Review

Minimal processing for healthy traditional foods

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The industry of fresh-cut fruits and vegetables is constantly growing due to consumers demand. New techniques for maintaining quality and inhibiting undesired microbial growth are demanded in all the steps of the production and distribution chain. In this review, we summarize some of the new processing and preservation techniques that are available in the fresh-cut industry. The combination of sanitizers with other intervention methods is discussed. The use of ultraviolet-C, modified-atmospheres, heat shocks and ozone treatments, alone or in different combinations have proved useful in controlling microbial growth and maintaining quality during storage of fresh-cut produce. In addition, combinations of physical and chemical treatments are also reviewed. The use of acidic or alkaline electrolyzed water (AcEW), chlorine dioxide, power ultrasound and bacteriocins and the potential applications to the fresh-cut products industry to control human microbial pathogens are presented.

Introduction

There is a general trend to increase fresh fruit and vegetable consumption mainly due to their health properties (Huxley, Lean, Crozier, John, & Neil, 2004). Different organizations (WHO, FAO, USDA, EFSA) recommend the increasing fruit and vegetable consumption to decrease the risk of cardiovascular diseases and cancer. The fresh-cut fruit and vegetable industry is constantly growing mainly due to the consumer’s tendency of health consciousness and their increasing interest in the role of food for maintaining and improving human well-being (Gilbert, 2000; Ragaert, Verbeke, Devlieghere, & Debevere, 2004). In fact, fruits and vegetables are basic ingredients of the highly demanded Mediterranean diet, associated with a beneficial and healthy function against numerous diseases (Flood et al., 2002; IFIC, 2001). This beneficial effect has been attributed to non-essential food constituents, phytonutrients, that pose a relevant bioactivity when frequently consumed as a part of regular diet (Steinmetz & Potter, 1996). This also corresponds to one of the traditional claims in proper dietary habits which aims for an increasing intake of fruits and vegetables (Liu et al., 2000). However, it is well-known that modern ways of life usually trend to a reduction of suitable intake of rich sources of antioxidant compounds, such as fruit and vegetables, being more emphasized in some parts of the population, especially children. It is known that a food which meets nutritional requirements is unlikely to be accepted by consumers if they do not like the flavor or other quality attributes (Da Costa, Deliza, Rosenthal, Hedderley, & Frewer, 2000). Additionally, it has been shown that consumer’s needs for convenience are correlated with food choice (Ragaert et al., 2004; Verlegh & Candel, 1999). Therefore, the fresh-cut fruit and vegetable industry is still working to increase the assortment of minimally processed vegetable products that meets consumer’s needs for ‘quick’ and convenient products that preserve their nutritional value, retain a natural and fresh color, flavor and texture, and contain fewer additives such as preservatives (Jongen, 2002). Fresh-cut fruits and vegetables emerged to fulfill new consumer’s demands of healthy, palatable and easy to prepare plant foods. ‘Minimal processing’ describes non-thermal technologies to process food in a manner to guarantee the food safety and preservation as well as to maintain as much as possible the fresh-like characteristics of fruits and vegetables (Manvell, 1997). Among others, visual properties of fresh-cut fruit and vegetable commodities are one of the most important...
Preservation techniques

During minimal processing (including peeling, cutting and grating operations), many cells are broken and intracellular products, such as oxidizing enzymes, are released (Laurila & Ahvenainen, 2002), accelerating the decay of the product. Additionally, the cut surfaces of any processed vegetable support better microbial growth. In fact, each step in the processing affects quality and microflora of fresh-cut fruit and vegetables. For these reasons, the cutting and shredding must be performed with knives or blades as sharp as possible made from stainless steel. However, many different solutions have been tested to avoid the acceleration of decay due to peeling, cutting or slicing. The newest tendency is called the immersion therapy (AR-USDA, 2005). Cutting a fruit while it is submerged in water will control turgor pressure, due to the formation of a water barrier that prevents movement of fruit fluids while the product is being cut. Additionally, the watery environment also helps to flush potentially damaging enzymes away from plant tissues. On the other hand, UV-C light has been also used while cutting fruit to cause a hypersensitive defense response to take place within its tissues, reducing browning and injury of in fresh-cut products (Lamikanra & Bett-Garber, 2005). Another alternative could be the use of water-jet cutting, a non-contact cutting method which utilizes a concentrated stream of high-pressure water to cut through a wide range of foodstuffs (Ingersoll Rand Ltd).

