Fresh fruits and vegetables—An overview on applied methodologies to improve its quality and safety

B. Ramos, F.A. Miller, T.R.S. Brandão, P. Teixeira, C.L.M. Silva

ABSTRACT

The consumers' demand for fresh fruits and vegetables has increased in recent years. These foods may be consumed raw or minimally processed, and therefore can be a vehicle of several pathogens. The microorganisms most frequently linked to produce-related outbreaks include bacteria (Salmonella spp., Listeria monocytogenes, Escherichia coli, and Shigella spp.), viruses and parasites.

There are many traditional technologies to reduce/eliminate the microorganisms present in food products. However, further research on this topic is still required, since none of the methods reported can control all the parameters necessary to achieve produce with an extending shelf-life, without compromising its quality.

In this paper, an analysis of the alternative and traditional methodologies is made, pointing out the significant advantage and limitations of each technique.

Industrial relevance: The significant increase in the incidence of foodborne outbreaks caused by contaminated minimally processed produce in recent years has become of extreme importance. The extensive knowledge of gentle (non-thermal) processes to enhance safety, preservation and shelf-life of these products is crucial for the food industry.

This manuscript presents non-thermal processes that have shown efficient microbial reductions on fresh produce and highlights some of their challenges and limitations.

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1. Introduction

Fruits and vegetables are essential components of the human diet and there is considerable evidence of the health and nutritional benefits associated with their consumption (Abadias, Usall, Anguera, Solson, & Vinas, 2008; Warriner, Ibrahim, Dickinson, Wright, & Waites, 2005). Due to the presence of high levels of micronutrients and fibers, their consumption is recommended by many organizations (World Health Organization—WHO, Food and Agriculture Organization—FAO, United States Department of Agriculture—USDA and European Food Safety Authority—EFSA) to reduce the risk of cardiovascular diseases and cancer (Allende, McEvoy, Luo, Artes, & Wang, 2006a; Ragaert, Verbeke, Devlieghere, & Debevere, 2004; Su & Arab, 2006; Warriner, 2005).

As a response to consumers’ demand for healthy, fresh-like and easy to prepare products, conjoin with consumer lifestyle changes, a wide variety of minimally processed fruits and vegetables (MPFVs) has been developed (Allende et al., 2006a; Froder et al., 2007; Scolari & Vescovo, 2004; Tournas, 2005).

Minimal food processing techniques constitute non-thermal technologies with guarantee of food preservation and safe standards as well as maintaining, as much as possible, the fresh-like characteristics of fruits and vegetables (Allende, Tomas-Barberan, & Gil, 2006b; Allende et al., 2006a). Minimally processed products aim to extend the product shelf-life of 5–7 days at 4 °C, while ensuring food safety and maintaining nutritional and sensory quality (Cliffe-Byrnes & O’Beirne, 2002).

The marketing of these types of foods continues to rise mainly due to their freshness, economic handling and attractive presentation (Little & Gillespie, 2008). They constitute a suitable meal for today’s lifestyles, because they do not need preparation and provide a great variety of vitamins, minerals and other phytochemicals, which are important in human health (Froder et al., 2007).

Fruits and vegetables require proper handling, preparation and storage in order to take full advantage of their nutrients. When these products are minimally processed, they are submitted to unit operations that include selection, cleaning, washing, trimming, peeling, cutting and shredding, sanitizing and packing. As these operations do not assure the absence of microorganisms, minimally processed fruits and vegetables, require refrigeration as a primary means of preservation (Froder et al., 2007; Tournas, 2005).

Consumers are becoming more aware about the limitations of commonly sanitizing techniques and are looking for safe food products that suffer minimal processing, with high quality retention. To satisfy these requirements, food industry is currently studying non-thermal techniques such as ozone based treatments, ultraviolet radiation, pulsed light, cold plasma, ultrasounds and novel packaging practices. All these technologies have a great potential in the field of minimally processed foods. However, there is a lack of available information about advantages and limitations of these technologies, when applied to food processing. The efficiency of the processes depends directly on the combination food/contaminant/process and important fresh characteristics to maintain.

This paper gathered information about these novel technologies and the ones commonly used, pointing out their most relevant advantages and limitations. An overview of produce microbiota patterns and outbreaks related to fruits and vegetables is presented, showing the importance of choosing an effective method for microbial inactivation on these products.

2. Produce microbiota

Fresh fruits and vegetables, including plant components as leaves, roots, bulbs and tubers, have different morphology and metabolic functions and consequently provide diverse ecological niches to microorganisms (Brackett, 1999; Burnett & Beuchat, 2000; Ponce, Roura, del Valle, & Fritz, 2002). The presence and number of microorganisms differ depending on the type of produce, agronomic practices, geographical area of production, and weather conditions before harvest. Harvest, transportation and further processing and handling of produce can greatly influence the microbiota pattern (Ahvenainen, 1996; Olimate & Holley, 2012).

The number and type of microorganisms found on fresh produce are highly variable. Mesophilic bacteria are around 10^3–10^6 CFU/g in raw vegetables after harvest, depending on the produce and the growing conditions (Oliveira et al., 2010; Zagory, 1999). Gram-negative bacteria dominate the microflora associated with most vegetables, whereas yeasts and moulds are often the majority microflora of raw fruits (Burnett & Beuchat, 2000; Tournas, 2005). The microflora of vegetables and fruits is made up largely of Pseudomonas spp., Erwinia herbicola, Flavobacterium, Xanthomonas, and Enterobacter agglomerans as well as various moulds, Alternaria, Penicillium, Fusarium and Aspergillus. Lactic acid bacteria, such as Leuconostoc mesenteroides and Lactobacillus spp., are also commonly found. Finally, yeasts such as Torulopsis, Saccharomyces and Candida are part of dominant microorganisms, mostly on fruits because of their high sugar content (Caponigro et al., 2010; de Azeredo et al., 2011; Pianetti et al., 2008). Pseudomonas spp. normally dominates and may make up 50–90% of the microbial population on many vegetables (Arvanitoyannis & Stratakos, 2010; Nguyenthe & Carlin, 1994; Zagory, 1999).

