Review article
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Post-harvest Technologies for Handling Operations of Fruits

Huma Qureshi[1], Saad Jahangir Khan[2], Muhammad Salman,[3] Muhammad Kalim,[3] Alina Khan[4], Alina Shahjehan[5]
[1]Department of Horticulture, The University of Haripur, Pakistan
[2]University: The University of Agriculture Peshawar, Pakistan
[3]University: The University of Agriculture Peshawar, Pakistan
4Times Institute - Multan, Pakistan
[5]The University of Agriculture Peshawar, Pakistan
Corresponding author:email: humaqureshi196@gmail.com

Abstract
Post-harvest technologies have enabled horticultural companies to satisfy worldwide needs for localized markets with large-scale production and international transportation of fresh products. Customers worldwide have regarded fruits as a crucial part of a healthy diet. Besides this, they also have wonderful tastes, containing plentiful minerals and well-being properties. Harvested items remain metabolically active, experiencing maturation or fatuity mechanisms that can be managed to maintain quality after harvest. The producer or grower has a prime role in preserving the quality of crops after harvest, which is very critical. The lack of post-harvest processes (precooling, transportation, storage, and packaging) may lead to significant nutritional and overall quality losses, deadly pathogenic epidemics, and economic difficulties for all parties in the supply chain, from producers to customers. Adequate post-harvest operations help to slow down maturation or senescence, reduce the risk of microbial infection, and inhibit the incidence of physiological diseases. Advances in post-harvest techniques include chemical treatment (1-Methylcyclopropene, Nitric Oxide, Salicylic Acid, Carboxymethyl Cellulose, Gum Arabic), physical treatments (hot water, hot air, Ultraviolet-C radiations, high-pressure processing, and edible coating), biocontrol agents, plasma techniques, etc. This review article described the advanced status of post-harvest treatments to uphold the standard of excellence and eliminate losses of fresh produce.

***Keywords*: **Post-harvest, healthy diet, physiological diseases, pathogenic epidemics, senescence, quality

Highlights:

- Post-harvest operations generally include cleaning, washing, grading, and packing fresh produce.
- Fruits have a very short storage life, which leads to losses and poor quality.
- Post-harvest operations extend the storage life while maintaining its qualitative attributes.
- To maintain and extend shelf life, a variety of physical, chemical, and gaseous treatments are available.

1. Introduction

Fresh fruits are high in vitamins, organic acids, carbohydrates, minerals, and other nutritive compounds, making them essential to most people's diets (Droby *et al*., 2009; Tian *et al*., 2013). Fresh fruits and vegetables have also been linked to improved human health due to their high supply of vitamins, fibre, minerals, and antioxidants, which are strong detectors against free radicals (El-Ramady *et al*., 2015). China has consistently ranked top worldwide for yearly fresh fruit output for over twenty years, followed by India, Brazil, the USA, Spain, Mexico, Italy, and Indonesia, per the official statistics from the Food and Agriculture Organisation (FAO). Pakistan faces fruit and vegetable losses of about 35–40% of their value after harvest (http://www.fao.org/statistics/en/). Fruits are classified based on climacteric and non-climacteric characteristics. The fruits that ripen after detaching from the tree and produce more ethylene are climacteric. On the other hand, the fruits that produce less ethylene and cannot ripen after detaching from the tree are said to be non-climacteric fruits (Chen *et al*., 2018). Avocado, apple, banana, mango, papaya, and pear are climacteric fruits, while cashew, grapes, blueberries, lemon, citrus, strawberries, and cherries are non-climacteric fruits (Funko *et al*., 2021).

Harvest is a point directly related to the post-harvest losses. There are two types of fruit maturity: physiological maturity and horticultural maturity. Physiological maturity refers to the point of development at which fruit attains maximum development and maturation. On the other hand, horticulture maturity refers to the point of development at which fruits and vegetables attain the maximum level of growth adequate for their envisioned use. Fruits are harvested when they are horticulturally mature, but they may be said to be immature physiologically (Reid, 1992). Fruits are highly perishable and can easily deteriorate due to various factors. Fruits picked prematurely might lose taste and fail to ripen correctly, while those picked later could be stiff or have a short shelf life. Post-harvest handling operations sometimes cause a surface cut or any injury that leads to a decline in the fruit's quality. Due to various factors, substantial-quality degradation and post-harvest losses are unavoidable at both the pre-harvest and post-harvest stages. Fresh fruits and veggies mature and decline in quality quickly throughout post-harvest distribution, sale, and storage, resulting in a loss of economic value (Zhang and

Jiang, 2019). Post-harvest science and technology research findings aim to keep it fresh and healthy between harvest, handling, and consumption and minimize postproduction expenditures. Over the last 20 years, many breakthroughs have already been achieved in determining the environmental and biological variables that influence the decay of harvested fruits (Chen *et al*., 2018).

Quality maintenance, enhanced shelf life, and fruit firmness are crucial during harvesting and post-harvest operations. To maintain quality and shelf life, fruits must be well managed. Many preharvest things influence the quality and shelf life of fruit, including genotypes and rootstocks (Dayal *et al*., 2016), nutrients and foliar spray (Singh *et al*., 2018), water quality (Asrey *et al*., 2013), tree maturity and canopy management (Asrey *et al*., 2013; Meena and Asrey, 2018a), use of growth hormones), The use of growth hormones as well as the application of post-harvest fungicides, precooling, and controlled and modified atmosphere storage have a significant impact on fruit shelf life and quality redection control Quarshi et al., 2023).

