Chapter 5

Technologies in Fresh-Cut Fruit and Vegetables

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5.1 Introduction

Fresh-cut fruit and vegetables (FCFV) consumption has increased significantly in recent years. Because of the changes in consumer lifestyles, there is an increased demand of fresh-cut foods, which are nutritious, functional, safe, attractive, and ready-to-eat. The consumers perceive these products as the most appealing, considering their attributes, such as fresh-like appearance, taste, flavor, and convenience (Garcia and Barrett 2002). However, FCFV products are very sensitive to spoilage and microbial contamination due to the processes used for its preparations (e.g. peeling, cutting, and grating). These processes caused mechanical injury to the plant tissues and promoted biochemical changes, microbial degradation, and the consequence is the loss of quality (Ayala-Zavala et al. 2009; González-Aguilar et al. 2010a; Rico et al. 2007). However, some alternatives are proposed in order to avoid biochemical problems due to mechanical injury (e.g. immersion therapy). Furthermore, several technologies are used to preserve the quality of fresh-cut produce, for example, ultraviolet light, controlled and modified atmospheres, edible coatings, heat treatments, and use of natural compounds (Fig. 5.1) (González-Aguilar et al. 2010a).

Most technologies/treatments involve the alteration of the natural conditions of the FCFV, extending their shelf life. For instance, irradiation, modified atmospheres, and high pressures, cause damage to vital molecules of food spoilage microorganisms

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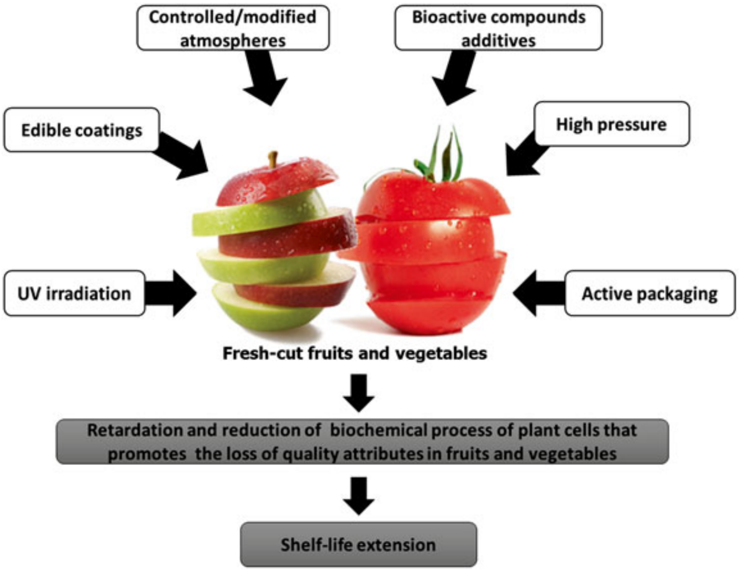

Fig. 5.1 Emerging and safe technologies to preserve quality of fresh-cut fruits and vegetables

(Charles et al. 2009; Kader et al. 1989; Norton and Sun 2008). Furthermore, edible coatings and active packaging are used to retard and reduce the biochemical process of plant cells that promotes the loss of quality. Nevertheless, some technologies used to preserve the quality of FCFV could induce some mechanisms that affect the metabolic activity of the treated produce, such as triggering of the antioxidant mechanism (González-Aguilar et al. 2010b). In addition, the innovative use of bioactive compounds as food additives could promote food's functionality as well as extend shelf life, enhance nutritional quality, and increase consumer's acceptance (Quirós-Sauceda et al. 2014; Rojas-Graü et al. 2009). This chapter describes the relevance of conventional and innovative technologies used to preserve the quality of FCFV products.

5.2 Fresh-Cut Produce: Their Biochemistry and Quality Parameters

Most of the current procedures and technologies applied in the fresh-cut industry are directed to manipulate fruit and vegetable biochemistry. For example, fruits can be divided into two groups according to their ripening mechanisms: climacteric and non-climacteric (White 2002). These differences in their biochemistry and ripening mechanisms result in different production of ethylene and respiration rates;

therefore, different storage conditions need to be maintained for preserving their quality attributes (Duque and Arrabaca 1999; Ku et al. 1999). Knowing the role of enzymatic systems during the ripening process of FCFV is essential to achieve its manipulation in order to enhance their quality parameters and shelf life (White 2002). Likewise, the complexity of produce metabolism and biochemistry is directly associated with the changes in their quality attributes. It is important to understand the ripening mechanism of the whole fresh produce in order to understand the possible changes that would occur in FCFV. For example, contemplating the effect of the respiratory process over the loss of firmness and texture of the whole produce could be useful to avoid these problems in FCFV; nevertheless, it has to be considered that the metabolic behavior of fresh produce could change after processing.

The ripening process requires large amount of energy and prolonged membrane integrity to perform catabolic and anabolic changes. In addition, the cell wall changes in terms of structure and composition, affecting firmness, metabolism of sugars and acids (flavor development), and biosynthesis of carotenoids and other pigments (color development) (Wakabayashi 2000; Merzlyak et al. 1999). Firmness is one of the most important quality attributes of FCFV, which depends on the strength and stability of cell wall. However, it is lost during the ripening process due to hydrolysis of cell wall polymers (Fischer and Bennett 1991). Considering that pectin is one of the major constituents of cell walls, its breakdown may affect cell adhesion and decrease tissue strength (Toivonen and Brummell 2008). On the other hand, other cell wall polymers are affected during the ripening process as stated by Gross and Sams (1984), these authors reported that in 15 of 17 different fruits, a total loss of non-cellulosic neutral sugars occurred during their ripening, being xylose the major neutral sugar loss. Similarly, in early stages of ripening occurred the depolymerization of xyloglucans of tomato, avocado, melon and kiwi fruit (Yakushiji et al. 2001). As stated before, this basic information can be used to reduce or delay the loss of this quality attribute in FCFV. This approach can be extrapolated to other quality parameters like appearance, texture, flavor, and nutritive value that are among the most important parameters contemplated for consumers preference (Lamikanra 2002; Kader 2002).

