consumers

Consumer preferences are opinions that people have about a product, whether it be an item or a service, and they are formed by the assessment of the options that are now available (Kotler and Keller, 2008). In order to satisfy people's needs and desires, consumer behavior analysis goes beyond simply looking at what people buy. It also explores the reasons behind their purchases as well as the timing, place, mode, and frequency of their acquisitions

(Schiffman et al., 2010). Fresh fruits and vegetables make up almost half of the food that households waste.

Fruits and vegetables account for 39% of all household waste, according to a report. A comparable percentage of about 40% is found in home waste, according to another study.

Consumer financial waste is caused by a number of factors, including excessive expenditure, poor home storage techniques, and inadequate preparation. Individuals' trash production is influenced by a number of factors, including material belongings and sociocultural elements including income, gender, habits, and home storage choices (Poat et al., 2018).

Inadequate Structure

It is crucial to remember that, in contrast to other durable agricultural products, fruits and vegetables must be sent to markets right away because of their rapid perishability; any delay could result in loss (Porat et al., 2018; Sudharshan, 2013; Tolani, 2013). Because of this, the supply chain for horticulture products depends on effective transportation. Limited transit options, an underdeveloped transportation network, impracticable roads, and the lack of reasonably priced temperature-controlled vehicles are some examples of inadequate infrastructure (Accorsi Gallo and Manzini, 2017; Cardoen, 2015; Modi, 2009; Negi and Anand, 2015).

Lack of Communication between Farmers and Facilities

Processing companies typically purchase raw materials through middlemen or agents rather than directly from farmers, which results in lower prices for farmers and higher costs for processors (Subrahmanyam, 2000). One major problem is linkage, which affects the availability of appropriate methods used in fruits and vegetables processing. This connection factor tends to increase the ratio of raw materials to finished goods. It's important to note that agricultural seasonality affects processing sectors, resulting in price fluctuations. Stabilizing F&V markets not only reduces the risk of price fluctuations but also facilitates the exchange of important pricing information between producers and processing units (Rottger, 2004).

Lack of Knowledge about Superior Seeds

When attempting to increase agricultural output, ideal weather, superior seeds, and fertile soil are taken into account (Afadhali and Rwanda, 2015). Many Indian farmers are unaware of the advantages of utilizing high-quality seeds for farming, such as enhanced health and increased resistance to diseases and pests (Negi and Anand, 2015).

Insufficient Tracking, Traceability, and Record-Keeping Facilities

Traceability guarantees the tracking of particular farm products along a supply chain, from the agricultural field to the store. To make item tracking easier, adequate documentation is necessary at every stage of the distribution process. To achieve effective food tracing, businesses must identify food items, collect pertinent data, and exchange it with different distribution chain participants (Tolani and Hussain, 2013; Winkworth-Smith, 2015). Effective information sharing and coordination among the various parties increase the effectiveness of the supply network (Chen, 2003; Gaur et al., 2005).

Commodity prices are reduced when traceability is properly implemented, and distributed goods may be recovered from the same vendor in the case of a recall.

Insufficient Facilities

Effective information sharing and coordination among the various parties increase the effectiveness of the supply network (Gaur et al., 2005). Commodity prices are reduced when traceability is properly implemented, and distributed goods may be recovered from the same vendor in the case of a recall. However, there are limitations to the technique. For instance, the traceability features have substantial implementation and maintenance costs, and not all supply chain participants may find the tracking software easy to use (Negi, 2015).

A Lot of Middlemen

Traceability ensures that certain agricultural products are monitored along the supply chain, from the field to the shop. To make item tracking easier, thorough documentation is essential at every stage of the supply chain. To achieve effective commodity tracing, businesses must identify food items, collect relevant data, and distribute it across various supply system participants. The efficiency of the manufacturing chain is increased by efficient information sharing and coordination between the different stakeholders. Strong traditional traders with political influence have a big impact on India's agricultural supply system. Overuse of middlemen in the distribution process interferes with the smooth flow of important information, which makes coordination difficult and reduces overall effectiveness (Bisht and Singh, 2024).

Techniques for Minimizing Losses Following Harvest

The nutrition, color, and texture of crops must be preserved by a variety of post - harvest procedures. Even though horticulture produce naturally deteriorates with time, certain processes and common storage practices can successfully slow down deterioration, increasing shelf or storage life.