The main goal of post-harvest operations is to use developing technologies to maximize and eliminate risks throughout processing methods. Fresh produce endures a sequence of biochemical modifications after harvest that produce colour, fragrance, distinctive aromas, and a decrease in acidity and tissue softness (El-Ramady *et al*., 2015; Salveit, 2005). The post-harvest timeframe entails a sequence of metabolic processes that can result in a higher concentration of organic acids, lipids, and phenolics, the generation of volatile components (aroma), variability in enzyme activity, degeneration of chlorophyll and the biosynthetic pathway of pigments, the destruction of pectin, and the transformation of starch into sugars, resulting in stiffness and weight loss as well as an increase in sweet taste (El-Ramady *et al*., 2015; Hörtensteiner, 2006; Lee and Kader, 2000; Prasanna *et al*., 2007; Hörtensteiner, 2006; Hörtensteiner, 2006; Lee and Kader, 2000; Prasanna et al. 2007).

Quantitative and qualitative losses happen at any point in the perishable item supply chain's post-harvest handling process, from harvesting, handling, packing, storage, and transportation to the final supply of fresh fruit to market. Post-harvest damages are influenced by various factors that vary greatly from location to location and are becoming increasingly hard to predict. Post-harvest management aims to provide full knowledge of all operations involved, from harvest through distribution, so that people can use the available techniques at each step and reduce losses while maintaining the highest quality throughout the supply chain. Careful attention must be given while handling the commodities and applying the various advanced operations to increase the shelf life and quality of the fruit (Asghari and Aghdam, 2010). Attention must be given to various steps after harvesting shown in Fig. (1).

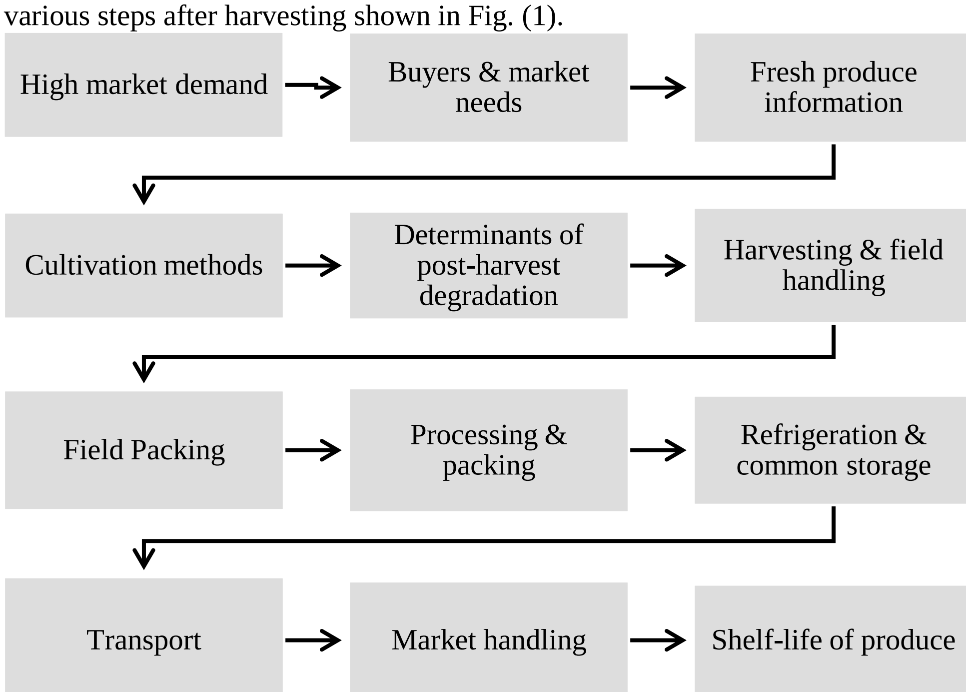

Figure 1: The important steps involved in post-harvest operations of fruits.

Fruits are living products more susceptible to post-harvest degradation, so adequate management is required to maintain shelf life and quality. To achieve desirable outcomes, some scientists used edible and non-edible films, salts, post-harvest sprays of various plant hormones, irradiation treatment, and other methods to extend shelf life and improve the quality of fresh fruits. Some of the most recent technologies include the use of brassinosteroids, methyl jasmonates, oxalic acid, and salicylic acid; edible coatings and films; irradiation; biocontrol agents; and advanced storage techniques such as controlled atmospheric storage (CA) and modified atmospheric packaging (MAP), all of which have reinvented the post-harvest sector. Numerous alternative chemicals and physical disinfection techniques have been tested over the years for their ability to lower pathogen populations and lengthen the shelf-life of fresh-cut produce, as well as their effects on the produce's texture, visual appeal, flavour, and nutritional value (Rico *et al*., 2007).

2. Fresh Fruits Handling:

2.1 Factors for Harvest:

Following harvesting, quality can only be maintained, not upgraded. However, collecting fruits, vegetables, and flowers at the right stage, shape, and quality is crucial. Produce that is either premature or overly mature may not last long during preservation. Handle the fruits gently and carefully to avoid any cuts or injuries. The crop quality at harvesting has a significant impact on its post-harvest viability. Skin cracks, bruising, stains, fester, rot, and other damage must be avoided in fruits meant for storage. These injuries occur during mechanical harvesting and provide an entry point for various microorganisms by increasing the respiration rate, enhancing ethylene synthesis, and increasing moisture loss. One nasty blemish on an apple can increase the rate of moisture loss by as much as 400%. To avoid mechanical damage, fragile crops like berries are picked by hand. One should be trained enough to know the maturity indices of the fruit to be harvested. Harvesters must be careful to protect the fruit when deposited in a basket or a field container after picking and produce must be protected from sun exposure. Harvesting should be done early in the morning or evening, the coolest parts of the day, to avoid sun damage or wilting. The precooling process is minimized if harvesting is done in the early morning or evening (Ahmad and Siddiqui, 2016; Aghdam and Bodbodak, 2014). Precooling is used to remove the field heat from produce before further handling. While picking produce, the following points must be kept in mind such as i) Handle the crop gently, ii) Harvest at the proper stage, iii) Harvest in the coolest part of the day and iv) Avoid mechanical damage (bruise, cut, or injury).

