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# Fresh-Cut Fruit and Vegetables: Emerging Eco-friendly Techniques for Sanitation and Preserving Safety

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<http://dx.doi.org/10.5772/intechopen.69476>

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## Abstract

The current high demand of minimally processed or fresh-cut fruit and vegetables results from the consumer's desire for healthy, convenient, fresh, and ready-to-eat plant food-derived commodities. Fresh-cut fruits and vegetables are usually packaged under active- or passive-modified atmosphere packaging, while its shelf life must be under refrigerated conditions. The most important goal to preserve quality and safety focuses on releasing the microbial spoilage flora, since every unit operation involved will influence the final load. Sanitation in the washing step is the only unit operation able to reduce microbial load throughout the production chain. Chlorine is widely used as an efficient sanitation agent, but some disadvantages force to find eco-friendly emerging alternatives. It is necessary to deal with aspects related to sustainability because it could positively contribute to the net carbon balance besides reducing its use. Several innovative techniques seem to reach that target. However, industrial changes for replacing conventional techniques request a fine knowledge of the benefits and restrictions as well as a practical outlook. This chapter reviews the principles of emerging eco-friendly techniques for preserving quality and safety of fresh-cut products in order to meet the expected market's demand.

**Keywords:** minimally processed, ready-to-eat, sanitizing, pathogens, food safety

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## 1. Introduction

The benefits of fruit and vegetables consumption on human health are well known, being linked with prevention of a grand array of diseases such as degenerative disorders, cancer, and cardiovascular, among others [1]. Consequently, their intake has been promoted among

consumers by nutritionists, researchers, and even at a governmental level (i.e., campaigns like *five-a-day*, etc.). However, the actual consumer's demand of new food was elaborated by the industry with the following characteristics: freshness, healthiness, and easy- or ready-to-eat. Particularly, minimally processed or fresh-cut (FC) fruit and vegetables connect well within such consumer needs. The main advantage of FC plant foods is that they have nearly the same properties as the whole intact product, but they do not need much elaboration time and are with a uniform and consistent quality [2]. NaOCl has been widely used in the FC industry as a strong sanitizing agent due to its powerful oxidizing properties [3]. Among the main NaOCl advantages are high effectiveness, comparatively inexpensive, and that they may be implemented in any size operations [4]. Nevertheless, NaOCl may produce unhealthy by-products in processed water (chloramines, chloroform, haloacetic acids, or other trihalo-methanes) that have been reported to present carcinogenic or mutagenic effects, with proven toxicity to liver and kidneys [3]. Therefore, NaOCl use in the FC industry has been forbidden in some European countries [5].

This chapter summarizes the principles and development of eco-friendly techniques for preserving safety of FC products in order to meet the expected market's demand.

## 2. Antimicrobial washing solutions

### 2.1. Peroxyacetic acid

Peroxyacetic acid (PAA), or peracetic acid, is a colorless organic peroxide that is a mixture of acetic acid and hydrogen peroxide. It is an eco-friendly sanitizer whose breakdown products are acetic acid, O<sub>2</sub>, CO<sub>2</sub>, and water. PAA is approved by the European Union as a disinfectant for drinking water and food areas and as an in-can preservative [6]. PAA is also permitted by the U.S. Food and Drug Administration as an additive for food [7]. The surface-cleaning concentrations range from 85 to 300 ppm, although 50 ppm has been reported to be enough [8]. PAA is mainly used in fruit and vegetable processing due to tolerance to several factors such as temperature, pH (1–8), hardness, and soil contamination. A recommended combination of 11% hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) and 15% PAA, at 80 ppm, was proposed for the disinfection of plant surfaces [4]. *Escherichia coli* O157:H7 and *Salmonella* spp. reductions of 2–3 log CFU g<sup>-1</sup> were reported in apples and melons treated with 70 ppm of PAA [9, 10]. Similarly, *E. coli* O157:H7, *Salmonella* spp., and *Listeria monocytogenes* inoculated on FC carrot shreds were reduced after PAA washing at 40 ppm for 2 min [11]. Mesophilic and psychrotrophic loads of FC Galia melon were reduced by 1 and 2 log CFU g<sup>-1</sup>, respectively, using PAA (68 ppm) [12]. The nutritional and sensory quality of FC iceberg lettuce was not affected by PAA (120 ppm), while natural microflora was reduced by approximately 1 log CFU g<sup>-1</sup> [13]. A similar *Salmonella typhimurium* reduction was achieved after the PAA treatment (40 ppm) in inoculated lettuce [14]. A PAA treatment of 80 ppm was more effective than 106 ppm of NaOCl to reduce *E. coli* O157:H7 and *Salmonella enterica* Montevideo on mung bean sprouts [15]. *E. coli* and *Salmonella enteritidis* reductions of 2–3 log CFU g<sup>-1</sup> were achieved in the kailan-hybrid broccoli with 100 ppm of PAA being more effective than 100 ppm of NaOCl [16].

## 2.2. Chlorine dioxide

Chlorine dioxide ( $\text{ClO}_2$ ) is a yellowish-green stable dissolved gas that has been used for the last decades for water treatment as a potential alternative to NaOCl.  $\text{ClO}_2$  has higher effectiveness over a broad range of pH, higher water solubility (10 times higher than NaOCl), higher oxidant capacity, lower reactivity with organic matter, and higher effectiveness at low concentrations than NaOCl [17]. Nevertheless,  $\text{ClO}_2$  is a very unstable substance and is highly explosive as a concentrated gas when concentrations  $\geq 10\%$  are reached in air. Hence,  $\text{ClO}_2$  must be generated on-site by two different procedures: reacting an acid with sodium chlorite or the reaction of sodium chlorite with chlorine gas then being obtained in either aqueous or gaseous forms, respectively [18]. The  $\text{ClO}_2$  is classified as a non-carcinogenic product since it does not ionize to produce weak acids (as occurred for chlorine and bromine) or to form carcinogenic by-products like trihalomethanes [19]. Gaseous  $\text{ClO}_2$  treatment (100 ppm) of several fresh products (tomatoes, lettuce, cantaloupe, alfalfa sprouts, oranges, apples, and strawberries) did not leave any chemical residues on them [20].  $\text{ClO}_2$  is approved in the USA for usage in washing whole fresh fruits and vegetables and shelled beans and pears with intact cuticles at maximum levels of 5 ppm and 1 ppm for peeled potatoes [19].

$\text{ClO}_2$  is considered as a strong microbicide at low levels such as 0.1 ppm, achieving also a rapid removal of biofilms which avoid bacterial re-growth [21]. The bactericidal effect of  $\text{ClO}_2$  is explained by the interruption of several cellular processes (proteins production and changes in the cell structure) when organic substances in bacterial cells react with  $\text{ClO}_2$ . On viruses,  $\text{ClO}_2$  reacts with peptone to prevent the protein formation being more effective than chlorine or ozone [21]. Inoculated pathogens like *Salmonella* spp., *E. coli* O157:H7, and *L. monocytogenes* were reduced on cabbage, carrot, lettuce, strawberry, and melon with  $\text{ClO}_2$  concentrations of 4–5 ppm [22–26].  $\text{ClO}_2$  treatment at 100 ppm of FC cucumber, lettuce, carrot, apple, tomato, and guava reduced total bacterial and coliform counts up to 3.5–4.0 log CFU  $\text{g}^{-1}$  being more effective than the same NaOCl concentration [27]. A  $\text{ClO}_2$  treatment of 3 ppm substantially prevented *E. coli* O157:H7 cross-contamination but was not effective for the inoculated *Salmonella* in FC Red Chard [28]. The effectiveness of  $\text{ClO}_2$  treatment of tomato processing water under a range of water quality and temperature was studied, which showed that an increase in temperature and  $\text{ClO}_2$  concentration reduced the contact time achieving a 6-log reduction of *S. enterica* within 2 min of contact time [29]. Acidified sodium chlorite (100–500 ppm) at low-moderate doses showed an initial antimicrobial efficacy on natural microflora and *E. coli* of FC tatsoi baby leaves as effective as that of 100 ppm NaOCl [30].

## 2.3. Hydrogen peroxide

Hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) is a strong oxidizer able to generate other cytotoxic-oxidizing species, like hydroxyl radicals, with strong bactericide (including spores) effect [31].  $\text{H}_2\text{O}_2$  is an eco-friendly disinfectant since it is rapidly decomposed into water and oxygen in the presence of catalase. Likewise, it is colorless and non-corrosive.  $\text{H}_2\text{O}_2$  is allowed for use in food processing and packaging but not as a sanitizing agent for fresh produce by the FDA [5]. However, high  $\text{H}_2\text{O}_2$  concentrations are needed to achieve good sanitising effects in FC products. However, such high concentrations may lead to browning being necessary the use of anti-browning agents

like sodium erythorbate [32]. Accordingly,  $2\text{--}3 \times 10^4$  ppm  $\text{H}_2\text{O}_2$  were needed to reduce *E. coli* O157:H7 by 1.6 log CFU  $\text{g}^{-1}$  in baby spinach [33]. *L. monocytogenes* reductions of 2.0–3.5 log CFU  $\text{cm}^{-2}$  were reported in melon surfaces after  $5 \times 10^4$  ppm  $\text{H}_2\text{O}_2$  treatment [34]. Effectiveness of  $\text{H}_2\text{O}_2$  treatment (3%) on inoculated *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* in whole cantaloupe rind surfaces was enhanced when applied at 80°C for 300 s [35].  $\text{H}_2\text{O}_2$  has been also found to extend the shelf life and reducing native microbial and pathogen populations in whole grapes, prunes, apples, oranges, mushrooms, melons, tomatoes, red bell peppers and lettuce, and in FC cucumber, zucchini, bell peppers, and melons [5, 36]. Nevertheless, the cross-contamination may not be avoided with  $\text{H}_2\text{O}_2$ , since it may still occur in the product washing water and its breakdown is rapid with low disinfection kinetics [37].

#### 2.4. Weak organic acids

Weak organic acids have been widely used as preservatives for the prevention of several quality degradation processes such as enzymatic and nonenzymatic browning, texture deterioration, and microbial spoilage. Contrary to NaOCl, weak organic acids do not produce toxic or carcinogenic compounds when they interact with organic molecules [38]. Therefore, several weak organic acids are considered as GRAS (Generally Recognized as Safe) by the FDA and European Commission being well accepted by consumers. The antimicrobial effect of weak organic acids is related to the cytoplasm acidification, osmotic stress, disruption of proton motive force, and synthesis inhibition of macromolecules [39]. Weak organic acids are more effective for bacteria than for yeasts and molds because of the low pH (2.1–2.7) of the applied solutions. Citric, acetic, lactic, and ascorbic acids are the most common acids applied in the food industry.

Citric acid, contrary to other acids, acts as a chelating agent of metallic ions of the medium, avoiding microbial growth [40, 41]. Citric acid treatment (0.52 mM) maintained microbial safety and visual quality of FC “Amarillo” melon during a shelf life of 10 days at 5°C [42]. A solution of 0.1 M citric and 0.5 M ascorbic acid achieved the same effectivity as 100 ppm NaOCl to control microbial growth and maintain quality of green celery crescents [43]. Citric and lactic acid dippings of  $0.5\text{--}1 \times 10^4$  ppm achieved comparable *E. coli* reductions of 1.9–2.3 log CFU  $\text{g}^{-1}$  to 100 ppm NaOCl in inoculated FC lettuce without significant efficacy enhancement from incrementing dipping times from 2 to 5 min [44]. Likewise, acetic and citric acid dippings of  $0.5\text{--}1 \times 10^4$  ppm achieved similar *L. monocytogenes* reductions of 0.8–1.0 log CFU  $\text{g}^{-1}$  to 100 ppm NaOCl in inoculated FC lettuce [44]. However, acetic acid and ascorbic acid dippings of  $0.5\text{--}1 \times 10^4$  ppm achieved lower *E. coli* reductions than 100 ppm NaOCl in inoculated FC lettuce [44]. The effectiveness of citric, acetic, lactic, malic, and propionic acid dippings ( $1 \times 10^4$  ppm) for inoculated *E. coli* O157:H7, *L. monocytogenes*, and *S. typhimurium* onto fresh lettuce was studied with reductions of 1.9–2.9, 1.1–1.7, 1.9–2.5, 2.3–3.0, and 0.9–1.5 log CFU  $\text{g}^{-1}$ , respectively [45].

#### 2.5. Calcium, sodium, and potassium-derived salts

Several salts are recognized as GRAS being a low-cost material for the food industry with high acceptance by the consumers, since it is not toxic. Calcium is used to retain the firmness of plant commodities by interaction with pectin to form calcium pectate maintaining then the cell wall structure. FC lettuce treated with  $15 \times 10^3$  ppm calcium lactate showed higher

crispness than samples treated with 120 ppm NaOCl after 1 day at 4°C [46]. Latter authors hypothesized that such finding could be owed to the activation of texture-related enzymes, like PME, by the calcium absorption in the lettuce, or an increase in diffusive processes by temperature, including the calcium. Similar results were obtained by  $15 \times 10^3$  ppm calcium lactate treatment at 50°C of sliced FC carrots to maintain the cortex turgor of plant cells and reduce the lignification degree in cut surfaces [47]. However, the calcium lactate antimicrobial properties have been scarcely studied. FC lettuce and carrots treated with  $3 \times 10^4$  ppm calcium lactate showed similar microbial loads than 120 ppm NaOCl after 10 days at 4°C [48]. Similarly,  $3 \times 10^4$  ppm calcium lactate treatment at 60°C of FC melon induced 1–2 log CFU g<sup>-1</sup> lower bacterial and yeasts and mold loads after 8 days at 5°C, while texture of such melon pieces was better maintained than samples washed with water at the same temperature [49]. Latter authors also found that other calcium salt treatments (calcium chloride and calcium propionate) maintained lower microbial loads in the FC melon samples after 8 days at 5°C. Calcium pre-treatments may also help to prevent enzymatic browning reactions during high-pressure processing (HPP) of peaches if the penetration of Ca<sup>2+</sup> reaches the target area, which is the tonoplast or vacuolar membrane as observed in peaches [50].

Sodium bicarbonate, sodium carbonate, sodium silicate, potassium bicarbonate, potassium carbonate, and potassium sorbate have been studied [51]. Among them, sodium carbonate and sodium bicarbonate (at 3% w/v) reduced up to 100% disease (*Penicillium* sp.) on inoculated fresh clementines and oranges [51]. Calcium carbonate maintained lower microbial loads in the FC melon samples after 8 days at 5°C [49]. However, little is known about the mode of action of these salts, although other possible mechanisms, apart from the high salt pH, like the induction of host defence responses might be involved [52].