However, the main steps throughout the processing chain of minimal processing fruits and vegetables are washing and disinfection. For this reason, guidelines for packing fresh or minimally processed fruits and vegetables generally specify a washing or sanitizing step to remove dirt, pesticide residues, and microorganisms responsible for quality loss and decay (Sapers, 2003). The current published data suggests that any of the available washing and sanitizing methods, including some of the newest sanitizing agents such as chlorine dioxide, ozone, and peroxyacetic acid, were not capable of reducing microbial population by more than 90 or 99% (Beuchat, Adler, Clavero, & Nail, 1998; Brackett, 1999; Sapers, 2003). Additionally, different washing and disinfection treatments may negatively affect the nutritional and sensory quality of the product (Laurila & Ahvenainen, 2002). However, little is known about nutritive value content of minimally processed produce (Beltrán, Selma, Marín, & Gil, 2005; Qiang, Demirkol, Erkal, & Adams, in press). On the other hand, in the search for effective disinfectant treatments for wash water sanitation, the postharvest handling industry often operates within areas of regulatory uncertainty. For applications to whole or peeled produce, handlers and processors may be assuming that these materials have an approved Generally Regarded as Safe (GRAS) status. Therefore, washing and disinfection of the produce before preparation or consumption is recommended but does not guarantee that fresh produce is pathogen free (Gorny & Zagory, 2002).

On the other hand, the potential of MAP to extend shelf-life for many foods is well documented (Brecht et al., 2003; Jacxsens, Devlieghere, & Debevere, 2001; Saltveit, 2003). It is known that beneficial modified atmospheres within fresh-cut produce packages are attained by correctly choosing packaging materials that will provide the appropriate levels of oxygen and carbon dioxide within a fresh-cut produce package (IFPA, 2003). In fact, there are a wide variety of polymers and gas mixtures available for packaging fresh-cut produce that should be optimize for each commodity (Barry-Ryan, Paccussi, & O’Beirne, 2000). However, there is still a major concern about the product safety associated with the use of MAP mainly due to the
desired suppression of spoilage microorganisms which extends the shelf-life if compared to food products stored in a normal air environment, and this may create opportunities for slower growing pathogenic bacteria (Rosnes, Sivertsvik, & Skara, 2003).

It would be expected that combinations of sanitizers and/or other intervention methods would have additive, synergistic or antagonistic interactions (Parish & Davidson, 1993; Rajkowski & Baldwin, 2003). According to this, the hurdle technology looks after the combination of different preservation techniques as a preservation strategy. The intelligent selection of hurdles in terms of the number required, the intensity of each and the sequence of applications to achieve a specified outcome are expected to have significant potential for the future of minimally processed fruit and vegetables (McMeekin & Ross, 2002).