Fruits are classified into two classes based on ethylene production, climacteric and non-climacteric fruits. Fruits which ripen after detaching from the tree and produce more ethylene are climacteric. On the other hand, the fruits which produce less ethylene and cannot ripen after detaching from the tree are said to be non-climacteric fruits (Chen *et al*., 2018). Avocado, Tomato, apple, banana, mango, papaya, bribe, fig, Guava, jackfruit, mango, muskmelon, papaya, plum, persimmon, and pear are climacteric fruits. At the same time, cashew, grapes, blueberries, lemon, citrus, strawberries, watermelon, pineapple, pepper, olive, lime, tamarillo, and cherries are non-climacteric fruits (Fukano and Tachiki, 2021).

Colour is the key factor through which fruits proceed toward maturity. The colour of the fruit is due to the natural pigments present in it. Primary pigments imparting colour quality are chlorophyll (green), carotenoids (red, yellow, and orange), anthocyanin (blue and red), betalin (red), and flavonoids (yellow) (Thomas, 2016). Similarly, different enzymes, such as polyphenol oxidase, may form grey, black, and brown-coloured pigments. Therefore, harvesting at proper colour formation is performed for better profit (Islam *et al*., 2019). Size, shape, or surface characteristics are used as maturity indices for harvesting fruits. Fruits with marketable size and flavour are harvested; usually, fruits with uniform sizes are preferred. Fruits should not be harvested at a small or overripe stage because both conditions affect the flavour and texture (Taghavi *et al*., 2019).

Total soluble solids (TSS) are an important factor influencing fruit quality during storage because they include soluble sugars like glucose, sucrose, fructose, and acids. During ripening and maturation, starch lysis occurs to simple soluble sugars, the amount of pectin increases, and fruit softening occurs (Afshar-Mohammadian and Rahimi-Koldeh, 2010). Likewise, titratable acidity (TA) is also a quality attribute that affects the quality of the fruits. Organic acids are utilized by fruits for different metabolic activities, resulting in a decrease in TA. Different organic acids (acetic, malic, fumaric, lactic, citric, and tartaric) are reported to be accountable for the titratable acidity of fruits (Kulkarni and Aradhya, 2005).

3. Post-harvest Treatment of Fruits:

Post-harvest processing procedures are required to ensure that produced fruits, and vegetables meet customer acceptance (Ahmad and Siddiqui, 2016). Post-harvest operations generally include cleaning, washing, grading, and packing fresh produce. Some crops, however, outline specific management or intervention strategies for shelf-life enhancement. Other treatments include curing, wax treatment, administration of growth regulators and essential oils, and wrapping operations, emphasizing packinghouse operations (Ahmad and Siddiqui, 2016). These treatments are useful to get familiar with the various results given below:

- Before fruits are consumed or maintained in moderate or refrigerated settings, they are often treated with surface coatings, fungicides, and other pesticides.
- Plant growth regulators are being used to slow down the ageing process.

- Rot is controlled with a variety of fungicides.
- Gamma rays have been used to minimize microbiological deterioration and to deter fruit flies from infesting the fruit.
- Essential oils are used to stop infections from growing, reduce the frequency of deterioration, extend the storage life, and maintain the inner quality of fruits.

Chilling injury is not a disease; it is a disorder caused by low temperatures during storage. Chilling injury is different from freezing injury because there is no accumulation of ice crystals in the cells of commodities. The severity of the chilling injury is related to both the low temperature and the duration of the storage (Rodrigues *et al*., 2020). Symptoms of chilling injury include weakness of tissues, surface or internal browning, failure to ripen, decay, development of a woolly or leathery texture, pitting, tissues becoming water-soaked, tissues being exposed to pathogens and microorganisms, internal discoloration, and surface lesions. Different post-harvest methods avoid chilling injury: temperature (hot water brushing, curing, and hot water dipping), PGRs (GA3, salicylic acid, etc.), and different waxes. Dipping fruits in hot water reduces the chilling injury; salicylic acid application on fruits avoids the chilling injury, and applying various waxes on fruits reduces the damage during storage, like the chilling injury (Wang and Wallace, 2004).

3.1 Critical temperature

Every fruit has a specific critical temperature below which undesirable alterations and reactions occur; thus, the storage temperature should be above the critical temperature of the commodity temperatures well above the freezing threshold (32°F, 0°C), causing chilling harm to plant components. Tropical and subtropical fruits seem to be the most vulnerable. Among them are bananas, citrus, avocados, papayas, honeydew melons, apples, figs, etc. Leaves that have been chilled might turn purple or reddish or, in some situations, wilt. The changes that occur due to the critical temperature give rise to various symptoms, such as loss of flavour, increased decay, internal breakdown, pitting, and discoloration (Kader and Rolle, 2004). Other symptoms include surface or internal browning, failure to ripen, decay, and developing a woolly or leathery texture.

3.2 Some post-harvest management techniques

Some techniques are used to reduce chilling injuries, including i) Physical Treatments, ii) Chemical Treatments, and iii) Gaseous Treatments.

Table 1: Optimum storage temperatures and relative humidity of different fruits

Fruit	Storage temperature	Relative humidity
Apple	-1 °C to 4 °C	90-95%
Apricot	-0.5°C to 0°C	90-95%
Asian pear	0°C	90%
Avocado	5 °C to 12 °C	85-95%
Banana	13 °C to 14°C	90-95%
Blackberry	0.5 °C to 0 °C	90%
Blueberry	0.5 °C to 0 °C	90%
Cherry	-1 °C to 0 °C	95%
Fig	-1 °C to 0 °C	90-95%
Grape	-0.5 °C to 0 °C	85-95%
Grapefruit	12 °C to 15°C	95%
Guava	8 °C to 10°C	90-95%
Lemon	7 °C to 12 °C	85-95%
Mango	10 °C to 13 °C	90 %
Olive	5 °C to 7.5 °C	90-95%
Orange	0 °C to 1 °C	85-95%
Papaya	7 °C to 13 °C	90-95%
Peach	-1 °C to 0 °C	90-95%
Pear	-1 °C to 0 °C	90-95%
Persimmon	0±1 °C	90-95%
Plum	-1 °C to 0 °C	90-95%
Strawberry	0 °C	90-95%

Since some crops, like tropical fruits, are sensitive to chilling injuries induced by cold storage, they must be managed with care along the cold chain. Many crops can be treated to increase their resistance to chilling damage. On the other hand, heating before cold storage is considered eco-friendly and is particularly effective at increasing chilling resistance for various items, including tomatoes (Afshar-Mohammadian and Rahimi-Koldeh, 2010; Lu *et al*., 2010). There seems to be a variety of post-harvest therapies for fruits and veggies, and plenty more are likely to become accessible in the future as this is a study field (Table 1) (Lu *et al*., 2010).

