8 Minimal Processing
Fruits and Vegetables

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8.1 INTRODUCTION

Eating habits are diverse in different parts of the world; however, some aspects in the production and consumption of food are universal, such as the consumption of minimally processed vegetables. According to market research conducted by ACNielsen Global Services in 66 countries, representing over 75% of consumers in the world, the global demand for food ready for consumption, among which are minimally processed vegetables, increased by 4% between 2005 and 2006. During that same period, the growth in sales of fresh, ready-to-eat salads increased by 10%.

This increase is due in part to two key trends observed in this comprehensive study: a growing focus on health, which includes the consumption of fresh vegetables, and the increased preference for convenience. To the extent possible, consumers want healthy products for their meals, available at a good value, convenient, safe, and with good quality.

In the fresh produce industry, especially with fruits and vegetables, minimally processed products have been defined as “any fruit or vegetable, or any
combination thereof, which has been physically altered from its original form, but has remained in its fresh condition” (IFPA, 1999). However, the activities implemented to minimally process fresh produce can cause damage to plant tissues, which accumulate during the succeeding stages of processing. Thus, the damage to the products during this processing will adversely affect the shelf life for commercial distribution, which will be shorter compared to the same products that are not minimally processed.

The plant tissues of these minimally processed products, according to Brecht (1995), respond physiologically similar to being subjected to stress. The physiological responses by the plants due to the minimal processing can accelerate the loss of quality and modify sensory attributes unique to each product. The main changes in the products are increased metabolic activity, enzymatic browning, and presence of microorganisms and pathogens in the plant tissues that have been processed.

8.2 EFFECTS OF MINIMAL PROCESSING OF FRUITS AND VEGETABLES

8.2.1 ACCELERATION OF PLANT METABOLISM AND BROWNING

The physical damage accrued during minimal processing, especially with wounding, causes disruption of the cellular membrane, putting enzymes and their substrates in direct contact which accelerates the loss of quality. Among these reactions, the most important ones related to loss of quality are the increase in the respiration rate (RR), the production of ethylene (EE), total soluble phenolics and phenylalanine ammonia-lyase activity (PAL), peroxidase (POD), catalases (CATs), and polyphenol oxidase (PPO), among others. These physiological changes, resulting from minimal processing, as well as the implications for shelf life and quality of the processed products have been described in detail for various fruits and vegetables (Priepke et al., 1976; Rolle and Chism, 1987; Avena-Bustillos et al., 1993; Kim et al., 1994; Nicoli et al., 1994; Brecht, 1995; Ahvenainen, 1996; Wiley, 1997; Watada and Qi, 1999; Soliva-Fortuny and Martín-Belloso, 2003; Oms-Oliu et al., 2010).

The increases in RR and EE are physiological and biochemical effects that are inversely related to the shelf life of minimally processed products (Watada et al., 1990). Increases in respiratory activity have been reported by several authors in melon (Durigan and Sargent, 1999), pineapple (Sarzi et al., 2001b), papaya (Sarzi et al., 2001a), guava (Mattiuz et al., 2001), onion (Cassaro, 1999), and potato (Rolle and Chism, 1987).

The increase in EE from mechanical injury accelerates senescence in plant tissues (Abeles et al., 1992). Ethylene resulting from the physical action of minimally processing was sufficient to accelerate the loss of chlorophyll from spinach, but not in broccoli (Abe and Watada, 1991). In spinach, this is because the increase in chlorophyllase activity is directly related to increased synthesis of ethylene (Sabater and Rodriguez, 1978; Rodriguez et al., 1987; Watada et al., 1990; Yamauchi and Watada, 1991). Increases in ethylene production have also been reported, mainly
for climacteric fruits such as melon (Abeles et al., 1992; Durigan and Sargent, 1999), tomato (Brecht, 1995), banana, kiwi (Abe and Watada, 1991), and zucchini (Abeles et al., 1992).

During minimal processing, parts of the surface membrane systems in the plant are negatively affected upon being cut (Rolle and Chism, 1987), which occurs after a more extensive enzymatic degradation (Watada et al., 1990; Brecht, 1995). In plant tissues, the cellular compartmentalization provides better contact between the ethylene-generating systems (Watada et al., 1990) and also an increase in the synthesis and activity of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase, which culminates in the accumulation of acid ACC, a precursor of ethylene (Hyodo et al., 1985), in the plant tissues. In the presence of O$_2$, ACC can be rapidly oxidized to ethylene, a reaction catalyzed by the enzyme ACC oxidase (Abeles et al., 1992). The ethylene produced in these tissues accelerates the degradation of other cellular membranes, disrupting and destroying the plant tissues (Brecht, 1995).