**Use of combined preservation methods**

**Photochemical processes**

Recently, many studies have demonstrated the effectiveness of surface decontamination techniques to reduce the microbial risk involved with the consumption of fresh fruits and vegetables (Erkan, Wang, & Krizek, 2001; Yau, Summer, Eifert, & Marcy, 2004). Non-ionizing, artificial ultraviolet-C (UV-C) radiation is extensively used in a broad range of antimicrobial applications including disinfection of water, air, food preparation surfaces, food containers (Wang, McGregor, Anderson, & Woolsey, 2005) and surface disinfection of vegetable commodities (Marquenie et al., 2002). The ultraviolet light acts as an antimicrobial agent directly due to DNA damage (Rame, Chaloupecky, Sojkova, & Bencko, 1997) and indirectly due to the induction of resistance mechanisms in different fruit and vegetables against pathogens (Liu et al., 1993; Nigro, Ippolito, & Lima, 1998). Exposure to UV-C also induces the synthesis of health-promoting compounds such as anthocyanins and stilbenoids (Cantos, Espín, & Tomás-Barberán, 2001). However, high UV doses, can cause damage to the treated tissue as previously described by Ben-Yehoshua, Rodov, Kim, and Carmeli (1992) and Nigro et al. (1998). Therefore, the possibility of decreasing the treatment intensity by combining two or more treatments to preserve the fruit and vegetable quality without decreasing the inactivation properties appears very promising (Marquenie, 2002). Additionally, UV-C light has already been recommended as best used in combination with other preservation techniques, since the accumulative damage due to microbial DNA appears effective in decreasing the overall number of bacteria cells, but does not result in complete sterilization (Rame et al., 1997). Further, these postharvest treatments can be easily added to other techniques such as chilling, disinfection and MAP to preserve quality of minimally processed fruits and vegetables (Maharaj, Arul, & Nadeau, 1999).

Many researchers have already tested the synergistic effects of combining UV-C light with chemical disinfection and/or MAP on vegetable produce. The beneficial effects of combining chlorinated water to disinfec fresh-cut fruit and vegetables with UV-C light treatments and storage in MAP has already been tested (Allende & Artes, 2003a,b; Allende, McEvoy, Yaguan, Artés, & Wang, 2006; López-Rubira, Conesa, Allende, & Artes, 2005). Most of these studies showed the effectiveness of microbial reductions in fresh-cut fruits and vegetables by using chemical disinfection, low UV-C light doses (from 1 to 4 kJ m\(^{-2}\)) and storage under conventional MAP, without any detrimental effect on the organoleptical quality of the product.

UV-C light has also been combined with other postharvest treatments such as mild thermal treatments. Improvements in keeping quality and reducing incidence of storage disease in various horticultural crops have been described by immersion in water at elevated temperatures (Delaquis, Stewart, Toivonen, & Moys, 1999; Loaiza-Velarde, Mangrich, Campos-Vargas, & Saltveit, 2003; Loaiza-Velarde, Tomás-Barberán, & Saltveit, 1997). Saltveit (2000) demonstrated the beneficial effects of a heatshock treatment to reduce browning in fresh-cut lettuce (e.g. 90 s at 45°C) due to the redirecting of protein synthesis away from the production of wound-induced enzymes of phenolic metabolism, and toward the production of innocuous heat shock proteins. Marquenie et al. (2002) tested the efficacy of heat treatments and UV-C light for controlling postharvest decay of strawberries and sweet cherries. In most of the cases, fungal inactivation was achieved for the treatments with the highest UV-C dose (10 kJ m\(^{-2}\)) combined with a long thermal treatment (15 min at 45°C). The sequence of the treatments seems to have an influence on microbial inactivation for strawberries. The fungal inactivation is greater when the ultraviolet treatment precedes the thermal treatment. The possibility of lowering the intensity of the heat treatment when preceded by an ultraviolet illumination results in a decrease of fruit damage caused by heating. Since less intense thermal conditions can be used, visual damage to the strawberries is also reduced.

