Postharvest treatments of horticultural produce

Dr. R.R. Sharma
Principal Scientist (Hort.)
Division of Food Science and Postharvest Technology
ICAR-Indian Agricultural Research Institute, New Delhi- 110 012, India
(Email: rrs_fht@rediffmail.com)

Introduction

Fruit and vegetables are a major source of essential vitamins and minerals, which are needed for wellbeing of human. Hence, these are rightly called as ‘protective foods’ by medical experts. Being highly active metabolically, these commodities are highly perishable in nature and thus require coordinated systematic handling to maintain quality and reduce losses and waste. It is estimated that around 25-30% of this valuable produce goes waste in the form of postharvest losses occurring between harvesting till they reach consumers. Hence, coordinated activities are required to reduce postharvest losses and waste of fresh fruits and vegetables because these commodities provide essential nutrients and represent sources of domestic and international revenue.

In general, attributes such as appearance, texture, flavour and nutritional value have been traditional quality criteria in fruits and vegetables, but increasingly safety (chemical, toxicological and microbial) and traceability are important for consumers. Fresh produce is often eaten raw or after minimal processing and food pathogen contamination can present risk of outbreaks of foodborne illnesses. Owing to multiple uncertainties along the supply chain, microbial contamination leading to spoilage and postharvest losses can occur at any of the stages in the continuum from farm to consumer. Therefore, postharvest treatments are essential to minimize microbial spoilage and reduce the risk of pathogen contamination for fresh fruits and vegetables..

Several postharvest physical, chemical and gaseous treatments are given to fresh fruits and vegetables to maintain fresh-like quality with high nutritional value and meet safety standards of fresh produce. These postharvest treatments can be combined with appropriate storage temperatures. In this chapter, we have attempted to review the status of postharvest treatments and emerging technologies that can be used to maintain quality and reduce wastage of fresh produce.

Table 1: An overview of different postharvest treatments of fresh fruits and vegetables

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Treatment	**Benefits of treatment**	**Example of Fruits**	**Examples of vegetables**
Heat treatment	Reduction in chilling injury, delay in ripening, killing of insects and reduction in decay	Mango, strawberry, kiwifruit, grape, plum, peach etc.	Potato, tomato, carrot, asparagus, broccoli, beans, celery, lettuce, spinach etc.
Edible coating	Provides a partial barrier, minimizes moisture loss; establishes modified atmosphere; preserves colour and texture; retains natural aroma	apples, pears, strawberry etc.	Carrots, celery etc.
Irradiations	Inhibits sprouting of tubers, bulbs and roots, meets quarantine requirements; a safe process	Mango, strawberry etc.	Potato, onion etc.
Nitric oxide	Inhibits ethylene biosynthesis, reduces respiration rate, water loss, browning, and lower incidence of postharvest diseases	Apple, banana, kiwifruit, mango, peach, pear, plum, strawberry, papaya, loquat etc.	Tomatoes
1-MCP	Reduces ethylene production, maintains fruit cell wall integrity and peel colour, and develop aroma and flavour	Apple, pear, avocado, kiwifruit, mango, nectarine, papaya, peach, nectarine, plum, persimmon, pineapple etc.	banana, broccoli, cucumber, pepper, tomato etc.
Antimicrobial and anti-browning agents	Retard browning, deterioration of texture and microbial growth	Apple, strawberry, orange, grapes and fresh-cut produce	Tomatoes, lettuce etc.
Sulphur dioxide	Prevents postharvest decay	Grapes, litchi, fig, banana, lemon, apple and blueberries	-
Ozone	Easy to use, can be incorporated into existing cold storage, washing system, better efficacy than chlorine	Apples, cherries, kiwifruit, onions, peaches, plums, table grapes etc.	carrots, garlic, potatoes etc.
Ethylene	Enhances ethylene production, triggers ripening process, improves fruit colour and quality	Banana, avocado, persimmon, kiwifruit, mango, citrus fruits etc.	Tomatoes

Modified atmosphere packaging (MAP)	Delay respiration, senescence, and slows down rate of deterioration	Apples, strawberry, banana, cherries, fresh-cut fruits etc.	Carrots, salad mix and leafy green vegetables
Controlled Atmosphere (CA) storage	Retards senescence, slows down the physiological and metabolic activities, reduces decay	Apple, pear, avocado, strawberry, cherry, kiwifruit, avocados, persimmon, pomegranate, banana, cranberry, mango, nectarine, peaches, plums etc.	cabbages, asparagus, broccoli,