3.3 Physical Treatments

3.3.1 Low-Temperature Treatment

Low-temperature preservation is the most popular and effective strategy for extending the shelf life of most fruits and vegetables (Table 1). The cooler temperatures might not only significantly slow respiration but also slow down many metabolic processes and the degradation rate. Fruit should be iced employing various methods, including precooling with cold air, cold water, direct contact with ice, or evaporation of water from the item. It is customary practice to store fruits at a cold temperature to decelerate their metabolic rate (Tareen *et al*., 2012). Many fruits keep best at temperatures below freezing, whereas others are damaged by extreme cold and should be stored around 45 to 55 °F. While some fruits are susceptible to low temperatures, injury caused by low temperatures is known as "chilling injury" (CI). Depending on the temperature and length of exposure, chilling injuries can occur at any plant growth and development stage. The signs and symptoms of low temperatures in fruits and vegetables differ depending on the kind, species, and growing conditions (soil, climate, moisture, and so on) (Tareen *et al*., 2012).

Low storage temperatures are intended to postpone ripeness and withering, limit moisture loss, slow respiration, and reduce decay incidence to preserve quality (Al Shoffe, 2018). Low temperature, according to Wang and Wallace (2004), impacts the maturation of fruits by inhibiting the production of ethylene, a plant hormone that stimulates respiration. Rapid cooling effectively lowers maturation and maintains the general perishability of *Mangifera indica* during harvesting, processing, preservation, and long-distance transit, according to Yahia (2011).

The most frequent strategy for preserving strawberry fruit quality after harvest is to cool the fruits immediately upon picking and then preserve them at a low-temperature range of 0 to 4°C (Liu, 2014). According to Junmatong *et al*. (2012), strawberry fruits maintained at low temperatures have titratable acidity, higher fruit firmness, total soluble solids, ascorbic acid content, and total terpenes; however, dehydrating stress seems to be more extreme in strawberries held at room temperature. Cooling is vital in retaining fruit and vegetable freshness during post-harvest techniques because it has various favourable benefits in upholding the highest standards (Tahir *et al*., 2018).

Low-temperature conditioning is an early approach for controlling CI in post-harvest fruits and vegetables that are successful in a variety of post-harvest agricultural products, including avocado, cucumber, eggplant, grapefruit, lemon, lime, mango, papaya, sweet pepper, Tomato, and zucchini squash (Li et al., 2015). Before cold storage, zucchini fruits pre-conditioned at 15 °C for 48 hours had lower CI indices (Morris and Brady, 2005).

3.3.2 High-Temperature Treatment (HT)

The effect of heat treatments on fruit quality parameters and post-harvest life has also been investigated. Fresh food produces more ethylene at high temperatures, which speeds up respiration and metabolic processes (Chaudhary *et al*., 2014). In addition, recent research has found that HT can help decrease CI in post-harvest fruits such as zucchini (Carvajal *et al*., 2017; Bokhary *et al*., 2020), mango (Vega-Alvarez *et al*., 2020), and cucumber (Nasef, 201). According to a recent study, treating zucchini with hot water for 15 minutes at 45 ºC stimulated arginine synthesis, forming polyamines and proline, which boosted chilling tolerance during cold storage (Bokhary *et al*., 2020). According to Hong et al. (2014), combining Bacillus amyloliquefaciens, sodium bicarbonate, and hot water could be a viable strategy for controlling post-harvest decline in citrus while ensuring fruit quality upon harvest. A 35 or 45°C hot water dip for 10 minutes reduced the CI in post-harvest kiwifruit stored at 0°C for 90 days; however, a 55°C hot water dip for 10 minutes enhanced the CI index (Ma *et al*. 2014). Physiological processes are affected by temperature; below the range, chilling injuries occur, and above the range, various stresses affect respiration and photosynthetic processes. Higher temperatures affect the photosynthetic mechanism in fruits by modulating enzyme activity. High temperatures directly affect enzymatic activity, which stops or slows down the photosynthetic process and leads to stress in plants (Lloyd and Farquhar, 2008).

High temperatures cause quick eradication of microbes and enzymes, which is necessary for pasteurization and sterilizing treatments, whereas short periods cause fewer unwanted quality changes. Some pests infest crops in the field and continue to do so until they are stored after harvest (Ma *et al*., 2014). Fruit and vegetable reliability and storability suffer from inadequate storage handling in retail stores and insect-caused damage (De Lima, 2011).

3.3.3 Controlled Atmosphere Storage (CA):

CA storage is called to control and regulate CO_2 and O_2 concentrations within gas-tight stores at the appropriate storage temperature, leading to tolerance to chilling injury. The following are some of the advantages of CA:

- At O_2 concentrations under 8% or CO_2 concentrations higher than 1%, vulnerability to ethylene activity is reduced.
- Post-harvest microbes (bacteria and fungi) greatly affect the prevalence and intensity of deterioration.
- Senescence is slowed, and accompanying physiological and biochemical processes, such as respiration, ethylene generation, and softening, are slowed.
- Low O_2 or high CO_2 can be an effective strategy for insect control in some fruits.