Enzymatic browning in cut tissues occurs as a result of decompartmentalization substrates and oxidative enzymes, because the tissue experiences a larger exposure to oxygen (Rolle and Chism, 1987). The process of injury and the increase of EE induce increases in PAL activity, which catalyzes the biosynthesis of phenylpropanoids. Browning occurs when products of phenylpropanoid metabolism, such as phenols and possibly other substrates, are oxidized in reactions catalyzed by phenolases such as PPO and POD (Brecht, 1995). In minimally processed lettuce, increased levels of EE led to higher levels of oxidative browning, through the induction of PAL and PPO. In this trial, the browning started 3 days after processing, but the visual quality of lettuce was completely degraded 6 days after processing, during storage at 2.5°C (Couture et al., 1993).

Ethylene and the occurrence of injury induced PAL activity, but apparently by different mechanisms (Abeles et al., 1992). The use of ethylene absorbers, however, did not prevent the onset of browning (Howard and Griffin, 1993), demonstrating, in accordance with Watada and Qi (1999), that the reductions of TR and EE at low temperatures (Kim et al., 1993; Howard et al., 1994) associated with modified atmosphere (Barth et al., 1993; Nicoli et al., 1994) reduce the enzymatic metabolism of minimally processed products, thus slowing the development of these undesirable symptoms in the processed products. Moreover, this enzymatic metabolism responsible for the undesirable symptoms of browning can be reduced by antioxidants, as discussed in the following text.

### 8.2.2 Pathogenic and Degrading Microorganisms

The presence and activity of pathogens that can adversely affect the quality of minimally processed and packaged products is another critically important consideration in the processing and marketing chain. The exudates from the cut tissue are an excellent medium for the growth of fungi and bacteria, and the subsequent handling of the processed products creates the potential for the development of microorganisms (Burns, 1995). The occurrence of food-borne diseases (FBDs), due to pathogens in minimally processed products, increases the risk of food
poisoning due to the fact that in most cases these products are consumed without any subsequent heat treatment (Nguyen-The and Carlin, 1994). The development of microbial contaminants in minimally processed products can be controlled by pH (O’Connor-Shaw et al., 1994), by low temperatures (Bolin and Huxsoll, 1991), by modified atmosphere (Priepke et al., 1976; López-Malo et al., 1994), and by sanitation (Hurst, 1995).

The reports of human infections associated with minimally processed foods have heightened the concern of public health agencies and consumers (Vanetti, 2004). FBDs of a biological origin have increased significantly, even in developed countries (Feitosa et al., 2008). According to the World Trade Organization, the majority of FBDs occurring in Latin American countries are caused by eating food contaminated with pathogenic microorganisms; in Brazil, over 60% of these diseases are caused by *Salmonella* sp., *Staphylococcus aureus*, *Clostridium perfringens*, *Bacillus cereus*, and *Clostridium botulinum* (Feitosa et al., 2008). In most of these cases, the cause was the inadequate process of washing and sanitizing the surface of fruits and vegetables resulting in contamination of the edible part, either in consuming the fresh product without processing or after the processing (i.e., minimally processed). The reduction of microbiological risk from the consumption of contaminated fruit or vegetables, either raw or minimally processed, must be subject to procedures that reduce or, in the best case scenarios, eliminate the surface contamination (Yaun et al., 2004).

### 8.3 ALTERNATIVES FOR THE MANAGEMENT OF PLANT METABOLISM AND BROWNING

The increase in metabolic activity in minimally processed vegetables promotes rapid chemical and biochemical reactions responsible for changes in sensory quality (color, flavor, aroma, and texture) and the reduction of its life as a food (Cantwell, 1992; Luengo and Lana, 1997; Chitarra, 1999). The senescence process can be accelerated when the temperature and atmospheric compositions in the packages are outside of the desired levels.