A. Physical treatments

(a) Heat treatment

Several studies have been conducted by scientists on the use of heat treatment as an alternative to chemical treatments for harvested fruits and vegetables. Such heat treatments include hot water dip, saturated water vapour heat, hot dry air and hot water rinse with brushing. Heat treatments bring beneficial effects in the harvested fruits and vegetables by several possible ways such as (i) through changes in physiological processes such as a reduction in chilling injury and delay of ripening processes by heat inactivation of degradative enzymes, (ii) by killing of critical insect contaminations, and (iii) by controlling the onset of fungal decay. Heat treatments can be of short- (up to 1 h) or long-term duration (up to 4 days). Heat treatments have been applied to firm potatoes, tomatoes, carrots and strawberries; to preserve the colour of asparagus, broccoli, green beans, kiwi fruits, celery and lettuce; to prevent development of overripe flavours in cantaloupe and other melons; and to generally add to the longevity of grapes, plums, bean sprouts and peaches (Table 2).

It has been demonstrated that heat shock by using hot water washing at temperatures ranging from 37 to 55°C for duration of 30 s to 3 min can improve the postharvest quality of spinach, apples and mandarin fruit. A clear mode of action of any water treatment is to wash-off the spores from the fruit surface. Hot water is a better vector of energy than air and has provided comparable reductions in fungal decay. Blue mould on grapefruit caused by *Penicillium* sp. has been controlled by dipping fruit in hot water for 2 min at 50°C. Improvements in the quality of bell pepper, apples, melons, sweet corn, kumquat and grapefruit have been reported with cold water cleaning in combination with brushing and a short HWR. Hot water treatments also influence the structure and composition of epicuticular waxes. Covering of cracks and wounds and the formation of anti-fungal substances in the wax after heating are thought to be possible modes of action.

Table 2: Effects of hot water dip treatment of decay control in fruits and vegetables

Commodity	Pathogens	Temperature (C)	Time (min)	Possible injuries
Apple	*Gloeosporium* sp.	45	10	Reduced storage life
	Penicillium expansum	45	10	-
Grapefruit	*Phytophthora citrophthora*	48	3	-
Green beans	*Pythium butleri*	52	0.5	-
	Sclerotinia sclerotiorum	52	0.5	-
Lemon	*Penicillium digitatum*	52	5-10	-
	Phytophthora sp.	52	5-10	-
Mango	*Collectotrichum gloeosporioides*	52	5	No stem rot control
Melon	Fungi	57-63	0.5	-
Orange	*Diplodia* sp.	53	5	Poor degreening
	Phomopsis sp.	53	5	-
	Phytophthora sp.	53	5	-
Papaya	Fungi	48	20	-
Peach	*Monolinia fructicola*	52	2.5	Motile skin
	Rhizopus stolonifer	52	2.5	-
Pepper (bell)	*Erwinia* sp.	53	1.5	Slight spotting

HWT and VHT are quite common in apple and mango in India. Although, heat treatment provides an alternative to fungicide applications, yet acceptance of this technology by fruit growers has been hampered by high-energy costs and also the need for added labour at the peak work period during harvest time.

(b) Edible coatings

Various types of waxes and edible surface coatings may be applied to fruits and vegetables to improve the cosmetic features (shine, color) of the product. Waxing is recommended only for good quality products because it does not improve the quality of inferior ones. This is done to supplement or replace the natural wax on the surface of a commodity, which may be removed during cleaning and packing. Several edible coatings including chitosan, *Aloe vera*, polyvinyl acetate, mineral oils, cellulose and protein based have shown desirable attributes on fresh produce with good barrier properties, without residual odour or taste and efficient antimicrobial activity

(c) Irradiation

Irradiation exposes food to radiant energy from γ rays and e-beam (high-energy electrons) that penetrate objects and break molecular bonds, including the DNA of living organisms. Ionizing radiation from cobalt-60 or caesium-137, or machine generated electron beams are used as a source of irradiation for extending shelf life of fresh produce. By inhibiting cellular reproduction, irradiation can neutralize pest and food safety problems.