UV-C light can also be used in advanced oxidation processes (AOP) (e.g. UV/ozone), which use UV oxidation as a destruction process that oxidizes organic constituents in water by the addition of strong oxidizers and UV light. In this case, oxidation of organic material or microorganisms is caused by direct reaction with the oxidizers, UV photolysis, and through the synergistic action of UV light, in combination with O\(_3\). The AOP as an oxidation step before biodegradation represent an alternative that may be more effective and less costly than O\(_3\) alone. This technology combines the potent
oxidizing action of O₃, which is able to convert many non-biodegradable organic materials into biodegradable forms, minimizing the accumulation of inorganic waste in the environment (Kim, Yousef, & Dave, 1999). Beltrán, Selma, Marin et al. (2005) tested treatments of 10 ppm total dose of ozone in water activated by UV-C in extending the shelf-life of fresh-cut lettuce. They concluded that ozonated water activated with UV-C could be an excellent alternative to chlorine for washing shredded lettuce not only by reducing microbial populations on the product but also by maintaining the visual quality and controlling browning without any detrimental effect on the antioxidant constituents when combining with active MAP.

Light pulses have been used successfully as a new technique for the inactivation of bacteria and fungi on the surface of food products when the major composition of the emitted spectrum is UV light (Marquenie et al., 2002). Very little information is available about the efficacy of light pulses to inhibit microbial growth and prolong shelf-life of fresh-cut fruits and vegetables. Some studies have focused on the microbial and sensory quality of fresh-cut vegetables using intense light pulses combined with MAP. Microbial reductions up to 2.04 log has been reported by the combination of both techniques, although the shelf-life of the product was not always extended (Gómez-López et al., 2005; Hoornstra, de Jong, & Notermans, 2002). Additionally, combination of pulsed light with mild heat treatments in strawberries and cherries has also been reported. Manvell (1997) prolonged the period without visible fungal growth for 1 or 2 days compared to the control.

Low-dose gamma irradiation is very effective reducing bacterial, parasitic, and protozoan pathogens in raw foods. Irradiation was approved by the FDA for use on fruits and vegetables at a maximum level of 1.0 kGy (IFT, 1983). It has already been tested in minimally processed fruit and vegetables observing that dose of 2.0 kGy strongly inhibited the growth of aerobic mesophilic and lactic microflora in shredded carrots (Chervin & Boisseau, 1994). Additionally, it has been combined with conventional disinfection methods such as chlorinated water or preservation technologies by using MAP (Foley, Euper, Caporaso, & Prakash, 2004; Hagenmaier & Baker, 1997; Prakash, Intahjak, Hui-bregtse, Caporaso, & Foley, 2000; Prakash, Guner, Caporaso, & Foley, 2000). They concluded that treating fresh-cut lettuce with low-dose irradiation of about 0.20–0.35 kGy combined with a chlorine (80–100 ppm NaOCl) wash and MAP, increases the microbiological shelf-life without adversely affecting the visual quality or flavor of the product. Additionally, when inoculated cilantro was treated with a combination of irradiation (1.05 kGy) and chlorination (200 ppm), Escherichia coli O157:H7 was reduced more than 7 log cycles without adversely affecting the sensory quality of the product. This combined treatment was more efficient than irradiation or chlorination alone.

Non photochemical processes

Many combinations of physical and chemical treatments have been tested in recent years to enhance the antimicrobial action of different disinfectant agents. Among them, the use of acidic electrolyzed water (AcEW) produced by the electrolysis of an aqueous sodium chloride solution as a disinfectant for minimally processed vegetable products has been successfully applied (Izumi, 1999). Koseki, Yoshida, Isobe, and Itoh (2001) washed lettuce in alkaline electrolyzed water (AlEW) for 1 min and then disinfected it in AcEW for 1 min, obtaining a 2 log cfu g⁻¹ reduction in viable aerobes. However, the combination of both washes did not improve the microbial reduction obtained by chlorinated or ozonated water. On the other hand, AcEW has been combined with ozone by using sequential washes (Wang, Feng, & Luo, 2004). Fresh-cut cilantro was washed in aqueous ozone for 5 min followed by a 5 min AcEW wash and failed to yield a higher aerobic bacteria reduction than AcEW alone. The authors theorized that the unexpected outcome may be caused by factors such as the internalization of microbes on cilantro surfaces.