3. Fruit and vegetable contamination

The natural microbial flora of raw fruits and vegetables is usually non-pathogenic for humans and may be present at the time of consumption (Ahvenainen, 1996; Food & Drug Administration, H. H. S., 2008). However, during growth, harvest, transportation and further processing and handling, the produce can be contaminated with pathogens from human, animal, or environmental sources (Ahvenainen, 1996; Brandl, 2006; Froder et al., 2007; Sánchez, Elizalduel, & Aznar, 2012). During peeling, cutting and shredding, the surface of the produce is exposed...
to air and to possible contamination with bacteria, yeasts and moulds. The protective epidermal barrier is breached, which will increase nutrient availability and provide large surface areas that may facilitate microbial growth and consequently decrease the product shelf-life (Conte, Scrocco, Brescia, & Del Nobile, 2009; Del Nobile, Lucciardello, Scrocco, Muratore, & Zappa, 2007; Guerzoni, Gianotti, Corbo, & Singaglia, 1996; Muriel-Galet et al., 2013). Additionally, the mechanical damage caused to cells during processing may increase the rate of tissue senescence, reducing their resistance to microbial spoilage (Badosa, Trias, Pares, Pla, & Montesinos, 2008; Barry-Ryan & O’Beirne, 1998; Garg, Churey, & Splittstoesser, 1990).

Another concern is the possible formation of foodborne pathogen biofilms on plant tissues enabling these to survive in harsh environment and may decrease the efficacy of commonly used sanitizers (Critzer & Doyle, 2010).

As a result, these products can be a vehicle of transmission of bacterial, parasitic and viral pathogens, capable of causing human illness.

The incidence of foodborne outbreaks caused by contaminated fresh fruits and vegetables has increased in recent years. The pathogens most frequently linked to these product contamination and human illness are included in Table 1.

Fig. 1 includes collected information of produce outbreaks, which is based on approximately 110 scientific papers and reports by CDC (Centers for Disease Control and Prevention), FDA (Food and Drug Administration) and WHO (World Health Organization).

From about 1100 produce reported outbreaks, in which an etiological agent was identified, 53.0% were caused by bacteria, 42.5% by viruses and 4.5% by parasites.

The produce most associated with outbreaks is the salad, since it has all kinds of mixed vegetables. Included in the “other vegetables” group are corn, beans, pepper, soy, radish and onion. In addition, WHO categorized lettuce and salads (all varieties), leafy vegetables (spinach, cabbage, raw watercress) and fresh herbs highest priority in terms of fresh produce safety from a global perspective (FAO/WHO, 2008; Goodburn & Wallace, 2013).

Cantaloupe, cucumber, maney and pawpaw are fruits included in the “other fruits” group. As it can be observed in Fig. 1, the microorganisms of main concern in produce outbreaks are the Norovirus and Salmonella spp. For this reason, several studies had been conducted to investigate the prevalence and contamination level of these microorganisms on fresh produce (Baert et al., 2011; Elviss et al., 2009; Patel, Hall, Vinjé, & Parashar, 2009; Stals, Baert, Van Coillie, & Uyttendaele, 2012).

Contamination of fresh fruits and vegetables is of special concern, because such produce is likely to be consumed raw, without any type of microbiologically lethal processing, thus posing a potential safety problem (Carrasco, Morales-Rueda, & García-Gimeno, 2012; Zweifel & Stephan, 2012). Safe production methods and proper disinfection/decontamination procedures are therefore critical steps in ensuring the safety of ready-to-eat fresh fruits and vegetables (Artés, Gómez, Aguayo, Escalona, & Artés-Hernández, 2009; Bharathi, Ramesh, & Varadaraj, 2001; Selma, Ibáñez, Allende, Cantwell, & Suslow, 2008b).

4. Minimally processed fruits and vegetables (MPFVs) shelf-life

Fruits and vegetables are among the most perishable foods in the market. They are rich in carbohydrates and poor in proteins, with pH

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Clostridium botulinum</em></td>
<td>Cabbage, pepper, garlic, potato and carrots</td>
</tr>
<tr>
<td><em>E. coli</em> O157:37</td>
<td>Alfalfa sprouts, cabbage, celery, coriander, watercress, lettuce, cabbage, berries, melons, and apple juice</td>
</tr>
<tr>
<td><em>L. monocytogenes</em></td>
<td>Bean sprouts, cabbage, chicory, cantaloupe, eggplant, lettuce, potatoes, radish and lettuce</td>
</tr>
<tr>
<td><em>Salmonella</em> spp.</td>
<td>Alfalfa sprouts, artichokes, beet leaves, celery, cabbage, cantaloupe, cauliflower, eggplant, endive, fennel, green onions, lettuce, mung bean sprouts, mustard cress, pepper, salad greens, spinach, unpasteurized fruit juice, tomatoes, watermelon, mamey and mango</td>
</tr>
<tr>
<td><em>Shigella</em> spp.</td>
<td>Celery, lettuce, green onions, salad vegetables and parsley</td>
</tr>
<tr>
<td><em>Staphylococcus</em> spp.</td>
<td>Lettuce, parsley, radish, salad vegetables and seed sprouts</td>
</tr>
<tr>
<td><em>Vibrio cholerae</em></td>
<td>Cabbage and coconut milk</td>
</tr>
<tr>
<td><em>Yersinia enterocolitica</em></td>
<td>Carrots, cucumbers, lettuce and tomatoes</td>
</tr>
<tr>
<td><strong>Viruses</strong></td>
<td>Lettuce, green onions, watercress, sliced melon, salads, diced tomatoes and fresh cut fruit</td>
</tr>
<tr>
<td><strong>Hepatitis A</strong></td>
<td>Lettuce, green onions, watercress, raspberries, frozen strawberries and berries</td>
</tr>
<tr>
<td><strong>Protozoa</strong></td>
<td>Lettuce, onions and green onions</td>
</tr>
<tr>
<td><em>Cryptosporidium</em> spp.</td>
<td>Lettuce, onions, green onions, raspberries and blackberries</td>
</tr>
<tr>
<td><em>Cyclospora</em> spp.</td>
<td>Lettuce, green onions, raspberries and blackberries</td>
</tr>
<tr>
<td>Method</td>
<td>Advantages</td>
</tr>
<tr>
<td>--------</td>
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</tr>
<tr>
<td>Chlorine (hypochlorite)</td>
<td>- Low cost - Easily available - Long history of use</td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>Aqueous - Higher antimicrobial efficacy at neutral pH than chlorine - Effectiveness less pH dependant compared to chlorine - Fewer potentially hazardous DBP formation than chlorine - Less corrosive than chlorine and ozone - Can delay ripening of produce due to ethylene elimination and inhibiting its production</td>
</tr>
<tr>
<td>Acidified sodium chlorite</td>
<td>- Greater efficacy than hypochlorite due to low pH at neutral pH - Effective in a wide pH range - Great penetration ability</td>
</tr>
<tr>
<td>Bromine</td>
<td>- Possible synergy with chlorine compounds</td>
</tr>
<tr>
<td>Iodine</td>
<td>- Less corrosive than chlorine at low temperature - Broad spectrum - Iodophor less volatile than iodine</td>
</tr>
<tr>
<td>Trisodium phosphate</td>
<td>- Less corrosive than most other compounds</td>
</tr>
<tr>
<td>Quaternary ammonium compounds</td>
<td>- Colorless, odorless - Stable at high temperature - Noncorrosive - Good penetrating ability - Relatively stable to organic compounds</td>
</tr>
<tr>
<td>Method</td>
<td>Advantages</td>
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<tr>
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</tr>
<tr>
<td>Organic acids (lactic, citric, acetic, tartaric or ascorbic acid)</td>
<td>- Easy to use</td>
</tr>
<tr>
<td>Hydrogen peroxide ($\text{H}_2\text{O}_2$)</td>
<td>- No harmful DBP formation</td>
</tr>
<tr>
<td>Peroxyacetic acid</td>
<td>- No harmful DBP formation</td>
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<tr>
<td>Calcium-based solutions</td>
<td>- Can significantly increase the calcium’s content of the final product</td>
</tr>
<tr>
<td>Ozone</td>
<td>Aqueous - High antimicrobial activity</td>
</tr>
<tr>
<td>Electrolyzed water (EW)</td>
<td>- Inactivates several pathogenic and spoilage microorganisms</td>
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</tbody>
</table>
values ranging from 7.0 to slightly acid, and exhibit a characteristic high water activity. These conditions make the produce adequate habitats for several bacteria, yeasts and moulds (Del Nobile, Conte, Cannarsi, & Sinigaglia, 2008; Gómez-López, Devileghe, Bonduelle, & Debevere, 2005; Selma, Allende, Lopez-Galvez, & Gil, 2008a). The resulting spoilage of fruits and vegetables is characterized by a brown discoloration, necrosis, loss of texture, exudation and/or production of off-odors or off-flavors (Ponce et al., 2002).