Drying

Dehydration, or removing moisture from food to extend its shelf life, is the oldest method of food preservation. By gradually lowering the moisture level of the fruit's tissue, this technique greatly lowers the chance of fruit deterioration. This method can be used in tropical areas by harnessing the heat produced by direct sunlight. Even though fruit tissues become discolored throughout the drying process, this method is the oldest and has been improved over time using a variety of techniques (Gupta, 1984). There are various drying techniques available, including dehydrator dryers that use artificial heat with regulated humidity, temperature, and airflow. Through the oven's heat source, oven dryers also control temperature.

Through the oven's heat source, oven dryers also control temperature. Several conventional drying methods have been used, such as high-temperature drying at temperatures above 50°C and low-temperature drying between 15 and 50°C.

Another method for drying is to freeze fruit juice and other liquids at temperatures between -10 and -40°C (Aravindh and Sreekumar, 2015).

Canning

Produce that is preserved in a sealed container has a longer shelf life. This method, which involves heat treatment and container storage, is applicable to perishable acidic fruits and vegetables. To aid in the peeling of the skin, the tomato, for example, is submerged in boiling water for approximately one minute before being put inside a container filled halfway with acetic acid, vitamin C, or citric acid (Parnell et al., 2004). Acidification is the process of adding ingredients like vinegar or lemon juice. This procedure is used to stop the dangerous bacterium Clostridium botulinum from growing.

Freezing

Fruit is preserved using this method by freezing it. A liquid experiences a phase shift known as freezing when it falls below its freezing point. This technique prolongs the fruit's life by preventing the formation of bacteria, which lessens deterioration. The fruit's ability to maintain its color and a comparatively high nutritional content is a crucial component of this preservation technique (Parnell et al., 2004). Freezers and cold storage rooms employ a range of freezing methods. These include contact (plate) freezing, liquid immersion freezing, air blast freezing, and cryogenic freezing. Fruits and vegetables are frequently preserved using the freezing technique, with air blast freezing and contact freezing being the most popular techniques (Bouzari et al., 2015).

New Storage

An essential component of fresh storage is maintaining the ideal physiological and physical conditions to increase the shelf life. In order to increase shelf life without sacrificing freshness, stored fruits are retained in their original, fresh state with an emphasis on reducing the metabolic processes and degradation. Cooling techniques are used to get the required storage temperature. Tomato fruits are kept in storage using a variety of chilling methods, including freezers, evaporative coolers, and controlled environment storage (Ayomide et al., 2019). Freezing is frequently used to preserve fruits and vegetables (Bouzari et al., 2015).

Regulated Atmospheric Pressure

The idea behind a controlled environment is to delay a fruit's respiratory process by increasing the amount of CO_2 and decreasing the amount of O_2 in the atmosphere. This extension of shelf life is achieved by changing the typical air composition (El- Ramady, 2015). Fruits can be kept fresher for longer by combining them with refrigeration, which changes the temperature within the storage space.

Standard air is composed of 21% O_2, 78% N_2, 0.93% Ar, 0.04% CO_2, and varying amounts of water vapor. The controlled atmosphere is stabilized by the addition of nitrogen (Babarinsa et al., 2015).

Ethylene Action Inhibitor Use

Waxing, high carbon dioxide levels, low oxygen levels, and ripening inhibitors are sometimes used to extend the product's shelf life (Lyndhurst et al., 2007). However, it is still challenging to find the optimal treatments for ripening inhibition and endogenous ethylene (C_2H_4). In order to keep ethylene levels below the cutoff, numerous chemical combinations have been investigated. Although small-scale farmers would not be able to afford them, ethylene absorbents such as calcium chloride ($CaCl_2$) and potassium permanganate ($KMnO_4$) offer significant economic potential when used in conjunction with controlled storage environments (Tessema, 2013).

Advancements in Retail Packaging

Packaging actively avoids food loss and waste in addition to holding food. In the produce industry, easily accessible "retail packages" such as apple bags, banana bunches, or individually wrapped zucchini provide a number of alluring benefits that go beyond mere practicality. These pre-packaged choices provide longer shelf life, better cleanliness, protection from damage, informative labels, and, in certain situations, even controlled environments to maximize freshness (Verghese et al., 2015). Developing an effective fruit and vegetable packaging strategy requires plan customization.

