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Investigation of Approaches to Preserve Postharvest Quality and Safety in Fresh-cut Fruits and Vegetables

[1]H.S. Hajizadeh and [2]M. Kazemi
[1]Department of Horticultural Sciences, College of Agriculture, University of Maragheh, Maragheh, Iran
[2]Young Researchers Club, Karaj Branch, Islamic Azad University, Karaj, Iran

Corresponding Author: H.S. Hajizadeh, Department of Horticultural Sciences, College of Agriculture, University of Maragheh, Maragheh, Iran Tel: 0098-0912-6167254

ABSTRACT
Fresh cut fruits and vegetables raise food safety concerns including physiological and pathological limitations since they are often processed in a ripe stage which makes them more susceptible to quality deterioration. In this review, we investigated some advances for the maintenance of fresh-cut fruits and vegetables quality, including synthetic chemicals or plant natural antimicrobials and antioxidants, calcium salts, hot water and anoxia treatments, different type of coating and atmosphere conditions. In this review Phenylalanine Ammonia-lyase (PAL), Polyphenol Oxidase (PPO) and membrane permeability were discussed. Although, increasing in browning enzymes activities is documented in some cases but it seems that the main reason for browning inhibition of the fresh-cut products may be because of the maintenance of compartmentation between enzymes and their substrates, preventing enzymatic reaction.

Key words: Fresh-cut, postharvest quality, safety, preserve methods

INTRODUCTION
Fresh-cut quality can be affected by both internal (e.g., morphological, physiological and biochemical defense mechanisms, genotype and processing maturity) and external factors (e.g., storage temperature, humidity, cutting-knife sharpness and chemical treatments) (Rolle and Chism, 1987; Watada and Qi, 1999; Emongor, 2004; Mahdavian *et al*., 2007; Mba *et al*., 2007; Safizadeh *et al*., 2007; Kazemi *et al*., 2011a-f; Shirzadeh and Kazemi, 2011). Hence, they underlying some modifications such as discoloration, decline in levels of nutrients such as ascorbate (Klein, 1987), development of off-odors, membrane breakdown, tissue softening and microbial contamination (Brecht, 1995; Varoquaux and Wiley, 1994; Ruiz-Cruz *et al*., 2010) after processing. By recognizing and controlling factors that have a deteriorative effect on quality and use of natural ways to reduce deterioration and decay without use of undesirable chemicals, good quality fresh-cut product with sufficient shelf-life can be attained. So, the primary solutions for resolving these problems and fresh-cut responses to the applied treatments will be addressed in this review.

NATURAL METHODS TO PRESERVE FRESH-CUT PRODUCTS
Temperature, essential oils, modified atmospheres and packaging are more natural prevail approaches for keeping quality of fresh-cut fruits and vegetables.

TEMPERATURE

Temperature is one of the most effective factors, controlling freshness and decay of the fresh-cut products and maintains good temperature control (the cool chain) is the firs factor in extending shelf-life of high quality fresh-cut products. Fresh-cut product invariably will be subject to temperature abuse during transportation, distribution and retail (Toivonen *et al.*, 2001).

Dea *et al.* (2010) results suggest that the Heat Water (HW) quarantine treatment applied to whole mangoes does not significantly affect the quality of fresh-cut Kent' mango slices stored at 5°C.

However, keeping them at temperatures between 0-10°C can reduce the chance of bacterial and fungal attack since cool temperatures keep some harmful microorganisms at bay but the cold can also cause injury.

Rivera-Lopez *et al.* (2005) showed that in storing Fresh-cut papaya at 5 and 10°C prevented loss of firmness. Also, Allong *et al.* (2000) demonstrated that a storage temperature of 5°C was more effective than 10°C in delaying the ripening and microbial growth while preserving sensory quality of fresh-cut mango slices.

ESSENTIAL OILS

Methyl Jasmonate (MJ, $C_{13}H_{20}O_3$) is a naturally occurring substance that is commonly found in plant tissues and is a part of the defense mechanism in plants which makes them more resistant to temperature changes and to attacks by insects, bacteria and fungi (Swenson, 1998; Ismail *et al.*, 2011; Ahmad *et al.*, 2005; Musyimi and Ogur, 2008).