## 2.6. Electrolyzed oxidizing water

Electrolyzed oxidizing water (EOW) is formed in an electrolysis chamber by the electro dialysis of a NaCl solution between an anode and a cathode [53]. Acidic EOW (pH 2.5–3.5; oxidation-reduction potential (ORP) 1000–1200 mV) is produced in the anode and alkaline EOW (pH 10–11.5; ORP -800 to -900 mV) is produced in the cathode. HCl, HOCl, Cl<sub>2</sub>, OCl<sup>-</sup>, and O<sub>2</sub> are formed in the anode, while the cathode produces hydroxyl ions, which can react with Na ions generating NaOH. EOW contains free chlorine as the main microbial inactivation agent showing higher microbicidal effect against pathogens and spoilage microorganisms than NaOCl [16, 54, 55]. EOW is considered as an eco-friendly technology that presents the following advantages over other sanitizing methods: easy-to-find and cheap materials (NaCl and water), simple and on-site production, and low operational expenses and trihalomethanes formation. Additionally, some cell electrodes, like boron-doped diamond electrodes, are able to oxidize organic matter, reducing then the environmental footprint of wastewater from fresh produce industry [56]. Nevertheless, EOW has a short shelf life, in some cases, being necessary to be produced on-site and recommended in a ventilated area due to the Cl<sub>2</sub> and H<sub>2</sub> production [5]. EOW has been approved at maximum concentration of 200 ppm by the FDA [57]. Neutral EOW (pH 7; ORP 700 mV) can be produced by the mixture of acidic and alkaline EOW [58]. The additional advantages from using neutral EOW are that it does not affect surface color, general appearance, or pH of FC vegetables [54].

EOW has been used in several works as an excellent disinfestation method of food equipment surfaces and tools reaching up to 9 log CFU cm<sup>-2</sup> reductions for several pathogen biofilms like *L. monocytogenes*, *E. coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* [59–61].

The EOW (15–50 ppm free chlorine) was early studied on FC carrots, spinach, bell pepper, potato, and cucumber being considered as an effective disinfectant able to reduce microbial loads by 0.6–2.6 log units without product discoloration [54]. Neutral EOW (100 ppm free Cl; pH 7) achieved 0.5, 1.3, and >2.1 log mesophilic, psychrophilic, and yeast and mold reductions, respectively, in FC kailan-hybrid broccoli, showing similar microbial loads and good sensory quality to NaOCl-treated (100 ppm) samples after 19 days at 5°C [62]. Neutral EOW also showed similar microbial effectiveness to NaOCl to reduce natural microflora of FC lettuce with no impact on its physical and sensory quality [63–65]. Acidic and neutral EOW treatments at 70 and 100 ppm free Cl were studied on two broccoli varieties showing neutral EOW (100 ppm) the best microbial reductions after shelf life comparing to NaOCl (100 ppm) [58]. Furthermore, EOW-treated samples showed higher (up to 30%) total phenolic content and more stabilized myrosinase activity (the enzyme responsible for the formation of the bioactive isothiocyanates (ITC) in broccoli) than NaOCl-treated samples after shelf life [58]. Microbial reductions of 1–2 log units were observed in FC mizuna baby leaves treated with acidic EOW (40–100 ppm free Cl) and neutral EOW (40–100 ppm free Cl), with similar microbial effectiveness to NaOCl 100 ppm, showing neutral EOW better bacteriostatic effects than acidic EOW in some cases [66]. The sensory quality, physical structure, and health-promoting compounds of EOW-treated FC mizuna baby leaves were not significantly affected [66]. Neutral EOW (100 ppm free Cl) treatment reduced counts of inoculated *E. coli* and *S. enteritidis* in FC kailan-hybrid broccoli by approximately 2.6 log CFU g<sup>-1</sup>. Nevertheless, the effectiveness of the last treatment was not increased when it was combined with ultraviolet (UV)-C (7.5 kJ m<sup>-2</sup>) treatment. Similarly, neutral EOW treatment (306 ppm free Cl) of romaine lettuce reduced inoculated *E. coli* O157:H7, *S. typhimurium*, and *L. monocytogenes* loads by 2.0 log CFU g<sup>-1</sup> [67]. *E. coli* O157:H7 grew slower in FC lettuce treated with NEW (50 ppm free Cl) during storage at 13–16°C, while no microbial growth was observed if the product was stored at ≤8°C [68].

The use of different organic and inorganic salts has been studied to increase electrolysis efficacy and avoid the corrosive effects of NaCl on equipment. Particularly, electrolyzed sodium bicarbonate allowed to control postharvest citrus rots as a result of direct inhibition and the induction of fruit resistance-response mechanisms showing normal electrolyzed water a less marked effect [69].

## 2.7. Ozone

Ozone (O<sub>3</sub>) is a colorless gas with a pungent odor having an oxidizing potential (+2.07 V) 1.5 times higher than that of chlorine, which oxidizes the cell components of the microbial cell wall [70]. Ozone half-life is very short, from seconds to hours depending on temperature and water quality [71]. Thus, O<sub>3</sub> is commercially generated on-site by submitting oxygen, or air, to ultraviolet radiation (285 nm) or through an electrical charge leading to the cleavage of oxygen molecules to form ozone [5, 72].

Ozone solubility is 12 times lower than that of NaOCl. Nevertheless, ozone concentrations as low as 1–5 ppm are enough to reach good antimicrobial reductions. Nevertheless, higher O<sub>3</sub> concentrations are needed when it is applied as a gas treatment since its penetration into the cells, to achieve the disinfection effect, is affected by the humidity of the air [40, 73]. The O<sub>3</sub> effectiveness may be increased at lower pH (more stable) and temperature (higher residual ozone concentrations), higher relative humidity of the storage room (increasing its solubility on the moisture present on produce surfaces), and purity of the water (ozone is consumed by the matrix components reducing its efficacy) [74]. Ozone is spontaneously decomposed to the non-toxic O<sub>2</sub> when applied. Accordingly, O<sub>3</sub> has been approved as a GRAS product by the FDA to be used in the food industry [75]. However, O<sub>3</sub> can cause irritation to eyes and throat (at concentration higher than 0.2 ppm) of plant operators, is highly corrosive to the equipment, and the physicochemical properties of treated produce may be altered [5].

An ozonated water treatment at 0.4 ppm for 3 min has been recommended to maintain microbiological quality and firmness of tomato slices while it did not affect the physicochemical quality and organic acid contents [76]. The levels of *Salmonella* spp. inoculated in melons were reduced between 4.2 and 4.8 log CFU/rind-disk (12 cm<sup>2</sup>) after a gaseous ozone treatment (10,000 ppm for 30 min under vacuum system) [77]. Counts of inoculated *E. coli* O157:H7 in spinach leaves were also decreased under a novel gaseous system capable of generating O<sub>3</sub> inside the sealed package at various geometries [78]. Respiration rate and browning of FC celery were reduced, while sensory quality was well maintained using ozonated water at 0.18 ppm for 5 min [79]. Ozonated water at 1 ppm reduced both enzyme activity and enzymatic browning of shredded lettuce [80]. Nevertheless, the latter enzyme inactivation showed a negative effect, as the reduction in activity of the texture-related pectin methyl esterase was correlated with a lower crispiness. FC rocket treated with ozonated water at 5 ppm for 10 min showed better sensory scores and microbial quality (psychrophilic and yeast and molds) than untreated samples after 12 days at 5°C, while total chlorophylls and carotenoids contents were unchanged [81]. Mesophilic, psychrotrophic, and yeast counts of FC tomato slices treated with ozonated water (3.8 ppm for 3 min) showed 1.9, 1.6, and 0.7 lower log units, respectively, than untreated samples after 10 days at 5°C [82]. The enzymatic antioxidant system of FC green peppers treated with gaseous ozone (6.42 mg cm<sup>-3</sup> for 15 min) was induced during storage at 5°C, while polyphenol oxidase activity was reduced. A synergistic effect was even observed when the latter ozone treatment was combined with modified atmospheric packaging (3% O<sub>2</sub>, 4% CO<sub>2</sub>, and 93% N<sub>2</sub>) of green peppers [83].

Nevertheless, O<sub>3</sub> seems to be not always highly effective. In that sense, low (<0.5 log units) inhibitory effect on mesophilic, psychrophilic, enterobacteria, molds, and LAB loads of FC “Galia” melon washed with ozonated water (0.4 ppm, up to 5 min) was observed after 10 days at 5°C, registering even higher yeast and molds compared to untreated samples [84]. However, FC ‘Galia’ melon washed for just 1 min with 80 ppm PAA showed the lowest microbial loads after 10 days at 5°C. However, the latter PAA antimicrobial effect was reduced when it was combined with ozonated water treatment. On the other side, FC “Galia” melon samples treated with ozonated water reduced respiration rates, while sugar contents and vitamin C were better maintained [84]. Shredded “Iceberg” lettuce treated with ozonated water (1 ppm, 120 s) showed lower sensory and microbiological quality than samples treated with NaOCl (200 ppm, 120 s) [85].

## 2.8. Essential oils

High antimicrobial properties have been studied with several plant essential oils (EOs) [86]. Generally, EOs possessing the strongest antibacterial properties are those that contain phenolic compounds such as carvacrol, eugenol, and thymol [87, 88]. In general, the mechanism of action of EOs against microorganisms involves the interaction of phenolic compounds with the proteins (porins) in the cytoplasmic membrane that can precipitate and lead to ions leakage of and other cell contents causing cell lysis [89]. Carvacrol solutions have shown good antimicrobial effects in different FC fruit and vegetables like lettuce, kiwifruit, apples, and melons treated with carvacrol-containing washing solutions [90–92]. Thymol (from thyme and oregano) and eugenol (from clove, *Syzygium* spp.) have also shown high antimicrobial and antioxidant effects on MAP-stored table grapes [93].

The EOs concentrations should be increased when tested *in vivo* in order to reach the same effectiveness than that observed *in vitro*. However, such high EOs concentrations may lead to EOs-related off-flavors transmission to the product. Furthermore, the lipophilic nature of EOs difficult their solution in the water-based washing solutions [86]. Therefore, the reduction of the EOs particle size (<100 nm) has been proposed as an alternative to improve EO antimicrobial efficiency through two important targets: (i) the possibility of enhancing physicochemical properties and stability; and (ii) the ability of improving biological activity of lipophilic compounds by increasing the surface area per unit of mass [94]. The antimicrobial and physical properties of different EOs (lemongrass, clove, tea tree, thyme, geranium, marjoram, palmarosa, rosewood, sage, or mint) have been reported to be enhanced when they were processed to nanoemulsions [94]. Such nanotechnology has been recently applied in FC carrots using nanoencapsulated carvacrol particles' incorporation in a washing solution, which reduced the characteristic off-flavors and EOs oxidation while keeping good microbial quality of the product during shelf life [95]. Furthermore, EOs may be included as antimicrobial agents in packaging films as reported of FC vegetables as proposed in a study using a carvacrol–polylactic acid film to inhibit *E. coli* ATCC 8739, *Fusarium oxysporum*, *Geotrichum candidum*, and *Phytophthora* spp. [96].

## 2.9. Isothiocyanates

Isothiocyanates (ITC) are sulfur compounds that can be formed in the *Brassica* vegetables after hydrolysis of glucosinolates by plant myrosinase. Antimicrobial activity of ITC has been reported for a wide range of foodborne microorganisms [97, 98]. The antimicrobial mechanism of ITC is not still clear, although it is hypothesized to be owed to the electrophilic nature of the central carbon atom located in the N=C=S group [99]. Among them, allyl-isothiocyanate has also shown high antimicrobial activity being listed as a GRAS [100]. FC lettuce treated with a washing solution of 75 ppm of benzyl-isothiocyanate (5 min) achieved a complete removal of total bacteria and inoculated *Salmonella* in the wash water, which proved to persist such antimicrobial effects in the processed water up to 48 h [101]. However, the low solubility of ITC highly limits its application as a sanitizing water treatment in the FR industry. Accordingly, integration of ITC in edible coatings of FC produce has been proposed with a longer antimicrobial effect due to slower release from the coating [96].

### 3. Biological-based methods

#### 3.1. Bacteriocins

Bacteriocins are toxins of protein nature that are synthesized by bacteria to inhibit the microbial growth of similar or closely related bacterial strains. The solubility of bacteriocins may increase at lower pH, facilitating diffusion of bacteriocin molecules [102]. Nisin is a food-grade bacteriocin produced by *Lactococcus lactis* that is widely used in the food industry. The antimicrobial activity of this bacteriocin is owed to its action on the cell membrane forming pores leading to the microbial cell death [103]. Nisin is principally effective against Gram-positive bacteria, while it is not active against Gram-negative bacteria due to their outer membrane [104]. However, the nisin efficacy may be increased also due to Gram-negative bacteria using chelating agents (e.g., ethylene diaminetetracetic acid [EDTA]), acids, or osmotic shock, with the outer membrane destabilized before the nisin application [103]. Attending to natural microflora, a mesophilic reduction of approximately 2 log CFU g<sup>-1</sup> was reached in FC “Galia” melon after a nisin (0.250 g L<sup>-1</sup>) treatment combined with EDTA (0.100 g L<sup>-1</sup>) and citric acid (2.0 g L<sup>-1</sup>) [105]. Nisin and other bacteriocins (pediocin, coagulin, plantaricin C, and lacticin 481) were also tested in FC lettuce inoculated with *L. monocytogenes*, inducing nisin and coagulin a reduction of pathogen viability by 1.2–1.6 log units [106]. The inclusion of nisin (IU mL<sup>-1</sup>) in a pectin coating applied on FC “Rojo Brillante” persimmon completely inhibited the growth of mesophilic bacteria and inoculated *E. coli*, *S. enteritidis*, and *L. monocytogenes* [107]. Nisin treatment (0.03% for 10 min) controlled microbial growth and maintained quality of Chinese yam during storage at 4°C [108]. Bacteriocin RUC9 produced by *L. lactis* reduced by 2.7 log units, the *L. monocytogenes* loads inoculated in FC lettuce, while nisin only achieved a pathogen reduction of 1.9 log units [109].

#### 3.2. Biological control

The use of biological preservation (strains of *Enterobacteriaceae*, lactic acid bacteria, yeasts, and molds) has also been studied in several products like lettuce, apples, peaches, and strawberries [110–113]. Recently, the application of the strain CPA-7 of *Pseudomonas graminis*, isolated from apples, could reduce the foodborne pathogens on FC apples, peaches, and melon [114, 115]. Such antimicrobial effects of these antagonists may be explained by the triggered activity of defence-related enzymes [116].

#### 3.3. Bacteriophages

Bacteriophages are viruses that infect and replicate in a bacteria causing their lysis and death [117]. Bacteriophages were earlier studied on FC fruit like apples and melons [118]. *S. typhimurium* and *S. enteritidis* inoculated in lettuce were highly reduced by 3.9 and 2.2 log units, respectively, using different lytic bacteriophages treatments for 60 min at room temperature [119]. Nevertheless, bacteriophages treatments should be optimized due to the impractical application in the FC industry. Accordingly, integration of bacteriophages in edible coatings of FC produce has been proposed as an effective antimicrobial coating in tomatoes, with such phages being stable up to 1 week at 4°C [120].