The literature search showed that increasing CO_2 and decreasing O_2 contents during low-temperature storage lower chilling injury in post-harvest agricultural products (Alba-Jim´enez *et al*., 2018). The CI index in post-harvest guava fruit could be greatly reduced by increased CO_2 levels (Alba-Jim´enez *et al*., 2018). However, not all agricultural items appear acceptable for high-CO_2 and low-O_2 CA storage. In contrast, one new survey showed that using high O_2 and low CO_2 CA storage to prevent CI in post-harvest white mushrooms was effective. Throughout this study, treatment of O_2 (80%) and CO_2 (20%) drastically reduced the CI index in white mushrooms (Li *et al*., 2019). Lower O_2 (LO) and ultra-low O_2 (ULO) CA storage are becoming more popular, with O_2 levels as low as 1.5–2.0 and 0.8–1.2 kPa, respectively (Hoehn *et al*., 2009). Chong et al. (2013) presented a hollow-fibre unit for creating a nitrogen-enriched atmosphere that regulates O_2 and CO_2 concentrations in CA preservation (Chong *et al*., 2013).

3.3.4 Modified Atmosphere Packaging (MAP):

Since the 1970s, modified atmosphere packaging (MAP) technology has been commercially feasible. MAP is widely used worldwide to maintain the quality and shelf-life of entire fruits and vegetables. However, this is becoming more widely employed to prolong the shelf-life of minimally processed fresh fruits and vegetables. The MAP is the process of altering the composition of the environment around a product to avoid spontaneous degradation and microbiological deterioration (Caleb *et al*., 2013; Mangaraj and Goswami, 2009), and it can be active or passive. The ultimate goal of these concepts (active or passive) is to achieve an ideal gas composition in package material when the product's respiration rate is as low as possible, and O_2 and CO_2 concentrations are not destructive to shelf life. The balance ratios of O_2 and CO_2 in passive MAP result from the product mass and respiration rate, which are influenced by the packaging sheets' temperature, surface area, holes, width, and gas flow properties. In active MAP, the appropriate atmosphere is placed in the package headspace before heat sealing, although the resulting atmosphere is determined by the same aspects that influenced passive MAP. The packaging system must first be designed to influence a successful MAP, which entails identifying the gas transmission rate in the packaging that is required to balance the metabolic activities of the commodity to be stuffed and, as a result, achieve a desirable gas level for its protection (Castellanos *et al*., 2016). Table 2 illustrates the recommended O_2 and CO_2 concentrations in MAP for various fruits (Mangaraj and Goswami, 2009; Sandhya, 2010; Castellanos *et al*., 2016).

Table 2: Post-harvest storage of various fruits contains CO_2 and O_2 concentrations.

Fruits	CO_2 concentration (%)	O_2 concentration (%)
Apple	1-3	2-3
Pear	2-5	2-3
Banana	2-8	2-5
Mango	5-8	3-7
Avocado	3-10	2-5
Orange	5-8	5-10
Feijoa	7-12	5-11

Depending on the atmospheric conditions, extending the shelf life by 40 % to twice for fruits is feasible. Apple (Hertog *et al*., 2001), banana (Santos *et al*., 2006), Ber varity was Gola, (Villalobos *et al*., 2014), blueberry (Almenar *et al*., 2008), grapes (Candir *et al*., 2012), Guava (Managaraj *et al*., 2014), papaya (Waghmare and Annapure, 2013), pear (Cheng *et al*., 2015), pomegranate (Banda *et al*., 2015), strawberry (Zhang et al., 2005), and others have all been effectively preserved using MAP methods.

3.3.5 UV Irradiations

Fruits and vegetables have 80–90% moisture content, and their harvest time has exceeded the desired threshold value by a substantial margin. Many such fruits decay due to microorganism attacks during procurement, processing, and storage. UV irradiation treatment has lately been brought to the post-harvest storage of fruits and vegetables by several scientists as a residue-free physical preservation approach (Zhang and Jiang, 2019). UV radiation functions as an antimicrobial agent against infections in certain fruits, either directly (because of its DNA-damaging ability) or indirectly (due to its mechanism of resistance induction). UV-B treatment at 5 kJ m^{-2} for 4 h drastically decreased the CI index, ion leakage, and malondialdehyde (MDA) level in mango fruits following maturation at ambient temperature after refrigerated conditions at

6 °C for 10 days in comparison to untreated fruit (Sayyari *et al*., 2004). Irradiation is used against some quarantine pests, including oriental fruit flies in papaya, fruit fly, and stone weevil in mango (Sayyari *et al*., 2004; Follet, 2004). High doses of radiation have a detrimental effect on post-harvest operations for fruits. However, the dose should be carefully selected whenever UV irradiation treats CI in post-harvest horticultural items (Gol *et al*., 2013). Edible coatings are thin films of extrinsic coatings placed on the surface of fresh food to strengthen the waxy cuticle or replace natural borders when the cuticle has been lost (Gol *et al*., 2013; Dhall, 2013). Plant-based thin films and extracts are more prevalent than chemically manufactured ones. They are antimicrobial and also create obstacles. It does have several beneficial effects on fruits, such as;i) Pomegranate fruit maturation is delayed (Varasteh *et al.*, 2017), ii) preserves papaya firmness (Marpudi *et al*., 2011), iii) restricts ethylene synthesis and slows the softening of plums (Valero *et al*., 2017), iv), suppresses blueberry weight loss (Duan *et al*., 2011),v) microbial rotting of kiwi fruit pieces is suppressed (Benitez *et al*., 2013).

3.3.7 Bio-control Agents

All fruits and vegetables are susceptible to fungal and bacterial infestation throughout preservation. Due to post-harvest microbial contamination, much fresh food is destroyed in processing, transit, and storage (Zhu, 2006; Singh and Sharma, 2007). Certain post-harvest infections significantly collapse the total bulk of the produce, lowering its value. Bioagents are more beneficial and ecologically friendly in this sector, which has a host-specific approach. Several products have already been created by extracting several microbes that have parasitic processes against a broad spectrum of disease-causing microbes. *Trichoderma harzianum* inhibits the growth of grey mould on strawberries, grapes, and bananas (Batta, 2007; Devi and Arumugam, 2005). Biocontrol agents help maintain shelf life by controlling many fruit diseases without harming humans or the environment (Singh and Sharma, 2007; Batta, 2007; Devi and Arumugam, 2005).