The effect depends on the doses, measured in kilograys (kGy). Low doses of irradiation (less than 1 kGy) only disrupt cellular activity enough to inhibit sprouting of tubers, bulbs and roots and delay senescence. Medium doses (1–10 kGy) reduce microbial loads while high doses (more than 10 kGy) kill a broad spectrum of fungi and bacteria spp. and pests. Most medium- and high-level doses are not appropriate for fresh produce because they can cause sensory defects (visual, texture and flavour) and/or accelerated senescence due to the irreparable damage to DNA and proteins. Irradiation presents an effective postharvest treatment for destroying bacteria, moulds and yeasts, which cause food spoilage, and also control insect and parasite infestation resulting in reduced storage losses, extended shelf life and improved parasitological and microbiological safety of foods.

Irradiation has been commercialized for control of potato and onion sprouting, and strawberry decay. Low-dose γ-irradiation on mango (0.3–0.7 kGy) resulted in delay in ripening and extension of shelf life by a minimum of 3–4 days.

While much of the focus of irradiation use on fresh fruits and vegetables has been for extending shelf life and reducing decay, it has been known for many decades that irradiation is effective at killing, sterilizing or preventing further development of a wide variety of insect pests of quarantine importance on perishable fruits and vegetables. Despite some misconceptions, exposing food to irradiation does not make the food itself radioactive. The irradiation process produces very little chemical change in food and does not change the nutritional value of food. Extensive research and testing has demonstrated that irradiated food is safe and wholesome, although there is always fear among the consumers for consuming irradiated food.

B. Chemical treatments

(a) Antimicrobial and anti-browning agents

Over the past decade, the increasing number of reported outbreaks of foodborne diseases has highlighted the concern of regulatory agencies, producers and the consumers about the microbial safety of fresh fruits and vegetables. Outbreaks have been associated with vegetables such as cabbage, celery, cucumber, leeks, watercress, lettuce and sprouts. Antimicrobial and anti-browning agents offer the possibility to maintain safety and can be grouped into chemical- and natural/bio-based agents. Chemical-based agents include chlorine-based solutions, peroxyacetic acid (PAA), organic acids, hydrogen peroxide (H_2O_2) and electrolysed water. A chlorine-based solution such as NaClO has been one of the commonly used disinfectants for fresh produce, owing to its very potent oxidizing properties and cost effectiveness. However, its efficacy as an antimicrobial agent is dependent on the levels of chlorine and at high levels may cause taste and odour defects on treated products. Additionally, chlorine-based compounds have been reported to have limited effectiveness in the reductions of microbial load on fresh produce. Surfactants, detergents and solvents, alone or coupled with physical manipulation such as brushing, may be used to reduce hydrophobic nature of the waxy cuticle or remove part of the wax to increase exposure of microorganisms to chlorine.

Peroxyacetic acid is a very strong oxidizing agent, with no harmful by-products which has been reported to be effective in controlling *E. coli.* on apples, strawberries, lettuce and cantaloupe

H_2O_2 possesses a bactericidal, sporicidal and inhibitory ability, owing to its property as an oxidant and being able to generate other cytotoxic oxidizing species, such as hydroxyl radicals. Treatment with H_2O_2 can extend the shelf life and reduce natural and pathogenic microbial populations in melons, oranges, apples, prunes, tomatoes, whole grapes and fresh-cut produce. However, H_2O_2 treatment requires a long duration of application and can cause injury on some produce. Also, it is accepted as a generally recognized as safe for some food applications but not yet approved as an antimicrobial agent.

Organic acid, ascorbic acid and calcium-based solutions have been applied largely to slow down enzymatic and non-enzymatic browning, deterioration of texture and microbial growth on fresh produce.