## 4. Physical-based treatments

### 4.1. Mild heat treatments

The use of mild heat treatments is a promising sanitizing technique for the FC industry, which may extend the FC product shelf life through microbial destruction and partial enzymatic inactivation. However, the treatment temperature and exposure time should be carefully selected for each product due to possible undesirable changes of sensory and nutritional quality. Fruit and vegetables treated by heat treatments within the range 40–60°C for 1–5 min, depending of the commodity, are still considered as a fresh product as it is defined [17, 121].

Hot water and vapor treatments have been studied in several fresh-cut commodities like pomegranate arils [122, 123], kiwifruit [124], lemons [125], peaches [126], apples [127], sunchoke [128], lettuce [46, 129, 130], rocket [131], spinach [132, 133], celery [134], eggplants [135], and onions [136]. PPO activity of fresh-cut pomegranate arils was 1.3-fold reduced by a hot water treatment at 55°C for 30 s, while total anthocyanins contents were similar to those of untreated samples after 7 days at 5°C [137].

Short vapor treatments, usually up to 15 s, usually steam jet-injection systems, have been also used as an alternative to hot water treatments due to less impact on sensory quality of the FC product. Accordingly, vapor treatment (95°C; 7–10 s) kept better quality of FC pomegranate arils [138] compared to the hot water (55°C; 30 s) treatment [139] during storage at 5°C, increasing the shelf life from 7 to 18 days. Furthermore, vapor heat treatments reduced up to 2-fold the total antioxidant capacity losses observed in fresh-cut pomegranate arils sanitized by conventional NaOCl treatment during shelf life [138]. Steam jet-injection treatment of fresh-cut lettuce for 10 s reduced respiration rate, partially inactivated browning-related enzymes and kept the mesophilic load as low as with a conventional NaOCl treatment [46]. Nevertheless, further research is needed to optimize the exposure conditions for FC commodities.

Heat treatments by microwave (750 W for 45–60 s) have been recently proposed to reduce natural microflora of FC carrots, which also prevented whitening and surface drying of samples during storage up to 7 days at 5°C [140]. The increased microbial growth due to plant cell disruption after the heat treatment may be controlled with the use of combined storage under modified atmosphere packaging.

### 4.2. UV radiation

Ultraviolet (UV) light is an electromagnetic radiation divided in four groups: UV-A, UV-B, UV-C, and vacuum UV [141]. UV-C radiation ( $\lambda = 190\text{--}280$  nm) is a promising sanitizing technology for FC products, which offers several advantages: it does not leave any residue, no legal restrictions, easy to use, and it does not require extensive safety equipment to be implemented [142, 143]. UV-C is a non-ionizing radiation, which means it is an electromagnetic radiation that does not carry enough energy/quantum to ionize atoms or molecules and is represented mainly by visible light, UV rays, microwaves, and infrared. UV-C radiation in the range 250–260 nm is lethal to most microorganisms, including bacteria, viruses,

protozoa, mycelial fungi, yeasts, and algae, showing the maxima germicidal effectiveness at 254 nm [144]. UV-C germicidal effect is based on the ability of this radiation to alter microbial DNA through dimer formation [142]. If the damage goes unrepaired, the accumulation of DNA photoproducts can be lethal to cells through the blockage of DNA replication and RNA transcription, which ultimately result in reproductive cell death. Nevertheless, it has been also stated that UV-C may lead to the conversion of bacteria in the viable but non-cultivable state as a strategy of protection against the UV-C germicidal effect (to economize on energy, induction of repair mechanisms, inhibit the generation of mutant bacteria, etc.) [145]. UV-C is a superficial sanitizing treatment with low penetration in the plant tissue as observed in carrot tissue where a transmittance below 20% was observed in a 0.1-mm layer of the carrot epidermis [146]. Accordingly, a UV-C treatment of 0.4 kJ m<sup>-2</sup> applied to iceberg lettuce internally inoculated (using vacuum system) with *Salmonella* Montevideo P2 did not achieve significant pathogen reduction, while the same UV-C dose achieved a 2-log CFU g<sup>-1</sup> reduction on the surface-inoculated lettuce [147]. UV-C effectiveness appears to be dependent on the treatment temperature, distance between sample and lamp, direction of lamp, UV intensity, and exposure time [148, 149]. Cell permeability may be changed with UV-C, depending on the tissue and UV dose, leading to increase of electrolytes, amino acids, and carbohydrates leakage, which can enhance the microbial growth [150]. Accordingly, the crucial point is to apply an appropriate UV-C dose that achieves the maximum microbial reduction without damaging the product.

The UV dose ( $D$ ; usually expressed in kJ m<sup>-2</sup>) is directly proportional to the product of UV intensity ( $I$ ; usually expressed in W m<sup>-2</sup>) and exposure time ( $t$ ) according to the equation:  $D = I \times t$ . The three pathogens regulated for FC products (according to the European Regulation [151]), *E. coli*, *Salmonella* spp., and *L. monocytogenes*, were inoculated in the kailan-hybrid broccoli, and the inactivation rates with UV-C doses up to 15 kJ m<sup>-2</sup> were modeled [149]. The inactivation curves showed a pronounced tailing effect achieving a UV-C dose of 2.5 kJ m<sup>-2</sup> *E. coli*, *S. enteritidis*, and *L. monocytogenes* reductions of 1.22, 2.61, and 0.72 log cycles, respectively. Hence, *S. enteritidis* was the most sensitive microorganism, while *L. monocytogenes* was the most resistant. Doses higher than 2.5 kJ m<sup>-2</sup> led to further additional inactivation in the inoculated kailan-hybrid broccoli, although the most important inactivating effect was achieved in the range 0–2.5 kJ m<sup>-2</sup> as similarly found in other FC products [149, 152].

The UV-C effectiveness on natural microflora has also been studied in several FC fruit and vegetables. UV-C treatments (0.49, 4.9, and 9.8 kJ m<sup>-2</sup>) of FC zucchini slices reduced microbial activity and deterioration during subsequent storage at 5 or 10°C [153]. Mesophilic loads of FC pomegranate arils were reduced by approximately 1 log units after 4.5 kJ m<sup>-2</sup>, while yeasts were reduced >1.8 log units [139]. Similarly, UV-C radiation doses (4.5–9 kJ m<sup>-2</sup>) of the kailan-hybrid broccoli reduced mesophilic loads by approximately 1.2 log units while enterobacteria and psychrophilic were unaffected [62, 154]. However, combination of UV-C with NEW in kailan-hybrid broccoli or with hot water (55°C for 30 s) in FC pomegranate arils did not achieve further microbial inactivations [62, 139]. FC tomatoes treated with a UV-C dose of 4 kJ m<sup>-2</sup> and stored for 21 days at 12°C under MAP (5 kPa O<sub>2</sub> +1 kPa CO<sub>2</sub>) retarded ripening and maintained better firmness

and sensory attributes than UV-C treated samples stored under air conditions [155]. The range of 0–2.5 kJ m<sup>-2</sup> UV-C dose achieved the most important mesophilic reductions in treated date palm [156]. The UV-C sanitizing effect has been studied in a wide FC products such as tomato [157], strawberry [158], watermelon [159], potatoes [160], and lettuce [161], among others.

Increases in bioactive compounds of several fruit and vegetables after UV treatments have been reported. Such enhancements of health-promoting compounds have been reported to be a consequence of the free radicals generated during irradiation that might act as stress signals and trigger stress responses leading to the observed bioactives increments [162]. Broccoli exposed to several UV-C doses (1.5–15 kJ m<sup>-2</sup>) registered increases in its polyphenols content (up to 25%) after 19 days at 5°C [154]. FC tomatoes UV-C treated (0.97 kJ m<sup>-2</sup>) showed higher total phenolic content than other samples treated with hot water (40°C, 30 min), ultrasounds (45 kHz; power of 80%; 30 min), or its combination, after 30 days at 10°C [157]. The lycopene content of watermelon was preserved with a UV-C dose of 2.8 kJ m<sup>-2</sup>, although a lower dose of 1.6 kJ m<sup>-2</sup> did not show the same benefit [159]. However, immediate bioactive increments after UV-C have been observed in several FC fruit and vegetables, being probably attributed to an enhanced compound extraction due to plant cell disruption as a consequence of the UV radiation. Therefore, phenolic compounds and flavonoid contents of FC mangoes were increased after UV-C doses of 2.46 and 4.93 kJ m<sup>-2</sup> [163]. Hydroxycinnamoyl acid derivatives of FC broccoli were also increased by 4.5–4.8-fold after UV-C treatments (4.5–9.0 kJ m<sup>-2</sup>) [154]. Total phenol and flavonoid contents of banana and guava were enhanced after UV-C treatment [164]. FC carrot treated with UV-C (9 kJ m<sup>-2</sup>) showed higher chlorogenic content on total antioxidant capacity than untreated samples on processing day [146]. Then, besides the interest of UV-C radiation as a microbial safety method, this non-ionizing radiation may also be used as a tool to enhance or better preserve the health-promoting compounds of plant products during shelf life [165].

Application of UV-B radiation (280–320 nm) has also been proposed as a friendly and cheap nonmolecular tool to enhance the phenolic compounds in carrots and other horticultural crops during postharvest life [166–168]. FC carrot shreds treated with a UV-B dose of 1.5 kJ m<sup>-2</sup> showed 23% higher total phenolic content (mainly chlorogenic acid) than untreated samples after 72 h at 15°C [169]. UV-A has also been reported to induce biosynthesis of anthocyanins in cherries [170], although its effects has not been widely reported, and further research must be conducted.

Low-light conditions during storage have been recently proposed as an innovative and eco-friendly postharvest technique to highly prolong the shelf life of FC products. Accordingly, the shelf life of FC lettuce (butterhead and iceberg) was highly extended when it was stored under low-light conditions ( $\approx 5 \mu\text{mol m}^{-2} \text{s}^{-1}$  PAR; using either fluorescent or LED light) compared to samples stored under dark conditions [171]. Thus, lighting delayed cut-edge browning, reduced ascorbic acid degradation while carbohydrates levels were highly increased, although light samples did not show net photosynthesis according to photosynthetic activity measurements. Latter authors hypothesized that the observed prolonged shelf life in lit samples could be due to the higher levels of sugar and ascorbate that may act as antioxidants, may maintain membrane integrity, and may supply enough respiratory substrate to prevent ATP depletion.

### 4.3. Pulsed light

Pulsed light (PL) is a preservation technology that involves the use of intense short duration (1  $\mu\text{s}$ –0.1 s) pulses of polychromatic light from UV to near infrared (100–1100 nm) emitted by an inert gas (e.g., xenon) lamp [172]. The microbicidal action of PL has been attributed to different mechanisms: photochemical, photothermal, and photophysical [173]. Several studies have shown the effects of PL treatments on inoculated microorganisms, native microflora, and quality aspects of FC spinach, lettuce, cabbage, carrot, mushrooms, avocado, and watermelon [174–179]. Microbial reductions up to 2.2 log units have been reported in different products such as lettuce, celery, spinach, bean sprouts, white cabbage, and green bell pepper, with the different antimicrobial effectiveness in different produce dependent on the location of microorganisms as well as the presence of protective substances present in the product [179, 180]. Further investigation may cover the reported microbial photoreactivation after PL treatments [181–184] and the PL efficiency due to shadow effects that is one of the main industrial limitations of PL technology.

### 4.4. Pulsed electric fields

Pulsed electric fields (PEFs) are based on the application of DC voltages for very short periods of time, usually  $\mu\text{s}$ , to the food material which is placed between two electrodes. PEF equipment consists of a treatment chamber, pulse generator, control system, data acquisition, and material-handling equipment [185]. PEF has been successfully applied for microbial inactivation in liquid food systems, although its application in plant tissues is limited due to the PEF-related plant cell disruption processes known as membrane breakdown, membrane permeabilization, or electroporation of the membrane [186]. Accordingly, PEF treatment (wave bipolar pulses at 2 kV  $\text{cm}^{-1}$  electric field strength, 1  $\mu\text{s}$  pulse width, and 100 pulses  $\text{s}^{-1}$ ) applied to blueberries (immersed in a saline fluid for PEF transmission) for just 2 min achieved 1 and 2 log unit reductions of inoculated *E. coli* and *L. innocua*, respectively [187]. Latter authors reported no PEF effects on color and appearance of blueberries, and the nutritional quality even enhanced, although PEF caused fruit softening. However, high electric field strength (333 V  $\text{cm}^{-1}$ ) applied on a single pulse has been reported to not alter structure-related properties of FC onions, while such undesirable effects were observed using several pulses ( $n \geq 10$ ) [185]. Accordingly, PEF is a promising technology to be used in FC produce, although the tissue changes as a function of the electrical field strength, and the number of pulses for each plant produce must be further investigated.

### 4.5. Cold plasma

Plasma is generated when an inert gas is in contact with electricity and is being considered as the fourth state of matter. Plasma is composed by charged particles, excited molecules, reactive species, and UV photons which induce microbial inactivation [188]. Plasma is generally classified as cold (non-thermal) and thermal plasma. Thermal plasma generation requires temperature and high pressure with heavy electrons. Cold plasma is generated at temperatures of 30–60°C under atmospheric or vacuum requiring low energy [189]. Among the main

advantages of cold plasma are lower cost operating temperature and water consumption, together with timely production of the acting agents and lack of residues during production when compared to thermal and chemical treatments [190–192]. Cold plasma can be generated using either of the following devices: resistive barrier discharge, dielectric barrier discharge, corona discharge, radio frequency discharge, glow discharge, and atmospheric pressure plasma jet [193]. Plasma jet may be considered as the fastest plasma generation method to achieve microbial inactivation ( $4.3 \pm 6.5$  min) [194]. The most widely used gas in the published research has been air, followed by pure Ar, mixtures of He/O<sub>2</sub> and Ar/O<sub>2</sub>, and pure N<sub>2</sub> [194]. The plasma inactivation capacity depends on several factors like the type of technology used to generate the plasma, the voltage, the feed gas, the treatment time, the species, the direct or indirect exposure and the concentration of the tested microorganisms, and the structural characteristics of the produce [192]. Cold plasma has a high potential to be used in the industry for fruit and vegetables according to studies of the last few years as recently reviewed [194]. Generally, plasma treatments are able to achieve microbial reductions of  $2.7 \pm 1.4$  log units, ranging from  $1.5 \pm 1.0$  log units for bacilli and spores to  $3.3 \pm 1.6$  Log for *Listeria* spp., with treatment times of  $22.2 \pm 7.5$  min for bacilli and spores and  $3.5 \pm 3.8$  min for *E. coli* spp. [194]. Cold plasma has been also reported to highly (42–89%) reduce enzymatic browning of FC apples and potatoes [195, 196]. Nevertheless, the bactericidal mechanisms of cold plasma are still unclear being dependent on lots of factors related to processing parameters, environmental elements, and microbial properties [197].