5.3 Impact of Processing Operations Over Fresh-Cut and Vegetables

Recently, FCFV have emerged as novel and healthy products, so that the fresh-cut industry is constantly growing, and needing to develop new technologies to reduce the undesirable effects of the processing, and preserve their fresh-like properties (Allende et al. 2006b; Soliva-Fortuny et al. 2002). Among the most common processing operations in fresh produce are the “minimal processing” technologies, which involves non-thermal methods (Manvell 1997). These are applied without

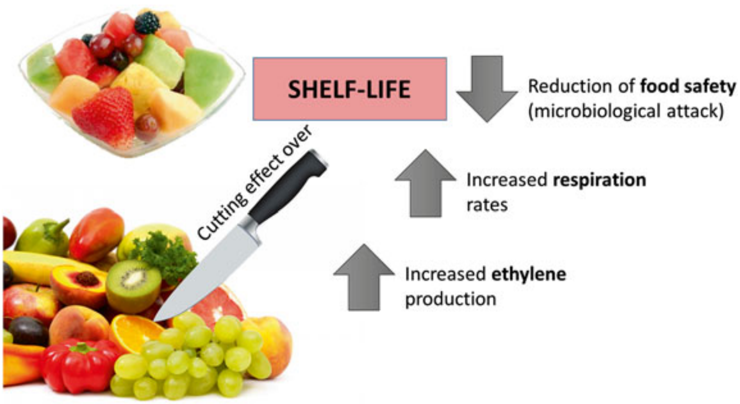

Fig. 5.2 Effect of cutting vegetable tissue over the shelf life of fresh-cut fruits and vegetables

compromising their fresh-like characteristics, and with minimal loss of color, flavor, and nutrients (Knorr et al. 2002). The replacement of the thermal technologies by the non-thermal ones is needed because in most cases, thermal energy induces various chemical reactions that lead to the quality deterioration in many foods (i.e. undesirable changes in sensory and nutritional qualities) (Ohlsson 1994). However, the minimal processing techniques such as peeling and cutting can also have a negative effect on the overall quality of FCFV; thus, reduces acceptability to the consumers due the promotion of a faster physiological deterioration, biochemical changes, and microbial degradation (Artés et al. 2007; Wiley 1994; Rolle and CHISM 1987).

Minimal processing of fruits and vegetables includes peeling, cutting, grating or trimming, and are used to obtain 100 % edible product. However, the minimal processing techniques eliminates the natural protective layer of fruits and vegetables, and promote many physical and physiological changes accelerating products decay (Fig. 5.2) (Gil and Allende 2012). In general, during minimal processing, the fruit and vegetable tissues are damaged, and many cells are broken, releasing intracellular products such as phytochemicals and enzymes (Baeza 2007; Allende et al. 2006b; Toivonen and DeEll 2002b). Nevertheless, the living tissues of FCFV need transform their stored biomolecules to maintain its "energized state" (Olarte et al. 2009). However, if respiration cannot supply enough energy to maintain its required energy state, the tissues will rapidly deteriorate and die (Olarte et al. 2009). Therefore, the loss of the "energized state" of FCFV results in loss of quality, and lower appeal to the consumers. Furthermore, on cutting or peeling of fresh produce, the outer periderm is removed and the resistance barrier to transpiration is lost, causing contamination of bacteria, yeast and moulds (Toivonen and DeEll 2002b; Allende et al. 2004; Lehto et al. 2011). Elevated respiration/transpiration rates and metabolic activities of spoilage microorganisms are the main reasons for shortened shelf life (Sinigaglia et al. 1999). In this sense, the effects of minimal processing over fruit ripening (i.e. ethylene and respiration), color changes, and food safety are discussed afterwards.

5.3.1 Ethylene Production

Ethylene (C_2H_4) is naturally produced by plants in the process of ripening of climacteric fruits; however, diseased or wounded tissue produces it in a higher levels (Yang and Oetiker 1994). The time line for the initiation of this response can range from a few minutes to an hour after wounds formation, and the maximal rates occur within 6–12 h (Toivonen and DeEll 2002a). The ethylene production is localized to tissues in the close vicinity of the wound or cutting injury. However, the response of wound tissue to ethylene production depends on the type and physiology of the tissue. For example, kiwifruit, tomatoes, winter squash, papaya and strawberry show increased ethylene production after cutting (Agar et al. 1999; Rivera-López et al. 2005; Watanabe et al. 2001; Steinite and Ievinsh 2002; Atta-Aly et al. 2000). However, cutting of pear (*Pyruscommunis* L.) not shown an increase, further, it has been found that cut pear slices have lower ethylene production as compared with whole fruit (Gorny et al. 2000; Toivonen and DeEll 2002a).