3.4 Chemical Treatments:

3.4.1 Oxalic Acid (OA):

OA is a chemical compound with the formula $C_2H_2O_4$. The enzymes polygalacturonase (PG) and pectin methyl esterase (PME), which are responsible for cell wall disintegration, are inhibited by OA, and the treated fruit retains its firmness (Wu *et al*., 2011). By delaying quality degradation and keeping certain bioactive chemical and antioxidant activity, OA (6mM) may be able to increase the storage life of pomegranates (Koyuncu *et al*., 2018). Fruit treated with 10 mM OA was reported to be the best at preserving enzymatic activities in *Ziziphus mauritiana*, with their least values recorded with this treatment (Ravi *et al*., 2018). As a positive abiotic activator, OA has been found in many studies to help alleviate CI in post-harvest horticulture products. In Hami melon, 15 mM OA treatment decreased the chilling injury index (Jing *et al*., 2018). Furthermore, external OA treatment dramatically reduced chilling injury in sweet persimmon after harvest. Therefore, OA is a low-cost treatment in post-harvest operations of fruits to reduce the detrimental effects and enhances their storability (Li *et al*., 2018a).

3.4.2 Salicylic acid (SA):

Salicylic acid is an intrinsic signalling component that controls response to stress and various plant developmental processes (Asghari *et al*., 2010). It is regarded as a safe chemical component for use after harvest. SA effectively slows the rate of post-harvest degradation. SA treatment on Red Delicious Apple enhanced total polyphenolic compounds and antioxidant properties in the initial stages of storage, with 2 mM SA concentrations having the highest potential, accompanied by 1mM and 4 mM SA concentrations, and 1 mM levels representing the greatest antioxidant capacity at the end of the process (Hadian-Deljou *et al*., 2017). Weight loss and deterioration are reduced in Murcott Mandarin Fruit when administered with salicylic acid (200 and 400 ppm) and putrescine (50 and 100 ppm). Compared to putrescine treatments, SA, notably at 400 ppm, reduced weight loss and deterioration more successfully, so it extended the storage time by maintaining fruit quality (Ennab *et al*., 2020). Post-harvest SA treatments have been shown to reduce chilling injury in cold-storage conditions of oranges (Rasouli *et al*., 2019) and lemons (Siboza *et al*., 2017).

3.4.3 Brassinosteroids (BRs):

Natural steroid hormones known as brassinosteroids play an important role in a plant's growth and reaction to biotic and abiotic stressors (Bajguz and Hayat, 2009). According to Zhu *et al*. (2010), BRs administration lowered illness occurrence, which was linked to H_2O_2 buildup. It is likely that the new post-harvest BRs treatments reduce post-harvest chilling injury while reducing deterioration and improving the nutritional content of fruits and vegetables (Wang *et al*., 2012).

Fresh fruits and vegetables must be consumed quickly because they have live cells that obtain energy through respiration during post-harvest life, resulting in ripening, edible fruit and increased susceptibility to decay. Post-harvest deterioration in fruits and vegetables is caused by persistent infections in the field or injury during the collecting and processing processes (Hussain *et al*., 2015). According to Zhu *et al*. (2010), BRs showed lower *Penicillium expansum*, induced post-harvest deterioration in jujube fruit by increasing the activities of Phenylalanine ammonia-lyase, Polyphenol oxidase, Catalase, and Superoxide dismutase. They postponed fruit senescence by suppressing ethylene formation and decreasing respiration rate. According to the findings, Epibrassinolide (EBR) treatment of Satsuma mandarins reduced deterioration and oxidative stress (Zhu *et al*., 2015a). EBR application, on the other hand, proved beneficial in minimizing peach fruit chilling damage (Gao *et al*., 2015). Furthermore, EBR treatment decreased enzymatic browning in lotus roots (Gao *et al*., 2016). At ambient temperatures, the use of EBR retarded the ageing of kiwifruits (Lu *et al*., 2019). The EBR treatment enhanced the vase life of daylilies by inhibiting flower yellowing (Yao *et al*., 2017). BRs influence several features of various horticultural crops, as evidenced by the literature (Zhu *et al*., 2010).

3.4.4 Methyl jasmonate (MeJA):

Jasmonic acid and its endogenous plant hormone-derived methyl jasmonate have been implicated in several physiological processes, mainly modulating oxidative stress in post-havest application. (Zapata *et al*., 2014). The JA as well as its endogenous plant hormone derivative, methyl jasmonate (MeJA), have indeed been involved in various physiological functions, primarily influencing plant defence responses such as antioxidant capability against infections and abiotic stress (Zuniga *et al*., 2020; Cao *et al*., 2008). Zuiga et al. (2020) indicated that a higher frequency of MeJA treatment improves anthocyanin, proanthocyanidin, ascorbic acid content, and catalase activity, which may play an important role in preventing reactive oxygen species, which induce stress in fruits during post-harvest storage (Cao *et al*., 2008).

MeJA is also used to reduce post-harvest infections and fruit deterioration. The majority of the research on MeJA as a postharvest remedy has concentrated on minimizing a variety of stress-induced injuries during the postharvest period, including chilling injury (CI), infection by some pathogens, mechanical stress, and salt stress, among others (Sayyari *et al*., 2011). MeJA at a concentration of 10 mol/L substantially decreased anthracnose in loquats (Zhang *et al*., 2006) and prevented rot induced by Botrytis cinerea in strawberries treated with 1 mol L^{-1} (Jim´enez-Munoz *et al*., 2021).