#### 4.6. Ultrasounds

Ultrasounds (US) are sound waves with amplitude higher than the upper audible limit of human threshold (above 20 kHz) that generate cavitation bubbles [198]. The antimicrobial properties derived from US is based on the combination of mechanical (responsible for the disinfection action leading to detachment) and chemical energy (responsible for the free radicals formation leading to destruction), produced from the collapse of latter generated bubbles, which increase the cell membranes permeability [40]. Consequently, DNA modifications of microbial cells are formed due to formed hot spots (due to collapse), with high temperatures and pressure, and released free radicals [199]. The US treatment should always ensure that US pressure levels (70 dB at 20 kHz or 100 dB at  $\geq 25$  kHz) are not surpassed according to UK Health Protection Agency recommendations [200]. The effectiveness of microbial inactivation achieved with US is influenced by microbial cell shape (high resistance of coccus), size (bigger cells are less resistant), Gram type (negative are less resistant), and cellular metabolism (anaerobes are less resistant) [201]. Among treatment parameters, US effectiveness is influenced by fluid temperature (optimum at 60°C which may be reduced to 20°C to avoid losses of produce sensory quality without highly affecting microbial US inactivation), water hardness, and dissolved gases content [202]. US treatment (40 kHz, 50 W) for 5 min of strawberries initially reduced natural mesophilic microflora by approximately 1 log unit [203]. However, latter authors showed that such initial antimicrobial effect was lost after 5 days at 8°C since similar reduction logs (regarding unwashed samples) to sterile water-washed (5 min) samples were achieved. On the other hand, such antimicrobial effects were maintained up to 9 days at 8°C when US treatment was combined with PAA (40 ppm) even showing a synergistic effect

on mesophiles and the highest initial reductions on inoculated *S. enterica* subsp. *Enterica*, with sensory, physicochemical, and nutritional quality highly maintained [203]. No statistical differences among the effects of different frequencies (25, 32, and 70 kHz; 10 min) on achieved log reductions (1.5 log) were observed in FC lettuce inoculated with *S. typhimurium* [202]. Inoculated *E. coli*, *S. enteritidis*, and *L. innocua* loads of FC lettuce were reduced by 2.3, 5.7, and 1.9 log units with a US treatment for 30 min at 37 kHz without high color changes, although sensory quality was not studied in a parallel experiment with non-inoculated samples [204]. However, the produce matrix is highly important for US effectiveness since lower pathogen inactivations were observed in different products [204, 205].

#### 4.7. High-pressure processing

High-pressure processing (HPP) uses elevated pressures, with or without the addition of heat, also called high-hydrostatic pressure processing since water is the most used pressure-transmitting fluid [206]. HPP is a promising eco-friendly sanitation treatment that may have a potential application in the FC industry. HPP may reach very high microbial inactivations as reviewed [207] while maintaining, or even enhancing, sensory properties of food products like aroma and taste. However, although the texture of tissues of firm FC products with low amounts of entrapped air remains unaffected, HPP may induce some alterations like water-soaked appearance of the product [208]. Furthermore, HPP may either enhance (leading to enzymatic browning reactions due to loss of membrane permeability and sub-cellular compartmentalization) or inhibit the activity of enzymes related to cell wall degradation in FC products [209]. HPP treatment (200–400 MPa, 3 min, 25°C) of FC persimmon induced changes in physicochemical quality (electrolyte leakage, texture, total soluble solids, pH, and color), which were a function of the amount of applied pressure compromising the consumer acceptance of the product [210]. However, latter authors reported that HPP may improve carotenoid extractability and tannin polymerization of FC persimmon, which could enhance its functionality and eliminate astringency, respectively. Plant cell membranes of FC peaches have been tried to be stabilized prior to HPP treatment (200 MPa for 10 min; 23–28°C) through penetration of  $\text{Ca}^{2+}$  into the plasma membrane using calcium chloride or calcium lactate soaking treatments (1–2% w/v for 5 min). Nevertheless, latter authors reported that loss of cell integrity due to HPP was not avoided with the calcium soakings probably due to a low  $\text{Ca}^{2+}$  penetration into the tonoplast membrane being recommended for future research a higher calcium concentration and/or improved  $\text{Ca}^{2+}$  impregnation (e.g., using vacuum infusion). Higher pressure levels (585 MPa) were more effective to inactivate enzymes and to preserve color of FC peaches than longer times being optimized a HPP treatment of 585 MPa for 1 min [211]. Nevertheless, due to the known baroresistance of some enzymes, like polyphenol oxidase (PPO), browning reactions may not be completely avoided during FC product shelf life, although MAP could limit such enzymatic activities due to low oxygen levels.

High-pressure carbon dioxide (HPCD) treatment has been proposed as another antimicrobial method being applied in FC carrots at 12 MPa (40°C) for 15 min and leading to complete inactivation of natural microflora being maintained after 28 days at 4°C together with the enzymatic stability [212]. HPCD treatment (12 MPa; 40°C; 20 min) of inoculated FC coconut

also achieved *S. typhimurium* reductions of 4 log units, which was even enhanced to 8 log units when HPCD was combined with a high-power ultrasound treatment (10 W delivered every 2 min of treatment) [213].

## 5. Packaging under non-conventional gas mixtures

Modified atmosphere packaging (MAP) is a postharvest preservation technique based on the packaging of a perishable product within an atmosphere that has been modified compared with air conditions. There are two types of MAP: active or passive. Active MAP consists in the replacement on the initial present gases by a desired mixture. Passive MAP is progressively generated as a result of respiration of the product and gas transfer through the film, which has a selected permeability to gases, until the desired gas equilibrium atmosphere is reached.

The use of superatmospheric O<sub>2</sub> concentrations (>75 kPa O<sub>2</sub>) during modified atmosphere storage (HO—high oxygen conditions) reduces aerobic and anaerobic microbial growth, prevents anaerobic fermentation, avoids non-desirable flavor changes, and inhibits enzymatic browning. The microbial toxicity to HO may be explained due to the unfavorable effects on the oxidation-reduction potential of the system, the oxidation of enzymes having sulfhydryl groups or disulfide bridges, and the accumulation of toxic reactive O<sub>2</sub> species [214]. HO-controlled atmosphere (75 kPa O<sub>2</sub> balanced with N<sub>2</sub>) inhibited the mesophilic count of FC lettuce during storage for 10 days at 7°C [215, 216]. Chinese bayberries, strawberries, and blueberries stored under HO-controlled atmospheres (60–100 O<sub>2</sub> kPa balanced with N<sub>2</sub>) inhibited decay during storage at 5°C and subsequent 2 days at 20°C, while chemical parameters and surface color were only slightly affected compared to samples stored under air conditions [217].

High CO<sub>2</sub> levels (maximum limits depending on the produce due to generation of related off-flavors) have also shown antimicrobial effects which are even stronger at low temperature because of enhanced CO<sub>2</sub> solubility. Accordingly, controlled atmosphere with 15 kPa CO<sub>2</sub> + 5 kPa O<sub>2</sub> (balanced with N<sub>2</sub>) showed similar inhibitory effect to high O<sub>2</sub> on mesophilic growth of FC lettuce than samples stored at 0 kPa CO<sub>2</sub> + 75 kPa O<sub>2</sub> (balanced with N<sub>2</sub>) [216]. Interestingly, a combined high O<sub>2</sub>/CO<sub>2</sub> effect may be obtained using active HO MAP. The latter beneficial gas conditions are a result of the produce respiratory activity that generates antimicrobial CO<sub>2</sub> levels, while O<sub>2</sub> is inevitably reduced due to a combined effect of respiration and film diffusivity processes. Hence, the addition of CO<sub>2</sub> is unnecessary when high O<sub>2</sub> atmospheres are injected during active HO MAP. Accordingly, kailan-hybrid broccoli stored under high O<sub>2</sub>/CO<sub>2</sub> (initial O<sub>2</sub>/CO<sub>2</sub> of 70/0.02 kPa changing to 50/30 after 19 days at 5°C) showed 2.8 log units lower natural microflora load safter 19 days at 5°C compared to samples stored under passive MAP conditions (1.5–3.0 kPa O<sub>2</sub> + 16–21 kPa CO<sub>2</sub>) [62]. Similarly, active HO MAP of inoculated kailan-hybrid broccoli showed 1.4 and 2.3 lower *E. coli* and *S. enteritidis* log units, respectively, after 19 days at 5°C regarding samples stored at passive MAP conditions [16]. However, such beneficial effect of HO was not observed when FC kailan-hybrid broccoli was stored at 10°C. Yeast and mold growth in FC pomegranate arils packaged under active MAP (initial O<sub>2</sub>/CO<sub>2</sub> of 70/0.02 kPa changing to 20/5.5 kPa after 14 days at 5°C) was

highly inhibited (up to 1.2 log units inhibition) during storage for 14 days at 5°C [139]. Such beneficial high O<sub>2</sub>/CO<sub>2</sub> effects on microbial growth of FC produce packaged under active HO MAP have also been observed in other studies [218, 219].

Enzymatic browning of FC produce has been shown to be reduced under HO atmospheres. Accordingly, active HO MAP (80 kPa O<sub>2</sub> + 20 kPa CO<sub>2</sub>) delayed browning of FC lettuce during storage for 10 days at 5°C [220]. Active HO MAP (initial O<sub>2</sub>/CO<sub>2</sub> of 80/0 kPa, balanced with N<sub>2</sub>) of FC pomegranate arils reduced enzymatic browning related to PPO [123, 137], while formed off-odors were highly controlled with active high CO<sub>2</sub> MAP (20 kPa CO<sub>2</sub> balanced with N<sub>2</sub>) [139]. Active HO MAP of FC celeriac, mushrooms, and chicory endives (initial O<sub>2</sub>/CO<sub>2</sub> of 95/0 kPa, balanced with N<sub>2</sub>, changing to 10–20/10–50 after 7 days at 4°C) were more effective to control enzymatic browning than low O<sub>2</sub> atmospheres [221]. It is hypothesized that high O<sub>2</sub> may cause substrate inhibition of PPO or high contents of colorless quinones formed cause feedback PPO inhibition. High O<sub>2</sub> levels kept the initial color and firmness of fresh-cut melon retarding anaerobic fermentation better than low O<sub>2</sub> atmospheres [222]. Pre-treatment of whole “Spartan” apple with 100 kPa O<sub>2</sub> (up to 19 days at 1°C) before cutting decreased surface browning, flesh softening, and off-flavor in FC apple slices [223]. Such inhibition of enzymatic browning was related to retention of cellular integrity while in low O<sub>2</sub> pre-treatment (1 kPa O<sub>2</sub>, balanced with N<sub>2</sub>) would have another inhibitory browning mechanism on apple slices. Furthermore, the 100 kPa O<sub>2</sub> pre-treatment before slicing apples can reduce the dependence on antioxidant additives to inhibit slices browning. Sensory quality of produce stored under high O<sub>2</sub> atmospheres has been shown to be better than low O<sub>2</sub> atmospheres due to fermentation processes [218].

High O<sub>2</sub> levels are also considered as postharvest abiotic stresses able to increase PAL activity and consequently phenolic biosynthesis as observed in carrot shreds stored under high O<sub>2</sub>-controlled atmosphere (80 kPa O<sub>2</sub> balanced with N<sub>2</sub>) [146]. Furthermore, high O<sub>2</sub> and CO<sub>2</sub> levels may be tolerated by FC carrots maintaining their fresh characteristics and reducing microbial growth [224]. Such abiotic stress may be used as a tool to increase the health-promoting compounds of plant material to subsequently obtain functional beverages after correspondent thermal or non-thermal treatments to ensure microbial quality and safety [225].

The use of MAP under mixtures of non-conventional gases such as Ar, He, Xe, or N<sub>2</sub>O has been proposed to maintain the quality of FC produce extending its shelf life. The latter gases may be chemically inert, but they have some physiological and/or antimicrobial properties, even though it does not seem to be through modification of enzyme activity [226]. Ar, He, or N<sub>2</sub> atmospheres mixed with low O<sub>2</sub> showed different diffusive properties, since Ar and He are monoatomic and smaller in size than N<sub>2</sub> [227]. Treatment of asparagus spears for 24 h at 4°C under an atmosphere of Ar and Xe at 2:9 (v:v) reduced RR and bract opening leading to a subsequent shelf life of 12 days at 4°C showing better quality than those samples treated with an atmosphere of 5 kPa O<sub>2</sub> + 5 kPa CO<sub>2</sub> [228]. Microbial quality and some bioactive compounds were highly preserved in FC red chard baby leaves stored under active He MAP (100%) during 8 days at 5°C [229]. N<sub>2</sub>O has a direct effect on cell metabolism achieving shelf life extension of FC produce. It may be explained since N<sub>2</sub>O has 77% solubility in fruit cell, while its absorption in tissues is completely reversible [230]. FC spinach leaves stored under active N<sub>2</sub>O MAP (100%)

showed low microbial growth after 8 days at 5°C, with chlorophylls and phenolics being well preserved [231]. Different N<sub>2</sub>O and N<sub>2</sub> combinations (including always 3% O<sub>2</sub>) were used as active MAP for FC lettuce and wild rocket during storage up to 12 days at 5°C, suggesting such results that N<sub>2</sub>O does not improve the produce quality compared to N<sub>2</sub> [232]. Lower microbial loads have also been observed in FC watercress and arugula leaves at the end of cold storage when active MAP containing N<sub>2</sub>, Ar, He, Xe, or N<sub>2</sub>O were used [233, 234].

## 6. Future research needs and conclusions

FC plant produce is greatly vulnerable to microbial spoilage, and cultivar selection is probably the most important factor in FC overall quality and shelf life. With the intention of better inhibition of microbial spoilage, and subsequently decrease in decay and safety problems, genetic cultivar selection should turn to retard ripening and senescence, low ethylene production and/or sensitivity, and enhanced firmness, well adapted to minimal processing and increased antioxidant systems. While chlorine is widely used by the FC industry to ensure safety, new eco-friendly techniques/technologies are needed to replace the latter chemical treatment due to the production of carcinogenic compounds. Several eco-friendly strategies such as ozone, UV-C light, natural antimicrobial substances, GRAS chemical, and biological compounds can decrease microbial loads of FC products and extend their shelf life. Other advanced techniques such as pulsed electric fields, ultrasounds, and high-pressure processing, among others, are promising sanitizing strategies for the FC industry due to high microbicidal rates. However, the treatment parameters of latter technologies to be applied in FC products need further research to be optimized for each specific commodity. Furthermore, the potential and limits of these innovative eco-friendly techniques must be well defined and included in the regulations. In that way, modeling tools to predict microbial inactivation and product shelf life are very useful, principally to optimize production and distribution. Application of nanotechnology to FC products is also a promising future in order to produce products with extended shelf life and excellent quality meeting always the food safety. Nevertheless, regulations related to nanoparticles' inclusion in food products need to be better defined by institutions. The combination of well-designed integrated production, handling, processing, and distribution chains for FC produces is crucial for achieving the high quality and safety demanded by consumers.