Minimally processed produce, due to processing operations that alter the physical integrity of these products, are more perishable than the original raw materials (Sanz, Gimenez, Olarte, Lomas, & Portu, 2002). The raw produce are expected to have a shelf-life of several weeks or months, while MPPFs have only a very short storage life of 4 to 7 days. Their shelf-life depends on various factors such as fruit and vegetable initial quality, production technology and the number and interactions among microbial groups (Watada & Qi, 1999). Although MPPFs should have storage lives up to 21 days, ethylene production, respiratory activity, enzymatic and non-enzymatic browning and nutrient release from cells that are stimulated by produce injuries, make this goal difficult.

The understanding of the processes that result in quality degradation is essential to develop technologies to extend MPPFs shelf-life and to maintain quality during processing and distribution (Pianetti et al., 2008).

5. Intervention methods to extend shelf-life and enhance safety

There are a variety of methods used to reduce microorganism’s population on whole and fresh-cut produce. The best method is to prevent contamination in the first place. However, this is not always possible and the use of techniques that reduce/eliminate pathogens is of extreme importance to prevent foodborne outbreaks (Corbo, Del Nobile, & Sinigaglia, 2006).

There are a number of chemical (Table 2) and physical (Table 3) methods that have proved to be moderately efficient in reducing the indigenous microflora and also the contaminating pathogens (Parish et al., 2003).

Chemical methods of cleaning and sanitizing produce surfaces usually involve the application of mechanical washing in the presence of sanitizers, followed by rinsing with potable water (Wei, Wolf, & Hammes, 2006). Physical methods are effective at removing bacteria from plant surfaces by the use of shear forces (Allende et al., 2007; Gil, Selma, López-Gálvez, & Allende, 2009).

5.1. Chemical methods

Several sanitizing agents may be used for fruit and vegetable washing with the intention of reducing the risk of microbial contamination, helping in the prevention of postharvest diseases and foodborne illness.

This section will describe, in more detail, the chemical methods industrially available for produce decontamination. An overview of the major advantages, limitations and effectiveness for each method is presented in Table 2.

5.1.1. Chlorine (hypochlorite)

In fruits, vegetables and fresh-cut produce, chlorine rinses are frequently used with concentrations varying from 50 to 200 ppm and with typical contact times of less than 5 min (Artés & Allende, 2005; Rico, Martin-Diana, Barat, & Barry-Ryan, 2007). Although chlorine is the most commonly used sanitizer, it is inactivated by organic material and during production can also lead to the liberation of chlorine vapours and formation of chlorinated by-products (DBPs), with potential adverse health effects (Parish et al., 2003; Rico et al., 2007). However, the benefits of chlorine use for the produce industry outweigh the concerns of potential formation of harmful by-products. Studies have shown that chlorine rinses can decrease the bacterial load by values ranging from <1 log CFU/g to 3.15 log CFU/g, depending on inoculation method, chlorine concentration, contact time, and the target bacteria (Baur, Klaiber, Wei, Hammes, & Carle, 2005; Beltrán, Selma, Tudela, & Gil, 2005b; Casteel, Schmidt, & Sobsey, 2008; Hua & Reckhow, 2007).

5.1.2. Chlorine dioxide

As an alternative to chlorine, raw fruits and vegetables can be sanitized with chlorine dioxide (ClO2) (up to 3 ppm), which has an oxidant capacity 2.5 times greater. In addition, ClO2 does not participate in chlorine reactions that result in harmful by-products (Keskinen, Burke, & Annous, 2009). Although chlorine dioxide reacts directly with cells amino acids and RNA, it is not clear whether it attacks the cell structure or the acids inside the cell. As drinking water disinfectant, it is highly effective against pathogenic organisms such as Legionella, Gardia cysts, Escherichia coli, Cryptosporidium and viruses by preventing protein formation (Francis & O’Beirne, 2002; Fu, Zhang, Wang, & Du, 2007; Gómez-López, Devlieghere, Ragaert, & Debevere, 2007a; Rico et al., 2007). For raw produce, this method is not so efficient at permitted concentration levels.