3.5 Gaseous Treatment:

3.5.1 Nitric Oxide (NO):

Post-harvest treatments with nitric oxide (NO), a reactive free radical gas, have postponed fruit ripening and withering. NO prevents ethylene production, extending the shelf life of certain fruits (Jim´enez-Munoz *et al*., 2021; Mcatee *et al*., 2013). NO could be used to extend the shelf life of papaya fruit and postpone changes in soluble sugar concentration. Furthermore, NO affects ethylene-induced fruit maturation not only through reducing ethylene formation but also by interacting with other phytohormones such as auxin, abscisic acid, jasmonic acid, salicylic acid, gibberellin, cytokinin, brassinosteroids, and polyamines [Palma *et al*., 2019; Steelheart *et al*., 2019b; Li *et al*., 2012]. Sozzi et al.'s (2003) studies show that papaya fruits were decontaminated with 60 mL/L NO and stored for 20 days at 20°C and 75% relative humidity after being fumigated for 3 hours. Over 20 days of storage, NO application significantly inhibited ethylene synthesis and respiratory rate (CO2 levels), minimized loss of weight, preserved rigidity, and deferred shifts in peel colour and soluble solid contents. When pears were treated with 10 L L1 NO gas for 2 hours, the ethylene maxima were postponed and reduced, and the softness was also reduced (Kolbert *et al*., 2021). The impacts of different nanoparticles (NPs) (chitosan NPs, metal oxide NPs, and carbon nanotubes) on intrinsic NO formation and triggering in various plants have been characterized as implicated in innate immunity, anti-fungal reactions, and stress resistance (Weller, 2003). NA also harms human health; foods contain more nitric oxide, which causes diseases (Ormerod *et al*., 1998). NA may injure the cells of the brain (Parkinson's disease), and cause headaches in migraine, Huntington disease, and Alzheimer's disease (Tomala *et al*., 2020).

3.5.2 1-Methylcyclopropene (1-MCP):

1-MCP is an ethylene inhibitor commonly used during post-harvest techniques to extend the shelf life of numerous fruits. The 1-MCP can be used as a pre-harvest remedy since it is non-toxic, consistent over time, and improves product quality(Tomala *et al*., 2020; Kanwal *et al*., 2020) and post-harvest (Zhu *et al*., 2020; Tomala *et al*., 2020). 1-MCP is an excellent long-distance transportation treatment for 'Idared' apples since it extends their shelf life and increases firmness (Gago *et al*., 2015). Apple was treated with 1-MCP at a level of 625 nl/L for 20 h at 0.5 ^{o}C, which minimized the internal ethylene emission (IEE) (Sivankalyani *et al*., 2015). Applying 1-MCP (300 ppb) at 20 ^{o}C for 18 h on avocado avoided chilling damage and lipid peroxidation (Zhu *et al*., 2020). The treatment of bananas with 450 nl/L of 1-MCP impacted the biosynthesis of aroma volatiles (Gaikwad *et al*., 2020). When mango was treated with 2.0 l/L at 20 ^{o}C for 12 h, it preserved the post-harvest quality of the fruit (Kou *et al*., 2020). The administration of 1.0 l/L of 1-MCP on persimmon for 18 h at 20 ^{o}C indicates that fruit softness and ethylene synthesis were postponed (Ullah *et al*., 2016). Post-harvest treatment with 1-MCP in nectarines reduced ethylene formation and fruit-softening enzyme activity (Grozeff *et al*., 2017). The contents of amino acids and glutathione in blueberry fruit have improved dramatically when 1-MCP is applied (Horvitz and Cantalejo, 2014). There are numerous possibilities for combining 1-MCP with advanced technologies to provide consumers with high-quality horticultural produce while lowering post-harvest losses, particularly for perishable fruits (Ullah *et al*., 2016; Horvitz and Cantalejo, 2014).

3.5.3 Ozone:

Gaseous Ozone is a powerful disinfectant that may clean storage facilities, inhibit bacteria, mould, and yeast from growing on food surfaces, control insects, and destroy mycotoxins. Ozone can replace standard disinfecting agents, according to recent studies and commercial uses (Horvitz and Cantalejo, 2014; Ali *et al*., 2014). Suslow (2004) found that fruits subjected to 2.5 ppm ozone exhibited higher total soluble solids, ascorbic acid content, carotene content, lycopene content, and antioxidant properties, as well as less weight loss at day 10. Apples, cherries, carrots, garlic, kiwis, onions, peaches, plums, potatoes, and table grapes have all been used for commercial purposes containing Ozone (Huyskens-Keil *et al*., 2011). Radiation and cleaning with ozonated water lowered respiration in white asparagus spears but increased spear tissue hardness (Niemira, 2012). Ozone, on the other hand, does not penetrate spontaneous openings or lesions well. Further studies are required to validate the possibilities and limitations of using Ozone for post-harvest treatments to improve fruit quality and safety (Niemira, 2012).

3.6 Cold Plasma Technique (CPT):

Food scientists have spent the last two centuries attempting to create technological advances to raise fresh fruit and vegetables' efficiency, safety, and shelf-life while meeting customer nutritional and sensory value requirements. Cold plasma is a food processing technique that uses cold ionized gases on fresh fruits to kill pathogens in meats, poultry, fruits, and vegetables. **Fig. 2** offers an outline of the processes causing plasma-induced deactivation of bacteria that have been exposed to plasma. The plasma emits electromagnetic energy that ionizes gases, although the energy generated by the CP varies depending on the application, such as packing, plastics, and polymer sectors (Misra *et al*., 2011).

Cold gas plasma technology uses power and a gas phase such as air, oxygen, nitrogen, or helium. The main mode of action is due to the cold plasma ionization framework's release of UV radiation and reactive chemical compounds (Misra *et al*., 2011). CPT has been demonstrated to be particularly efficient against E. coli O157:H7 and Salmonella spp. (Fernandez *et al*., 2013; Tappi *et al*., 2016).

