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Approaches for prolonging the shelf-life of vegetables and fruits

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Abstract
As most fresh produced fruits and vegetables are perishable, they cannot be satisfactorily preserved under natural circumstances for an extended period of time. Conventional preservation techniques exists, nevertheless they have disadvantages like expensive manufacturing costs, short shelf lives, unwanted residue, etc. Therefore, cutting-edge techniques like cold chain, ozone, cold plasma, microwave heating, and UV-C (ultraviolet-C) non-ionizing radiation help maintain the vegetables and fruits fresh in addition to superior quality by lowering the microbial load. High surface to volume ratios and antibacterial effectiveness that prolongs shelf life are among the possibilities of nanotechnology.

Keywords: Shelf-life, cold chain, UV-c, cold plasma, nanotechnology, edible coatings

1. Introduction

Fruits and vegetables are advantageous due to their delightful flavour and ability to fulfil a variety of nutrient requirements; in addition to giving the body the calories it requires (Ma *et al*. 2017) [21]. After being harvested, their tissues are still living and in the process of going through biological functions including respiration, dormancy and transpiration (Romanazzi *et al*. 2016) [33]. Therefore, quality degradation happens post harvesting. Quality degradation means are inclusive of processes like off-flavor, wilting, browning, softening and nutritive value deficit. These occurrences shorten the shelf life of fresh vegetables and fruits, making them unfit for using up by humans (Duan *et al*. 2016; Bastianello *et al*. 2016; Deng *et al*. 2017; Caprioli *et al*. 2016) [11, 2, 9].

According to reports, a lack of appropriate shelf life extension techniques causes 20% to 40% of fruits and vegetables to undergo deterioration globally (El-Ramady *et al*. 2015) [13]. Consequently, extension of vegetables and fruits' shelf lives duration has gained importance within the food sector (Liu *et al*. 2020) [20]. Freshness-keeping strategies let fruits and vegetables last longer on the shelf by deferring the ripening process, averting microbial contamination (Minas *et al*. 2012; Liu *et al*. 2020) [26, 20] and regulating transpiration. Numerous methods for extending shelf life have been devised thus far by researchers. Using a cold chain is a crucial tactic to combat such losses. Produce that is particularly perishable should be stored in a temperature- and relative humidity-controlled environment to preserve both quantity and quality. This will aid to raise household incomes, upgrade the security of nutrition along with food, and safeguard the environment (Makule *et al*. 2022) [23].

Of these procedures, fruit preservation makes substantial utilization of ozone, either as a gas or as a water-soluble form. Because of its ability to oxidise nucleic acids, proteins, membranes, enzymes, lipids along with other components of cells, ozone possesses antibacterial properties. Using ozone for storing small fruit has been extensively documented for its ability to prevent the growth of pathogenic microbes and becoming spoiled (Bridges *et al*., 2018; Contigiani *et al*. 2018) [5, 8]. In the entire and slightly processed fruit and vegetable business, cold plasma application is widely employed as a novel method to address microbial growth. The goal is to preserve the food items' antioxidant and nutritional qualities while substituting traditional disinfecting methods (Bagheri *et al*. 2020) [1].

Microwave cooking preserves the major colour and antioxidant activity of photochemical constituents at increased levels in fruits and vegetables. In comparison to traditional pasteurisation, microwave sterilisation efficiently inactivates the enzyme activity and has little influence on the texture, colour, and radical scavenging activity of fruits and vegetables (Jan *et al*. 2023) [18].

Although radiation may increase the storage life, ensure food and nutrition safety, and maintain quality when administered in the proper dosages, it is an underutilised technology in the fresh fruit and vegetable industry. Strawberry shelf life is increased by UV-C irradiation, which has been effectively employed as an alternate method of microbial disinfection. After harvest, nanotechnology can help preserve fresh produce (Maraei, and Elsawy, 2017) [24]. It focuses using nanomaterials to enhance traditional preservation techniques like packaging and coating, and developing eco-friendly nano-preservation technology to improve postharvest handling (Liu *et al*. 2020) [20]. This review will concentrate on the aforementioned methods to prolong the shelf life of fruits and vegetables.