Different studies have shown that production of ethylene thru wounds in fruits is controlled by a coordinated expression of 1-aminocyclopropane-1-carboxyl acid synthase (ACCS) and ACC oxidase (ACCO) genes, the latter was revealed to have often a positive feedback control by ethylene (Druege 2006; Yu and Yang 1980; Hyodo 1991; Kato et al. 2000; Dong et al. 2001; Ayub et al. 1996). In addition, it has been reported that cutting induces ethylene production via induction by the same genes (Zheng et al. 2005). Moreover, the increase in ethylene production after damages by cutting and wounds is greater in pre-climacteric and climacteric than post-climacteric tissues. Furthermore, the ethylene production after cutting is void in non-climacteric fruits; however, this increases in climacteric fruits and may accelerate the fruit ripening (Brecht 1995). For example, the ethylene production in response to slicing in fruits like banana and cantaloupe depends on their maturity if the fruit is cut in pre or post-climacteric phase (Toivonen and DeEll 2002b; McGlasson 1969; Luna-Guzmán et al. 1999). Therefore, the maturity of the product must be considered before cutting and processing, especially for climacteric fruits.

Since ethylene production exerts its effects through metabolic reactions, the exposure of fruit tissue at their lowest recommended storage temperature will reduce the response (Woolf and Ferguson 2000). The storage temperature has an effect on wound induced ethylene production. It has been observed that storage of cantaloupe pieces at 0–25 °C completely suppressed wound-induced ethylene as compared to higher storage temperatures (Sangsuwan et al. 2008). Similar reduction in ethylene production from other fresh-cut fruits and vegetables could be expected at low post-cutting storage temperatures.

5.3.2 Respiration (Shelf Life)

Cutting operation in fresh-cut produce induces a series of complex events as a defense mechanism to repair the damage caused in the tissue (Sinigaglia et al. 1999). Besides the increased the ethylene production, respiration is one of the most common responses to the wounds, and it is considered as an important indicator of the product shelf life (Surjadinata and Cisneros Zevallos 2003). Increased rate of ethylene production in response to cutting may stimulate the respiration and leads to a faster senescence and deterioration of vegetative tissues (Fonseca et al. 2002). The rate of respiration increase in FCFV may range between 1.2 and 7.0, depending on the produce cutting grade and storage temperature (Ahvenainen 1996). The increased respiration after cutting is due to the energized state of all living tissues. Therefore, after cutting the tissues, the increased respiration provides energy and carbon skeletons for the anabolic reactions similar to ripening (Helena Gomes et al. 2010).

The visual appearance of FCFV has also been reported to be influenced by the increased respiration rate. This process results in a depletion of the carbohydrate reserve in fruits and vegetables. As the respiration rate increases, an uncontrolled increase in O_2 consumption occurs, which is often an indication of oxidative browning (Manvell 1997). These metabolic reactions use substrate carbohydrates involved in fruit organoleptic quality such as sugars and organic acids. Hence, as the organic acids are natural pH indicators involved in fruit color, their decay may lead to changed color (FAO 1995). Additionally, the increased respiration, can alter organic acids (i.e. sugar-to-acid ratio), and may result an insipid taste of the FCFV product (Manvell 1997). Some of the effects of the metabolic changes can be diminished by storing the FCFV product at their optimal storage temperature.

5.3.3 Color Changes (Visual Appeal)

The appearance of FCFV is a decisive factor for customer acceptance, and it strongly affects the decision to buy the product (Toivonen and Brummell 2008). After minimal processing of fresh produce, the metabolic reactions that stimulate respiration and/or ethylene production result in some undesirable effects (discoloration, texture changes, faster ripening, and senescence) that affect consumer acceptability (Gil and Allende 2012). Specifically, the browning and discoloration effects are the most common undesirable changes that affect the color and consequently affect the visual appearance of fresh produce (Toivonen and Brummell 2008).

As mentioned before, during minimal processing, fresh produce undergo to different types of stress with the initiation of some decay reactions. For example, the enzymatic browning in several FCFV starts with cellular disruption, causing the release of phenolic compounds stored within the vacuoles in cell wall compartments. Once oxygen penetrates the wounded tissue, the phenolic compounds are the substrate for the enzyme Polyphenol Oxidase (PPO) (Yoruk and Marshall 2003). The PPO in the presence of oxygen can catalyse two different reactions: the hydroxylation of monophenols and the oxidation of *o*-diphenolsto o-Quinones. Once the *o*-phenols are oxidized to o-Quinones a non-enzymatic polymerization of quinines occurs, leading to the formation of melanins that are pigments of high molecular mass and dark in color (Queiroz et al. 2008).

On the other hand, changes in color may also occur due to a loss of the natural pigments presents in the fruits and vegetable tissue. Chlorophyll (green color), carotenoids (yellow to red color), anthocyanins (red, purple or blue color) and other types of pigments (blue and red color), are commonly secondary metabolites produced during maturity process and when the plant tissue undergoes different types of stress (Basak et al. 1996; Crozier et al. 2008). Therefore, the loss of these compounds result in loss of fresh produce color, e.g. the green color discoloration of lettuce due to the enzymatic browning (i.e. chlorophyll loss) (Martín-Diana et al. 2007). Likewise, the changes in anthocyanins in fresh-cut strawberries are directly affected by their storage temperature. The improper storage conditions results in the loss of the natural red and purple colors of strawberries, reducing their market acceptability (Odriozola-Serrano et al. 2009). Therefore, appropriate storage conditions and correct techniques should be considered to inhibit the enzymes responsible for color changes in all FCFV products.

5.3.4 Microbiological Contamination (Food Safety)

The FCFV offer a number of advantages over the whole produce; however, the fresh-cut industry and the evolving processes used to maintain freshness face considerable challenges. Among the main problems are the high spoilage rates associated to the high metabolic activity and microbial contamination. The fresh-cut produce are full of juices and rich in nutrients, which promotes the microbial growth (Brecht 2006). When a whole fruit is cut or sliced, the layer protection afforded by the fruit skin is lost, leaving the fruit tissue susceptible to pathogens attack and water loss (Ayala-Zavala et al. 2008a). In addition, lack of sanitization or pre-harvest management of fruits, make them excellent carriers of pathogenic microorganisms that often lead to outbreaks of food borne illness (Joshi et al. 2013).

