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REVIEW ARTICLE

OPTIMIZING POST-HARVEST HANDLING PRACTICES TO REDUCE LOSSES AND ENHANCE QUALITY OF FRUITS AND VEGETABLES.

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ABSTRACT

Post-harvest activities start only after the harvest of fruit and vegetables. Harvesting time and method vary according to the crop, variety, and availability of resources. Harvesting of both pre- and over-mature crops leads to a shortening of shelf life. Due to the perishable nature of fruits and vegetables, the harvesting must be done at the proper stage of maturity. It's important to handle them carefully because they don't last long once they're harvested. Inadequate handling practices for produce have led to significant losses in terms of time and money. A significant amount of commodity loss is being caused by the lack of appropriate handling procedures and chemical treatment. Factors contributing to post-harvest losses include poor handling practices, inadequate storage facilities, and inefficient transportation systems, particularly in developing nations. Loss can be reduced by using appropriate handling techniques such as cleaning, grading and sorting, pre-cooling, packing, storing, and transportation. Recent advancements in post-harvest technologies, such as robot-assisted sorting and controlled atmosphere storage, will also help in reducing losses and extending shelf life. The data were gathered from several reliable sources and have been presented in own words, providing insights into strategies for minimizing post-harvest losses and enhancing the quality of fruits and vegetables.

KEYWORDS

Post-harvest handling, Fruits, Vegetables, Loss reduction, Quality enhancement

1. INTRODUCTION

The post-harvest stage of crop production happens shortly after harvesting and includes operations such as cooling, cleaning, sorting, and packing. This stage is critical in determining whether the crop will be sold fresh or as a component in processed foods. Horticultural foods are living organisms with similar respiratory systems to humans. After harvest, produce undergoes respiration and changes its qualities based on storage conditions (Nations, 2007). A post-harvest loss occurs when a product's quantity or quality changes after harvest, including availability, edibility, purity, or quality, that impede consumption affecting its intended use or value. A number of studies have been undertaken to assess the post-harvest loss of fruits and vegetables. Estimated post-harvest losses for fresh fruits and vegetables range from 20 to 30%, with the potential to reach 50% in unfavorable situations (APO and FAO, 2006). Post-harvest losses are far more challenging and expensive than pre-harvest losses in terms of money and man-hours (Adeoye et al., 2009). Harvesting is the first stage in which horticultural crops are separated and taken for processing, so it is considered a critical stage. Harvesting time is one of the major factors that degrades the quality of produce. Both pre-mature and over-mature harvesting shorten the storage life, so a proper stage of harvesting is necessary (Pokhrel, 2020). Along with harvesting time other processes like sorting, grading, storage, cooling, transportation, and packaging affect the shelf life of fruits and vegetables. Horticultural products suffer from high perishability, physical and mechanical injuries, and inadequate storage facilities, leading to significant market losses.

Poor handling of the packed produce during loading and unloading, rough roads that cause the vehicles to vibrate the most, a lack of storage space, packages that are packed into the vehicles too tightly, a lack of air conditioning in the vehicles that causes the produce to deteriorate and finally loss of the produce. Due to a lack of advanced methods of transportation, losses from transportation can be large, especially in developing nations (Devkota et al., 2014). Depending on the product, transportation losses of various fruits and vegetables from Nepal's border to various Indian marketplaces varied from 15 to 36% (Bhattarai, 2018). The effective marketing of fruits and vegetables has drawn a lot of attention worldwide in the last few years. The costs of fruits and vegetables are highly variable because there are inadequate marketing channels, marketing services, and infrastructure. Traditional fruit and vegetable marketing is still dominant in Nepalese agriculture due to a to a lack of market knowledge. Still, traditional channels like small local haat bazaars and retailers are being used in Nepal to deliver the produce from the farm gate to the consumer. The channel starts from farmer to middleman, to wholesalers, to retailers, and finally to consumers (ADB, 2019).

These days, many organizations view post-harvest loss reduction programs as a crucial part of their efforts to lower food insecurity. Post-harvest loss is becoming more widely acknowledged as a component of an integrated strategy to fulfill agriculture's promise and satisfy the world's growing requirements for food and energy. Consequently, lowering post-harvest loss is essential to meeting the issue of feeding a growing global population, as is increasing the productivity of current farmland, increasing the utilization of today's crops, and sustainably bringing additional acreage into production. This study aims to assess the effectiveness of handling techniques, identify contributing factors, evaluate current post-harvest practices for fruits and vegetables, and offer recommendations for reducing losses and enhancing food security.