Cold plasma was used to decontaminate fresh-cut products such as apples, melons, lettuce, and mangoes (Niemira and Sites, 2008; Tappi *et al*., 2014; Sharma *et al*., 2009; Ziuzina *et al*., 2014). Ziuzina *et al*. (2014) reported that the cold plasma techniques for 120 seconds lowered Salmonella, E. coli, and L. monocytogenes to nearly zero on cherry tomatoes, Ziuzina *et al*. (2014) found that using cold plasma for 120 seconds lowered *Salmonella*, *E. coli*, and *L. monocytogenes* to nearly zero. Niemira and Sites (2008) investigated the deactivation of *E. coli* and *Salmonella Stanley* pathogens using gliding arc cold plasma. These two pathogens ' elimination levels increased with an increased gas flow rate. Nonetheless, there is still a lack of information regarding the physicochemical modifications in the product following exposure to cold gas plasma.

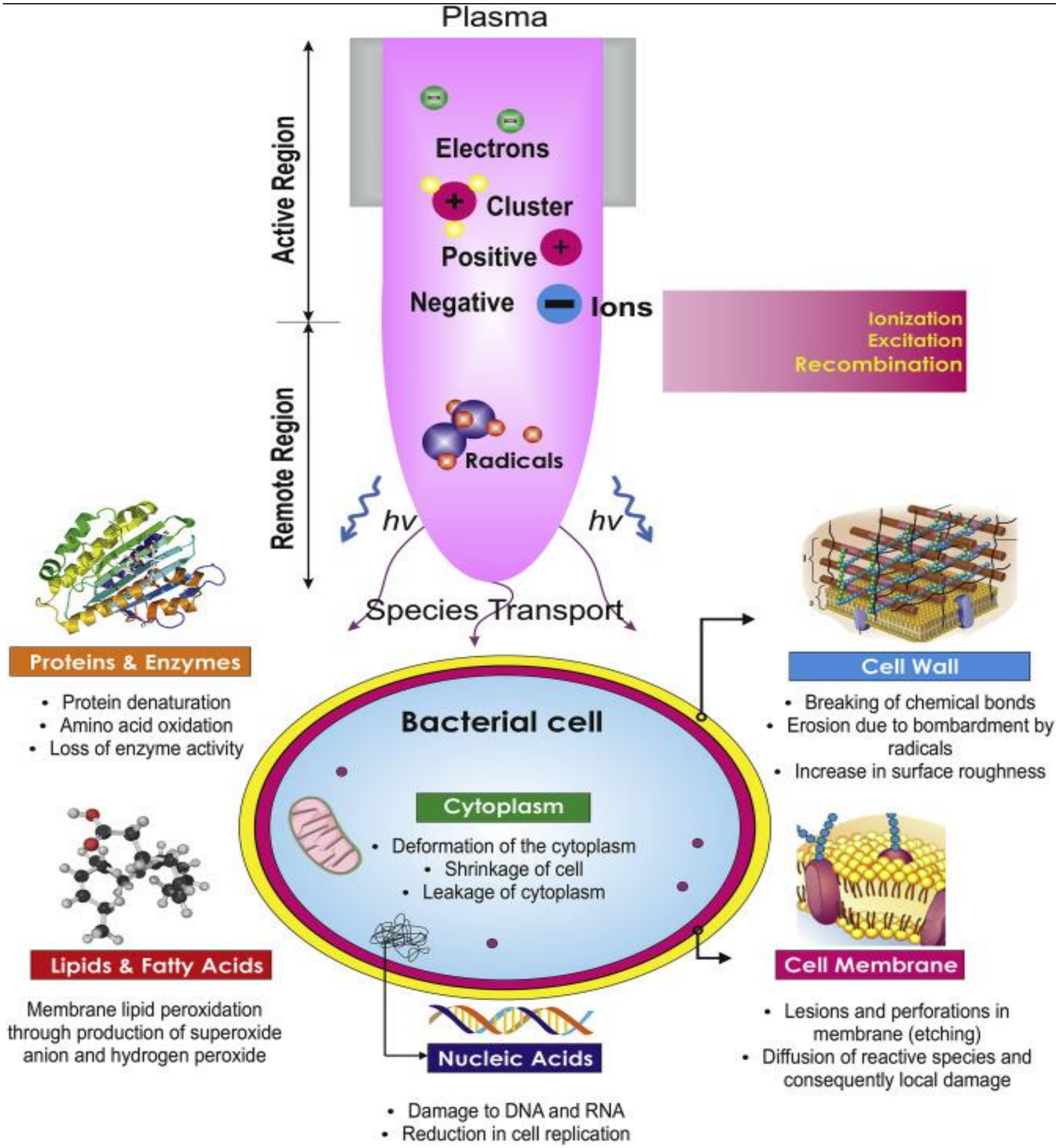

Figure 2: An illustration of the mechanism of cold plasma on the structure of the bacterial cell, performance and sterility were degraded (Han *et al.*, 2022).

Conclusion:

Fruits are a rich resource of healthy nutrients, and their daily consumption releases significant health benefits to the human body. Demand for fruits has increased because of rising customer awareness about their diets. A scarcity of high-value fruits is also on the way, requiring post-harvest technology to minimize the losses. Fruits have a very short storage life, which leads to losses and poor quality. However, the limited method to prepare the products will speed up the ripening process and expose the commodities to microbial infection, reducing shelf life. This investigation aimed to build awareness about extended storage life while maintaining its qualitative attributes. To maintain and extend shelf life, a variety of physical, chemical, and gaseous treatments are available. Treatment modalities may be appropriate for only some items and rotting situations, and the efficacy of existing therapies on emergent quality issues must be evaluated. Cold plasma is a novel and developing technology that can be used to sterilize food surfaces. However, knowledge of the impacts of cold plasma on fruit quality alterations is currently limited. Given cold plasma's high oxidative activity, its impact on bioactive chemicals in fruit tissue must be thoroughly investigated to reveal the nature of gas plasma's effect on biochemical tissue response. In general, cold plasma is a promising technology for improving product quality and extending the shelf life of fruits.

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