The risk of microbial contamination after cutting or wounding processes is higher than those of fresh/whole fruits and vegetables (Harris et al. 2003). This high risk resides in two major factors: the high water content and the wound caused to the tissues (Saranraj 2012). When tissues are wounded either by slicing, cutting or peeling, their release nutrients that attracts and enhance the microbial growth (including mesophilic bacteria, coliforms, yeast and moulds) (Olaimat and Holley 2012). Once the microorganisms grow in the FCFV surface they can form biofilms, and their elimination and disinfection become much more difficult (Wirtanen et al. 2001). The microbial biofilms are complex structures in which bacterial populations are enclosed in a cell matrix, forming aggregates by adhering to each other or to the food matrix (Costerton et al. 1995). However, the ability to attach, grow and spread to any surface within a biofilm is almost ubiquitous among bacteria (Van Houdt and Michiels 2010). The cells associated with the biofilms have advantages in growth and survival over planktonic cells. These advantages are due to the formation of exopolysaccharide (EPS) matrix, which surrounds the biofilm. The EPS matrix is a protective mechanism of bacteria against their environment, therefore, it protects the biofilm from sanitizers and supplies nutrients (James et al. 1995).

Nevertheless, the proliferation of biofilm formation by microorganisms on fresh-cut produce is currently retarded or inhibited by using antimicrobial substances as natural organic acids and plant essential oils (Rojas-Grau and Martin-Belloso 2008; Ayala-Zavala et al. 2008c, 2009; Senhaji et al. 2007; Viuda-Martos et al. 2008). Furthermore, some treatments are used in combination with these substances, such as surface treatments or dipping fruit pieces for edible coatings. In addition, in order to reduce microbial contamination and foodborne risks, packaging guidelines for minimally processed FCFV must be followed (Pasha et al. 2014).

5.4 Emerging Technologies in Preservation of Fresh-Cut Quality Parameters

FCFV are very susceptible to quality loss in terms of sensorial, microbial and nutritional parameters. As mentioned earlier, the major causes of quality loss are attributed to the processing operations (cutting, trimming or peeling), elevated ethylene production, and respiration rates (González-Aguilar et al. 2010a, b). Therefore, the maintenance of quality attributes of these products is a big challenge. Hence, some emerging technologies including UV irradiation, controlled atmosphere, pulsed electric field, high pressure, edible coatings, and active packaging have been suggested to preserve and improve the quality of FCFV (Table 5.1).

5.4.1 UV Irradiation

Ultraviolet light (UV) is a type of non-ionizing radiation with wavelengths from 100 to 400 nm. This is usually classified into three types: UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (100–280 nm). UV-C irradiation has its maximum at 254 nm and it has one of the highest germicidal action, and mostly used for surface decontamination, and controlling microorganism, thus preserve the quality in whole and FCFV products (Vicente et al. 2005; González-Aguilar et al. 2010a). It has been reported that low doses of UV-C irradiation stimulate beneficial reactions in biological systems, and this phenomenon is known as *hormesis*. These effects include delay of senescence and fruit ripening, induction of natural defenses and elicitors against fungi and bacteria (González-Aguilar et al. 2010b).

The induction of resistance against pathogens by irradiation of UV-C is correlated with the activation of the plant defense mechanism, and microbial DNA damage (González-Aguilar et al. 2007b). The treatment induces a stress that stimulates the production of phenylalanine ammonia-lyase (PAL), an enzyme that plays a key role in the synthesis of antifungal chemical species such as phytoalexins (scoparone and Resveratrol), flavonoids, and degrading fungal cell-wall enzymes (chitinases, glucanases) (Charles et al. 2009; El-Ghaouth et al. 1998). The stimulation of the plant defense system can also trigger the accumulation of these compounds and

Table 5.1 Use of emerging technologies in preservation of fresh-cut fruit and vegetables quality parameters

Type of fresh–cut product	Treatment conditions	Effect	References
UV irradiation			
"Tommy Atkins" mango	UV-C irradiation for 1 to 10 min at 5 °C	Chilling injury symptoms and deterioration was reduced. Antioxidant capacity was improved	González-Aguilar et al. (2007b)
Bell pepper	7 kJ m^{-2} UV-C light at 10 °C	Reduction of chilling injury incidence and severity	Vicente et al. (2005)
Watermelon cubes	4.1 kJ m^{-2} UV-C light	Reduction of microbial populations, keeping quality of the product	Fonseca and Rushing (2006)
	1.6 and 2.8 kJ m^{-2} UV-C light stored at 5 °C during 8 days		Artés-Hernández et al. (2010)
Melon	Cubes cut under 20 W/m^2 and exposed to 1,200 J/m^2 UV-C light and stored at 6 °C	2 log reduction for microbial counts, compared than untreated sample	Manzocco et al. (2011)
Peaches	UV-C irradiation (250–280 nm) for 3,5 and 10 min stored for 14 and 21 days at 5 °C	Significantly reduced chilling injury, increasing the resistance of fruit deterioration	González Aguilar et al. (2004)
"Haden" mango	UV-C irradiation energy levels of 2.46 and 4.93 kJ m^{-2} for 10 min and stored at 25 °C	Reduced the decay, improved the general appearance and reduced the number of fungal infections	González-Aguilar et al. (2007a)
Controlled/modified atmospheres			
Cantaloupe	Film-sealed containers flushed with 4 kPa O_2 plus 10 kPa CO_2 and stored at 5 °C	Shelf life of cubes for 9 days showing better color retention, reduced translucency, respiration rate and microbial population	Bai et al. (2001)
"Tommy Atkins" and "Kent" mango cubes	Mango cubes placed on a plastic screen and flushed with 4 kPa O_2 plus 10 kPa CO_2 (for "Tommy Atkins") and 2 kPa O_2 plus 10 kPa CO_2 (for "Kent"), then were stored at 10 °C	The marketable period was extended by 1–2 days	Rattanapanone et al. (2001)