ClO2 gas has received attention due to its greater penetration ability than liquid. Several studies showed the efficacy of this gas on produce surface decontamination, particularly against pathogens like E. coli O157:H7 and Listeria monocytogenes (Du, Han, & Linton, 2003; Gómez-López, Ragaert, Jeyachandran, Debevere, & Devlieghere, 2008; Han, Linton, Nielsen, & Nelson, 2000; Mahmoud, Bhagat, & Linton, 2007; Singh, Singh, Bhunia, & Stroshine, 2002). Different factors can influence the lethality of the ClO2 gas treatment, such as ClO2 gas concentration, time of exposure, relative humidity, and temperature.

ClO2 is a promising non-thermal technology for reducing pathogenic and spoilage bacteria on fresh produce. However, research efforts in this area are still required (Mahmoud et al., 2007).

5.1.3. Acidified sodium chlorite

This compound can be used on raw fruits and vegetables as a spray or dip in the range of 500 to 1200 ppm. Applications of acidified sodium chlorite showed a substantial antimicrobial effect against E. coli O157:H7 and Salmonella inoculated onto cantaloupes, honeydew melons and asparagus spears. However, the number of studies is still limited, and there is a need for more information on the general usefulness of using acidified sodium chlorite in produce sanitizing (Artés et al., 2009; Beuchat, 1998; Parish et al., 2003).

5.1.4. Bromine and iodine

These chemicals showed antimicrobial activity although some health related issues limit their use on produce.

Bromine has synergistic antimicrobial relationship when added to chlorine solutions, but there are safety concerns about the production of brominated organic compounds and their impact on human and environmental safety (Beuchat, 1998; Parish et al., 2003).

Elemental iodine and non-ionic surfactant or carrier combinations—iodophores, have a broad spectrum of antimicrobial activity and are less corrosive than chlorine at low temperatures. However, iodine-containing solutions used as direct contact produce sanitizers are limited due to a reaction between iodine and starch that result in a blue-purple colour (Ayala-Zavala & Gustavo, 2010; Parish et al., 2003).

5.1.5. Trisodium phosphate (TSP)

Solutions with 15% TSP are effective in Salmonella inactivation on tomato surface. However, even at 15%, only about a 2 log10 reduction was achieved (Beuchat, 1998; Zhuang & Beuchat, 1996). It was concluded that the use of TSP as a disinfectant for removal of Salmonella from the surface of mature green tomatoes has good potential. The use of TSP to remove L. monocytogenes from shredded lettuce was demonstrated to be less promising (Parish et al., 2003; Weissinger, Chantarapann, & Beuchat, 2000). Solutions containing more than 10% TSP damaged the
sensory quality of lettuce. It should be noted that the pH of TSP solutions is around 11–12, limiting their commercial application as a disinfectant of fruits and vegetables (Parish et al., 2003).

5.1.6. Quaternary ammonium compounds
Quaternary ammonium compounds commonly called “QAC” are cationic surfactants that are able to penetrate food contact surfaces more readily than other sanitizers. Their antimicrobial activity is greater against the fungi and gram-positive bacteria than gram-negative bacteria (Aase, Sundheim, Langsrud, & Rørvik, 2000; To, Favrin, Romanova, & Griffiths, 2002). Although they are not approved for direct food contact, QAC may have some limited usefulness on whole produce, since the product must be peeled prior to consumption (Parish et al., 2003). As mentioned for iodine compounds, QAC direct food contact would require regulatory approval and a demonstration that the produce are safe for consumption (Dunn, 1949; Rossmoore, 2001).

5.1.7. Organic acids
Organic acids (e.g. lactic, citric, acetic or tartaric acid) have been described as strong antimicrobial agents due to environment pH reduction, disturbance of membrane transport and/or permeability, anion accumulation, or a reduction in internal cellular pH (Parish et al., 2003). Less direct antibacterial activities include interference with nutrient transport, cytoplasm membrane damage resulting in leakage, disruption of outer membrane permeability, and influence on macromolecular synthesis (Beuchat, 1998; Inatsu, Bari, Kawasaki, Ishihi, & Kawamoto, 2005; Miller et al., 2009). Citric and ascorbic acids are commonly used in fruit and vegetable washing and added in fruit juices (Velazquez, Barbini, Escudero, Estrada, & de Gusman, 2009).

5.1.8. Hydrogen peroxide (H₂O₂)
This compound possesses bacteriostatic and bactericidal activity due to its strong oxidizing power and also to the generation of cytotoxic agents (hydroxyl radical). It is used as antimicrobial or bleaching agent in the range of 0.04–1.25% up to 80 ppm in produce wash water (Akbas & Olmez, 2007; Alexandre, Brandão, & Silva, 2012a; Hwang, Cash, & Zabik, 2001).

For a better effectiveness of this compound, H₂O₂ concentrations of 2–4% should be used. Lower concentrations (1–2%) are not effective in reducing the bacterial load and higher concentrations (4–5%) interfere with the overall quality of the produce (Beltrán et al., 2005b; Olmez & Kretzschmar, 2005; Rico et al., 2007). Although the antimicrobial efficacy of this H₂O₂ can be comparable to 100–200 ppm of chlorine treatment at room temperature, higher microbial reductions were achieved with H₂O₂ and a higher overall quality was maintained when higher temperatures (50–60 °C) were applied (Parish et al., 2003).

5.1.9. Peroxyacetic acid
It is a combination of peracetic acid (CH₃CO₃H) and hydrogen peroxide (H₂O₂), usually commercialized as a liquid. It is a strong oxidant agent and is used to wash fruits and vegetables in concentrations up to 80 ppm. Peroxyacetic acid is effective on the inactivation of pathogenic microorganisms in suspension at lower concentrations than the ones required when using chlorine. However, studies revealed that 80 ppm of peroxycetic acid in wash water is not sufficient to obtain a substantial reduction in the microbial load of fresh-cut fruits and vegetables (Artés et al., 2009; Rico et al., 2007; Sapers, 2006).

5.1.10. Calcium-based solutions
These solutions are widely used for delicate fruits and products with high senescence index, as it maintains produce firmness. One of the compounds most utilized is calcium lactate, because it has antibacterial properties due to its ability to uncouple microbial transport processes. In a study with fresh-cut lettuce and carrots this compound demonstrated the same effectiveness as chlorine in reducing microbial load (Martin-Diana et al., 2005a; Rico et al., 2007).