(b) Nitric oxide

Nitric oxide (NO) is a highly reactive free radical gas and acts as a multifunctional signalling molecule in various plant physiological processes, such as fruit ripening and senescence of fresh fruits and vegetables. Endogenous NO concentrations decrease with maturation and senescence, thereby offering an opportunity for modulation of their levels with exogenous Optimum NO levels delay the climacteric phase of many tropical fruits, prolong the postharvest storage life by impeding ripening and senescence, suppress biosynthesis of ethylene, reduce ethylene production and, consequently, delay in fruit ripening. NO gas is applied as a fumigant or released from compounds such as sodium nitroprusside, S-nitrosothiols and also diazeniumdiolates used as a dipping treatment. Reduced ethylene production during ripening in NO-fumigated fruit has been claimed owing to binding of NO with 1-aminocyclopropane-1-carboxylic acid (ACC) and ACC oxidase to form a stable ternary complex, thus limiting ethylene production. Other mechanism of NO action include the inhibition of ethylene biosynthesis, cross-communication with other phytohormones, regulation of gene expression and amelioration of oxidative postharvest stress.

Successful application of NO has been reported for apple, banana, kiwifruit, mango, peach, pear, plum, strawberry, tomato, papaya, and loquat. Commercial application of NO in fresh fruits and vegetables, however depends upon the development of a smart carrier/controlled release system for NO.

(c) Sulphur dioxide

Sulphur dioxide (SO_2) is widely used on table grapes to prevent decay during storage, by either initial fumigation of fruit from the field followed by weekly fumigation of storage rooms or slow release from in-package pads containing sodium metabisulphite (e.g. grape guard). SO_2 technology has also been tested for control of postharvest decay on other fruits such as litchi, fig, banana, lemon or apple. There are disadvantages of using SO_2 as the SO_2 concentration necessary to inhibit fungal growth may induce injuries in grape fruits and sulfite residues pose a health risk for some individuals. Nevertheless, SO_2 treatment is a widespread process because of its advantages of universal antiseptic action and economic application.

C. Gaseous treatments

(a) Ozone

Recent research and commercial applications have verified that ozone can replace traditional sanitizing agents. Ozone is a very pungent, naturally occurring gas with strong highly reactive oxidizing properties. Ozone is reported to have 1.5 times the oxidizing potential of chlorine and 3000 times the potential of hypochlorous acid. Contact times for antimicrobial action are typically four to five times less than that for chlorine. Ozone rapidly attacks bacterial cell walls and is more effective than chlorine against the thick-walled spores of plant pathogens and animal parasites, at practical and safe concentrations. Its treatment has been reported to be effective in asparagus spears, apples, cherries, carrots, garlic, kiwi, onions, peaches, plums, potatoes and table grapes. However, ozone does not penetrate natural openings or wounds efficiently. Additional research is needed to define the potential and limits of the effective use of ozone for postharvest treatments for the quality and safety of fresh fruits and vegetables.

(b) Ethylene

Endogenous ethylene production and its exogenous application exhibit both beneficial and deleterious effects on horticultural fresh produce. Beneficial effects of exogenously applied ethylene includes triggering ripening, improving fruit colour and quality in some crops, such as bananas and avocados, kiwifruit, persimmon, tomato, mangoes, de-greening of citrus fruits. The deleterious effects of ethylene in postharvest phase horticultural commodities has also been documented, such as shorter storage life, promotion of senescence, fruit softening, discoloration (browning) and russet spotting in lettuce, yellowing of leafy vegetables and cucumbers and increased susceptibility of fresh horticultural produce. Therefore, ethylene management plays a pivotal role in maintaining postharvest life and quality of climacteric and non-climacteric fruits. Most commercial strategies for maintaining horticultural commodities involve storing at low temperatures, blocking ethylene biosynthesis and its action, minimizing exposure produce to ethylene during ripening, harvest, storage and transport by controlling temperature and atmospheric gas composition.

Beneficial effects of ethylene biosynthesis inhibitors such as aminoethoxyvinylglycine alone on postharvest quality have been demonstrated in apples and stone fruits and in combination with controlled atmosphere (CA) storage.

(c) 1-Methylcyclopropene

The discovery and patenting of cyclopropenes as inhibitors of ethylene perception represents a major breakthrough in controlling ethylene responses of horticultural products. Of the cyclopropenes, 1-MCP proved to be extremely active, but unstable in the liquid phase. However, 1-MCP can be complexed with α-cyclodextrin to maintain its stability; this development represented a major step towards its commercialization as it was then possible to release 1-MCP from the complex to expose to the horticultural products. Regulatory approval for use of 1-MCP has been obtained in more than 50 countries, and approval for use of the technology continues to occur around the world. 1-MCP is registered for use on apple, avocado, banana, broccoli, cucumber, date, kiwifruit, mango, melon, nectarine, papaya, peach, pear, pepper, persimmon, pineapple, plantain, plum, squash and tomato. 1-MCP affects many ripening and senescence processes, including pigment changes, softening and cell wall metabolism, flavour and aroma, and nutritional properties, but to varying degrees in both non-climacteric and climacteric products. Its effects depend on genotype, cultivar and maturity.