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2. HARVESTING

Table 1: Maturity Indices of Fruits	
Fruit	**Maturity indices**
Apple	11-12% SSC based on variety, color changes toward yellowish green
Banana	The finger's cross-section loses its angularity and turns from dark green to light green.
Guava	Skin color changes from dark green to greenish yellow color
Kiwi	TSS = 14-15%, firmness = 14 lbs.
Mango	Depending on the variety, color turns yellow and shape changes
Lemon	> 30% juice by volume
Strawberries	Two thirds of the berry's surface is pink or red in color.
Pomegranate	Minimum 1.85% TA

Source: (Dhatta and Mahajan, 2007)

The stage at which fruit and vegetables are harvested determines their post-harvest life and quality. The stage of harvesting has an impact on post-harvest operations such as marketing, transportation, and storage. Fruits should be picked when they reach their maximum dry weight, which is known as physiological maturity. On the other hand, vegetables should be picked when they reach horticultural or field maturity. Fruits and vegetables can be harvested manually, using tools, or by machine based on the crop, its cultivation, and the available resources. Harvesting must be done at the cooler part of the day, especially during the morning because there is high humidity and fruits are heavy, turgid, and healthy (Budhathoki et al., 2022). However, harvesting during the hottest part of the day typically causes the product to wilt and shrivel due to increased field heat. Harvesting vegetables during or right after rain is not advised since it fosters an environment that encourages the growth of microbes (SM, 2019).

Table 2: Vegetables Maturity Days from the Planting Days		
Crop	**Early Variety (days)**	**Late Variety (days)**
Tomato	65	100
Radish	22	40
Okra	50	60
Potato	90	120
Peas	58	77
Cabbage	62	110
Cauliflower	55	65
Broccoli	70	150
Muskmelon	75	90
Mustard	40	60
Onion	85	120
Pumpkin	110	120
Eggplant	70	85
Carrot	60	85
Beans	56	72

Source: (El-Ramady et al., 2015)

3. POST-HARVEST HANDLING

Post-harvest handling in agriculture refers to the phase of crop production that comes right after harvest, which includes packing, sorting, cooling, and cleaning. A crop starts to wither the moment it is taken out of the ground or split off from its parent plant. Fruits and vegetables must receive proper post-harvest care because it affects their freshness, flavor, nutritional content, and general quality. The post-harvest life of produce depends upon how the crops are managed after harvest, which might determine the quality of the finished product.

3.1 Cleaning, Sorting and Grading

The first step in preparing horticultural produce is cleaning. Cleaning is the process of removing foreign material (dirt, sand, stone, diseased portion) from a commodity. To perform cleaning, chlorine is one of the best agents. It gives the best result when a solution is made (100–150 ppm). It helps in controlling inoculum buildup during packing house operations. For best results, the pH of the wash solution should be between 6.5 and 7.5. Mangoes and bananas should be washed to remove latex. Kiwifruit should be dry-cleaned or brushed after curing or storage (Dhatta and Mahajan, 2007). Sorting is the process of separating horticultural produce on the basis of shape, size, and color. A new modern technology for sorting is robot-sorted fruit based on size and color (Dewi et al., 2020). Basically, grading is the process of making a homogeneous group of fruits and vegetables on the basis of shape, color, size, and physical parameters. The main purpose of grading is that it saves time and energy during processing operations and reduces handling losses during the transportation of agricultural produce. Recently, fruit grading machines with machine vision systems and NIR inspection systems have been widely developed, and data on fruit quality has been managed in databases (Londhe et al., 2013). Also, a mobile grading machine system has been developed for citrus fruit grading; it collects information on crops like fruit yield, diameter, and sugar content of fruit in each part of the tree (Kohno et al., 2011). In recent years, the development of image analysis and computer vision systems has been a helpful tool in the quality assessment of horticultural produce. This technique is applied in the grading and sorting of fruits and vegetables (Joy. P.P. and Divya. B., 2015).

3.2 Precooling

Precooling is a simple cooling operation that is done immediately after the harvesting of the commodities to reduce field heat (Akbudak et al., 2012). Many horticulture products are susceptible to degradation, so the immediate removal of field heat as quickly as possible is necessary. There are various types of pre-cooling techniques. Precooling reduces the respiration rate and also lowers different physiological activities. The following are mostly feasible for farmers: room cooling, forced air cooling, vacuum cooling, package ice cooling, hydro cooling, and cryogenic cooling (Senthilkumar et al., 2015). The technical process of cooling is the transfer

of heat or exchange of heat between horticulture produce and mediums such as ice, cold air, vacuum, and cold water through heat transfer processes like radiation, convection, and conduction (Kitinoja, and Thompson, 2010). Precooling reduces microbiological activity, metabolic activity, respiration rate, and ethylene production while lowering ripening, water loss, and decay. This preserves the quality and shelf life of harvested fruit (Shahi et al., 2012).