5.1.11. Ozone
Ozone is a strong antimicrobial agent with high reactivity and penetrability. When used in water, ozone concentrations range from 0.03 to 20.0 ppm. When used in the gas form, the concentration reaches higher doses such as 20,000 ppm (Manganaris, Vasilikakis, Diamantidis, & Mignani, 2006; Martin-Diana et al., 2005b; Rico et al., 2007; Safneter, Bai, Abbott, & Lee, 2003).

Ozonated water has been commonly applied for sanitation purposes of fresh-cut vegetables achieving some microbial reductions and extending the produce shelf-life (Alexandre, Brandão, Silva, 2011a, 2012b; Alexandre, Santos-Pedro, Brandão, & Silva, 2011b; Miller, Silva, & Brandão, 2013).

Several studies showed that gaseous ozone is generally more effective than in aqueous solutions (Klockow & Keener, 2010). This treatment was effective against pathogenic and spoilage microorganisms, while assuring an acceptable product quality (Al-Haddad, Al-Qasemi, & Robinson, 2005; Baur et al., 2005; Beltrán, Selma, Marin, & Gil, 2005a; Hua & Reckhow, 2007; Olmez & Akbas, 2009; Parish et al., 2003; Pascual, Llorca, & Canut, 2007).

Other studies are dealing with in-package gaseous ozone action. Results indicated that this treatment is very effective against E. coli O157:H7, also extending produce shelf life. However, in some products, like spinach, notable colour degradation can occur (Al-Haddad et al., 2005; Klockow & Keener, 2010; Oner, Walker, & Demirci, 2011).

5.1.12. Electrolyzed water (EW)
There are two types of electrolyzed water with sanitizing properties: acidic electrolyzed water or electrolyzed oxidizing water (AEW) and neutral electrolyzed water (NEW). These solutions are conventionally generated by electrolysis of aqueous sodium chloride (0.5–1.0% NaCl), and an electrolyzed acidic solution (AEW) or an electrolyzed basic solution (NEW) is produced at the anode and cathode, respectively.

The AEW has a strong bactericidal effect on pathogenic and spoilage microorganisms (Selma et al., 2008a). This effect is attributed to its low pH (2.1–4.5), high oxidation–reduction potential (higher than 1000 mV), and the presence of active oxidizers such as hypochlorous acid (Keskinen et al., 2009; Rico et al., 2007).

Electrolyzed basic solution has also a strong bactericidal effect, with pH values ranging from 5.0 to 8.5 and oxidation–reduction potential values ranging from 500 to 700 mV (Graça, Abadias, Salazar, & Nunes, 2011).

5.2. Physical methods
Some physical methods are also available for reducing the microbiological load of produce. An overview of the major advantages, limitations and effectiveness for each physical method is present in Table 3.

5.2.1. Modified packaging
The simple form is vacuum packaging (VP), in this the products are packed in a low O₂ permeable film, the air is evacuated and the package is sealed (Arvanitoyannis, 2012).