2. Shelf-life enhancing techniques of fresh vegetables and fruits

2.1 Cold chain

When perishable goods are handled continuously in a low-temperature environment during the value chain's post-harvest stages, it's referred to as a "cold chain." Precooling, bulk storage, distribution, retail cooling, and home refrigeration are steps in the cold chain pathway for food before it is consumed after harvest. At least one of the previously specified processes must be involved in a cold chain, even though they don't all have to (Makule *et al*. 2022] [23]. Fresh food begins to lose more water via transpiration and respiration soon after harvest, most likely as a result of stress during harvest. Water lose affects the freshness and weight of the product; in severe situations, the produce loses all of its value. Consequently, cooling fresh fruit quickly after harvesting improves its shelf life and nutritive value and delays/eliminates freezing damage by diminishing rates of transpiration, respiration, microbial growth and ethylene formation.

To increase the lifespan and nutritional value of fresh vegetables and fruits, the best possible control of cold storage conditions is required. These conditions include relative humidity levels, the distance between storage containers, temperature, mixing compatible produce, air flow, and product in- and outflow, which should follow the "First In, First Out" rule (You *et al*. 2021) [41]. Actually, the idea is to preserve the climacteric goods at comparable stages of maturation and each crop individually. Crops that are compatible can be stored together because this isn't always possible to store each crop separately. For example, pears and apples should be kept apart from onions and celery due to aroma transmission. Celery shouldn't be stored with onions, and citrus fruits shouldn't be kept with veggies that have strong scents. Crops that produce ethylene, like tomatoes and bananas, should be stored apart from those crops that are sensitive to ethylene, like potatoes and cucumbers. In addition, before produce is stored, the temperature in cold storage facilities should be lowered to the required level for the specific items being stored.

A steady supply of electricity, sufficient startup and operating funds, are prerequisites for cold storage. Farmers in impoverished nations frequently lack access to these prerequisites. Because of this, small-scale farmers are unable to utilise sustainable cold storage facilities or maintain uninterrupted cold chains. Improving cold storage in food value chains generally has a positive impact on development, enhancing local management capabilities and increasing access to appropriate infrastructure, boosting rural farmers' incomes, and driving economic growth through cost and energy savings (Makule *et al*. 2022) [23].

2.2 UV-C non-ionizing radiation

It is commonly acknowledged that UV light in the "C" band lowers microbial contamination and lengthens shelf life. Because UV-C radiation kills microorganisms including bacteria, viruses, fungus, to the greatest extent possible, it is recognised as a germicide. Nevertheless, the treatment relies on upon several elements, including UV radiation exposure duration, wavelength, dosage, and light source (Kim *et al*., 2017) [19]. UV-C has a high efficacy of killing microorganisms at 265 nm by penetrating their cell membranes and damaging their RNA or DNA, which prevents them from reproducing and causes cell death. As a result, the radiation has no effect on the product's odour, taste, flavour, pH, or other characteristics, nor does it create any residues or toxins throughout the procedure. Studies also showed that because of how much light each cell absorbs, the smaller cells had a higher resistance to UV-C radiation. Furthermore, due to their distinct cell membranes, thickness, and reduced pyrimidine base count, yeasts and moulds exhibit greater resistance than other microorganisms. Light-emitting diodes, mercury lamps with low and medium pressure, and pulse lights are a few UV sources. Both direct and indirect processes can be used to inactivate microorganisms. Ultra-structural alterations are also induced by indirect photochemical effects, such as the production of free radicals.

Low levels of UV light causes fruits to produce antifungal chemicals, which delays softening and ripening and lessens the damage caused by cold. The delay in softening brought on by modifications in the actions of proteins and enzymes involved in the breakdown of cell walls. The cell wall proteins and enzymes responsible for softening fruit include pectin-methylesterases, polygalacturonases, endoglucanases, and expansins. There have been reports that UV-C radiation is particularly efficient at inhibiting a wide variety of microorganisms. In many microbes, it results in the physical shifting of electrons and the breakage of DNA links, which inactivates the cell. It has been demonstrated to preserve the general quality and extend the shelf life of harvested fresh vegetables. Better nutritional and sensory characteristics could be maintained, ripening, softening, and electrolyte leakage, chlorophyll degradation could be delayed, the plant's resistance to freezing harm could be increased, and respiration rate and weight loss could be decreased. Additionally, exposure to UV-C radiation causes phytoalexins to accumulate, which is critical for protecting fresh produce from diseases of plants and encoding proteins linked to pathogenesis (Idzwana *et al*. 2020) [15].