(continued)

Table 5.1 (continued)

Type of fresh–cut product	Treatment conditions	Effect	References
Watercress	Samples placed in plastic container in a humidified atmosphere (nitrogen argon, helium, nitric dioxide and air) for 13 days at 5 °C	The respiratory rate and microbial growth was reduced up to 3 days of storage and no significant effects were observed on C_2H_4 production	Silveira et al. (2014)
Apple slices	Slices were dipped in calcium ascorbate (6 or 12 %) and stored under vacuum for 28 days at 4 °C	Significant improvement in quality as measured by sensory, chemical and visual properties. The shelf life was of 21–28 days	Aguayo et al. (2010)
High pressure			
Cut apple	High pressure (150 MPa) flushed with argon and stored at 4 °C for 2 weeks	Respiration rate and ethylene production were lower; also, the browning and microbial growth were delay	Wu et al. (2012b)
Carrots	High pressure carbon dioxide (5 MPa) at 20 °C for 20 min	1.86 $\log_{10}$ cycle reduction for aerobic bacteria and 1.25 for yeasts and molds were achieved	Bi et al. (2011)
Pineapple	Combination of pressure-time of high pressure argon treatment at 1.8 MPa for 60 min and stored at 4 °C for 20 days	Delayed the microbial growth and shelf life extension of 6 days was achieved during cold storage	Wu et al. (2012a)
Avocado slices	> 300 MPa at 20 °C for 17 h	Reduction of respiration rates and ethylene production 1 h after treatment. Also, some peroxidase activity reduction	Woolf et al. (2013)
Edible coatings			
Apple slices	Apples slices coated with alginate-apple puree edible coatings with the addition of lemongrass, oregano oil and vanillin and stored for 21 days at 4 °C	Reduction in the rates of O_2 depletion and CO_2 production. Inhibition of the growth of psychrophilic aerobes yeasts and molds	Rojas-Graü et al. (2007)

(continued)

Table 5.1 (continued)

Type of fresh–cut product	Treatment conditions	Effect	References
Melon	Slices coated with alginate, pectin and gellan-based during 15 days at 4 °C	Increased water vapor resistance, preventing dehydration. Also, an inhibitory effect on ethylene production and a reduced of the wounding stress	Oms-Oliu et al. (2008b)
Pear	Alginate-based, pectin-based and gellan-based edible coatings containing *N*-acetylcysteine at 0.75 % (w/v) and glutathione at 0.75 % (w/v) stored for 14 days at 4 °C	Increased water vapor resistance and reduced ethylene production. The incorporation of additives reduced microbial growth and browning for 2 weeks without affecting firmness	Oms-Oliu et al. (2008a)
"Kent" mango	Samples coated with alginate-based edible coating as carrier of ascorbic and citric acid and stored at 4 °C	Maintained higher color values of fresh-cut fruit and increased the antioxidant potential	Robles-Sánchez et al. (2013)
Mango	Mucilage-oil coating in fresh-cut mango slices during 9 days at 6 °C	Treatment retards loss of ascorbic acid and the drop in sensory acceptability, fewer changes in color and decreases activity POD enzyme. Also, inhibited the decay incidence and slowed microbial growth	Alikhani (2014)
Active packaging			
Strawberry	Samples were packed with low-dose of chlorine dioxide (5 ppm) sachets for 3 weeks at 4 °C	Titratable acidity retention and maintaining brightness values	Aday and Caner (2011)
Tomato	Tomato slices were packaged with garlic oil capsule sachets and exposed to 100 % humidity during 5 weeks at 5 °C	The release of garlic oil from capsules reduced microbial growth and preserved sensory quality	Ayala-Zavala et al. (2010)
Spinach	Allylisothiocyanate vapor was encapsulated in calcium alginate and used as packaging system on spinach leaves at 25 °C	Antimicrobial effects against Escherichia coli O157:H7 and molds and yeasts	Seo et al. (2012)

other phytochemicals such as carotenoids and vitamin C, which exhibit antioxidant potential, and improve the nutritional status of the products (González-Aguilar et al. 2007a, b). However, in addition to the above physiological effects produced by UV-C irradiation, there is also damage to the microbial DNA.

Several studies have been published on UV-C as a method to preserve the quality of different FCFV. Pre-storage application of UV-C reduced chilling injury in pepper (Vicente et al. 2005), delayed senescence yellowing, chlorophyll degradation, and pheophytin accumulation in broccoli (Costa et al. 2006). Likewise, its application can control the storage rot in strawberry, reduced pathogen growth and induced disease resistance in other fresh produce (Rivera-Pastrana et al. 2013; Bu et al. 2013; Bonomelli et al. 2004). Chilling injury symptoms and deterioration of "Tommy Atkins" mangoes were reduced by UV-C irradiation during storage at 5 °C (González-Aguilar et al. 2007b). In addition, the effect of short UV-C doses (0.4–8.14 kJ m^{-2}) over the shelf life of the processed lettuce was studied (Allende et al. 2006a). UV-C effectively delays the senescence and deterioration of fresh-processed lettuce during storage (Allende et al. 2004, 2006a).