#### 8.3.1 COOLING

Maintaining the cold chain at appropriate temperatures for each fresh product, from the processing to markets, is undoubtedly the most important technique available to slow the adverse effects of minimal processing; lowering the temperature reduces enzymatic processes, such as RT and EE (Wills et al., 1998), and thus slows the processes of senescence and increases the shelf life of minimally processed products. The drop in temperature, however, must be maintained at levels sufficient to keep the cells alive, but also to preserve product quality during storage and marketing.

With vegetables such as lettuce and chicory, after being cut, packaged, and stored at 4°C, the RT increased compared to control and intact leaves stored under the same conditions (Priepke et al., 1976). This response was also observed in minimally processed melons (McGlasson and Pratt, 1964), tomatoes (Lee et al., 1970), and kiwi (Watada et al., 1990).
8.3.2 MODIFIED ATMOSPHERE

Modified atmosphere can be defined as a packaging system designed to change the composition of normal air (78% nitrogen, 21% oxygen, 0.03% carbon dioxide, in addition to trace amounts of noble gases) in order to provide an internal atmosphere that facilitates an extended shelf life and maintain the quality of the fresh products in these conditions (Moleyar and Narasimham, 1994; Phillips, 1996).

Thus, the packaging material must have selective permeability to gases, allowing desirable changes to occur within the gaseous composition of the internal atmosphere. The concentrations of oxygen (O$_2$), carbon dioxide (CO$_2$), ethylene (C$_2$H$_4$), and water vapor are used to form packaging systems of modified atmosphere that are passive or active.

In the first case, the atmosphere is altered passively with respiration of the product in the packaging, either increasing the partial pressure of CO$_2$ or reduction of O$_2$ in the interior of the packaging until an atmospheric balance is reached. In this atmospheric balance, the CO$_2$ produced by respiration diffuses through the selective packaging into the environment at the same rate that the O$_2$ outside the packaging enters the packaging to compensate for the oxygen consumed during respiration. In the case of modified atmosphere, a gas mixture with defined concentrations of O$_2$ and CO$_2$ is injected into the package so that the atmospheric equilibrium is reached quickly. However, the concentrations at equilibrium will be maintained by the RR of the product and the level of permeability of the packaging to these gases.

With passive or active modified atmosphere, the reduction in O$_2$ partial pressure reduces respiratory metabolism (Wills et al., 1998) and ethylene production (Yang and Hoffman, 1984; Abeles et al., 1992). Moreover, the CO$_2$ accumulating inside the packaging acts as an inhibitor of respiration (Wills et al., 1998) and of ethylene action (Yang and Hoffman, 1984; Abeles et al., 1992). Thus, there is simultaneously the effect of reducing both respiration and ethylene production, coupled with lower activity of this hormone, dramatically increasing the marketing period of these products without the accelerated loss of quality (Saltveit, 1999). The atmosphere created inside the package can easily be transported with the product, ensuring that the increase in CO$_2$ concentration does not reach undesirable concentrations, nor that the reduction of O$_2$ concentration will facilitate anaerobic respiration.

Atmospheres with 5%–15% CO$_2$ and 2%–8% O$_2$ have been shown to be effective in maintaining the quality of minimally processed products; however, for each fresh product, there is a specific atmosphere that maximizes its shelf life (Cantwell, 1992).

Minimally processed collard green packaged in polyolefin plastic film with both passive and active modified atmosphere (0% O$_2$ + 5% CO$_2$) maintained vitamin C levels and good consumer acceptance for 12 days when stored at 10°C and then for 20 days at 5°C (Teles, 2001).

Minimally processed cantaloupe melons in packaging injected with 4% O$_2$ plus 10% CO$_2$ retained better color and reduced respiratory activity more effectively than passive modification of the atmosphere (Bai et al., 2001). This same product stored at 3°C, injected with 5% O$_2$ + 20% CO$_2$, was effective in controlling microbial activity,
and under these conditions, the melons maintained good quality for 12 days, while melons not packaged using modified atmosphere maintained good quality for only 6 days (Arruda et al., 2004).

Pineapples minimally processed and stored at 5°C with active modified atmosphere (2% O₂ + 10% CO₂ and 5% O₂ and 5% CO₂) using polyethylene plastic film laminated with polypropylene (PP) provided greater firmness compared to pineapples not stored in modified atmosphere (Prado et al., 2003). However, according to the authors, these gas compositions promoted the browning of pineapple tissues, stimulating the activity of PPO.