Chlorine dioxide (ClO₂) has been recognized as a strong oxidizing agent with a broad biocidal effectiveness due to the high oxidation capacity of about 2.5 times greater than chlorine (Benarde, Israel, Oliveri, & Granstrom, 1965). Many studies have demonstrated its antimicrobial activity (Han, Guentert, Smith, Linton, & Nelson, 1999; Han, Sherman, Linton, Nielsen, & Nelson, 2000) since its use was allowed in washing fruits and vegetables by the FDA (1998). Singh, Singh, and Bhunia (2003) studied the efficacies of aqueous chlorine dioxide, ozonated water and thyme essential oil alone or sequentially in killing mixed strains of E. coli O157:H7 inoculated on alfalfa seeds. They found that the sequential washing procedure (thyme oil followed by ozonated water and aqueous ClO₂) was significantly more effective in removal of E. coli O157:H7. However, the use of the combination of these techniques may adversely affect the organoleptical properties.

Power ultrasound, as used for cleaning in the electronics industry, has a potential application to fresh produce decontamination (Seymour, Burfoot, Smith, Cox, & Lockwood, 2002). Ultrasonic fields consist of waves at high amplitude, which form cavitation bubbles, which generate the mechanical energy which has a ‘cleaning action on surfaces’ (Scherba, Weigel, & O’Brien, 1991; Sala, Burgos, Condon, Lopez, & Rose, 1995; Raso, Pagan, Condon, & Sala, 1998). Seymour et al. (2002) reported that cavitation enhances the mechanical removal of attached or entrapped bacteria.
on the surfaces of fresh produce by displacing or loosening particles through a shearing or scrubbing action, achieving an additional log reduction when applying to a chlorinated water wash. Scouten and Beuchat (2002) studied the combined effect of chemical, heat and ultrasound treatments in killing or removing Salmonella and E. coli O157:H7 on alfalfa seed postulating that combined stresses and enhanced exposure of cells to chemicals would result in higher lethality. They observed that ultrasound treatment at 38.5–40.5 kHz enhances the effectiveness of chemical sanitizers in killing pathogenic growth. The use of hot water (55 °C) also contributes to an increase of lethality, although, combination of heat with ultrasound is more detrimental to seed viability compared with heat treatment alone. Delaquis et al. (1999) also reported treatments of hot water combined with chemical disinfectants such as chlorine, since the lethality of chlorine is known to increase with temperature (Weber & Levine, 1944). They reported that warm chlorinated water washes offer an attractive alternative to retard by several days the development of spoilage microflora as well as brown discoloration (Delaquis et al., 1999).

A newer tendency has been reported by Bari et al. (2005), who combined the efficacy of chemical disinfectant with the antimicrobial effect of bacteriocins produced by lactic acid bacteria. They investigated the efficacy of nisin and pediocin treatments in combination with EDTA, citric acid, sodium lactate, potassium sorbate and phytic acid in reducing Listeria monocytogenes on fresh-cut produce. They concluded that pediocin and nisin applications in combination with organic acids caused a significant reduction of native microflora and inoculated populations on fresh produce.

Finally, the combined use of several disinfectant agents has been widely report in the last few years (Beltrán, Selma, Tudela, & Gil, 2005; Ukuku, Bari, Kawamoto, & Isshiki 2005; Uyttendaele, Neyts, Vandervalmen, Notebaert, & Debevere, 2004). Combinations of lactic acid, chlorinated water, thyme essential oil solution, sodium lactate, citric acid, hydrogen peroxide, ozone and peroxycacetic acid were already tested. In general, combinations of chemical disinfectants maintain better both, sensory and microbial quality of the product. Therefore, for the future, more studies should be carried out to determine the synergistic effects of combining technologies.

Conclusions
Judging from the available literature, it could be concluded that there are many and very different technologies that can be presently used to reduce loss of quality and increase safety of fresh-cut fruits and vegetables, but any of them has the final solution to control all the parameters that maintain the quality and shelf-life of minimally processed products.

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References