## Acknowledgements

The authors are grateful to European Union, DG, for Science Research and Development (CRAFTProgramContractsSMT4-CT98-5530,QLK1-1999-707917,andOLK1-CT-2002-70791), 7th Framework Programme (FP7-BBBE.2013.1.2-02), Spanish Ministry for Education and Science and Spanish Ministry of Economy and Competitiveness (Projects ALI-95-0001, ALI-98-1006, AGL2005-08189-C02-01/ALI; AGL2007-63861/ALI; AGL2010-19201-C04-02-AGR; AGL2013-48830-C2-1-R), the Consejería de Educación y Cultura de la Comunidad

Autónoma de la Región de Murcia (SUE-OA 06/02-0008), and Fundación Séneca de la Región de Murcia in Spain (Project AGR/92, PS96/CA/d3, AGR/3/FS/02 and 00553/PI/04) for financial support. We also acknowledge the following companies for financing research and development contract with us: Repsol Petróleo S.A. (Madrid), Plásticos de Alzira, S.A., Sakata Seed Iberica S.L.U. (Valencia), Primaflor SAT (Almería), Canarihorta (Las Palmas de Gran Canaria), Frutas Hermanos Mira S.L. (Alicante), Kernel Export S.L., Frutas Esparza S.L., Perichán SAT, Pozosur S.L. (Murcia), and Sakata Seed (Valencia). The good skills and work of all researches whenever involved in the Postharvest and Refrigeration Group are very much appreciated.

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## References

- [1] Slavin JL, Lloyd B. Health benefits of fruits and vegetables. *Advances in Nutrition: An International Review Journal*. 2012;**3**:506-516. DOI: 10.3945/an.112.002154
- [2] Artés F, Allende A. Processing lines and alternative preservation techniques to prolong the shelf-life of minimally fresh processed leafy vegetables. *European Journal of Horticultural Science*. 2005;**70**:231-245
- [3] Nieuwenhuijsen MJ, Toledano MB, Elliott P. Uptake of chlorination disinfection by-products; a review and a discussion of its implications for exposure assessment in epidemiological studies. *Journal of Exposure Analysis and Environmental Epidemiology*. 2000;**10**:586-599. DOI: 10.1038/sj.jea.7500139
- [4] Suslow TV. Postharvest Chlorination- Basic Properties and Key points for Effective Disinfection. University of California: Division of Agriculture and Natural Resources; 1997. p. 8003
- [5] Artés F, Gómez P, Aguayo E, Escalona V, Artés-Hernández F. Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities. *Postharvest Biology and Technology*. 2009;**51**:287-296. DOI: 10.1016/j.postharvbio.2008.10.003

- [6] European Union (EU). Commission implementing regulation (EU) 2016/672 approving peracetic acid as an existing active substance for use in biocidal products for product-types 11 and 12. Official Journal of the European Union. 2006;L116:3-7
- [7] Food and Drug Administration (FDA). Title 21: Food and Drugs. Section. Part 173: Secondary direct food additives permitted in food for human consumption [Internet]. 2016. Available from: <https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=173> [Accessed: 2017-07-10]
- [8] Stampi S, De Luca G, Zanetti F. Evaluation of the efficiency of peracetic acid in the disinfection of sewage effluents. *Journal of Applied Microbiology*. 2001;**91**:833-838. DOI: 10.1046/j.1365-2672.2001.01451.x
- [9] Park CM, Beuchat LR. Evaluation of sanitizers for killing *Escherichia coli* O157:H7, *Salmonella* and naturally occurring microorganisms on cantaloupes, honeydew melons, and asparagus. *Dairy Food and Environmental Sanitation*. 1999;**19**:842-847
- [10] Wright JR, Summer SS, Hackney CR, Pierson MD, Zoecklein W. Reduction of *Escherichia coli* O157:H7 on apples using wash and chemical sanitizers treatments. *Dairy Food and Environmental Sanitation*. 2000;**20**:120-126
- [11] Ruiz-Cruz S, Acedo-Félix E, Díaz-Cinco M, Islas-Osuna MA, González-Aguilar GA. Efficacy of sanitizers in reducing *Escherichia coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* populations on fresh-cut carrots. *Food Control*. 2007;**18**:1383-1390. DOI: 10.1016/j.foodcont.2006.09.008
- [12] Silveira A, Aguayo E, Leglise A, Artés F. Emerging sanitizers and clean room improved the microbial quality of fresh-cut 'Galia' melon. In: 3rd International Symposium on Food and Agricultural Products: Processing and Innovations; 24-26 September 2007; Naples. Milan: Associazione Italiana Di Ingegneria Chimica (AIDIC); 2007. CDrom
- [13] Vandekinderen I, Devlieghere F, De Meulenaer B, Ragaert P, Van Camp J. Optimization and evaluation of a decontamination step with peroxyacetic acid for fresh-cut produce. *Food Microbiology*. 2009;**26**:882-888. DOI: 10.1016/j.fm.2009.06.004
- [14] Ge C, Bohrerova Z, Lee J. Inactivation of internalized *Salmonella Typhimurium* in lettuce and green onion using ultraviolet C irradiation and chemical sanitizers. *Journal of Applied Microbiology*. 2013;**114**:1415-1424. DOI: 10.1111/jam.12154
- [15] Neo SY, Lim PY, Phua LK, Khoo GH, Kim SJ, Lee SC, Yuk HG. Efficacy of chlorine and peroxyacetic acid on reduction of natural microflora, *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Salmonella* spp. on mung bean sprouts. *Food Microbiology*. 2013;**36**:475-480. DOI: 10.1016/j.fm.2013.05.001
- [16] Martínez-Hernández GB, Navarro-Rico J, Gómez PA, Otón M, Artés F, Artés-Hernández F. Combined sustainable sanitising treatments to reduce *Escherichia coli* and *Salmonella enteritidis* growth on fresh-cut kailan-hybrid broccoli. *Food Control*. 2015;**47**:312-317. DOI: 10.1016/j.foodcont.2014.07.029

- [17] Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garrett EH, Farber JN, Busta FF. Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. *Comprehensive Reviews in Food Science and Food Safety*. 2003;**2**:161-173. DOI: 10.1111/j.1541-4337.2003.tb00033.x
- [18] Betts G, Everis L. Alternatives to hypochlorite washing systems for the decontamination of fresh fruit and vegetables. In: Jongen W, editor. *Improving the Safety of Fresh Fruit and Vegetables*. 1st ed. Wageningen: Woodhead Publishing Limited; 2005. p. 351-372. DOI: 10.1533/9781845690243.3.351I
- [19] European Food Safety Authority (EFSA). Scientific opinion on the safety of gaseous chlorine dioxide as a preservative slowly released in cold storage areas. *EFSA Journal*. 2016;**14**:4388-4406. DOI: 10.2903/j.efsa.2016.4388
- [20] Trinetta V, Vaidya N, Linton R, Morgan M. Evaluation of chlorine dioxide gas residues on selected food produce. *Journal of Food Science*. 2011;**76**:T11–T15. DOI: 10.1111/j.1750-3841.2010.01911.x
- [21] United States Environmental Protection Agency (EPA). Chapter 4: Chlorine dioxide. In: EPA, editor. *EPA Guidance Manual: Alternative Disinfectants and Oxidants*. Office of Water (4607);1999. p. 36
- [22] Keskinen LA, Burke A, Annous BA. Efficacy of chlorine, acidic electrolyzed water and aqueous chlorine dioxide solutions to decontaminate *Escherichia coli* O157:H7 from lettuce leaves. *International Journal of Food Microbiology*. 2009;**132**:134-140. DOI: 10.1016/j.ijfoodmicro.2009.04.006
- [23] Mahmoud BSM, Bhagat AR, Linton RH. Inactivation kinetics of inoculated *Escherichia coli* O157:H7, *Listeria monocytogenes* and *Salmonella enterica* on strawberries by chlorine dioxide gas. *Food Microbiology*. 2007;**24**:736-744. DOI: 10.1016/j.fm.2007.03.006
- [24] Mahmoud BSM, Linton RH. Inactivation kinetics of inoculated *Escherichia coli* O157:H7 and *Salmonella enterica* on lettuce by chlorine dioxide gas. *Food Microbiology*. 2008;**25**:244-252. DOI: 10.1016/j.fm.2007.10.015
- [25] Sy KV, Murray MB, Harrison MD, Beuchat LR. Evaluation of gaseous chlorine dioxide as a sanitizer for killing *Salmonella*, *Escherichia coli* O157:H7, *Listeria monocytogenes*, and yeasts and molds on fresh and fresh-cut produce. *Journal of Food Protection*. 2005;**68**:1176-1187. DOI: 10.4315/0362-028X-68.6.1176
- [26] Rodgers SL, Cash JN, Siddiq M, Ryser ET. A comparison of different chemical sanitizers for inactivating *Escherichia coli* O157:H7 and *Listeria monocytogenes* in solution and on apples, lettuce, strawberries, and cantaloupe. *Journal of Food Protection*. 2004;**67**:721-731
- [27] Chung CC, Huang TC, Yu CH, Shen FY, Chen HH. Bactericidal effects of fresh-cut vegetables and fruits after subsequent washing with chlorine dioxide. *International Proceedings of Chemical, Biological & Environmental Engineering*. 2011;**9**:107-112
- [28] Tomás-Callejas A, López-Gálvez F, Sbodio A, Artés F, Artés-Hernández F, Suslow TV. Chlorine dioxide and chlorine effectiveness to prevent *Escherichia coli* O157:H7 and *Salmonella* cross-contamination on fresh-cut Red Chard. *Food Control*. 2012;**23**:325-332. DOI: 10.1016/j.foodcont.2011.07.022

- [29] López-Velasco G, Tomás-Callejas A, Sbodio A, Artés-Hernández F, Suslow TV. Chlorine dioxide dose, water quality and temperature affect the oxidative status of tomato processing water and its ability to inactivate *Salmonella*. *Food Control*. 2012;**26**:28-35. DOI: 10.1016/j.foodcont.2011.12.016
- [30] Tomás-Callejas A, López-Velasco G, Artés F, Artés-Hernández F. Acidified sodium chlorite optimisation assessment to improve quality of fresh-cut tatsoi baby leaves. *Journal of the Science of Food and Agriculture*. 2012;**92**:877-885. DOI: 10.1002/jsfa.4664
- [31] Ölmez H, Kretzschmar U. Potential alternative disinfection methods for organic fresh-cut industry for minimizing water consumption and environmental impact. *LWT – Food Science and Technology*. 2009;**42**:686-693. DOI: 10.1016/j.lwt.2008.08.001
- [32] Sapers GM, Miller RL, Pilizota V, Kamp F. Shelf-life extension of fresh mushrooms (*Agaricus bisporus*) by application of hydrogen peroxide and browning inhibitors. *Journal of Food Science*. 2001;**66**:362-366. DOI: 10.1111/j.1365-2621.2001.tb11347.x
- [33] Huang Y, Ye M, Chen H. Efficacy of washing with hydrogen peroxide followed by aerosolized antimicrobials as a novel sanitizing process to inactivate *Escherichia coli* O157:H7 on baby spinach. *International Journal of Food Microbiology*. 2012;**153**:306-313. DOI: 10.1016/j.ijfoodmicro.2011.11.018
- [34] Ukuku DO, Fett W. Behavior of *Listeria monocytogenes* inoculated on cantaloupe surfaces and efficacy of washing treatments to reduce transfer from rind to fresh-cut pieces. *Journal of Food Protection*. 2002;**65**:924-930. DOI: 10.4315/0362-028X-65.6.924
- [35] Ukuku DO, Mukhopadhyay S, Geveke D, Olanya M, Niemira B. Effect of hydrogen peroxide in combination with minimal thermal treatment for reducing bacterial populations on cantaloupe rind surfaces and transfer to fresh-cut pieces. *Journal of Food Protection*. 2016;**79**:1316-1324. DOI: 10.4315/0362-028x.jfp-16-046
- [36] Sapers G. Hydrogen peroxide as an alternative to chlorine for sanitizing fruits and vegetables. IFIS Publishing-Food Science Central [Internet]. 2003. Available from: <https://foodinfo.ifis.org/> [Accessed: 2017-07-10]
- [37] Van Haute S, Tryland I, Veys A, Sampers I. Wash water disinfection of a full-scale leafy vegetables washing process with hydrogen peroxide and the use of a commercial metal ion mixture to improve disinfection efficiency. *Food Control*. 2015;**50**:173-183. DOI: 10.1016/j.foodcont.2014.08.028
- [38] Lianou A, Koutsoumanis KP, Sofos JN. Organic acids and other chemical treatments for microbial decontamination of food. In: Demirci A, Ngadi MO, editors. *Microbial Decontamination in the Food Industry*. 1st ed. Cambridge: Woodhead Publishing; 2012. p. 592-664. DOI: 10.1533/9780857095756.3.592I
- [39] Carpenter CE, Broadbent JR. External concentration of organic acid anions and pH: Key independent variables for studying how organic acids inhibit growth of bacteria in mildly acidic foods. *Journal of Food Science*. 2009;**74**:R12–R15. DOI: 10.1111/j.1750-3841.2008.00994.x