It has been reported that MJ treatment can reduce the development of chilling injury symptoms in zucchini (Wang and Buta, 1994) and mango (Gonzalez-Aguilar *et al.*, 2000). In addition, MJ has been shown to suppress the fungal growth in grapefruit (Droby *et al.*, 1999), reduce decay and maintain the postharvest quality of papayas (Gonzalez-Aguilar *et al.*, 2003) and inhibit the microbial contamination of fresh-cut celery and peppers (Buta and Moline, 1998). In raspberry, it is demonstrated that MJ increases the resistance of tissues against decay by enhancing their antioxidant system and their free radical scavenging capability (Wang *et al.*, 1996; Wang and Lin, 2000).

The exposure of the sliced pineapple to a MJ emulsion decreased microbiological growth by 3 logs after 12 days of storage at 7°C, with no effect on firmness or color of the fruit (Martinez-Ferrer and Harper, 2005). The results of Wang and Buta (2003) showed that kiwifruit slices treated with different concentrations of methyl jasmonate, maintained good quality after 3 weeks at 10°C compared to the controls. Also, Moline *et al.* (1997) declared that the most effective treatment in reducing decay in strawberries and in reducing the growth of *Botrytis cinerea* was MJ.

PACKAGING AND MODIFIED ATMOSPHERE

Packaging fresh-cut fruit products in polymeric films that help in creating a suitable passive modified atmosphere can also be an effective supplement to proper temperature management in maintaining their quality (Martinez-Ferrer *et al.*, 2002; Fonseca *et al.*, 2005).

The use of anti-browning dips such as Nature Seal AS-1 can control the surface browning of apple slices as well as improve the texture to a small degree. However, the matching of an appropriate film to bag the slices is important ensure complete control of browning and to control other deteriorative processes. Oxygen levels can get too low in the wrong bag and this can lead to off-flavor development as a result of anaerobic respiration. The challenge is to select a package system which will have low enough oxygen to assist in quality retention without leading to off-flavor development. Generally a range of 2 to 5% oxygen is recommended for apples.

Modified and controlled atmospheres help maintain quality and extend storage life by inhibiting metabolic activity, decay, browning (Gunes and Lee, 1997) and especially by inhibiting ethylene biosynthesis and action (Kader, 1986; Kader *et al.*, 1989; Mathooko, 1995). The most common atmospheres consist of reduced O_2 and elevated CO_2 levels. Carbon monoxide is also sometimes included for inhibition of browning and microorganism growth (Kader *et al.*, 1989).

The project for evaluating the effect of packaging and modified atmosphere on fresh-cut Salad savoy (*Brassica oleracea* L.) showed that packages with 16.6 and 21.4 Oxygen Transmission Rate (OTR) films attained the desired O_2 (1.4-3.8 kPa) and CO_2 levels (3.6-6.3 kPa) on day 10 and throughout the storage period and maintained freshness with high overall quality scores (Kim *et al.*, 2004).

Odriozola-Serrano *et al.* (2010) investigated bioactive composition of fresh-cut strawberries stored under super atmospheric oxygen, low-oxygen or passive atmospheres. They proposed that 2.5 kPa O_2+7 kPa CO_2 atmospheres are better choice to prevent oxidation of the main antioxidant compounds in fresh-cut strawberries.

In the other project on fresh-cut pineapple, the main effect of reduced (8 kPa or lower) O_2 levels was better retention of the yellow color of the pulp pieces, as reflected in higher final chroma values, whereas elevated (10 kPa) CO_2 levels led to a reduction in browning (higher L values). Modified atmosphere packaging allowed conservation of pulp pieces for over 2 weeks at 5°C or lower without undesirable changes in quality parameters (Marrero and Kader, 2006).

Another technology that is being explored is the use of pre-slicing treatment of whole apples with high oxygen. The high oxygen treatment leads to better firmness retention, lowered browning and reduction of anaerobic volatile accumulation in slices made from treated apples (Toivonen *et al.*, 2001). Donadon and Durigan (2004) compared three types of polymeric films for packaging 'Tommy Atkins' mango slices and found that those packed in the polyethylene terephthalate (PET) clamshell trays had a shelf-life of 14 days at 3°C versus 11 days for the mango cubes in the other packages. Singh *et al.* (2007) concluded that the shelf-life of fresh-cut mangoes could be extended by packaging in PET containers. Chonhenchob *et al.* (2007) reported that extended shelf-life was observed in fresh-cut mangoes packed in PET due to reduced oxygen and elevated carbon dioxide concentrations.