Every packaging unit must guarantee proper ventilation, cooling, and temperature control to meet the respiration patterns and environmental preferences of certain products, with an emphasis on controlling high CO_2 and low O_2 levels. MAP protects the delicate freshness and quality of mangoes, strawberries, and even cooked kale during their transportation and shelf life by altering the air inside the container (Brecht et al, 2003). Although plastic sheets and containers have long been the norm for packaging, in recent years edible waxes and coatings have gained wider recognition as dependable substitutes. Similar barriers between food and environment are provided by these edible alternatives, which are composed of proteins, lipids, and polysaccharides frequently in composite forms (Valdes et al., 2017).

Post-Harvest Management Practices

Harvesting

Because lower or higher maturity levels of produce shorten storage life and increase spoiling, fruits and vegetables should be gathered very carefully after monitoring the proper maturity level and quality (Ahmad and Siddiqui, 2015). Therefore, to preserve the highest quality, care must be given when harvesting horticultural goods. Postharvest physiologists divide the shelf life of fruits and vegetables into three stages: maturation, ripening, and senescence. When produce reaches the maturity stage, it is ready for harvest. Climacteric fruits can be picked when they are ripe, half-ripe, or mature green.

In order to allow ripening and senescence to take place during the post-harvest phase, producers aiming to reach far-off markets must have harvested their produce in the mature green stage. This avoids mechanical harm during harvesting and gives growers enough time to prepare fruits and vegetables for the market.

Additionally, to prevent excessive field heat generation, fruit picking should be done in the early or late hours of the day (Adhikari and Arati, 2021).

Pre-Cooling after Harvest

To eliminate excessive field heat, harvested fruits and vegetables must be pre-cooled. Field heat should be eliminated as soon as feasible before any postharvest handling operations because it is typically high and undesired during the harvesting stage of many fruits and vegetables (Bachmann and Earles, 2000). According to Shahi et al. (2012), pre-cooling preserves quality and prolongs the shelf life of harvested horticultural products by minimizing the effects of microbial activity, metabolic activity, respiration rate, and ethylene production, as well as lowering ripening rate, water loss, and decay. Dipping harvested food in cold water (hydro-cooling) combined with a disinfectant such as sodium hypochlorite is an inexpensive but efficient method of precooling.

According to research, well-ventilated room cooling is appropriate for preserving the temperature of previously cooled fruits and vegetables. However, the forced convention approach was shown to be appropriate for keeping packaged produce because it removes heat 75–90% faster than room chilling. Cooling techniques have an impact on the horticultural products' storage system, packing method, and commodity condition. A variety of cooling techniques have been employed, including thatch/roof house cooling, room cooling, hydro cooling, and forced air cooling. When compared to hydro cooling and forced air cooling, room cooling was found to lower the produce's temperature more gradually (Makule et al., 2022).

Packaging

According to Bachmann and Earles (2000), fruits and vegetables need to be packaged properly to minimize both chemical and physical harm. A thorough analysis of packaging technologies was necessary to overcome the losses of packed fruits and vegetables since improper fruit and vegetable packing increased the losses during handling and transportation (Idah et al., 2007; Adhikari and Aarati, 2021). Perishable goods are packaged using a variety of materials.

Packaging Types

Consumer packaging includes polythene bags for frozen fresh peas, ventilated pouches for grapes, net bags for citrus fruits, onions, and potatoes, trays for baby corn, tamarind, and brinjal, and sleeve packs. Transport packaging includes palletization, unitization, plastic crates, sacks, wooden boxes, such as corrugated fiberboard boxes, and plastic corrugated boxes. Depending on the goods, different packing materials are used.

The majority of underdeveloped nations, including Nepal, frequently employ wooden crates, cardboard boxes, woven palm baskets, plastic crates, nylon sacks, jute sacks, and polythene bags as packaging materials. The majority of the aforementioned conventional packaging does not provide the commodity with all the protection it requires.

While most packing materials, such as nylon sacks, don't enable adequate aeration within the packaged commodity, resulting in a build-up of heat due to respiration, other materials, such as wooden baskets, have rough surfaces and edges that can cause mechanical injuries to the produce (Adhikari and Aarati, 2021). In order to protect fruits and vegetables with high moisture content (perishable products) and high respiration rates, a number of packaging techniques have been developed in the contemporary era.

Methods of Packaging

Active packaging According to Himi et al. (2007), active packaging, also known as interactive packaging, is a packaging system in which certain additives are introduced to the package material to increase safety, shelf life, sensory qualities, and product quality. Active packaging is getting more and more popular, and there will be plenty of new opportunities to apply this technology in the future (Scetar and Galic, 2017). It prolongs a food's shelf life by interacting with the interior gas environment. It consists of carbon dioxide emitters, ethanol emitters, oxygen scavengers, ethylene absorbers, and humidity absorbers.