- [40] Meireles A, Giaouris E, Simões M. Alternative disinfection methods to chlorine for use in the fresh-cut industry. *Food Research International*. 2016;**82**:71-85. DOI: 10.1016/j.foodres.2016.01.021
- [41] Gurtler JB, Mai TL. Preservatives – Traditional preservatives – Organic acids. In: Batt CA Tortorello ML, editors. *Encyclopedia of Food Microbiology*. Oxford: Academic Press; 2014. pp. 119-130
- [42] Aguayo E, Allende A, Artés F. Keeping quality and safety of minimally fresh processed melon. *European Food Research and Technology*. 2003;**216**:494-499. DOI: 10.1007/s00217-003-0682-7
- [43] Gómez P, Artés F. Ascorbic and citric acids to preserve quality of minimally processed green celery. In: *Proceedings of the IV Postharvest Iberian Symposium*; 6-9 October 2004; Oeiras. Lisbon: APH; 2004. pp. 369-373
- [44] Akbas MY, Olmez H. Inactivation of *Escherichia coli* and *Listeria monocytogenes* on iceberg lettuce by dip wash treatments with organic acids. *Letters in Applied Microbiology*. 2007;**44**:619-624. DOI: 10.1111/j.1472-765X.2007.02127.x
- [45] Park SH, Choi MR, Park JW, Park KH, Chung MS, Ryu S, Kang DH. Use of organic acids to inactivate *Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Listeria monocytogenes* on organic fresh apples and lettuce. *Journal of Food Science*. 2011;**76**:M293-M298. DOI: 10.1111/j.1750-3841.2011.02205.x
- [46] Martín-Diana AB, Rico D, Frías J, Henahan GTM, Mulcahy J, Barat JM, Barry-Ryan C. Effect of calcium lactate and heat-shock on texture in fresh-cut lettuce during storage. *Journal of Food Engineering*. 2006;**77**:1069-1077. DOI: 10.1016/j.jfoodeng.2005.08.037
- [47] Rico D, Martín-Diana AB, Frías JM, Barat JM, Henahan GTM, Barry-Ryan C. Improvement in texture using calcium lactate and heat-shock treatments for stored ready-to-eat carrots. *Journal of Food Engineering*. 2007;**79**:1196-1206. DOI: 10.1016/j.jfoodeng.2006.04.032
- [48] Martín-Diana AB, Rico D, Barry-Ryan C, Frías JM, Mulcahy J, Henahan GTM. Comparison of calcium lactate with chlorine as a washing treatment for fresh-cut lettuce and carrots: Quality and nutritional parameters. *Journal of the Science of Food and Agriculture*. 2005;**85**:2260-2268. DOI: 10.1002/jsfa.2254
- [49] Aguayo E, Escalona VH, Artés F. Effect of hot water treatment and various calcium salts on quality of fresh-cut 'Amarillo' melon. *Postharvest Biology and Technology*. 2008;**47**:397-406. DOI: 10.1016/j.postharvbio.2007.08.001
- [50] Techakanon C, Barrett DM. The effect of calcium chloride and calcium lactate pretreatment concentration on peach cell integrity after high-pressure processing. *International Journal of Food Science & Technology*. 2017;**52**:635-643. DOI: 10.1111/ijfs.13316
- [51] Youssef K, Ligorio A, Sanzani SM, Nigro F, Ippolito A. Control of storage diseases of citrus by pre- and postharvest application of salts. *Postharvest Biology and Technology*. 2012;**72**:57-63. DOI: 10.1016/j.postharvbio.2012.05.004

- [52] Youssef K, Sanzani SM, Ligorio A, Ippolito A, Terry LA. Sodium carbonate and bicarbonate treatments induce resistance to postharvest green mould on citrus fruit. *Postharvest Biology and Technology*. 2014;**87**:61-69. DOI: 10.1016/j.postharvbio.2013.08.006
- [53] Ongeng D, Devlieghere F, Debevere J, Coosemans J, Ryckeboer J. The efficacy of electrolysed oxidising water for inactivating spoilage microorganisms in process water and on minimally processed vegetables. *International Journal of Food Microbiology*. 2006;**109**:187-197. DOI: 10.1016/j.ijfoodmicro.2005.12.013
- [54] Izumi H. Electrolyzed water as a disinfectant for fresh-cut vegetables. *Journal of Food Science*. 1999;**64**:536-539. DOI: 10.1111/j.1365-2621.1999.tb15079.x
- [55] Ju S-Y, Ko J-J, Yoon H-S, Seon S-J, Yoon Y-R, Lee D-I, Kim S-Y, Chang H-J. Does electrolyzed water have different sanitizing effects than sodium hypochlorite on different vegetable types? *British Food Journal*. 2017;**119**:342-356. DOI:10.1108/BFJ-06-2016-0283
- [56] Kapalka A, Fóti G, Comminellis C. Kinetic modelling of the electrochemical mineralization of organic pollutants for wastewater treatment. *Journal of Applied Electrochemistry*. 2008;**38**:7-16. DOI: 10.1007/s10800-007-9365-6
- [57] Food and Drug Administration (FDA). Food Additive Status List. [Internet]. 2013. Available from: <https://www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm091048.htm> [Accessed: 2017-07-10]
- [58] Navarro-Rico J, Artés-Hernández F, Gómez PA, Núñez-Sánchez MÁ, Artés F, Martínez-Hernández GB. Neutral and acidic electrolysed water kept microbial quality and health promoting compounds of fresh-cut broccoli throughout shelf life. *Innovative Food Science and Emerging Technologies*. 2014;**21**:74-81. DOI: 10.1016/j.ifset.2013.11.004
- [59] Arévalos-Sánchez M, Regalado C, Martín SE, Meas-Vong Y, Cadena-Moreno E, García-Almendárez BE. Effect of neutral electrolyzed water on lux-tagged *Listeria monocytogenes* EGDe biofilms adhered to stainless steel and visualization with destructive and non-destructive microscopy techniques. *Food Control*. 2013;**34**:472-477. DOI: 10.1016/j.foodcont.2013.05.021
- [60] Kim C, Hung Y-C, Brackett RE, Frank JF. Inactivation of *Listeria monocytogenes* biofilms by electrolyzed oxidizing water. *Journal of Food Processing and Preservation*. 2001;**25**:91-100. DOI: 10.1111/j.1745-4549.2001.tb00446.x
- [61] Deza MA, Araujo M, Garrido MJ. Inactivation of *Escherichia coli*, *Listeria monocytogenes*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* on stainless steel and glass surfaces by neutral electrolysed water. *Letters in Applied Microbiology*. 2005;**40**:341-346. DOI: 10.1111/j.1472-765X.2005.01679.x
- [62] Martínez-Hernández GB, Artés-Hernández F, Gómez PA, Formica AC, Artés F. Combination of electrolysed water, UV-C and superatmospheric O<sub>2</sub> packaging for improving fresh-cut broccoli quality. *Postharvest Biology and Technology*. 2013;**76**:125-134. DOI: 10.1016/j.postharvbio.2012.09.013

- [63] Wang, H. Feng, H., Luo, Y. Surface treatment of fresh-cut lettuce with acidic electrolyzed water to extend shelf life. In: Proceedings of the Annual Meeting of the Institute of Food Technologist (IFT); 12-16 July 2003; Chicago IL. Chicago: IFT; 2003. p. 265
- [64] Rico D, Martín-Diana AB, Barry-Ryan C, Frías JM, Henehan GTM, Barat JM. Use of neutral electrolysed water (EW) for quality maintenance and shelf-life extension of minimally processed lettuce. *Innovative Food Science and Emerging Technologies*. 2008;**9**:37-48. DOI: 10.1016/j.ifset.2007.05.002
- [65] Koseki S, Itoh K. Prediction of microbial growth in fresh-cut vegetables treated with acidic electrolyzed water during storage under various temperature conditions. *Journal of Food Protection*. 2001;**64**:1935-1942. DOI: 10.4315/0362-028X-64.12.1935
- [66] Tomás-Callejas A, Martínez-Hernández GB, Artés F, Artés-Hernández F. Neutral and acidic electrolyzed water as emergent sanitizers for fresh-cut mizuna baby leaves. *Postharvest Biology and Technology*. 2011;**59**:298-306. DOI: 10.1016/j.postharvbio.2010.09.013
- [67] Yang H, Swem BL, Li Y. The effect of pH on inactivation of pathogenic bacteria on fresh-cut lettuce by dipping treatment with electrolyzed water. *Journal of Food Science*. 2003;**68**:1013-1017. DOI: 10.1111/j.1365-2621.2003.tb08280.x
- [68] Posada-Izquierdo GD, Pérez-Rodríguez F, López-Gálvez F, Allende A, Gil MI, Zurera G. Modeling growth of *Escherichia coli* O157:H7 in fresh-cut lettuce treated with neutral electrolyzed water and under modified atmosphere packaging. *International Journal of Food Microbiology*. 2014;**177**:1-8. DOI: 10.1016/j.ijfoodmicro.2013.12.025
- [69] Fallanaj F, Ippolito A, Ligorio A, Garganese F, Zavanella C, Sanzani SM. Electrolyzed sodium bicarbonate inhibits *Penicillium digitatum* and induces defence responses against green mould in citrus fruit. *Postharvest Biology and Technology*. 2016;**115**:18-29. DOI: 10.1016/j.postharvbio.2015.12.009
- [70] Horvath ML, Bilitzky L, Huttner J. Fields of utilization of ozone. In: Clark RJH, editor. *Ozone*. New York (USA): Elsevier Science Publishing Co.; 1985. pp. 257-316
- [71] Antoniou MG, Andersen HR. Evaluation of pretreatments for inhibiting bromate formation during ozonation. *Environmental Technology*. 2012;**33**:1747-1753. DOI: 10.1080/09593330.2011.644586
- [72] Graham DM. Use of ozone for food processing. *Food Technology*. 1997;**51**:72-75. DOI: 10.1016/j.lwt.2003.10.014
- [73] Horvitz S, Cantalejo MJ. Application of ozone for the postharvest treatment of fruits and vegetables. *Critical Reviews in Food Science and Nutrition*. 2014;**54**:312-339. DOI: 10.1080/10408398.2011.584353
- [74] Tzortzakis N, Chrysargyris A. Postharvest ozone application for the preservation of fruits and vegetables. *Food Reviews International*. 2017;**33**:270-315. DOI: 10.1080/87559129.2016.1175015
- [75] Food and Drug Administration (FDA). Title 21: Food and Drugs. Section. Part 173: Secondary direct food additives permitted in food for human consumption [Internet].

2016. Available from: <https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=173.368> [Accessed: 2017-07-10]
- [76] Aguayo E, Escalona V, Silveira AC, Artés F. Quality of tomato slices disinfected with ozonated water. *Food Science and Technology International*. 2014;**20**:227-235. DOI: 10.1177/1082013213482846
- [77] Selma MV, Ibanez AM, Cantwell M, Suslow T. Reduction by gaseous ozone of *Salmonella* and microbial flora associated with fresh-cut cantaloupe. *Food Microbiology*. 2008;**25**:558-565. DOI: 10.1016/j.fm.2008.02.006
- [78] Klockow PA, Keener KM. Safety and quality assessment of packaged spinach treated with a novel ozone-generation system. *LWT – Food Science and Technology*. 2009;**42**:1047-1053. DOI: 10.1016/j.lwt.2009.02.011
- [79] Zhang L, Lu Z, Yu Z, Gao X. Preservation of fresh-cut celery by treatment of ozonated water. *Food Control*. 2005;**16**:279-283. DOI: 10.1016/j.foodcont.2004.03.007
- [80] Rico D, Martín-Diana AB, Frías JM, Henahan GTM, Barry-Ryan C. Effect of ozone and calcium lactate treatments on browning and texture properties of fresh-cut lettuce. *Journal of the Science of Food and Agriculture*. 2006;**86**:2179-2188. DOI: 10.1002/jsfa.2594
- [81] Gutiérrez DR, Chaves AR, Rodríguez SDC. Use of UV-C and gaseous ozone as sanitizing agents for keeping the quality of fresh-cut rocket (*Eruca sativa* mill). *Journal of Food Processing and Preservation*. 2017;**41e**:1-13. DOI: 10.1111/jfpp.12968
- [82] Aguayo E, Escalona VH, Artés F. Effect of cyclic exposure to ozone gas on physicochemical, sensorial and microbial quality of whole and sliced tomatoes. *Postharvest Biology and Technology*. 2006;**39**:169-177. DOI: 10.1016/j.postharvbio.2005.11.005
- [83] Chen J, Hu Y, Wang J, Hu H, Cui H. Combined effect of ozone treatment and modified atmosphere packaging on antioxidant defense system of fresh-cut green peppers. *Journal of Food Processing and Preservation*. 2016;**40**:1145-1150. DOI: 10.1111/jfpp.12695
- [84] Silveira AC, Aguayo E, Artés F. Emerging sanitizers and clean room packaging for improving the microbial quality of fresh-cut 'Galia' melon. *Food Control*. 2010;**21**:863-871. DOI: 10.1016/j.foodcont.2009.11.017
- [85] Baur S, Klaiber R, Hammes WP, Carle R. Sensory and microbiological quality of shredded, packaged iceberg lettuce as affected by pre-washing procedures with chlorinated and ozonated water. *Innovative Food Science & Emerging Technologies*. 2004;**5**:45-55. DOI: 10.1016/j.ifset.2003.10.002
- [86] Burt S. Essential oils: Their antibacterial properties and potential applications in foods—A review. *International Journal of Food Microbiology*. 2004;**94**:223-253. DOI: 10.1016/j.ijfoodmicro.2004.03.022
- [87] Hirasaka K, Takemasa M. Antimicrobial and antioxidant properties of spices. In: Hirasaka K, Takemasa M, editors. *Spice Science and Technology*. New York (USA): Marcel Dekker Inc.; 1998. pp. 163-200

- [88] Rota C, Carraminana JJ, Burillo J, Herrera A. *In vitro* antimicrobial activity of essential oils from aromatic plants against selected foodborne pathogens. *Journal of Food Protection*. 2004;**67**:1252-1256. DOI: 10.4315/0362-028X-67.6.1252
- [89] Nychas GJE, Skandamis PN, Tassou CC, Antimicrobials from herbs and spices. In: Roller S, editor. *Natural Antimicrobials for the Minimal Processing of Foods*. Boca Raton FL (USA): CRC Press; 2000
- [90] Bagamboula CF, Uyttendaele M, Debevere J. Inhibitory effect of thyme and basil essential oils, carvacrol, thymol, estragol, linalool and p-cymene towards *Shigella sonnei* and *S. flexneri*. *Food Microbiology*. 2004;**21**:33-42. DOI: 10.1016/S0740-0020(03)00046-7
- [91] Onursal CE, Eren I, Güneşli A, Topcu T, Çalhan O, Bayindir D. Effect of Carvacrol on Microbial Activity and Storage Quality of Fresh-cut 'Braeburn' Apple. Leuven, Belgium: International Society for Horticultural Science (ISHS); 2014. pp. 215-221
- [92] Roller S, Seedhar P. Carvacrol and cinnamic acid inhibit microbial growth in fresh-cut melon and kiwifruit at 4 and 8°C. *Letters in Applied Microbiology*. 2002;**35**:390-394. DOI: 10.1046/j.1472-765X.2002.01209.x
- [93] Valero D, Valverde JM, Martínez-Romero D, Guillén F, Castillo S, Serrano M. The combination of modified atmosphere packaging with eugenol or thymol to maintain quality, safety and functional properties of table grapes. *Postharvest Biology and Technology*. 2006;**41**:317-327. DOI: 10.1016/j.postharvbio.2006.04.011
- [94] Salvia-Trujillo L, Rojas-Graü A, Soliva-Fortuny R, Martín-Belloso O. Physicochemical characterization and antimicrobial activity of food-grade emulsions and nanoemulsions incorporating essential oils. *Food Hydrocolloids*. 2015;**43**:547-556. DOI: 10.1016/j.foodhyd.2014.07.012
- [95] Martínez-Hernández GB, Amodio ML, Colelli G. Carvacrol-loaded chitosan nanoparticles maintain quality of fresh-cut carrots. *Innovative Food Science & Emerging Technologies*. 2017;**41**:56-63. DOI: 10.1016/j.ifset.2017.02.005
- [96] Gao H, Zhou Y, Fang X, Mu H, Han Q, Chen H-J. Development and characterization of an antimicrobial packaging film coating containing AITC or carvacrol for preservation of fresh-cut vegetable. In: *Book of Abstracts of the III International Conference on Fresh-Cut Produce: Maintaining Quality and Safety*; 13-18 September 2015; Davis. Davis: UC Davis; 2015. p. 175
- [97] Tiwari BK, Valdramidis VP, O' Donnell CP, Muthukumarappan K, Bourke P, Cullen PJ. Application of natural antimicrobials for food preservation. *Journal of Agricultural and Food Chemistry*. 2009;**57**:5987-6000. DOI: 10.1021/jf900668n
- [98] Jang M, Hong E, Kim GH. Evaluation of antibacterial activity of 3-butenyl, 4-pentenyl, 2-phenylethyl, and benzyl isothiocyanate in *Brassica* vegetables. *Journal of Food Science*. 2010;**75**:412-416. DOI: 10.1111/j.1750-3841.2010.01725.x
- [99] Sofrata A, Santangelo EM, Azeem M, Borg-Karlson A-K, Gustafsson A, Pütsep K. Benzyl isothiocyanate, a major component from the roots of *Salvadora persica* is highly