5.4.2 Controlled/Modified Atmospheres

Some of the technologies used to preserve the quality of the FCFV are the controlled and modified atmospheres (CA/MA), and their beneficial effects have been well documented (Yahia 2010). CA/MA is a passive or active dynamic process that consists in altering the gases surrounding a commodity to produce a composition different from that of air. This is achieved by the interaction between two processes; the respiration rate of the fresh-cut product and the transfer of gases through the packing material (Caleb et al. 2012). Low levels of O_2 and high levels of CO_2 reduce respiration rates and help to delay senescence, thus extends the storage life and maintain nutritional and sensory quality of the fresh-cut produce (Yahia 2010; González-Aguilar et al. 2010b).

Passive CA/MA can be generated inside a package by relying on the natural respiration of produce and film permeability to attain the desired gas composition over time (Charles et al. 2003). While, active CA/MA implies a rapid process of gas replacement or displacement, or the use of gas scavengers or absorbers to establish a desired gas mixture within a package. This involves the addition of active agents into a packaged food product, such as O_2, CO_2 and ethylene scavengers (Kader et al. 1989). Once the package is closed, no further control on the gas composition is required, and the composition will inevitably change due to FCFV respiration and film gas permeability. However, the positive effects of CA/MA depend on several factors such as type of FCFV, concentrations of gases, temperature, and duration of storage (González-Aguilar et al. 2010b). Extremely low levels of O_2 and high CO_2 favors fermentative processes, which might cause the formation of acetaldehyde and the occurrence of off-flavor compounds (Thompson 2010).

Therefore, the atmospheric concentrations recommended for preservation depend on the products. In general, FCFV are more tolerant to higher CO_2 concentrations than intact products, because of the smaller diffusion resistance.

5.4.3 High Pressure Processing

High pressure processing (HPP) is a method that has shown great potential in the preservation of FCFV industry. HPP at refrigeration, ambient or moderate heating temperature allows inactivation of pathogenic and spoilage microorganism, and it can play a key role in the extending of the shelf life of fresh-cut produces (Norton and Sun 2008). In addition, HPP has been considered as an alternative for inactivation of enzymes, such as polyphenols oxidases (PPO) (Garcia and Barrett 2002). An important advantage of this technology is that HPP acts uniformly throughout a food, regardless of size, shape and geometry, and also has minimal effects on the taste, flavor, texture, appearance, and nutritional values of food (Norton and Sun 2008; Manas and Pagán 2005).

In general, microbial inactivation provided by HPP mainly targets cell membranes of treated cells, but in some cases, additional damages occur, such as extensive solute loss during pressure treatment, protein denaturation and key enzyme inactivation (Manas and Pagán 2005; Norton and Sun 2008). Nevertheless, an effective preservation has been reported from combinations of HPP with other processing techniques, such as pH, pulsed electric fields and with CO_2 (Raso and Barbosa-Cánovas 2003). Furthermore, when used in conjunction with mild thermal processes, HPP has been found to significantly increase the inactivation of bacterial spores.

5.4.4 Edible Coatings

Edible coatings have been used in the fresh-cut industry as an emerging technology to reduce the deleterious effects that minimal processing imposes on intact fruit and vegetable tissues. An edible coating is defined as a thin layer of edible material applied to the surface of food products to extend its shelf life, by reducing moisture and solute migration, gas exchange, respiration, and oxidative rates, as well as by reducing or even suppressing physiological disorders (Quirós-Sauceda et al. 2014; Kester and Fennema 1986). Compounds most commonly used to form edible coatings include chitosan, starch, cellulose, alginate, carrageenan, zein, gluten, whey, carnauba, beeswax and fatty acids (González-Aguilar et al. 2010a). Coatings with selective permeability to gases are capable of decreasing the interchange of O_2 and CO_2 between coated FCFV and the environment, thereby, slowing down the metabolic activity by decreasing the internal O_2 concentration and increasing CO_2 concentration (Olivas and Barbosa-Cánovas 2005). Therefore, in fresh-cut produce, edible coatings decrease respiration and senescence while protecting aroma, texture and color throughout the storage (González-Aguilar et al. 2010a). However, although reduction of gas transfer from the product to the environment is desirable, extremely impermeable coatings may induce anaerobic conditions that can lead to a decrease in the production of characteristic aroma and volatile compounds (Olivas and Barbosa-Cánovas 2005).

Nevertheless, the use of the edible coatings can have more innovative uses beyond their current applications. Edible coatings can be utilized as encapsulating matrices of many bioactive compounds to improve the quality of FCFV. This could allow a controlled release of bioactive compounds so they could be available at a desired time with a specific rate (Quirós-Sauceda et al. 2014; Rojas-Graü et al. 2009). The most common bioactive compounds incorporated to coatings are antioxidants, antimicrobials, flavors and probiotics. This application is an interesting tool to extend shelf life, and to reduce the risk of pathogen growth on food surfaces, thus it could provide a functional product with health benefits (Rojas-Graü et al. 2009). In addition, the encapsulation of bioactive compounds into edible coatings can protect these additives against diverse environmental factors.

5.4.5 Active Packaging

Active packaging plays an additional role in maintaining the quality and safety of fresh-cut produce as compared to the traditional packaging. The active packaging systems are specifically designed to control product's deteriorative reactions, and to maintain the nutritional, and sensory qualities of foods. This method use active ingredients in the packaging material or the headspace (Ayala-Zavala et al. 2008b; Ozdemir and Floros 2004). In general, an active packaging is defined as an intelligent or smart system that involves interactions between package or components inside of an internal gas atmosphere (Ozdemir and Floros 2004; Floros et al. 1997). Important examples of active ingredients include oxygen scavengers, carbon dioxide emitter/absorbers, moisture absorbers, ethylene absorbers, ethanol emitters, flavor releasing/absorbing systems, time-temperature indicators, and antimicrobial films. Besides the incorporation of individual agents, the active packaging system could be more sophisticated, and have a multifunctional active system with the addition of two or more active ingredients (Ozdemir and Floros 2004). The migration of the active compounds may be achieved by direct contact between food and the packaging material or through gas phase diffusion from the inner packaging layer to the food surface (Mehyar and Han 2011).