According to Kader (1995), the tolerances to low concentrations of O₂ and high CO₂ concentrations with minimally processed vegetables can vary considerably; very low partial pressures of O₂ and/or very high CO₂ can cause physiological damage in products such as anaerobic respiration. Lettuce quality, for example, is negatively affected from exposure to high levels of CO₂ (Ke and Saltveit, 1989). Cameron et al. (1995) argue that CO₂ concentrations above 2% can lead to browning of veins in lettuce; however, Ballantyne et al. (1988) found no change in color of lettuce for up to 20 days when placed in packaging with CO₂ concentrations above 10%. Pirovani et al. (1998) found that the visual quality of lettuce was better when packed in PP film and stored at 4°C at ambient concentrations of O₂ and 12% CO₂. The concentrations of CO₂ and O₂ reached on the eighth day were 1.5% O₂ and 12% CO₂, while in the other packages tested (polyethylene, polyolefin, and polyvinyl chloride [PVC]), the average internal concentrations of O₂ and CO₂ were 17% and 2%, respectively. Based on these studies, there is no consensus on the effect of different partial pressures of CO₂ and O₂ in terms of damage to the fresh-cut products. Thus, more detailed scientific studies should be conducted in this area.

In the selection of packaging used with modified atmosphere, the following characteristics should be considered: respiratory activity of the product, storage temperature, film permeability to gases, surface and film thickness, and the mass of the product being packaged. It is important to take into consideration that both respiratory activity and permeability of the film are sensitive to temperature changes and respond to these changes differently. It is expected then that the system (product + packaging) under modified atmosphere will maintain the desired atmospheric balance within a specified temperature range (Zagory, 2000).

8.3.3 Trends in Packaging for Minimally Processed Products

The use of packages made of plastic or polymer films is a common way to control the atmosphere around the product. In selecting the type of packaging to be used, it is important to take into consideration the characteristics of the products to be packaged, such as quantity, weight, use of clear packaging, and the biochemical composition as related to RR in a specified space according to the shelf life desired. This knowledge permits the practitioner to know whether they should use a packaging with low or high barriers to gas exchange, moisture, or light. In addition, the information related to importance of gas exchanges is important to know.

The plastic packages shaped in bags, pots, cups, and trays are the ones with easiest application and serve various functions, such as containing the product, being attractive to the consumer, and facilitating consumption. There are many
types of plastic materials available. The most common ones with their desirable properties are highlighted as follows:

- **Low-density polyethylene**: lower cost, high gas and water vapor permeability, and sturdy which allows the packaging to be used as bags to create layers for products to be stored in multilayers. These are also used for microperforated films to facilitate water vapor exchange.
- **Expanded polystyrene**: used in the manufacture of trays, often with a PVC coating, thinner film, elasticity, and with good weldability. Polystyrene can also be used to make pots.
- **PVC, PP, and polyethylene terephthalate (PET)**: used for production of trays with or without lids.

When you want to control the gaseous environment in the space between the product and packaging with the use of active modified atmosphere, there should be multilayered coextruded film, such as PP-nylon, PP-ethylene vinyl alcohol-PP, and polyvinyl vinylidene, among others. These materials have low permeability to gases, making it necessary to extract the air with a modest vacuum before injecting the desired gas mixture. Gorny (2001) lists the ideal concentrations of O\(_2\) and CO\(_2\) to be used in modified atmosphere systems for various minimally processed fruits and vegetables.

The use of low temperatures, associated with modified atmosphere during storage, reduces the elevation of respiration and ethylene synthesis in minimally processed vegetables such as lettuce (Singh et al., 1972a,b), broccoli (Barth et al., 1993), and melon (O’Connor-Shaw et al., 1994), and also in fruits such as apple (Kim et al., 1993; Nicoli et al., 1994), kiwi, pineapple, and papaya (O’Connor-Shaw et al., 1994).

Another system using active modified atmosphere is realized by creating a partial vacuum inside the package; this is especially recommended for roots and tubers. In this system, the film used should allow only low levels of permeability to gases, such as those found in nylon multilayer films (Durigan et al., 2007).

Moreover, there is interest to replace petroleum-based packaging materials with biodegradable materials, characterized by edible films, the purpose of which is to mimic the plant cuticle that can be removed during the stages of processing.