5.2.1.1. Modified atmosphere packaging (MAP). Modified atmosphere packaging (MAP) involves the modification of the internal atmosphere composition of a package by reducing the amount of oxygen (O₂) and replacing it by carbon dioxide (CO₂) and/or nitrogen (N₂). This process intends to extend the post-harvest life of whole and pre-cut commodities by reducing their respiration rate and the production of ethylene, minimizing metabolic activity, delaying enzymatic browning, and retaining visual appearance (Cui, Shang, Shi, Xin, & Cao, 2009). The gas re-balancing can be achieved either
<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Effectiveness</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified atmosphere</td>
<td>- Extends storage life of the fresh produce by 50–400%</td>
<td>- Often produces high levels of CO₂ with a consequent development of off-flavors and potential stimulation of pathogens growth</td>
<td>- Effective on preserving the quality of fresh and processed vegetables and in reducing the postharvest disease incidence for several fruits and vegetables</td>
<td>Arvanitoyannis (2012), Cliffe-Byrnes and O’Beirne (2002), Cui et al. (2009), Graça et al. (2011), Kim, Hung, and Brackett (2000), Rico et al. (2008), and Saltveit (2003)</td>
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<tr>
<td>packaging (MAP)</td>
<td>- In general, fresh-cut products are more tolerant to higher CO₂ concentrations than the intact product</td>
<td>- Temperature control necessary</td>
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<td></td>
<td>- Reduced economic losses</td>
<td>- Different gas formulations per product type and target microorganism</td>
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<tr>
<td></td>
<td>- Provides a high-quality product</td>
<td>- Packaging material, and temperature per product and/or the target microorganism(s)</td>
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<tr>
<td></td>
<td>- Odorless and convenient packages</td>
<td>- CO₂ dissolving to food could lead to package collapse and increased drip</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>- Sealed packages can act as barriers to further product recontamination</td>
<td>- Plastic films may be environmentally undesirable</td>
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<td>- Delay of ripening</td>
<td>- Incorrect use of the packaging due to the insufficient labeling</td>
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<td></td>
<td>- Improved presentation, clear view of product and all-around visibility</td>
<td>- Non-efficacious operation of the A&amp;I packaging</td>
<td></td>
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<tr>
<td>Active and Intelligent</td>
<td>- Food quality and sensorial improvements</td>
<td>- Can occur migration of substances from the package to the food</td>
<td>- Efficient on product shelf life improvement</td>
<td>Dainelli et al. (2008), Kerry et al. (2006), and Yim, Takhistov, and Miltz (2005)</td>
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<tr>
<td>packaging (A&amp;I)</td>
<td>- Food safety improvement</td>
<td>- Incorrect use of the packaging due to the insufficient labeling</td>
<td>- Monitors the integrity and safety of the packed product</td>
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<td></td>
<td>- Delays oxidation</td>
<td>- Non-efficacious operation of the A&amp;I packaging</td>
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<td></td>
<td>- Monitization of the temperature along transport</td>
<td>- Regulation does not cover the use of this type of packaging</td>
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<td></td>
<td>- Control of respiration rate, microbial growth, and moisture migration</td>
<td>- Non-uniformity of international legislation</td>
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<td></td>
<td>- Can be used to check the effectiveness and integrity of active packaging systems</td>
<td>- Labeling requirements</td>
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<td>- Optical issues</td>
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<td></td>
<td></td>
<td>- Scarce information on formulation/structure/property relationships</td>
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<tr>
<td>Nanocomposite packaging</td>
<td>- Environment friendly</td>
<td>- Increased viscosity (limits process ability)</td>
<td>- Development of new food-packaging materials with improved characteristics</td>
<td>de Azeredo (2009, 2013)</td>
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<td></td>
<td>- Improvement of mechanical properties e.g. strength, modulus and dimensional stability</td>
<td>- May reduce impact performance</td>
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<td></td>
<td>- Low permeability to gases, water and hydrocarbons</td>
<td>- Optical issues</td>
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<td></td>
<td>- Thermal stability</td>
<td>- Scarce information on formulation/structure/property relationships</td>
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<td></td>
<td>- Chemical resistance</td>
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<td></td>
<td>- Electrical conductivity</td>
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<td>- Optical clarity in comparison to conventionally filled polymers</td>
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<td></td>
<td>- Can be conducted after packaging</td>
<td>- Produce quality may be affected specially at high doses</td>
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<td></td>
<td>- Delays ripening and senescence of climacteric fruits</td>
<td>- Product texture alterations</td>
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<td></td>
<td>- Extends shelf-life of produce</td>
<td>- Effective in reducing bacterial and molds of climacteric fruits</td>
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<td></td>
<td>- Low energy costs</td>
<td>- Gamma rays and X-rays have higher penetration ability than electron beams</td>
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<tr>
<td>Method</td>
<td>Advantages</td>
<td>Limitations</td>
<td>Effectiveness</td>
<td>References</td>
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<td>Ultraviolet light (UV)</td>
<td>- Absence of residual toxicity&lt;br&gt;- Equipment relatively inexpensive and easy to use&lt;br&gt;- Can reduce deterioration of the produce&lt;br&gt;- Exposure to UV also induces the synthesis of health-promoting compounds such as anthocyanins and stilbenoids</td>
<td>- Pre-treatment normally necessary&lt;br&gt;- Difficulties in accurately measure the UV dose&lt;br&gt;- Increase produce stress and respiration rate, and induce a lignification-like process&lt;br&gt;- Low penetration depth&lt;br&gt;- Limited application on solid food and opaque surfaces&lt;br&gt;- Can cause off-flavors and color changes&lt;br&gt;- Exposure to UV also induces the synthesis of health-promoting compounds such as anthocyanins and stilbenoids</td>
<td>- Effective in reducing microbiota growth in fruits and vegetables&lt;br&gt;- Germicidal at UV-C interval</td>
<td>Alexandre, Brandão, and Silva (2012c), Neves, Vieira, and Silva (2012), and Ohlsson and Bengtsson (2002)</td>
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<tr>
<td>Pulsed Light (PL)</td>
<td>- Rapid and effective on microbial inactivation in solid and liquid foods&lt;br&gt;- Few residual compounds&lt;br&gt;- Medium cost&lt;br&gt;- Low energy input</td>
<td>- Food composition affects the efficacy&lt;br&gt;- Efficacy decreases at high contamination levels&lt;br&gt;- Possible resistance in some microorganisms&lt;br&gt;- Possible adverse chemical effects</td>
<td>- Inactivates spoilage and pathogenic microorganisms</td>
<td>Choi, Cheigh, Jeong, Shin, and Chung (2010), Gómez-López, Ragaert, Debevere, and Devlieghere (2007b), Guerrero-Beltrán et al. (2005), and Orns-Olou, Martin-Belloso, and Soliva-Fortuny (2010)</td>
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<td>High Pressure Processing (HPP)</td>
<td>- Microbial and enzymatic inactivation&lt;br&gt;- No degradation in flavor and nutrients&lt;br&gt;- No evidence of toxicity&lt;br&gt;- Positive consumer appeal&lt;br&gt;- Uniformity of treatment throughout food</td>
<td>- Affects porous integrity&lt;br&gt;- Expensive equipment&lt;br&gt;- Foods should have approx. 40% free water for antimicrobial effect</td>
<td>- Effective in inactivating most vegetative pathogenic and spoilage microorganisms at pressures above 200 MPa</td>
<td>Chawla, Patil, and Singh (2011), Considine, Kelly, Fitzgerald, Hill, and Sleator (2008), and Guerrero-Beltrán et al. (2005)</td>
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<td>Ultrasound (US)</td>
<td>- Enhance the penetration of solutions to inaccessible sites&lt;br&gt;- Reduction of process times and temperature</td>
<td>- Needs to be combined with other process to be effective&lt;br&gt;- Changes on food structure and texture&lt;br&gt;- Penetration affected by solids and air in product</td>
<td>- Effective against common food bacteria pathogens&lt;br&gt;- Also effective against vegetative cells, spores and enzymes</td>
<td>Alexandre et al. (2012b), Cao et al. (2010), Chemat, Zill e, and Khan (2011), Mukhopadhyay and Ramaswamy (2012), and Sagong et al. (2011)</td>
</tr>
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<td>Cold Plasma</td>
<td>- High efficiency&lt;br&gt;- Low impact on the internal product matrix&lt;br&gt;- No residues&lt;br&gt;- Resource-efficient&lt;br&gt;- Can be used on vegetables tissues surfaces&lt;br&gt;- No ‘shadow effects’ (all product is treated)</td>
<td>- Scarce information about the mechanism of inactivation&lt;br&gt;- Physicochemical changes in the product may occur&lt;br&gt;- Inactivation is affected by type of microorganisms, inactivation medium, number of cells, operating gas mixture, gas flow, and physiological state of cells</td>
<td>- Inactivation of E. coli O157:H7, Salmonella, S. aureus and L. monocytogenes by 1.5–3.7 log CFU/cm²&lt;br&gt;- Scarce information about interactions with the food or packaging materials&lt;br&gt;- Scarce information about the stability of the plasma for large-scale operation</td>
<td>Bermúdez-Aguirre et al. (2013), Critzer and Doyle (2010), Fernández et al. (2013), Fernández and Thompson (2012), Knorr et al. (2011), Perini, Liu, Shama, and Kong (2008), and Surowsky et al. (2013)</td>
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</table>
using active or passive techniques inside a package made of various types and/or combinations of films (Saxena, Bawa, & Raju, 2008). A drawback of this method is related with the levels of CO₂ generated inside the packages that can not only inhibit the aerobic spoilage microorganisms, but can also allow or even stimulate pathogen growth (Rodriguez-Aguilera, Oliveira, Montanex, & Mahajan, 2009; Rosa, Sapata, & Guerra, 2007).

5.2.1.2. Active and intelligent packaging. In the last decades, one of the most innovative developments in the area of food packaging is the active and intelligent (A&I) packaging, based on deliberate interactions with the food or food environment (Restuccia et al., 2010).