Oms-Oliu *et al.* (2008) investigated the effect of alginate, pectin and gellan-based edible coatings on the shelf-life of fresh-cut 'Piel de Sapo' melon. They concluded all coatings prevent of dehydration and ethylene production and did not improve microbiological stability of fresh-cut melon packaged under passive modified atmosphere. In general, pectin-based coating seemed to best maintain sensory attributes.

The application of the edible coatings retarded the microbiological deterioration of fresh-cut apples. Also, Alginate and gellan edible coatings effectively prolonged the shelf-life of Fuji apple wedges by 2 weeks of storage compared with the control apple with 4 days shelf life (Rojas-Grau *et al.*, 2008).

Our researches on intact apple (Hajizadeh *et al.*, 2006) and mushroom (unpublished data), showed that packaging of intact fruits in poly propylene film along with active modified atmosphere were the most effective treatment in extending the shelf life of fruits, so it seems that similar treatment can be used for apple and mushroom slices. Nevertheless application of these treatments needs to more researches and understanding different physiological mechanism between sliced and intact fruit.

CHEMICAL COMPOUNDS TO PRESERVE FRESH-CUT PRODUCTS

Fresh-cut products and color preservation: One of the limitations of fresh-cut fruit products is that they are often processed in a ripe stage, which makes them more susceptible to quality deterioration once they are cut and packaged (Toivonen and DeEll, 2002). On the other hand, This product is subject to enzymatic browning and must be treated with a browning inhibitor to prevent development of unsightly discoloration (Sapers *et al*., 2002). Enzymatic browning represents a major challenge in fresh-cut fruits (Son *et al*., 2001; Sapers *et al*., 2002). Browning occur when the products of phenyl propanoid metabolism, such as various phenolic and possibly other substrates (e.g., anthocyanin) are oxidized in reactions catalyzed by phenolases such as polyphenoloxidase (PPO) or peroxidases. Chemical dips (such as ascorbic and citric acid, calcium chloride and other compounds) have been shown to be effective in retarding browning and softening of several types of fruit such as apple (Son *et al*., 2001; Cocci *et al*., 2006), pineapple (Gonzalez-Aguilar *et al*., 2004) and pear (Dong *et al*., 2000; Arias *et al*., 2008). Arias *et al*. (2008) has recently shown that the use of modified atmospheres combined with an anti-browning treatment (ascorbic acid+4-hexylresorcinol+$CaCl_2$) could be successfully applied to 'Conference', 'Williams' and 'Abate Fetel' pears. Trindade *et al*. (2003) concluded that the most suitable conditions for quality preservation of fresh-cut 'Tommy Atkins' mango were dipping in a solution of 3.5% (w/w) calcium chloride at 35°C for 20 min and packaging under active modified atmosphere (5% oxygen+5% carbon dioxide). Under these conditions, fresh-cut mango maintained good quality for 5 days at 5°C.

Fresh cut apples turn brown when iron-containing chemicals in the apple react with oxygen in the air. We see this every day when iron objects rust. The chemical reaction is called 'oxidation'. There are several ways to inhibit oxidation. Chemical anti-oxidants can be added to food. Lemon juice, for example, will inhibit the browning of a freshly cut apple because lemons are high in citric acid, an anti-oxidant. Sulphur dioxide, used in the commercial processing of many foods, does the same thing. Removing the air (and thus the oxygen) from food can also inhibit oxidation. This is one reason can food stays fresh so long. Because the enzymes involved in oxidation need water to work, the reaction can be also slowed by de-hydrating (removing water from) food.

Apple cultivars have different capacity for browning, hence, choosing apples that are less prone to discoloration is necessary for fresh cut industry. A study found that 'Arangeh' tend to brown the least. 'Granny Smith' and 'Golden Smoty' apples also showed minimal browning. Golden Delicious apples were in the middle and Red Delicious apples browned the most. In Granny, Smith and Fuji wedges were treated with a pH 2.9 dip containing ascorbic acid, citric acid and sodium hexametaphosphate suppressed browning for at least 3 week at 4°C, whereas formulations without hexametaphosphate failed within 1 week (Pilizota and Sapers, 2004). Results showed that incorporation of the antioxidant to the coating reduced browning compared to the use of the antioxidant alone. Increasing AA and Cys content decreased browning of coated samples. The most effective treatments were WPC-BW-based coatings with 1% AA or 0.5% Cys.