The most commonly used materials in these edible coatings are lipids (oil or paraffin wax, beeswax, carnauba wax, vegetable oil, mineral oil, etc.), polysaccharides (alginate, starch, cellulose, gums, pectin, chitosan, etc.), and proteins (casein, gelatin, collagen, albumin, etc.) (Cuq et al., 1995; Guilbert and Biquet, 1996; Cutter, 2006; Freire, 2008). The use of such coatings on minimally processed fruits and vegetables requires very specific considerations which depend on several factors, such as the ability to both protect and positively interact with processed product in terms of their sensory properties and functional stability of biochemical, physicochemical, and microbiological aspects (Vilas Boas et al., 2007).

Films made from polysaccharides, particularly starch, are those which currently have the greatest potential for use (Davis and Song, 2006). They have lower costs when compared to traditional films currently being used and are as such considered a low-cost technique. The films made with starches possess physical characteristics...
similar to synthetic polymers which allow transparent, odorless, flavorless, and a median permeability to CO$_2$, and low permeability to O$_2$. Studies on the production and use of edible films with starch incorporated with antimicrobial agents have been found to be effective in extending shelf life of minimally processed vegetables (Garcia et al., 2000; Durango et al., 2006). In minimally processed carrots, coating with starch (4%), associated with chitosan (0.5% and 1.5%), reduced the population of S. aureus and Escherichia coli at 2.56 and 4.18 log cycles, respectively (Durango et al., 2006). Minimally processed garlic coated with polymers of agar-agar, embedded with antimicrobial substances (acetic acid, chitosan, acetic acid + chitosan), had low counts of fungi and aerobic mesophiles (Geraldine et al., 2008).

The use of alginate as polymer matrix for edible coatings has also been studied in several minimally processed fruits; for example, the shelf life of apples was extended by 2 weeks when using alginate as a polymer matrix in the processing (Rojas-Graü et al., 2008). Alginites are linear polymers formed by residues of α-γ-gulurônico (G) and β-d-mannuronic (M) present in varying proportions and sequences in the cell wall and intercellular spaces of brown algae, such as Laminaria digitata and Macrocystis pyrifera (King, 1983). To produce the gel which is used in the film formation, the alginate must react with polyvalent cations, with calcium ions being the most effective gelling agents (Allen et al., 1963). Calcium ions play a critical role in keeping the alginate chains together through ionic interactions after the formation of hydrogen bonds between the chains, which produce a gel with a three-dimensional network structure (King, 1983).

There have been a number of studies implemented on the incorporation of antimicrobial agents in edible films. Some of these materials, such as essential oils and organic acids, have been evaluated for their effectiveness in controlling the quality and safety in food products. These combinations have been used in food packaging as active packaging, which provide direct interaction with the product. It is important that the use of these products be implemented in accordance with the various laws related to the use of antimicrobials in food. Minimally processed fruits using these formulations are emerging as alternatives to improve their quality and shelf life (Rojas-Graü et al., 2009). In minimally processed melon “Pele de Sapo,” Raybaudi-Massilia et al. (2008) studied the effect of malic acid and essential oils of cinnamon, palmarosa, and lemongrass incorporated into edible alginate films. The incorporation of essential oils in the film used in this study provided 21 days of shelf life due to the reduction in microbical activity. In terms of the sensory studies, the palmarosa had the highest acceptance by consumers.

The use of fruit purees can also be an alternative in the preparation of edible coatings for minimally processed fruit (McHugh et al., 1996; Senesi and McHugh, 2002). The use of fruit purees is related to the presence of biopolymers, especially polysaccharides such as starch, pectin, and cellulose derivatives in their structure (Kaya and Maskan, 2003). The edible coatings made from apple puree provided an excellent barrier to oxygen, but not to water vapor (McHugh et al., 1996). However, the addition of a hydrocolloid, such as alginate, improved the barrier properties of these coatings (Mancini and McHugh, 2000). Minimally processed apples (“golden”) with edible coatings showed less browning and less moisture loss and thus maintained the characteristic flavor and aroma for a longer time (McHugh and Senesi, 2000).
The films on minimally processed apples “Royal Gala” showed an average decrease of 38% in respiratory rates and more than 50% in ethylene production compared to the control, with alginate being the most effective fruit puree (Fontes et al., 2008).

Studies using mango puree to produce edible films showed that the coating reduced weight loss and slowed the ripening of mangoes in fresh and minimally processed mangoes; they had a longer shelf life under these experimental conditions (Sothornvit and Rodsamran, 2008). According to Azeredo et al. (2010), edible films made from fruit puree can combine the mechanical properties to increase shelf life along with the color and aroma from the pigments and volatile compounds of fruits.