2.3 Cold plasma

Food may be processed at low temperatures without experiencing a noticeable increase in temperature because cold plasma can be produced at room temperature and atmospheric pressure. In contrast to low-pressure or decreased-pressure applications, this gentle operating condition prevented undesirable phase transitions while enabling continuous food processing (Schlüter, *et al*., 2013) [36]. It is a flexible method of germicide application that works well on a broad range of vegetables and fruits. Cold plasma is a promising sterilisation method since it can render a variety of food-borne microbes inactive unaccompanied by losing any of the food's nutritional value. Benefits of Cold plasma include strong antibacterial efficacy, short time periods, power efficiency and low temperature operation escorted by minimal impact on the environment and quality of food (Bourke *et al*., 2018) [4]. Apples, tomatoes, and blueberries are just a few of the fruits that have had microbes removed using cold plasma (CP). An extensive assortment of vegetables and fruits can be treated using cold plasma, a flexible method of germicide application.

2.4 Microwave

The application of heat and its gradual dispersion throughout plant tissue through conduction or similar processes can often lead to a decrease in the concentration of vital nutrients as well as compounds associated with flavor. Some instances of these heating techniques include high-temperature/short-time treatments, radio frequency, hot air and hot water treatments. The goal of using microwaves in place of traditional heating in this situation was to quickly and efficiently raise the temperature without creating a temperature gradient. Using this technology, fruits and vegetables are treated fast in order for obtaining minimum processed products, to restrict the growth of microorganisms while, decreasing the loss of quality and assuring the least amount of negative effect on environment as well as the lack of residues in the processed produce (Usall *et al*. 2016) [40]. However, an overly long or intense microwave treatment might cause an excessive temperature increase, leading to non-uniform heating that damages the fruit tissue (Palumbo *et al*. 2022) [29]. Because of this, a number of obstacles have to be removed for the purpose of execution of a successful microwave process for fresh and minimally processed food on an industrial scale.

2.5 Ozone

The fresh produce business has long employed ozone, a well-known strong oxidising agent, as an antimicrobial agent. It is generally recognised as safe -GRAS (Glowacz *et al*. 2015) [14]. There are two applications for ozone. The storage environment of the harvested product is periodically or constantly supplemented with gaseous ozone. Immediately following the harvest of vegetables or during the washing process, aqueous ozone is applied. In the hindmost instance, the produce can be sprayed, rinsed, or dipped in water that has dissolved ozone (Sarron *et al*. 2021) [35]. Ozone has a fast rate of reaction with nucleic acid, enzymes inside cells, and portions of the envelopes, spore coatings, and viral capsids of microorganisms. It also breaks down fast with no oxidation residue left behind and doesn't produce any hazardous halogenated compounds. Ozone degrades spontaneously throughout the water treatment procedure, generating hydroxyl free radicals (•OH). The primary reactive oxidising agents, the •OH radicals, are extremely effective in inhibiting viruses and bacteria. Organic compounds will undergo oxidation by ozone to form safer elements. For example, cyanide and ammonia will be broken down into nitrogen and water. In all processes, oxygen is the principal by-product following oxidation. The food industry may profit from the usage of ozone because, unlike other disinfectants, it leaves no chemical residues on the surface of vegetables and fruits. Fresh produce, like apples, lettuce, blueberries, papaya, tomato and strawberries, can effectively lower their microbial counts by being treated with ozonated water before being stored and gaseous ozone exposure (Glowacz *et al*. 2015) [14].

2.6 Edible coatings or Bio-nanocomposite coatings

It is widely acknowledged that edible coatings or bio-nanocomposite films can preserve postharvest quality. The process of applying edible coatings is easy, inexpensive, safe, and environmentally friendly, making it a viable method for preserving vegetables and fruits. Nanomaterial-based edible coatings have also demonstrated impressive advantages for fruit and vegetable storage. These coatings not only help to preserve the comprehensive attribute of the vegetables and fruits but also keep them safe throughout transit without inflicting any physical harm. Because of its bio-degradable, antibacterial, film-production, and non-toxic qualities, chitosan is considered to be among the greatest coverings for a variety of foods that is both edible and safe for biological systems (Shiekh *et al*. 2013) [38].