Fresh-cut products and texture preservation: Firmness retention is an important quality parameter in fresh-cut fruits and vegetable products (Agar *et al*., 1999; Gorny *et al*., 1999). An important aspect of the fresh-cut industry is texture. Fresh-cut produce must have a reasonable shelf-life which is the time between when produce is cut and when it is consumed. If not ripe enough, it won't taste good. But if the product is cut at too ripe stage, then it will deteriorate even more rapidly.

Lamikanra and Watson (2004) study the effect of calcium dipping and temperature on the quality of Fresh-cut Cantaloupe Melon and showed that Fruit dipped in solution at 4°C had lower respiration and moisture loss rates than treated fruit at ambient temperature. Also, Calcium treatment lowered lipase activity at both temperatures but the effect was more notable in fruit treated at the lower temperature.

Botelho *et al.* (2006) investigated the quality of fresh-cut and intact strawberry during storage at 5°C. Fruits were dipped in sodium isocyanurate solution and packaged in polyethylene terephthalate (PET) trays. Results showed that fresh-cut strawberry had lower SSC and firmness, lighter colour and higher respiratory activity than intact fruit and showed good quality for up to 4 d after cutting compare to intact strawberry which stored for 8 days.

Treatment fresh-cut 'Blanquilla' pears with 1-MCP before cutting and peeling considerably improved their textural properties and color and allows fresh cut 'Blanquilla' pears to be sold up to about 5 d after processing. Treatment with 1-MCP could be a viable alternative to common technologies for extending the shelf-life of 'Blanquilla' pears as a fresh-cut product (Arias *et al.*, 2009).

Ergun *et al.* (2007) studied Physiology of fresh-cut 'Galia' (*Cucumis melo* var. *reticulatus*) from ripe fruit treated with 1-methylcyclopropene and demonstrated that 1-MCP treatment deferred loss of physical deterioration of fresh-cut 'Galia' cubes at 5°C by 2-3 d compared with controls.

Fresh-cut products and flavor preservation: Flavor quality of fruits and vegetables is influenced by genetic, preharvest, harvest and postharvest factors. The longer the time between harvest and eating, the greater the losses of characteristic flavor (taste and aroma) and the development of off-flavors in most fruits and vegetables. Postharvest life based on flavor and nutritional quality is shorter than that based on appearance and textural quality. Thus, it is essential that good flavor quality be emphasized in the future by selecting the best-tasting genotypes and using an integrated crop management system including harvest at the maturity or ripeness stage and use the postharvest handling procedures that will maintain optimal flavor and nutritional quality of fruits and vegetables between harvest and consumption (Kader, 2008). Marrero and Kader (2006) researches on the optimal temperature and modified atmosphere for keeping quality of fresh-cut pineapples showed that the very low respiration rates (CO_2 production of about 0.3 L kg^{-1} sec^{-1}) of pulp pieces at 0, 2.2 and 5°C allowed the use of a MA film such as Mylar®, with a low O_2 transmission rate, without development of permanent off-odors or flavors due to anaerobiosis.

SAFETY

Generally, there is a positive correlation between longer shelf-life of fresh-cut fruits and low aerobic plate count, low total plate count and especially low yeast and mold counts. Thus, it is very important to avoid sources of microbial contamination and to wash the fruits with disinfected water before cutting (Kader, 2008). Fresh-cut products are particularly susceptible to microbial growth owing to the removal of plant protective tissues and the release of cellular fluids from cutting (Heard, 2002), which results in shelf life reduction and food-borne illnesses given that fresh-cut products are marketed as prewashed and ready to eat and not subject to further microbial killing steps, the development and proper application of sanitizing agents to remove microorganisms and control pathogen cross contamination effectively is critical to ensure the quality and safety of fresh-cut produce (Cruz *et al.*, 2006).

There are many reports about using of disinfectants for mango such as 80% ethanol (Thambaramaya, 1997; Plotto *et al.*, 2006), peroxyacetic acid (100 ppm) (Narciso and Plotto, 2005), vanillin solutions (Ngarmsak, 2007) before cutting.

A major consideration in safety has been identified as inoculation of the nutrient-rich flesh of vegetables and fruits with human pathogens from the surface tissues, which are less conducive to growth and development than internal tissues. Safety must be of primary concern in any fresh-cut product.