Currently, most active packaging technologies for fruits and vegetables depend on sachet technology, which contains the active ingredients inside small bags placed in the food package (Mehyar and Han 2011). However, sachets have low consumer acceptance due to possible accidental ingestion of their contents. In addition, the high moisture content and high transpiration rate of FCFV may lead to the dissolution of the hydrophilic toxic sachet contents. Therefore, active film/container is more appropriate for FCFV products (Kerry and Butler 2008).

5.5 Bioactive Compounds as Additives to Extend Shelf Life

As discussed earlier fresh-cut produce are spoiled easier than the raw product. In brief, there are two major issues to be considered in order to extend their shelf life; first is the visual appearance, and second is their safety. So far, we have mentioned some of the most common changes in FCFV products once fresh produce undergo stress by the minimal processing techniques, and emerging technologies applied in FCFV to diminish those changes. Recently, novel technologies applied in the food industry involve the use of natural compounds with bioactive properties. This enhances the shelf life by protecting the FCFV products from microbial contamination. In this context, several research projects have asserted that phytochemicals could enhance or extend the shelf life of FCFV products (Schieber et al. 2001; Wijngaard et al. 2009, 2012).

Different organic acids such as citric acid, lactic acid, and ascorbic acid are usually applied as a dip. These are strong antimicrobial agents against psychrophilic and mesophilic microorganisms in fresh produce (Uyttendaele et al. 2004; Bari et al. 2005). Likewise, some natural bioactive compounds, such as ascorbic acid, N-acetylcysteine and 4-hexylresorcinol, are used in order to protect the color of FCFV products (Rojas-Graü et al. 2006; González-Aguilar et al. 2001). However, the most common bioactive compounds with proven efficacy are volatile compounds, essential oils, and phenolic compounds (Fig. 5.3) (Ayala-Zavala et al. 2011). These compounds extend the shelf life of FCFV as well as provide health benefits (Ayala-Zavala et al. 2008b, d; González-Aguilar et al. 2010a).

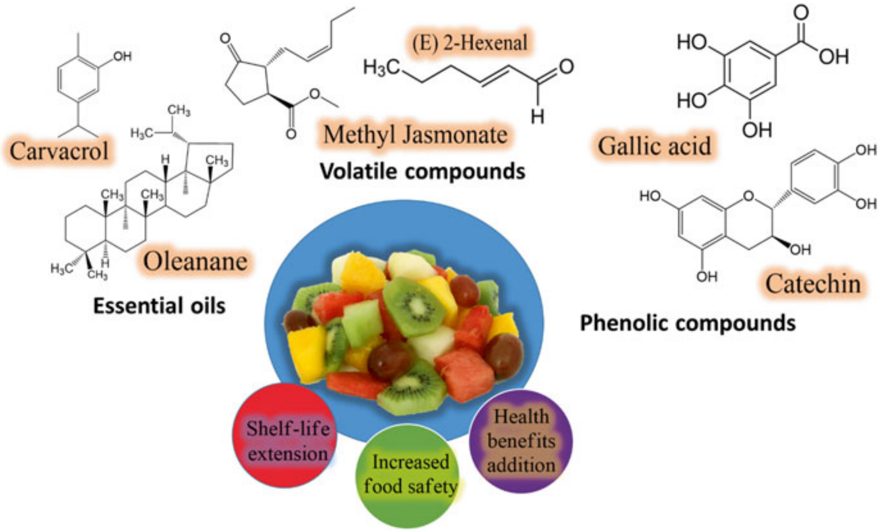

Fig. 5.3 Benefits in application of the most common bioactive compounds as additives in fresh-cut products

5.5.1 Volatile Compounds

Volatiles are low molecular weight organic compounds (less 250 g/Mol) with high vapor pressure at room temperature (Hewett et al. 1998). Plants produce a wide range of volatile compounds, some are important for flavor quality in fruits, vegetables, spices, and herbs, and are generally recognized as safe (GRAS) (Kays 1991). The volatile and semi-volatile compounds in plant constituents play important roles in the plant growth, such as plant-plant competition and cooperative co-evolution, plant's defense against insects, pests, herbivores and pathogens (Yang et al. 2013). Some studies have shown that the exposure of some fresh-cut products to volatile compounds, such as methyl jasmonate, can significantly reduce the risk of microbial contamination (Wang and Buta 2003; González-Aguilar et al. 2010b). Additionally, these volatile compounds also reduce the browning effects after cutting the tissues of fresh produce, and prevents the damage by chilling injury (Wang and Buta 2003).

Moreover, it has been shown that the application (E) 2-hexanal prevents microbial contamination of the FCFV products, especially against *Botrytis cinerea* and *Aspergillus flavus* (Gardini et al. 2001; Fallik et al. 1998). Likewise, the compounds released by plant tissue through lipoxygenase pathway, such as six carbon aldehydes, have been found to inhibit hyphal growth of *Alternaria alternate* and *B. cinerea* (González-Aguilar et al. 2010b). Furthermore, volatiles compounds such as jasmonates have been used as elicitors as they play key roles as signal molecules in plant defense responses against biotic stress (microbial contamination). These also induce the synthesis of antioxidants such as vitamin C and phenolic compounds (Solis et al. 2004).