3.3 Packaging

The process of covering produce to prevent external contamination and mechanical injuries so that harvested produce will be delivered to the consumer in a safe condition is called packaging (Prasad and Kochhar, 2014). Food quality in terms of freshness and nutritional value is a growing issue for consumers, who prefer to purchase food based on its color, texture, scent, and other attributes, so proper packaging is important to maintain post-harvest quality (Fu et al., 2023). Packaging material that reduces the release of ethylene gas from fruit and vegetables has great application in post-harvest horticulture. For example, the application of potassium permanganate, which oxidizes ethylene to CO_2 and H_2O (Zhang et al., 2022). Packaging requirements are based on elements such as water loss, microbiological infections, heat accumulation, and the type of package needed. It is advised to use locally accessible wrapping and cushioning materials. Crop-specific sizes of corrugated cardboard boxes (for apples and mandarin) and plastic trays or crates (for tomato, mandarin) according to local conditions can be used for packaging (Bhattarai, 2018).

Different packaging materials are used by developing countries, among which nylon sacks, plastic or wooden crates, woven palm baskets, cardboard boxes, and polythene bags are common (Idah et al., 2007). Not all packaging materials give proper protection; for example, nylon sacs prevent adequate air circulation, wooden baskets have rough surfaces and edges which cause mechanical injury, wooden crates don't have enough height, so it creates lots of pressure on the base (Arah et al., 2016). The packaging needs to be strong enough to withstand mechanical stresses, devoid of chemicals, allow for quick cooling of the contents, and possess adequate mechanical strength.

3.4 Storage

Storage is the technique of carefully preserving agricultural products to protect them from deteriorating after they have reached their usual shelf life (Kiaya, 2014). Fruits and vegetables should be stored primarily to increase their shelf life and duration of availability. Fresh produces are live things that continue to perform all necessary physiological functions even after being harvested. Controlling the rate of respiration, transpiration, ripening, as well as any undesirable biochemical changes and disease infection, is therefore the main goal of storage (Becker and Fricke, n.d.). There are three types of storage: common storage, refrigerated storage, and controlled atmosphere storage. Fruit storage facilities have a direct impact on its physiochemical quality, and using storage technology correctly helps to extend the shelf life of harvested produce (Faqeerzada et al., 2018).

Due to its significant impact on biological reaction rates, temperature is the most crucial environmental element. The pace of a biological reaction rises two to three times for every 10 °C increase in temperature within the physiological range of temperatures (0–30 °C). The lowest temperature that prevents chilling injury to fresh produce is the ideal storage setting for fruits and vegetables. The lowest temperature that prevents chilling injury to fresh produce is the ideal storage setting for fruits and vegetables. The controlled atmosphere (CA) storage method, which maintains low levels of oxygen (O_2) and high levels of carbon dioxide (CO_2), is the most significant advancement in storage technology. This storage offers constant monitoring and adjustment of oxygen (O_2) and carbon dioxide (CO_2). Many fruits can be preserved for two to four times longer than usual under CA conditions (Khan et al., 2017). Zero energy storage system works on the principle of evaporative cooling. It is one of the easiest and cheapest storage technology that can be prepared by using locally available resources like bricks, sand, bamboo, etc. It can maintain a high humidity level of approximately 95% and a lower temperature of 10 to 15 °C, which can prolong the shelf life and preserve the quality of horticulture goods (Mishra et al., 2020).

Table 3: Storage of fruits and vegetables

Commodity	Temperature (°C)	Relative Humidity (%)	Shelf Life
Asparagus	0-2	95	2-3 weeks
Beans (green)	5-7	90-95	7-10 days
Carrot	0	90-95	2-5 months
Cauliflowers	0	90-95	2-4 weeks
Cucumbers	7-10	90-95	10-14 days
Cabbage	0	90-95	3-6 weeks
Pepper	7-10	90-95	2-3 weeks
Courgettes	0-10	90	5-14 days
Eggplants, Brinjal	7-10	90	1 week
Melons	0-4.4	85-90	5-14 days
Okra	7-10	90-95	7-10 days
Onion (dry)	0	65-70	1-8 months
Potatoes (white)	5-10	93	2-5 months
Potatoes (sweet)	12-16	85-90	4-6 months
Tomatoes (ripe)	7-10	85-90	4-7 days
Tomatoes (green)	12-20	85-90	1-3 weeks
Watermelons	4.4-10	90	2-3 weeks
Apples	1-4.4	85-90	3-8 months
Avocados	4.4-12.5	85-90	2-4 weeks
Mangoes	12	85-90	2-3 weeks
Pineapples	7-12.5	85-90	2-4 weeks
Pawpaw	7	85-90	1-3 weeks
Carnations	0-2	90-95	3-4 weeks

Source: (Liberty et al., 2013)