- active against gram-negative bacteria. PLoS One. 2011;**6**:e23045. DOI: 10.1371/journal.pone.0023045
- [100] EFSA. EFSA panel on food additives and nutrient sources added to food (ANS): Scientific opinion on the safety of allyl isothiocyanate for the proposed uses as a food additive. EFSA Journal. 2010;**8**:1943-1983
- [101] Pablos C, Fernández A, Thackeray A, Marugán J. Effects of natural antimicrobials on prevention and reduction of bacterial cross-contamination during the washing of ready-to-eat fresh-cut lettuce. Food Science and Technology International. 2017;**23**:403-414. DOI: 10.1177/1082013217697851
- [102] Galvez A, Abriouel H, Lopez RL, Ben Omar N. Bacteriocin-based strategies for food biopreservation. International Journal of Food Microbiology. 2007;**120**:51-70. DOI: 10.1016/j.ijfoodmicro.2007.06.001
- [103] Bari ML, Ukuku DO, Kawasaki T, Inatsu Y, Isshiki K, Kawamoto S. Combined efficacy of nisin and pediocin with sodium lactate, citric acid, phytic acid, and potassium sorbate and EDTA in reducing the *Listeria monocytogenes* population of inoculated fresh-cut produce. Journal of Food Protection. 2005;**68**:1381-1387. DOI: 10.4315/0362-028X-68.7.1381
- [104] Hansen JN, Sandine WE. Nisin as a model food preservative. Critical Reviews in Food Science and Nutrition. 1994;**34**:69-93. DOI: 10.1080/10408399409527650
- [105] Silveira AC, Conesa A, Aguayo E, Artés F. Alternative sanitizers to chlorine for use on fresh-cut "Galia" (*Cucumis melo* var. *catalupensis*) melon. Journal of Food Science. 2008;**73**:M405-M411. DOI: 10.1111/j.1750-3841.2008.00939.x
- [106] Allende A, Martinez B, Selma V, Gil MI, Suarez JE, Rodriguez A. Growth and bacteriocin production by lactic acid bacteria in vegetable broth and their effectiveness at reducing *Listeria monocytogenes* in vitro and in fresh-cut lettuce. Food Microbiology. 2007;**24**:759-766. DOI: 10.1016/j.fm.2007.03.002
- [107] Sanchís E, González S, Ghidelli C, Sheth CC, Mateos M, Palou L, Pérez-Gago MB. Browning inhibition and microbial control in fresh-cut persimmon (*Diospyros kaki* Thunb. cv. Rojo Brillante) by apple pectin-based edible coatings. Postharvest Biology and Technology. 2016;**112**:186-193. DOI: 10.1016/j.postharvbio.2015.09.024
- [108] Lin H, Lin Y, Hung Y-C, Chen Y, Fan M. Effects of nisin treatment on microbial growth and quality of fresh-cut Chinese yam during storage. In: Book of Abstracts of the III International Conference on Fresh-Cut Produce: Maintaining Quality and Safety; 13-18 September 2015; Davis. Davis: UC Davis; 2015. p. 145
- [109] Randazzo CL, Pitino I, Scifò GO, Caggia C. Biopreservation of minimally processed iceberg lettuces using a bacteriocin produced by *Lactococcus lactis* wild strain. Food Control. 2009;**20**:756-763. DOI: 10.1016/j.foodcont.2008.09.020
- [110] Alegre I, Viñas I, Usall J, Anguera M, Figge MJ, Abadías M. An *Enterobacteriaceae* species isolated from apples controls foodborne pathogens on fresh-cut apples and peaches. Postharvest Biology and Technology. 2012;**74**:118-124. DOI: 10.1016/j.postharvbio.2012.07.004

- [111] Trias R, Bañeras L, Badosa E, Montesinos E. Bioprotection of Golden Delicious apples and Iceberg lettuce against foodborne bacterial pathogens by lactic acid bacteria. *International Journal of Food Microbiology*. 2008;**123**:50-60. DOI: 10.1016/j.ijfoodmicro.2007.11.065
- [112] Fan Y, Xu Y, Wang D, Zhang L, Sun J, Sun L, Zhang B. Effect of alginate coating combined with yeast antagonist on strawberry (*Fragaria × ananassa*) preservation quality. *Postharvest Biology and Technology*. 2009;**53**:84-90. DOI: 10.1016/j.postharvbio.2009.03.002
- [113] Mari M, Martini C, Spadoni A, Rouissi W, Bertolini P. Biocontrol of apple postharvest decay by *Aureobasidium pullulans*. *Postharvest Biology and Technology*. 2012;**73**:56-62. DOI: 10.1016/j.postharvbio.2012.05.014
- [114] Alegre I, Viñas I, Usall J, Teixidó N, Figge MJ, Abadías M. Control of foodborne pathogens on fresh-cut fruit by a novel strain of *Pseudomonas graminis*. *Food Microbiology*. 2013;**34**:390-399. DOI: 10.1016/j.fm.2013.01.013
- [115] Abadías M, Altisent R, Usall J, Torres R, Oliveira M, Viñas I. Biopreservation of fresh-cut melon using the strain *Pseudomonas graminis* CPA-7. *Postharvest Biology and Technology*. 2014;**96**:69-77. DOI: 10.1016/j.postharvbio.2014.05.010
- [116] Plaza L, Altisent R, Alegre I, Viñas I, Abadías M. Changes in the quality and antioxidant properties of fresh-cut melon treated with the biopreservative culture *Pseudomonas graminis* CPA-7 during refrigerated storage. *Postharvest Biology and Technology*. 2016;**111**:25-30. DOI: 10.1016/j.postharvbio.2015.07.023
- [117] Simões M, Simões LC, Vieira MJ. A review of current and emergent biofilm control strategies. *LWT – Food Science and Technology*. 2010;**43**:573-583. DOI: 10.1016/j.lwt.2009.12.008
- [118] Leverentz B, Conway WS, Camp MJ, Janisiewicz WJ, Abuladze T, Yang M, Saftner R, Sulakvelidze A. Biocontrol of *Listeria monocytogenes* on fresh-cut produce by treatment with lytic bacteriophages and a bacteriocin. *Applied and Environmental Microbiology*. 2003;**69**:4519-4526. DOI: 10.1128/aem.69.8.4519-4526.2003
- [119] Spricigo DA, Bardina C, Cortes P, Llagostera M. Use of a bacteriophage cocktail to control *Salmonella* in food and the food industry. *International Journal of Food Microbiology*. 2013;**165**:169-174. DOI: 10.1016/j.ijfoodmicro.2013.05.009
- [120] Vonasek E, Choi A, Sanchez J, Nitin N. Incorporating bacteriophages into edible dip coatings to control food pathogens on fresh produce. In: *Book of Abstracts of the III International Conference on Fresh-Cut Produce: Maintaining Quality and Safety*; 13-18 September 2015; Davis. Davis: UC Davis; 2015. p. 115
- [121] Food and Drug Administration (FDA). Title 21: Food and Drugs. Section. Part 101: Food Labelling [Internet]. 2016. Available from: <https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=101&showFR=1&subpartNode=21:2.0.1.1.2.6> [Accessed: 2017-07-10]
- [122] Peña-Estévez ME, Gómez PA, Artés F, Aguayo E, Martínez-Hernández GB, Otón M, Galindo A, Artés-Hernández F. Quality changes of fresh-cut pomegranate arils during

- shelf life as affected by deficit irrigation and postharvest vapour treatments. *Journal of the Science of Food and Agriculture*. 2015;**95**:2325-2336. DOI: 10.1002/jsfa.6954
- [123] Maghoumi M, Mostofi Y, Zamani Z, Talaie A, Boojar M, Gómez PA. Influence of hot-air treatment, superatmospheric O<sub>2</sub> and elevated CO<sub>2</sub> on bioactive compounds and storage properties of fresh-cut pomegranate arils. *International Journal of Food Science & Technology*. 2014;**49**:153-159. DOI: 10.1111/ijfs.12290
- [124] Beirão-da-Costa S, Empis J, Moldão-Martins M. Fresh-cut kiwifruit structure and firmness as affected by heat pre-treatments and post-cut calcium dips. *Food and Bioprocess Technology*. 2014;**7**:1128-1136. DOI: 10.1007/s11947-013-1151-3
- [125] Martínez-Hernández GB, Gómez P, Orihuel-Iranzo B, Bretó J, Artés-Hernández F, Artés F. Innovative and sustainable postharvest treatments to control physiological disorders and decay in lemon fruit during long transport and commercialization. In: VIII International Postharvest Symposium, Cartagena. 2016
- [126] Obando-Ulloa JM, Jiménez V, Machuca-Vargas A, Beaulieu JC, Infante R, Escalona-Contreras VH. Effect of hot water dips on the quality of fresh-cut Ryan Sun peaches. *Idesia (Arica)*. 2015;**33**:13-26. DOI: 10.4067/S0718-34292015000100002
- [127] Aguayo E, Requejo-Jackman C, Stanley R, Woolf A. Hot water treatment in combination with calcium ascorbate dips increases bioactive compounds and helps to maintain fresh-cut apple quality. *Postharvest Biology and Technology*. 2015;**110**:158-165. DOI: 10.1016/j.postharvbio.2015.07.001
- [128] Wang Q, Nie X, Cantwell M. Hot water and ethanol treatments can effectively inhibit the discoloration of fresh-cut sunchoke (*Helianthus tuberosus* L.) tubers. *Postharvest Biology and Technology*. 2014;**94**:49-57. DOI: 10.1016/j.postharvbio.2014.03.003
- [129] Murata M, Tanaka E, Minoura E, Homma S. Quality of cut lettuce treated by heat shock: Prevention of enzymatic browning, repression of phenylalanine ammonia-lyase activity, and improvement on sensory evaluation during. *Bioscience, Biotechnology, and Biochemistry*. 2004;**68**:501-507. DOI: 10.1271/bbb.68.501
- [130] Hägele F, Baur S, Menegat A, Gerhards R, Carle R, Schweiggert RM. Chlorophyll fluorescence imaging for monitoring the effects of minimal processing and warm water treatments on physiological properties and quality attributes of fresh-cut salads. *Food and Bioprocess Technology*. 2016;**9**:650-663. DOI: 10.1007/s11947-015-1661-2
- [131] Koukounaras A, Siomos AS, Sfakiotakis E. Impact of heat treatment on ethylene production and yellowing of modified atmosphere packaged rocket leaves. *Postharvest Biology and Technology*. 2009;**54**:172-176. DOI: 10.1016/j.postharvbio.2009.07.002
- [132] Gómez F, Fernández L, Gergoff G, Guiamet JJ, Chaves A, Bartoli CG. Heat shock increases mitochondrial H<sub>2</sub>O<sub>2</sub> production and extends postharvest life of spinach leaves. *Postharvest Biology and Technology*. 2008;**49**:229-234. DOI: 10.1016/j.postharvbio.2008.02.012

- [133] Glowacz M, Mogren LM, Reade JPH, Cobb AH, Monaghan JM. Can hot water treatments enhance or maintain postharvest quality of spinach leaves? *Postharvest Biology and Technology*. 2013;**81**:23-28. DOI: 10.1016/j.postharvbio.2013.02.004
- [134] Loaiza-Velarde JG, Mangrich ME, Campos-Vargas R, Saltveit ME. Heat shock reduces browning of fresh-cut celery petioles. *Postharvest Biology and Technology*. 2003;**27**:305-311. DOI: 10.1016/S0925-5214(02)00118-7
- [135] Barbagallo RN, Chisari M, Caputa G. Effects of calcium citrate and ascorbate as inhibitors of browning and softening in minimally processed 'Birgah' eggplants. *Postharvest Biology and Technology*. 2012;**73**:107-114. DOI: 10.1016/j.postharvbio.2012.06.006
- [136] Siddiq M, Roidoung S, Sogi DS, Dolan KD. Total phenolics, antioxidant properties and quality of fresh-cut onions (*Allium cepa* L.) treated with mild-heat. *Food Chemistry*. 2013;**136**:803-806. DOI: 10.1016/j.foodchem.2012.09.023
- [137] Maghoumi M, Gómez PA, Mostofi Y, Zamani Z, Artés-Hernández F, Artés F. Combined effect of heat treatment, UV-C and superatmospheric oxygen packing on phenolics and browning related enzymes of fresh-cut pomegranate arils. *LWT – Food Science and Technology*. 2013;**54**:389-396. DOI: 10.1016/j.lwt.2013.06.006
- [138] Peña-Estévez ME, Gómez PA, Artés F, Aguayo E, Martínez-Hernández GB, Galindo A, Torecillas A, Artés-Hernández F. Changes in bioactive compounds and oxidative enzymes of fresh-cut pomegranate arils during storage as affected by deficit irrigation and postharvest vapor heat treatments. *Food Science and Technology International*. 2016;**22**:665-676. DOI: 10.1177/1082013216635323
- [139] Maghoumi M, Gomez PA, Artes-Hernandez F, Mostofi Y, Zamani Z, Artes F. Hot water, UV-C and superatmospheric oxygen packaging as hurdle techniques for maintaining overall quality of fresh-cut pomegranate arils. *Journal of the Science of Food and Agriculture*. 2013;**93**:1162-1168. DOI: 10.1002/jsfa.5868
- [140] Martínez-Hernández GB, Amodio ML, Colelli G. Potential use of microwave treatment on fresh-cut carrots: physical, chemical and microbiological aspects. *Journal of the Science of Food and Agriculture*. 2016;**96**:2063-2072. DOI: 10.1002/jsfa.7319
- [141] Gray NF. Ultraviolet disinfectio. In: Percival SL, Chalmers RM, Embrey M, Hunter P, Sellwood JPW-J, editors. *Microbiology of Waterborne Diseases*. London: Academic Press; 2014. pp. 617-630.
- [142] Bintsis T, Litopoulou-Tzanetaki E, Robinson RK. Existing and potential applications of ultraviolet light in the food industry – A critical review. *Journal of the Science of Food and Agriculture*. 2000;**80**:637-645. DOI: 10.1002/(SICI)1097-0010(20000501)80:6<637::AID-JSFA603>3.0.CO;2-1
- [143] Yaun BR, Sumner SS, Eifert JD, Marcy JE. Inhibition of pathogens on fresh produce by ultraviolet energy. *International Journal of Food Microbiology*. 2004;**90**:1-8. DOI: 10.1016/S0168-1605(03)00158-2