5.5.2 Essential Oils

The most studied bioactive compounds applied to fresh-cut products are essential oils (EOs). These are volatile and natural complex compounds characterized by a strong odor, and are formed by aromatic plants as a secondary metabolites (Bakkali et al. 2008). EOs represent the most important aromatic fraction of plant and vegetal tissues. These compounds are constituted by a complex mixture of terpenes, alcohols, ketones, aldehydes and esters. The most common constituents within EO are terpenes. They are made from combinations of several 5-carbon-base (C5) units called isoprene. Terpenes or terpenoids are active against bacteria, fungi, virus, and protozoa (Scortichini and Rossi 1991; Inoue et al. 2004; Dalleau et al. 2008; Solis et al. 2004; Herman 1992). It was reported that 60 % of EOs derivatives examined to date were inhibitory to fungi, while 30 % inhibited bacteria (Chaurasia and Vyas 1977).

However, the mechanisms of antimicrobial activity are not fully elucidated. The general accepted hypothesis establishes that the components of EOs acts in several targets of the bacterial cell. For example, the hydrophobicity of EOs enables them to partition in the lipids of the cell membrane and mitochondria, rendering them permeable and leading to leakage of cell contents (Cox et al. 2000). Physico-chemical conditions that improve the action of EOs are low pH, low temperature, and low oxygen levels (Burt 2004). However, EO's treatments can affect the aroma and sensory properties of the fresh-cut product. EO of citrus fruits such as mandarin, cider, and lime preserved the quality of fresh-cut fruit and salads without affecting consumer acceptance (Lanciotti et al. 2004). Therefore, the addition of these bioactive compounds to FCFV products represents an excellent choice to extend their shelf life and consumer acceptance.

5.5.3 Phenolic Compounds

Phenolic compounds comprise a wide and diverse group of molecules classified as secondary metabolites in plants. These compounds have a large range of structures and functions (Haminiuk et al. 2012). Phenolic compounds are considered as important plant secondary metabolites due to their abundance and beneficial properties. These substances are synthesized during the normal development of the plant and once the plant tissue undergoes diverse types of stress, their synthesis is triggered (Naczk and Shahidi 2004). More than 8,000 different phenolic compounds have been identified in 16 different classes with diverse chemical structures and molecular weight (Velderrain-Rodríguez et al. 2014). Among those different classes of phenolic compounds, phenolic acids and flavonoids are the most studied as food additives.

The flavonoids have been identified as an excellent food additive capable of ensure food safety by preventing the microbial attack in FCFV (Weidenbörner et al. 1990). It has been shown that flavonoids can protect fresh produce against spoilage fungi, such as *Fusarium oxysporum* (banana and grape), *Aspergillus japonicus* (pokhara and apricot), *Aspergillus oryzae*(orange), *Aspergillus awamori* (lemon), *Aspergillus phoenicis* (tomato), *Aspergillus tubingensis* (peach), *Aspergillus niger* (apple), *Aspergillus flavus* (mango), *Aspergillus foetidus* (kiwi) and *Rhizopus stolonifer* (date) (Sharma and Kumar 2009; Wanchaitanawong et al. 2005; Al-Hindi et al. 2011). The phenolic compounds have also the ability to interfere with cellular metabolic activity. The most common proposed mechanisms include substrate complex formation, membrane disruption, enzyme inactivation and metal chelation (Holley and Patel 2005). However, due to their proven antimicrobial activity, these compounds have been recently applied as food additives within diverse matrixes, such as edible coatings.

The phenolic compounds as applied in meat products. For example, tea catechins were found to be more efficient than α-tocopherol (both applied at 300 mg/kg level) in the inhibition of minced muscle lipid oxidation in fresh meats, poultry and fish. However, the changes in color of FCFV can be prevented using phenolic compounds. As well as other non-phenolic compounds (i.e. citric and malic acid), some phenolic compounds such as phenolic acids and anthocyanins are capable of lower the pH of a system. This can reduce the browning produced by the PPO activity

(Ayala-Zavala et al. 2011; Williams and Hrazdina 1979). Moreover, anthocyanins are applied as colorants in food products (Stintzing and Carle 2004). Furthermore, the information about phenolic compounds are in abundance, thus it makes them more attractive as food additives (Schieber et al. 2001; Wijngaard et al. 2012; Ayala-Zavala et al. 2010; Joana Gil-Chávez et al. 2013). Hence, the fresh-cut industry could prevent several economic losses by extracting phenolic compounds from different by-products, such as peels, seeds, and unused flesh.

5.6 Conclusion

The consumer awareness about the healthy diet and its benefits has increased the demand of FCFV. However, the minimal processing applied to fresh-cut produce accelerates the ripening processes and renders them susceptible to microbial contamination, resulting in a short shelf life. Recently, some studies have been focused on reducing the undesirable effects of minimal processing such as cutting or peeling on the quality of FCFV. The elucidation of the mechanisms that lead fruits and vegetables to spoilage once they are subjected to minimal processing, enables the fresh-cut industry to develop and apply efficient methods to extend shelf life to preserve the quality of the products, and hence, the consumers acceptance. Emerging technologies such as UV irradiation, controlled atmospheres, high-pressure processing, edible coatings, and active packaging are applied to diminish the undesirable effects of minimal processing, thereby keeping the quality of fresh-cut produce for a longer period. Likewise, natural bioactive compounds such as fruit and vegetable phytochemicals, besides extending the shelf life and provide diverse health benefits, could prevent microbial spoilage of FCFV.

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