### 8.4 ALTERNATIVES FOR MANAGEMENT OF MICROORGANISMS

The Food and Drug Administration (FDA, 2011), under the ruling 21 C.F.R. 173.315, has approved the use of sodium hypochlorite, chlorine dioxide, hydrogen peroxide, peracetic acid, and ozone as plant protection agents in the processing of fresh fruits and vegetables.

The use of chlorine, between 150 and 200 mg L\(^{-1}\), was sufficient to control fungi and bacteria in minimally processed cabbage (Fantuzzi, 1999; Silva, 2000) and collards (Carnelossi, 2000). In minimally processed carrots, the chlorine concentration (between 150 and 200 μL L\(^{-1}\)) is recommended based on type of processing (slices, cubes, sticks, or grated) (Silva, 2003). Lower residual chlorine concentrations, ranging from 5 to 20 mg L\(^{-1}\), were effective in controlling microorganisms in minimally processed pineapple and papaya (Sarzi, 2002), mango (Donadon et al., 2007), melon (Bastos et al., 2000), guava (Mattiuiz et al., 2003), and star fruit (Teixeira et al., 2007).

However, although chlorine is a potent disinfectant with strong oxidizing properties, studies have shown that it cannot completely oxidize organic materials, leading to the formation of unwanted by-products when in water, such as chloroform (CHCl\(_3\)) and other trihalomethanes, which are suspected carcinogens.

In alkaline pH, chlorine can also react with organic nitrogen bases to produce chloramine (NH\(_2\)Cl), which is a known carcinogen.

Chlorine dioxide (ClO\(_2\)) in aqueous solution has been postulated as an alternative to sodium hypochlorite (NaClO) for minimally processed products, with the advantage of avoiding the risks associated with the formation of trihalomethanes. Chlorine dioxide gas (ClO\(_2\)) can be produced commercially on-site by the reduction of sodium chlorate or by the oxidation of sodium chloride and chlorine gas (Cl\(_2\)) using expensive equipment which also requires trained personnel to operate and maintain (Andrade and Pinto, 2008). In this context, when the chlorine dioxide was used in the sanitization of minimally processed products, the formation of the trihalomethanes was negligible in minimally processed carrots (Klaiber et al., 2005), lettuce (López-Gálvez et al., 2009), and other commercially prepared salads (COT, 2006).

Hydrogen peroxide (oxygenated water) is characterized by containing a pair of oxygen atoms (–O–O), which are highly oxidative with the release of O\(_2\) in aqueous solutions and thus create antimicrobial activity, mainly for Gram-positive and Gram-negative bacteria (Andrade and Pinto, 2008). It is used in the formulation of sanitizer...
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solutions based on peracetic acid. The O$_2$ released is corrosive and requires care in handling and strict management of the active ingredient concentration.

Peracetic acid is known for its germicidal properties and therefore has been recommended as a potential substitute for chlorine, with the advantage of having good biodegradability (Andrade and Pinto, 1999). However, for some minimally processed fruits and vegetables, peracetic acid, when acidified in the medium, can induce a loss of selective permeability of cell membranes, causing cell decompartmentalization, with the consequent loss of tissue structure and the formation of undesirable flavor compounds (personal observation).

Ozone (O$_3$), which is highly volatile and toxic, has to be prepared on-site using expensive equipment that requires trained personnel for its operation. Inhalation of 20 ppm for 1 h or 50 ppm for 30 min can be fatal. However, the use of oxygenated water was found to be effective in reducing microbial populations and in controlling the physiological metabolism of minimally processed celery (Zhang et al., 2005) and cantaloupe (Selma et al., 2008).

Currently, one can say that there is a demand for alternative strategies in controlling microorganisms in postharvest practices. Such strategies consider the use of natural chemical compounds, generally classified as safe substances (GRAS substances), as reviewed by Oms-Oliu et al. (2010). There is a need for more research on more effective treatments with less chemical risk, such as electrolyzed water (Al-Haq and Sugiama, 2004; Abadias et al., 2008; Huang et al., 2008) and pulsating ultraviolet (UV) light (CFSAN-FDA, 2000).