Active packaging refers to the incorporation of certain agents into packaging systems (whether loose within the pack, attached to the inside of packaging materials or incorporated within the packaging materials themselves) to improve food quality and safety and therefore extend their shelf life (Dainelli, Gontard, Spyropoulos, Zondervan-van den Beucken, & Tobbak, 2008; Kerry, O'Grady, & Hogan, 2006). The nature of the active agents that can be added is very diverse (organic acids, enzymes, bacteriocins, fungicides, natural extracts, ions, ethanol, etc.) as well as the nature of the materials into which they are included (papers, plastics, metals or combinations of these materials; Dainelli et al., 2008; Restuccia et al., 2010).

The wide diversity of active packaging devices has specific applications to individual food products for which the shelf-life can be extended substantially, so long as the food's unique spoilage mechanisms are understood and controlled. Many studies can be found, regarding applications of active packaging to food industry (Bolumar, Andersen, & Orlien, 2011; Cruz-Romero, Murphy, Morris, Cummins, & Kerry, 2013).

The purpose of intelligent packaging is to give indication on, and to monitor, the freshness of the food. Substances responsible for the active or intelligent function can be contained in a separate container, for instance in a small paper sachet or as substances directly incorporated in the packaging material (Arvanitoyannis, 2012; Dainelli et al., 2008).

Intelligent packaging gives information to the manufacturer, retailer and consumer based on its ability to sense, detect, or record external or internal changes in the product's environment. It can be used to check the effectiveness and integrity of active packaging systems (Arvanitoyannis, 2012; Kerry et al., 2006).

5.2.1.3. Nanocomposite packaging. Currently the food industry uses packages that are non-degradable, generating environmental problems. Several biopolymers have been exploited to develop materials for eco-friendly food packaging, however their poor mechanical and barrier properties have limited their use (de Azeredo, 2009; Duncan, 2011; Roy, Saha, Kitano, & Saha, 2012).

The use of fillers with at least one nanoscale dimension (nanoparticles) produces nanocomposites. These have larger surface area, which favors the filler–matrix interactions and the performance of the resulting material. Recently, using nanocomposite materials improved fundamental characteristics of food-packaging materials such as strength, barrier properties, antimicrobial properties, and stability to heat and cold (Rhim, Park, & Ha, in press).

Some of the applications associated with nanotechnology include the development of new food-packaging materials with improved mechanical, barrier and antimicrobial properties (de Azeredo, 2009; Duncan, 2011; Roy et al., 2012).

Nanoscale technologies can be a promising technique to improve produce packaging. However, more studies are required before their application in food industry.

5.2.2. Irradiation

Gamma-ray, X-ray, and electron beams are called ionizing radiations, because they are capable of producing ions, electronically charged atoms or molecules. They have the same mechanisms in terms of their effects on foods and microorganisms. The principal target of ionizing radiation is water that produces free radicals, which react, destroy or deactivate bacterial components (Allende et al., 2006b; Rico et al., 2007; Soliva-Fortuny & Martin-Belloso, 2003). Low-dose irradiation is applied to fresh fruits and vegetables to delay produce maturation, and is very effective in reducing bacterial, parasitic, and protozoan pathogens (Lu, Yu, Gao, Lu, & Zhang, 2005; Prakash, Inthajak, Huibregtse, Caporaso, & Foley, 2000).

This treatment has been approved by the FDA for use on fruits and vegetables at a maximum level of 1.0 kGy (Parish et al., 2003). However, FDA evaluated a petition, filed by the Food Irradiation Coalition, asking for the use of irradiation to enhance safety of fresh-cut produce at doses up to 4.5 kGy. In response, they ruled that only for iceberg lettuce and spinach shelf-life extension up to a maximum dose of 4.0 kGy can be used. The use of ionizing radiation on the remaining foods included in the petition remains under review (Food & Drug Administration, H. H. S., 2008).

5.2.3. Ultraviolet light (UV)

Ultraviolet radiation is classified according to wavelength: UV-A, also known as near-ultraviolet radiation, ranges from 315 to 400 nm; UV-B, mid-range UV, from 280 to 315 nm; and UV-C, far-UV, from 100 to 280 nm (Prakash et al., 2000).

UV-C is the most common applied to fresh fruits and vegetables, since it acts directly or indirectly as an antimicrobial agent. UV-C can cause direct bacterial DNA damage or may induce resistance mechanisms against pathogens in different fruits and vegetables. Low doses of UV-C radiation (254 nm) also reduce decay of a wide range of fruits and vegetables when applied after harvest (Ben-Yehoshua & Mercier, 2005).

5.2.4. Pulsed light (PL)

An alternative technology to UV light is pulsed light (PL) also known as high intensity light pulse (HILP) (Palgan et al., 2011).

This treatment is rapid and effective on microbial inactivation in solid and liquid foods and involves a wide broad-spectrum light in the wavelength range of 100–1100 nm. Pulsed light kills microorganisms using short time high frequency pulses of an intense broad spectrum, rich UV-C light. Explanations for its mechanism of action have been given in terms of structural changes of microbial DNA, comparable to the effect caused by continuous ultraviolet sources, but additional mechanisms seem to be involved (Pataro et al., 2011; Vicente et al., 2005).

Since the PL decontamination effect seems to depend on microbial light absorption, certain food components could also absorb the effective wavelengths and decrease the efficiency of this treatment (Ramos-Villarroel, Aron-Maffei, Martin-Belloso, & Soliva-Fortuny, 2012).

Current literature on vegetable and fruit decontamination with PL is scarce (Palgan et al., 2011), therefore more data is necessary to evaluate the suitability of this technology.

5.2.5. High pressure processing (HPP)

High pressure processing is a method where food is subjected to elevated pressures (in the range of 100–1000 MPa) to achieve microbial and enzymatic inactivation, without the degradation in flavour and nutrients associated with traditional thermal processing.

HPP processing can increase chemical or microbial stability and make desirable textural changes in food products. These achievements will depend on pressure, treatment time, and types of enzymes and/or microorganisms (Guerrero-Beltrán, Barbosa-Cánovas, & Swanson, 2005).

As the process can be operated at ambient or even chill temperatures, there is little heat damage to nutrients or natural flavours and colours, which results in high quality products. As shown in several studies, HPP can be suitable for fruit and vegetable products processing. This treatment provides high quality...
food with higher safety and extended shelf-life, while maintaining similar characteristics to fresh products (Guerrero-Beltrán et al., 2005; Laboissonière et al., 2007; Schlüter, Foerster, Geyer, Knorr, & Herppich, 2009).