Despite the challenges, successful commercialization of SmartFresh for treatment of avocados, bananas, melons, persimmons and tomatoes has resulted from careful attenuation of 1-MCP concentrations and/or ripening stage at harvest.

Recently, 1-MCP formulations have been approved by the Environmental Protection Agency and other regulatory authorities for preharvest applications, and these are marketed as Harvista for FFV. Semi-commercial trials have been carried out in several US locations, Argentina, Brazil, Canada, Chile, New Zealand and South Africa. Harvista has useful effects on delaying fruit drop, slowing fruit maturation and ripening, and in maintaining postharvest quality, including improving the effects of SmartFresh.

(d) Controlled atmosphere (CA) storage

CA storage refers to the monitoring and adjustment of the CO_2 and O_2 levels within gas tight stores at optimum storage temperature. Thus, the atmosphere is controlled rather than established passively as in MAP. In most cases, the concentrations of CO_2 are higher and those of O_2 are lower, optimum concentrations depending on the specific product and the purpose of the CA storage conditions. Reduced O_2 and elevated CO_2 levels affect both primary (glycolysis, fermentation and aerobic respiration) and secondary (e.g. processes involved in ethylene production and action, pigments, phenolics and volatiles) metabolism.

Each fruit or vegetable has an optimal range of O_2 and CO_2 for maintaining quality and extending shelf life, and these can differ for whole and fresh-cut products of the same fruit or vegetable.

Use of CA technology is limited to relatively only few fruits and vegetables, the major crop being apples. Others are cabbages, onions, kiwifruits, avocados, persimmons, pomegranates, nuts and dried fruits, and vegetables.

(e) Hypobaric storage

Hypobaric or low-pressure storage results in very low O_2 around the product and delay ripening and senescence but has yet to find commercial acceptance because of high cost and safety. These issues may be addressed in the future.

(f) Modified atmosphere packaging (MAP)

MAP generally involves the packaging of a whole or fresh-cut product in plastic film bags, and can be either passive or active. In passive MAP, the equilibrium concentrations of O_2 and CO_2 are a function of the product weight and its respiration rate, which is affected by temperature and the surface area, perforations, thickness and permeability to gases of films used in packaging. In active MAP, the desired atmosphere is introduced in the package headspace before heat sealing, but the final atmosphere will eventually be a function of the same factors that affect passive MAP. Correct equilibrium atmosphere can delay respiration, senescence, and slow down the rate of deterioration, thereby extending product storage life. More recently, active MAP also includes technologies to adsorb substances, such as O_2, ethylene, moisture, CO_2, flavours/odours, and release substances such as CO_2, antimicrobial agents, antioxidants and flavours.

D. Emerging technologies

In the recent years, few more technologies have been standardized. Of them, thermal or cold plasma technology is one of the most important emerging techniques for decontaminating fresh fruits and vegetables. Plasma is composed of ionized gas molecules, which have been dissociated via an energy input. Depending on the mode of particles activation and the excitation energy, they can generate high or low temperatures, referred to as thermal or cold plasma, respectively. Cold plasma at atmospheric pressure can be generated by transforming argon gas into plasma at radio frequency of 27 MHz or by electric discharge between two electrodes separated by dielectric barriers. Three basic mechanisms have been suggested for the inactivation microbial spores in plasma environments, including the erosion of microbial spore surface atom by atom through adsorption of reactive free radicals ‘etching’; direct destruction of DNA via UV irradiation and volatilization of compounds from the spore surface by UV photons through intrinsic photo-desorption. However, more research is required for a complete understanding of this technology, the mechanism and its effects on food enzymes and postharvest quality attributes of fresh fruits and vegetables. Safety of gases, consumer perception and the translation of laboratory scale to large commercial scale, also requires further investigation.

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