The potential for human pathogen contamination is indicated by numerous outbreaks of Escherichia coli O157:H7 food poisoning associated with unpasteurized apple cider which is found in the orchard environment and may be detected on fresh apples (Riordan *et al.*, 2001) and can grow in wounds on the apple surface (Gunes and Hotchkiss, 2002), creating opportunities for preharvest contamination. It has been established that *Clostridium botulinum* can grow on romaine lettuce and shredded cabbage in pouches (Petran *et al.*, 1995). Survival and growth of *L. monocytogenes* on apple slices was demonstrated by Conway *et al.* (2000). *Listeria innocua* was able to survive and grow in a chilled, neutral pH browning inhibitor solution similar to that widely used by fresh-cut apple processors (Karaibrahimoglu *et al.*, 2004). So, use of an acidic formulation probably would have suppressed survival and growth of *L. monocytogenes* in the dip, thereby preventing cross contamination of the fresh-cut product (Pilizota and Sapers, 2004).

Ruiz-Cruz *et al.* (2010) investigated the effect of four sanitizers include Sodium hypochlorite (OCl), Peroxyacetic Acid (PA), Acidified Sodium Chlorite (ASC) and carvacrol on microbiological, sensorial and nutritional quality (total phenols, vitamin C and antioxidant capacity) of fresh-cut jalapeno peppers and stored them at 5°C for 27 days. They demonstrated that all sanitizers (except for carvacrol) maintained microbiological and overall quality of jalapeno peppers and ASC was the most effective sanitizer even though it was used at concentrations lower that those currently approved by the FDA.

DISCUSSION

Important considerations in quality of fresh-cut items include a consistent and fresh appearance, acceptable texture, characteristic flavor and sufficient shelf-life to survive the distribution system. Cutting of produce removes the natural protection of the epidermis and destroys the internal compartmentation that protects enzymes from substrates. The consequences of cutting of vegetables appear to be less severe than the cutting of fruits (Brecht, 1995). Microbial decay is the major source of spoilage of fresh-cut produce, since washing and chlorinated water dips only partially remove the microorganisms intrinsic to produce. All sanitizers were capable of controlling microbial growth without inducing major loss of antioxidant capacity and phytochemicals. Carvacrol was the only sanitizer that reduced sensory acceptability of fresh-cut jalapeno peppers however, carvacrol treated samples retained the highest levels of phytochemical and antioxidant capacity. Calcium application often results in reduced rates of respiration and ethylene production, increased firmness and reduced incidence of physiological disorders and decay (Conway and Sams, 1987; Garcia *et al.*, 1996). The ability of calcium to confer rigidity to the tissue components at low temperatures, possibly through improved covalent cross linking, was indicated by viscosity measurements indicating higher values for pulverized cantaloupe melon with added calcium at 4°C than fruit blended under similar conditions at ambient temperature.

Browning-inhibitor formulations generally contain a reducing agent, such as ascorbic acid and also may contain other browning inhibitors or adjuncts, such as citric acid, a calcium salt, cysteine, polyphosphates, or 4-hexylresorcinol (Sapers, 1993; Sapers *et al.*, 2002). Such formulations may be acidic or neutral in pH. One of the most widely used browning inhibitors is a neutral product containing calcium ascorbate, marketed as Nature Seal TM (Chen *et al.*, 2000).

With temperature being the main factor in fresh-cut pineapple conservation, the main advantage of atmosphere modification was a better retention of color. Reduction of O_2 concentration to 8% or lower improved the final appearance as reflected by higher final chroma values. Increasing CO_2 concentration to 10% had the added advantage of retained Luminosity (L) of the pulp pieces. This could be due to a lower activity of browning enzymes such as polyphenol oxidase. Also, elevated CO_2 atmospheres may have delayed microbial growth.