Electrolyzed water is a chlorine-based disinfectant that provides a high efficiency of sanitization with low amount of free chlorine, so it is considered an environmentally friendly method for disinfecting minimally processed fruits and vegetables (Koide et al., 2009). Studies have shown that electrolyzed water destroys the transport of proteins within the cell membranes of fungi and bacteria, leading to the rupture of membranes and increased infiltration of the electrolyzed water. In fungi, the electrolyzed water induces oxidation of the cell walls and disrupts the metabolism of organic compounds; also the more resistant survival structures of fungi can be eliminated, depending on the concentration used (Huang et al., 2008). The electrolyzed water is considered more effective as a bactericide and fungicide than chlorine, because it penetrates more easily in the irregularities of the fruit surface (Al-Haq et al., 2005) and minimally processed vegetables such as celery (Zhang et al., 2005). Cut cabbage in slightly acidic water (pH 6.1 with 20 mg L$^{-1}$ available chlorine) was more effective in controlling microorganisms (aerobic bacteria, molds, and yeasts) than the hypochlorite solution containing 150 mg L$^{-1}$ of available chlorine, which is traditionally recommended (Koide et al., 2009).

Another technology used for surface decontamination of minimally processed fruits and vegetables is short-wave radiation in the UV region (Allende et al., 2006; Krishnamurthy et al., 2007). Radiation emitted between 200 and 280 nm (UV-C) induces the formation of breaks in DNA molecules, preventing reproduction and protein synthesis, resulting in a germicidal effect (Bintsis et al., 2000); this provides the advantage of not generating by-products or waste of chemicals capable of altering the sensory characteristics of the final product (Guerrero-Beltrán and Barbosa-Canovas, 2004). The UV-C can be applied continuously or pulsed. In the
continuous model, also known as conventional, the UV-C is applied continuously. In the case of the pulsed model, UV light, stored in a capacitor, is released in intermittent flashes, instantly increasing the energy intensity which makes the pulsed UV more effective and faster to inactivate microorganisms (CFSAN-FDA, 2000). This model presents an additional advantage compared to conventional methods, the flash that occurs every 300μs creates a large temperature gradient between the inner and outer parts of the cell which causes a disruption of the microorganisms membrane, further expanding the effect of the pulsed UV mechanism (McDonald et al., 2000). Several reviews of the applications of UV in the postharvest of fruit and vegetables can be found in Allende and Artes (2003), Smith et al. (2002), Yaun et al. (2004), and Geveke (2005).

The application of UV-C in minimally processed fruit causes an increase in the concentrations of antioxidants, polyphenols, and flavonoids (Alothman et al., 2009). Thus, according to these authors, in addition to its use for decontaminating the surfaces of minimally processed fruits, this new technology can be used to increase the beneficial compounds for consumer health.

In the future, it is expected that systems using electrolyzed water and pulsed UV will be used to guarantee the safety of minimally processed foods than the currently used chlorine-based compounds, but without changing the sensory properties and nutritional quality of these products.

GLOSSARY OF SPECIES

<table>
<thead>
<tr>
<th>Products</th>
<th>Species (Binomial Name)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>Malus domestica Borkh.</td>
</tr>
<tr>
<td>Banana</td>
<td>Musa spp.</td>
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<tr>
<td>Broccoli</td>
<td>Brassica oleracea L. var. italica group</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Brassica oleracea L. var. capitata</td>
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<tr>
<td>Carrot</td>
<td>Daucus carota L.</td>
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<tr>
<td>Celery</td>
<td>Apium graveolens L.</td>
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<td>Chicory, endive, escarole</td>
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<tr>
<td>Collard</td>
<td>Brassica oleracea L. var. acephala</td>
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<td>Garlic</td>
<td>Allium sativum L.</td>
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<td>Guava</td>
<td>Psidium guajava L.</td>
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<td>Kiwi</td>
<td>Actinidia deliciosa</td>
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<td>Lettuce</td>
<td>Lactuca sativa L.</td>
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<td>Mango</td>
<td>Mangifera indica L.</td>
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<td>Melon</td>
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<td>Allium cepa L.</td>
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<td>Papaya</td>
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<tr>
<td>Tomato</td>
<td>Lycopersicon esculentum Mill.</td>
</tr>
<tr>
<td>Zucchini</td>
<td>Cucurbita pepo</td>
</tr>
</tbody>
</table>
REFERENCES


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