Edible coatings are recommended as practicable options to preserve fresh vegetables and fruits because of their capacity for preventing moisture loss, aroma loss, water uptake by the produce, along with oxygen penetration. The bio-nanocomposite films and coatings aid to further limit weight loss by cutting water loss. Additionally, edible coatings extend the texture, shelf life and appearance of the food by creating semi-permeable barriers to gases (including carbon dioxide and oxygen) and moisture (Duran *et al*. 2016; Jafarzadeh *et al*. 2018) [12, 16]. reducing the gases that cause fruits and vegetables to decay is essential. This may be achieved by using edible films and coatings that have oxygen scavengers and humidity control systems (Restuccia *et al*. 2010) [32]. Resende *et al*. (2018) [31], reported that chitosan/cellulose nanofibril coating reduces respiration, minimises oxygen diffusion, and postpones the oxidation of strawberries by ascorbic acid

By coating the fruit with a semi-permeable material, it is possible to hold-up ripening of fruits through regulating the fruit's ethylene content. According to Meindrawan *et al*. (2018) [25], the coating has the potential to limit CO_2 diffusion out of the tissue and reduce the amount of oxygen consumed for respiration. It may also be a suitable substitute for the application of chemical treatments and disinfectants. The ethylene content of tomatoes packed in bio-nano-composite films was substantially less as compared to tomatoes packaged in chitosan and control film (Jafarzadeh *et al*. 2021) [17].

2.7 Nanotechnology

Fresh vegetables and fruits are especially vulnerable to ethylene, water permeability, and oxygen that are among the primary causes of deteriorating food quality. Using nanotechnology applications in food packaging is the best course of action in this respect. When producing food packaging, biodegradable materials are typically used as a means to minimise environment defilement. Lately, the use of bio-polymer coatings on food surfaces has shown promise for the preservation of produce (Ncube *et al*. 2020; Rashidi *et al*. 2011) [28, 30].

Numerous metal nanoparticles and metal-oxide nanoparticles, like silicon oxide, titanium-dioxide, gold, zinc, silver, and so forth, been extensively employed in a number of employment of active packaging (Bikiaris *et al*. 2013) [3]. It is a purposefully created packaging system that incorporates elements that have the potential to release antioxidants, antimicrobials, or absorb oxygen into or out of packaged food. When active ingredients like oxygen absorbers, water vapour, antimicrobials, and nanoparticles are combined with a polymer, the packaging becomes more resilient and efficient in prolonging the storage life and quality of food (Majid *et al.* 2018) [22]. These nanoparticles interact with food's organic ingredients directly or by slowly migrating and reacting with it. Silver nanoparticles are amongst the abundantly employed nano-particles attributable to their well-established anti-bacterial properties averse to pathogenic bacterial strains [Sharma *et al*. 2017] [37].

In addition, they suppress a number of fungi and viruses. Additionally, it has been noted that silver nanoparticles can increase reactive oxygen species (ROS) production and block respiratory chain enzymes. By absorbing and breaking down ethylene, silver-nanoparticles have shown that they can extend the storage life of vegetables and fruits. Another nanoparticle that the FDA has approved as "GRAS" is zinc oxide, which can therefore be utilised as an ingredient or food additive in regular applications [Mohammad *et al*., 2022) [27].

3. Conclusion

Food preservation has become essential for increasing the shelf life of food to help feed millions of people worldwide since tonnes of fruits and vegetables are wasted every single day. Maintaining an accurate and precise balance between technology and cost-effectiveness in terms of design is crucial. While conventional techniques of preservation exist, they are limited by factors such as high manufacturing costs, inadequate shelf-life, undesired residue, etc. The advantages of cold plasma, UV-C radiation, microwaves, and nanotechnology-related shelf life extension techniques might potentially offset the drawbacks of conventional preservation techniques.

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