As mentioned before, modified atmosphere packaging is widely used for fresh-cut vegetables and fruits. Semi permeable plastic films are chosen for MAP so that the film permeability and product respiration can combine to produce a desirable steady state atmosphere within the package (Kader *et al.*, 1989). Undesirable atmospheres can lead to reduced quality due to off-flavor and discoloration (Mateos *et al.*, 1993). Because of the relative perishability of fresh-cut products, the atmosphere in the MAP is often actively established, either by flushing with the desired atmosphere or by pulling a slight vacuum and then injecting a desired gas mixture. Novel approaches such as chemical disinfection (Hong and Gross, 1998), edible coatings (Li and Barth, 1998), natural plant products (Buta *et al.*, 1999; Leepipattanawit *et al.*, 1997), ethylene absorbents (Abe and Watada, 1991), gamma irradiation (Chervin and Boisseau, 1994; Hagenmaier and Baker, 1997), heat shock (Loaiza-Velarde *et al.*, 1997), microbial competition (Breidt and Fleming, 1997), non thermal physical treatments (Hoover, 1997) and pulsed-microwave irradiation (Shin and Pyun, 1997) have been studied as potential alternatives or adjuncts to MAP.

Application of aqueous solutions of calcium salts can help maintain fresh-cut tissue firmness (Izumi and Watada, 1995). Although, calcium chloride has been most commonly used for this purpose, it has recently been shown that calcium lactate is as effective without imparting a bitter flavor as calcium chloride can at higher concentrations (Luna-Guzman *et al.*, 1999). Oxidative browning at the cut surface may be the limiting factor in storage of many fresh-cut vegetables and fruits. Low temperatures employed in the handling and storage of fresh-cut fruits suppress many biological processes; however, tissue softening, deterioration and accumulation of hydrolytic enzymes can continue at relatively high rates (Lamikanra *et al.*, 2000; Karakurt and Huber, 2003; Lamikanra and Watson, 2004). Applications of dilute hypochlorite (Ayhan *et al.*, 1998), calcium salt dips (Luna-Guzam and Barrett, 2000; Saftner *et al.*, 2003), controlled or modified atmospheres (Qi *et al.*, 1999; Bai *et al.*, 2003), edible films and coatings (Hoa *et al.*, 2002; Chen *et al.*, 2009) and irradiation (Palekar *et al.*, 2004) have proven to be of benefit in extending the shelf-life of fresh-cut tissues.

In general, it is clear that 1% $CaCl_2$ is a key compound that can be applied for maintaining firmness and extending shelf life of fresh cut fruits and vegetables cubes regarding of literature review. Mangos must be ripened, at least partially (almost ready-to-eat), before cutting to assure better flavor quality in the fresh-cut products (Kader, 2008). So, it seems the time of harvesting can be one of the factors affecting on fresh-cut fruits flavor. Different methods have been used to prevent deterioration and browning of fresh-cut produce. Traditionally, sulphites have been used to prevent browning, however, their use in processed fruits and vegetables was banned by the Food and Drug Administration in 1986 as a result of adverse reactions developed in certain consumers. An alternative is to inhibit browning and deterioration by using natural products derived from plants (Ahvenainen, 1996). Different effective methods on preserving freshness quality of fruits

Table 1: Different effective methods on preserving freshness quality of fruits and vegetables

Fresh-cut product	Chemical treatment	Shelf-life (days)	Temperature (°C)	Reference
Cantaloupe melon	Calcium dipping	12	4	Lamikanra and Watson (2004)
Strawberry	Sodium isocyanurate solution	Up to 4	5	Botelho *et al*. (2006)
Pear	1-MCP	Up to 5	5	Arias *et al*. (2009)
Melon	1-MCP	3-Feb	5	Ergun *et al*. (2007)
Apple	Ascorbic acid+citric acid+sodium hexametaphosphate	21	4	Pilizota and Sapers (2004)
Kiwifruit	Methyl jasmonate	21	10	Wang and Buta (2003)
Pineapple	Methyl jasmonate	12	7	Martinez-Ferrer and Harper (2005)

and vegetables with their shelf life were classified in Table 1. With regards to the data, it can be concluded that Methyl jasmonate may be a practical treatment to ensure the safety and the quality of fresh-cut fruits and vegetables if it is applied with low temperatures which most effective temperature with no chilling damage on fruits and vegetables is 5°C as obtained from literature review. This review has attempted to classify existing knowledge, highlighting effectiveness and differences between approaches to preserve quality of fresh-cut products and it is hoped that such a perspective will lead to use of the most effective method with less limitation on quality and safety of fresh-cut fruits and vegetables. All these approaches and coming technologies may offer improvements in the future. Future research developments will lead to improved scope of the fresh-cut program and hopefully reduce processing costs.

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