5.2.6. Ultrasound

The use of ultrasound within the food industry has been a subject of research and development for many years. Power ultrasound (US) has emerged as an alternative processing technology to food conventional thermal approaches (Oey, Lille, Van Loey, & Hendrickx, 2008; Rico et al., 2007). Ultrasound is used at frequencies in the range of 20–100 kHz and requires the presence of a liquid medium for power transmission. On its own, US is not significantly effective on decreasing high load microbial contamination (Alexandre et al., 2012b; Sagong et al., 2011). Due to this reason, this treatment has been used in combination with aqueous sanitizers (e.g. organic acids, chlorine, and chlorine dioxide), showing better results (Cao et al., 2010). The US potential is to improve the aqueous sanitizer’s effectiveness by enhancing the penetration of these solutions to inaccessible sites (hydrophobic pockets and folds in leaf surfaces on fruits and vegetables) (Seymour, Burfoot, Smith, Cox, & Lockwood, 2002).

5.2.7. Cold plasma

An emerging antimicrobial technology for decontaminating infected surfaces is the use of non-thermal ionized gases (cold gas plasmas). Briefly, plasma is composed of gas molecules, which have been dissociated by an energy input. It is constituted by photons, electrons, positive and negative ions, atoms, free radicals and excited or non-excited molecules that, in combination, have the ability to inactivate microorganisms (Fernández, Shearer, Wilson, & Thompson, 2012).

This flexible sanitizing method uses electricity and a carrier gas, such as air, oxygen, nitrogen, or helium. The primary modes of action are due to UV light and reactive chemical products of the cold plasma ionization process (Niemira, 2012).

In food processing, the direct application of cold plasma as well as semi-direct or indirect treatment with thermal plasma is of interest as these can be used to treat the food at low temperatures (≪70 °C). For applications in the food sector, preference should be given to processes carried out at atmospheric pressure (e.g. plasma jet, dielectric barrier discharges) because they allow continuous process control and do not accelerate undesirable phase transitions, compared to applications at reduced pressure (p < 1013 mbar) or low pressure (p < 10 mbar) (Schlüter et al., 2013).

Studies on produce had shown that cold plasma is highly effective on the removal of surface human pathogens, such as E. coli O157:H7 and Salmonella spp. (Fernández, Noriega, & Thompson, 2013; Misra, Tiwari, Raghavarao, & Cullen, 2011; Niemira, 2012; Schlüter et al., 2013; Wang et al., 2012).

The degree of inactivation can be affected by the type of microorganisms, the inactivation medium, number of cells, operating gas mixture, gas flow, and physiological state of cells, among others (Bermúdez-Aguirre, Wemlinger, Pedrow, Barbosa-Cánovas, & García-Pérez, 2013).

There is scarce information about physicochemical changes that might occur in the product due to the interaction of charged species from plasma with the food components (Bermúdez-Aguirre et al., 2013; Knorr et al., 2011; Surowsky, Fischer, Schlueter, & Knorr, 2013).

5.3. Biological methods

In an attempt to prevent growth of pathogens and spoilage microorganisms on produce, research on the application of biocontrol agents has been made. This method is known as biopreservation and consists on extension of the shelf-life and improvement of food safety using microorganisms and/or their metabolites. Some particular microorganisms that have been studied as possessing an antagonistic effect on pathogens are the lactic acid bacteria (LAB). This bacterial group is naturally present in food products and studies suggested that when LAB are applied to produce surfaces they are strong competitors for physical space and nutrients, and/or may produce a wide range of antimicrobial metabolites such as organic acids, hydrogen peroxide, diacetyl and bacteriocins that negatively affect pathogens (Sagong et al., 2011). Bacteriocins are “generally recognized as safe” (GRAS) and have been commonly employed in combination with other food additives as protective agents in fresh-cut produce (Rodgers, 2001, 2008).

Therefore, biopreservation is a promising innovative way of extending the shelf-life of fresh fruits and vegetables, and reducing microbial hazards (Settanni & Corsetti, 2008). Thus, further research on microbial interactions as a pathogens control mitigation strategy in produce is needed.

5.4. Combined methods

Hurdle technology refers to a combination of the different above mentioned preservation techniques that supplement and enhance each other. The most important hurdles commonly used are based on storage temperatures, water activity, pH, redox potential, modified atmosphere, and addition of preservatives (Rahman, Jin, & Oh, 2011; Randazzo, Pitino, Scifo, & Caggia, 2009; Trías, Badosa, Montesinos, & Bañeras, 2008a; Trías, Bañeras, Badosa, & Montesinos, 2008b). The hurdle technology consists on the use of a sequence of mild treatments (low intensity) to inhibit or inactivate the factors responsible for food spoilage, avoiding the use of single treatments at more severe conditions. Efficacy of the combined preservation methods is usually dependent upon the types of treatment, type and physiology of the target microorganisms, characteristics of produce surfaces, exposure time and concentration of cleaner/sanitizer, pH, and temperature (Singla, Ganguli, & Ghosh, 2011). The main goal is to use preservation techniques that prolong storage stability and do not have detrimental effects on the quality attributes of the produce (Parish et al., 2003).

6. Conclusions

Most of the techniques reviewed in this paper have not yet been adopted by the fresh-cut and minimally processed fruit and vegetable industry. Chlorine continues to be the most commonly used sanitizer due to its efficacy, cost-effectiveness ratio and simple use. The effectiveness of all of these technologies depends on the microbial sensitivity to the sanitizer agent used and, consequently, variable results are commonly reported by researchers. In part, the lack of efficiency can be attributed to the disinfectant inaccessibility to structures and tissues that support the growth of microbial flora. Further investigation on specific pathogens/produce combinations is needed.

It can be concluded that there are many different technologies to reduce/eliminate the microorganisms present in fresh-cut fruits and vegetables. The proper use of these techniques will allow an increase safety of the minimally processed products. However, none of the sanitizing methods can control all the parameters that maintain the quality and shelf-life of MFPVs. Therefore, additional studies using combined methods or using competitive microflora to extend and enhance the safety of this kind of products are crucial.

Acknowledgments

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and Rosmarinus officinalis L. to inhibit bacteria and autochthonous microflora associated with minimally processed vegetables. Food Research International, 44(5), 1541–1548.


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