Intelligent Packaging

Also referred to as smart packaging, intelligent packaging is described as a packaging system that functions as a monitoring system to keep an eye on certain characteristics of the food it contains and can notify the manufacturer, retailer, and consumer of the condition of these characteristics (Robertson, 2016). In order to indicate to the consumer how fresh the food is and whether it has spoiled due to a temperature change during storage or a leak in the packaging, intelligent packaging can change color. It comprises Time Temperature Indicators (TTIs), such as carbon dioxide and oxygen indicators. Compared to conventional systems, they are an efficient means of preserving the safety and freshness of the product (Nayik and Muzaffar, 2014; Adhikari and Arati, 2021).

Modified Atmospheric Packaging

The process of sealing actively respiring produce in polymeric film packages to alter the O2 and CO2 levels within the package atmosphere is known as modified atmospheric packaging, or MAP of products. It enhances moisture retention in addition to furthermore aids in maintaining settings that, if not sterile, at least lessen exposure to pollutants and pathogens, extending the produce's shelf life (Mangaraj and Goswami, 2009). Film packaging has detrimental impacts such as increased susceptibility to decay, uneven ripening in unsuitable CO2/O2 off-flavours and off-odours, commencement and/or aggravation of physiological diseases, and enhanced decay due to excessive humidity (Irtwange, 2006).

According to Chamara et al. (2000) and Adhikari and Arati (2021), it can be advised to package individual hands of a banana cultivar known as "Kolikuttu" in low-density polyethene (LDPE) bags with a wrapped ethylene absorber in order to prolong their shelf life at room temperature. In nations where cold storage is expensive or difficult to get, this might have significant economic implications.

Storage

Depending on the type of commodity and the intended storage duration, fruits and vegetables are stored using a variety of methods, including ground storage, ambient storage, refrigerated storage, air cooled storage, zero energy storage, modified atmospheric storage, hypobaric storage, and controlled atmospheric storage.

Controlled Atmosphere Storage (CAS)

One of the most significant advancements in fruit and vegetable storage systems is controlled atmosphere storage (CAS), since the type of gas present in the storage has an impact on how long the products may be stored. The CAS technology slows down the natural senescence process, removes ethylene, and adds carbon monoxide by reducing oxygen (O_2) and increasing carbon dioxide (CO_2) relative to the surrounding atmosphere. This lowers the respiration/metabolic rate of the commodity. Since higher CO_2 levels often have a detrimental effect on the growth and development of microorganisms, the advantage of controlled environment storage is related to the decrease in food deterioration from pests and diseases (Thompson et al., 2018). As a result, keeping fruits and vegetables in a controlled environment can greatly lower postharvest losses and provide defense against insects and microbes.

Storage in a controlled atmosphere is extensively used for long-term storage of apples, pears, and kiwi fruits. Even at ideal storage temperatures, CA stores have a higher relative humidity (90–95%) than typical cold stores, which preserves the crispness of fresh foods and minimizes weight loss. This makes them beneficial for crops that ripen after harvest or decay quickly. However, due to the high carbon dioxide and low oxygen levels, controlled atmospheric storage is fatal to humans (Thompson et al., 2018).

Modified Atmosphere Storage

Modified atmosphere storage and controlled atmosphere storage share a similar concept. However, there is no environmental control in this storage. The shop is made airtight in MAS, and fresh items' respiratory activity is permitted to alter the atmosphere as CO2 is created and oxygen is consumed. As the storage organ continued to breathe, CO2 grew, and O2 decreased. Fresh hydrated lime can be added to the bag to prevent excessive CO2 buildup in MAS. Many perishable fresh horticulture crops kept under refrigeration have had their shelf lives extended by the use of modified environment storage. By adding various gases to the food packaging, MAP treatment extends its shelf life. Appropriate gas mixes can slow the growth of microorganisms.

In commercial operations, apples are mostly stored in controlled-atmosphere storage (CAS) and modified-atmosphere storage (MAS), with minor amounts of cabbage and pears. Fresh foods and a growing variety of mildly processed goods are packaged in modified atmosphere packaging (MAP), which is becoming more and more common as new uses are created. Raw or cooked meats, poultry, fish, seafood, veggies, fresh pasta, cheese, baked goods, sandwiches, potato chips, coffee, and tea are a few examples of MAP items (Fang and Wakisaka, 2021; Adhikari and Arati, 2021).