Table 4: C.A. storage for fruits and vegetables

Commodity	Temperature Range (°C)	Temperature Range (°F)	O2 (%) Range	CO2 (%) Range
Strawberry	0-5	32-41	10	15-20
Apple	0-5	32-41	2-3	1-2
Kiwifruit	0-5	32-41	2	5
Nuts and dried fruits	0-25	32-77	0-1	0-100
Bananas	10-15	54-59	2-5	2-5
Cantaloupe	3-7	38-45	3-5	10-15
Lettuce	0-5	32-41	2-5	0
Onions	0	32	1-2	0-1
Cucumber	12	54	1-4	0

Source: (Kaur et al., 2021)

3.5 Transportation

Markets are located far away from production points in most of the developing countries, like Nepal. Harvested produce is brought to the market through trolleys, buses, motorcycles, or manually (Abimbola, 2014). Road vehicles are the primary means of transporting fruits and vegetables. In addition, they are carried in smaller amounts by sea, interior waterways, and air. Losses of up to 20% may happen when transporting goods. Transportation can be one of the main causes of product loss since it prolongs the period between production and consumption, especially for fresh items (Navya Sri et al., 2022). The main issues that cause produce to be lost during transportation include inadequate refrigeration, inadequate infrastructure, improper loading and unloading procedures, and inadequate transport methods (Sawicka, 2020). Other major factors that contribute to the post-harvest loss of fruits and vegetables include transporting them for longer periods of time without the use of cushioning materials, in uncovered vehicles, mixing products from different sources, overfilling, and loading with other harmful chemicals (Daba Hirpa et al., 2011; Emana et al., 2017; Kuyu and Tola, 2018; Yigzaw et al., 2016). Ethylene producing and ethylene sensitive commodities must be transported separately. To reduce loss, produce should be carefully stacked and placed in well-ventilated containers. Stacking should ensure efficient circulation of cold air throughout the vehicle. Ensure timely transportation of fruits and vegetables for effective marketing and quality maintenance. The majority of transportation losses are caused by physical and mechanical injuries, as well as uncontrolled circumstances such as temperature and humidity. Transporting horticulture items in refrigerated containers is convenient and reduces loss. In developing nations, the initial investment for refrigeration and operations might be prohibitively expensive, making it inaccessible to many people. Transportation during the cold hours of the night or early morning can significantly reduce waste. An efficient transportation system reduces post-harvest loss and balances product price fluctuations across the country's marketplaces.

3.6 Marketing

Planning, coordinating, and managing the flow of horticultural products from the farm to the customer is known as marketing. It includes a number of steps that guarantee the smooth and successful transportation of agricultural products from the site of production to the site of consumption. Due to the perishable and seasonal nature of horticultural produce, marketing of it is quite difficult compared to other commodities. The supply of horticulture commodities is therefore vulnerable to a number of problems, such as extreme price fluctuations (Shankar & Singh, 2017). Marketing challenges in developing economies like Nepal include limited marketing education, a preference for foreign products, low demand for non-essential items, high production costs, and poor infrastructure (Ewah and keng, 2009). Costs needed fpr transportation, loading and unloading, loss of weight, market toll, tips and donations and house rent are all included in the market price, so these costs are the major problems faced by small farmers during the marketing of produce (Hoq et al., 2012). Fruits and vegetables have a distinct pricing spectrum from producer to consumer, which is determined by the demand and supply of operations between numerous intermediaries at different levels of the marketing system. Furthermore, marketing arrangements at different stages play a vital effect on pricing levels at various stages, viz., from the farm gate to the ultimate user (Neeraj et al., 2017). Fruits and vegetables are distributed through the following three marketing channels in Nepal (Adhikari and G.C., 2021).

Channel 1: Farmer - Retailer - Consumer

Channel 2: Farmer - Consumer

Channel 3: Farmer – Assembler – Retailer – Consumer

In Nepal, farmers receive less return on investment, while consumers overpay due to the presence of intermediaries. Also, the excessive market supply of fruits and vegetables leads to higher losses. This inhibits farmers from producing fruits and vegetables. Efficient marketing strategy and proper selection of marketing channels are necessary to minimize the losses that arise due to this.

4. Conclusion

It is clear that maintaining the quality and increasing the shelf life of fruits and vegetables requires appropriate post-harvest management. By harvesting them at the right time and implementing effective handling practices like cleaning, sorting, and pre-cooling, we can minimize losses. Techniques such as modified-atmosphere packaging show potential for reducing spoilage and extending shelf life. However, there is still improvement required, particularly for challenges like inadequate infrastructure and inefficient transportation systems. This study concludes that by using suitable postharvest handling procedures and treatment technologies, the quality of the harvested fruit can be preserved and its shelf life can be increased. Developing nations will have significant challenges in dealing with postharvest losses as long as these basic post-harvest techniques are not implemented.

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