Hypobaric Storage

Fruit is kept cold under a partial vacuum in a process known as hypobaric storage. Temperatures of 5°C (40°F) and pressures as low as 80 and 40 millimeters of mercury are typical situations. Even after months of storage, hypobaric circumstances provide an exceptionally high-quality fruit because they lower respiration rates and ethylene production (Bower, 2007). Low-pressure storage, LPS, and sub-atmospheric pressure storage are other names for hypobaric storage. Another type of controlled environment storage is hypobaric storage, where produce is kept in a partial vacuum. To maintain the oxygen level and reduce water loss, the vacuum chamber is constantly vented with water-saturated air. In hypobaric storage, ripening is slowed down by a decrease in both the partial pressure of oxygen and the ethylene level. At normal atmospheric pressure, lowering the air pressure to 10 kilopascals is comparable to lowering the oxygen concentration to roughly 2.1%. Since hypobaric storage is costly to build, it is not commonly utilized in our nation (Celik and Arican, 2014; Adhikari and Arati, 2021).

Cellar Storage

These subterranean or partially subterranean spaces are frequently located beneath a home. The cellar is often excavated on the terrace facing north. Except for one side facing the entrance, it is built so that all sides are covered with dirt. There are windows and a double-door system that allow for ventilation. The storage will have a temperature that is 15˚C lower than the surrounding air. Water can be supplied via narrow channels or perforated pipelets to raise the relative humidity in arid regions. In Britain, cellars have historically been utilized on a domestic scale to store potatoes, apples, cabbage, and onions during the winter (Tarasov et al., 2021).

Rustic Storage

Seed potatoes (tubers) are mostly stored in rustic storage. In order to take advantage of the lower temperatures in the area, this kind of storage is typically constructed at higher elevations in hills and mountains (Gautam and Bhattarai, 2012). Instead of using brick walls, chicken wire mesh, bamboo, or wooden sticks throughout the building, a thatch house is built with diffused sunlight inside. Seed potatoes are kept one after the other in a wooden rack within storage. The tubers are given access to diffused sunlight. Potatoes create tiny sprouts with a slower growth rate when exposed to diffused light.

Zero-Energy Cold Storage

Although it seems very complex, Zero Energy Cold Storage (ZECS) is based on the idea of a conventional basement with direct evaporative cooling. It is a structure intended to maintain fruits at a steady, cool temperature and humidity level so they won't be harmed. In order to prevent spoiling, it keeps fruit cool in the summer and prevents freezing in the winter. Anywhere there is a water supply and locally accessible materials like brick, sand, bamboo, straw, gunny bag, etc., zero-energy cold storage can be set up. The chamber can keep the relative humidity at around 90% while lowering the temperature by 10–15°C. According to Lal Basediya et al. (2013), this kind of chilling chamber works best during the dry season and maintains a high humidity of roughly 95%, which can extend the shelf life and preserve the quality of horticulture produce (Adhikari and Arati, 2021).

Transportation

From the farm yard to the collecting facility and then to the wholesale market and retail locations, the majority of losses happen during transportation. Depending on the item, transportation losses of various fruits and vegetables from Nepal's border to various Indian marketplaces varied from 15 to 36% (Adhikari and Arati, 2021).

Conclusion

Post-harvest management plays a critical role in safeguarding the quality, nutritional content, and economic potential of horticulture crops. This chapter's study shows that losses happen throughout the whole supply chain, from harvesting and storage to transportation, packing, and retail handling. These losses are frequently brought on by poor infrastructure, a lack of technical expertise, and systemic inefficiencies. Implementing scientifically informed harvesting procedures, adequate pre-cooling, appropriate packaging materials, and enhanced cold chain logistics can greatly minimize losses. Additionally, cutting-edge technologies like ethylene inhibitors, clever packaging, and controlled and changed environment storage provide workable ways to prolong shelf life and preserve market quality.

Strengthening farmer–industry ties, increasing the use of high-quality seeds, and enhancing traceability and record-keeping systems are critical for developing resilient supply chains. To ensure sustainable horticultural output and improved food availability, eliminating post-harvest losses ultimately requires an integrated strategy that combines technological innovation, infrastructure development, and capacity building.

Disclosure Statement

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