- [144] Sharma G. Ultraviolet light. In: Robinson RK, Batt C, Patel P, editors. *Encyclopedia of Food Microbiology-3*. London: Academic Press; 1999. pp. 2208-2214
- [145] Ben Said M, Masahiro O, Hassen A. Detection of viable but non cultivable *Escherichia coli* after UV irradiation using a lytic Q $\beta$  phage. *Annals of Microbiology*. 2010;**60**:121-127. DOI: 10.1007/s13213-010-0017-4
- [146] Formica-Oliveira AC, Martínez-Hernández GB, Aguayo E, Gómez PA, Artés F, Artés-Hernández F. UV-C and hyperoxia abiotic stresses to improve healthiness of carrots: Study of combined effects. *Journal of Food Science and Technology*. 2016;**53**:1-12. DOI: 10.1007/s13197-016-2321-x
- [147] Hadjok C, Mittal GS, Warriner K. Inactivation of human pathogens and spoilage bacteria on the surface and internalized within fresh produce by using a combination of ultraviolet light and hydrogen peroxide. *Journal of Applied Microbiology*. 2008;**104**:1014-1024. DOI: 10.1111/j.1365-2672.2007.03624.x
- [148] Kim Y-H, Jeong S-G, Back K-H, Park K-H, Chung M-S, Kang D-H. Effect of various conditions on inactivation of *Escherichia coli* O157:H7, *Salmonella Typhimurium*, and *Listeria monocytogenes* in fresh-cut lettuce using ultraviolet radiation. *International Journal of Food Microbiology*. 2013;**166**:349-355. DOI: 10.1016/j.ijfoodmicro.2013.08.010
- [149] Martínez-Hernández GB, Huertas J-P, Navarro-Rico J, Gómez PA, Artés F, Palop A, Artés-Hernández F. Inactivation kinetics of foodborne pathogens by UV-C radiation and its subsequent growth in fresh-cut kailan-hybrid broccoli. *Food Microbiology*. 2015;**46**:263-271. DOI: 10.1016/j.fm.2014.08.008
- [150] Artés-Hernández F, Escalona VH, Robles PA, Martínez-Hernández GB, Artés F. Effect of UV-C radiation on quality of minimally processed spinach leaves. *Journal of the Science of Food and Agriculture*. 2009;**89**:414-421. DOI: 10.1002/jsfa.3460
- [151] European Union (EU). Commission regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs. *Official Journal of the European Union*. 2005;**L338**:1-26
- [152] Escalona VH, Aguayo E, Martínez-Hernández GB, Artés F. UV-C doses to reduce pathogen and spoilage bacterial growth *in vitro* and in baby spinach. *Postharvest Biology and Technology*. 2010;**56**:223-231. DOI: 10.1016/j.postharvbio.2010.01.008
- [153] Erkan M, Wang CY, Krizek DT. UV-C irradiation reduces microbial populations and deterioration in *Cucurbita pepo* fruit tissue. *Environmental and Experimental Botany*. 2001;**45**:1-9. DOI: S0098-8472(00)00073-3
- [154] Martínez-Hernández GB, Gómez PA, Pradas I, Artés F, Artés-Hernández F. Moderate UV-C pretreatment as a quality enhancement tool in fresh-cut Bimi<sup>®</sup> broccoli. *Postharvest Biology and Technology*. 2011;**62**:327-337. DOI: 10.1016/j.postharvbio.2011.06.015
- [155] Robles P, De Campos A, Artés-Hernández F, Gómez P, Calderón A, Ferrer M, Artés F. Combined effect of UV-C radiation and controlled atmosphere storage to preserve tomato quality. In: V Congreso Iberoamericano de Tecnología Postcosecha y Agroexportaciones; Cartagena (Spain). 2007

- [156] Jemni M, Gómez PA, Souza M, Chaira N, Ferchichi A, Otón M, Artés F. Combined effect of UV-C, ozone and electrolyzed water for keeping overall quality of date palm. *LWT – Food Science and Technology*. 2014;**59**:649-655. DOI: 10.1016/j.lwt.2014.07.016
- [157] Pinheiro JC, Alegria CSM, Abreu MMMN, Gonçalves EM, Silva CLM. Evaluation of alternative preservation treatments (water heat treatment, ultrasounds, thermosonication and UV-C radiation) to improve safety and quality of whole tomato. *Food and Bioprocess Technology*. 2016;**9**:924-935. DOI: 10.1007/s11947-016-1679-0
- [158] Marquenie D, Michiels CW, Geeraerd AH, Schenk A, Soontjens C, Van Impe JF, Nicolai BM. Using survival analysis to investigate the effect of UV-C and heat treatment on storage rot of strawberry and sweet cherry. *International Journal of Food Microbiology*. 2002;**73**:187-196. DOI: 10.1016/S0168-1605(01)00648-1
- [159] Artés-Hernández F, Robles PA, Gómez PA, Tomás-Callejas A, Artés F. Low UV-C illumination for keeping overall quality of fresh-cut watermelon. *Postharvest Biology and Technology*. 2010;**55**:114-120. DOI: 10.1016/j.postharvbio.2009.09.002
- [160] Rocha ABO, Honório SL, Messias CL, Otón M, Gómez PA. Effect of UV-C radiation and fluorescent light to control postharvest soft rot in potato seed tubers. *Scientia Horticulturae*. 2015;**181**:174-181. DOI: 10.1016/j.scienta.2014.10.045
- [161] Allende A, Artés F. UV-C radiation as a novel technique for keeping quality of fresh processed 'Lollo Rosso' lettuce. *Food Research International*. 2003;**36**:739-746. DOI: 10.1016/S0963-9969(03)00054-1
- [162] Fan X, Toivonen PM, Rajkowski KT, Sokorai KJ. Warm water treatment in combination with modified atmosphere packaging reduces undesirable effects of irradiation on the quality of fresh-cut iceberg lettuce. *Journal of Agricultural and Food Chemistry*. 2003;**51**:1231-1236. DOI: 10.1021/jf020600c
- [163] González-Aguilar GA, Zavaleta-Gatica R, Tiznado-Hernández ME. Improving postharvest quality of mango 'Haden' by UV-C treatment. *Postharvest Biology and Technology*. 2007;**45**:108-116. DOI: 10.1016/j.postharvbio.2007.01.012
- [164] Alothman M, Bhat R, Karim AA. Effects of radiation processing on phytochemicals and antioxidants in plant produce. *Trends in Food Science & Technology*. 2009;**20**:201-212. DOI: 10.1016/j.tifs.2009.02.003
- [165] Rawson A, Patras A, Tiwari BK, Noci F, Koutchma T, Brunton N. Effect of thermal and non thermal processing technologies on the bioactive content of exotic fruits and their products: Review of recent advances. *Food Research International*. 2011;**44**:1875-1887. DOI: 10.1016/j.foodres.2011.02.053
- [166] Scattino C, Castagna A, Neugart S, Chan HM, Schreiner M, Crisosto CH, Tonutti P, Ranieri A. Post-harvest UV-B irradiation induces changes of phenol contents and corresponding biosynthetic gene expression in peaches and nectarines. *Food Chemistry*. 2014;**163**:51-60. DOI: 10.1016/j.foodchem.2014.04.077

- [167] Castagna A, Dall'Asta C, Chiavaro E, Galaverna G, Ranieri A. Effect of post-harvest UV-B irradiation on polyphenol profile and antioxidant activity in flesh and peel of tomato fruits. *Food Bioprocess Technology*. 2014;**7**:2241-2250. DOI: 10.1007/s11947-013-1214-5
- [168] Du WX, Avena-Bustillos RJ, Breksa 3rd AP, McHugh TH. Effect of UV-B light and different cutting styles on antioxidant enhancement of commercial fresh-cut carrot products. *Food Chemistry*. 2012;**134**:1862-1869. DOI: 10.1016/j.foodchem.2012.03.097
- [169] Formica-Oliveira AC, Martínez-Hernández GB, Díaz-López V, Artés F, Artés-Hernández F. Effects of UV-B and UV-C combination on phenolic compounds biosynthesis in fresh-cut carrots. *Postharvest Biology and Technology*. 2017;**127**:99-104. DOI: 10.1016/j.postharvbio.2016.12.010
- [170] Kataoka I, Beppu K, Sugiyama A, Taira S. Enhancement of coaration of Satohnishiki sweet cherry fruit by postharvest irradiation with ultraviolet rays. *Environment Control in Biology*. 1996;**34**:313-319. DOI: 10.2525/ecb1963.34.313
- [171] Woltering EJ, Witkowska IM, Schouten R, Harbinson J. Low intensity postharvest lighting improves quality and shelf life of fresh-cut lettuce. In: *Book of Abstracts of the III International Conference on Fresh-Cut Produce: Maintaining Quality and Safety*; 13-18 September 2015; Davis. Davis: UC Davis; 2015. p. 115
- [172] Oms-Oliu G, Martín-Belloso O, Soliva-Fortuny R. Pulsed light treatments for food preservation. A review. *Food and Bioprocess Technology*. 2008;**3**:13. DOI: 10.1007/s11947-008-0147-x
- [173] Gómez-López VM, Ragaert P, Debevere J, Devlieghere F. Pulsed light for food decontamination: A review. *Trends in Food Science and Technology*. 2007;**18**:464-473. DOI: 10.1016/j.tifs.2007.03.010
- [174] Ramos-Villarroel AY, Martín-Belloso O, Soliva-Fortuny R. Bacterial inactivation and quality changes in fresh-cut avocado treated with intense light pulses. *European Food Research and Technology*. 2011;**233**:395-402. DOI: 10.1007/s00217-011-1533-6
- [175] Ramos-Villarroel AY, Aron-Maftei N, Martín-Belloso O, Soliva-Fortuny R. Influence of spectral distribution on bacterial inactivation and quality changes of fresh-cut watermelon treated with intense light pulses. *Postharvest Biology and Technology*. 2012;**69**:32-39. DOI: 10.1016/j.postharvbio.2012.03.002
- [176] Ramos-Villarroel AY, Aron-Maftei N, Martín-Belloso O, Soliva-Fortuny R. The role of pulsed light spectral distribution in the inactivation of *Escherichia coli* and *Listeria innocua* on fresh-cut mushrooms. *Food Control*. 2012;**24**:206-213. DOI: 10.1016/j.foodcont.2011.09.029
- [177] Oms-Oliu G, Aguiló-Aguayo I, Martín-Belloso O, Soliva-Fortuny R. Effects of pulsed light treatments on quality and antioxidant properties of fresh-cut mushrooms (*Agaricus bisporus*). *Postharvest Biology and Technology*. 2010;**56**:216-222. DOI: 10.1016/j.postharvbio.2009.12.011
- [178] Izquier A, Gómez-López VM. Modeling the pulsed light inactivation of microorganisms naturally occurring on vegetable substrates. *Food Microbiology*. 2011;**28**:1170-1174. DOI: 10.1016/j.fm.2011.03.010

- [179] Agüero MV, Jagus RJ, Martín-Belloso O, Soliva-Fortuny R. Surface decontamination of spinach by intense pulsed light treatments: Impact on quality attributes. *Postharvest Biology and Technology*. 2016;**121**:118-125. DOI: 10.1016/j.postharvbio.2016.07.018
- [180] Gómez-López VM, Devlieghere F, Bonduelle V, Debevere J. Intense light pulses decontamination of minimally processed vegetables and their shelf-life. *International Journal of Food Microbiology*. 2005;**103**:79-89. DOI: 10.1016/j.ijfoodmicro.2004.11.028
- [181] Lee E, Lee H, Jung W, Park S, Yang D, Lee K. Influences of humic acids and photo-reeactivation on the disinfection of *Escherichia coli* by a high-power pulsed UV irradiation. *Korean Journal of Chemical Engineering*. 2009;**26**:1301-1307. DOI: 10.1007/s11814-009-0208-5
- [182] Lasagabaster A, de Marañon IM. Survival and growth of *Listeria innocua* treated by pulsed light technology: Impact of post-treatment temperature and illumination conditions. *Food Microbiology*. 2014;**41**:76-81. DOI: 10.1016/j.fm.2014.02.001
- [183] Maclean M, Murdoch LE, Lani MN, MacGregor SJ, Anderson JG, Woolsey GA. Photoinactivation and photoreactivation responses by bacterial pathogens after exposure to pulsed UV-light. In: *Proceedings of the 2008 IEEE International Power Modulators and High-Voltage Conference; 27-31 May 2008; Las Vegas*. Boston: IEEE; 2008. pp. 326-329
- [184] Gomez-Lopez VM, Devlieghere F, Bonduelle V, Debevere J. Factors affecting the inactivation of micro-organisms by intense light pulses. *Journal of Applied Microbiology*. 2005;**99**:460-470. DOI: 10.1111/j.1365-2672.2005.02641.x
- [185] Asavasanti S, Ersus S, Ristenpart W, Stroeve P, Barrett DM. Critical electric field strengths of onion tissues treated by pulsed electric fields. *Journal of Food Science*. 2010;**75**:E433-E443. DOI: 10.1111/j.1750-3841.2010.01768.x
- [186] Lebovka NI, Praporscic I, Vorobiev E. Combined treatment of apples by pulsed electric fields and by heating at moderate temperature. *Journal of Food Engineering*. 2004;**65**:211-217. DOI: 10.1016/j.jfoodeng.2004.01.017
- [187] Jin TZ, Yu Y, Gurtler JB. Effects of pulsed electric field processing on microbial survival, quality change and nutritional characteristics of blueberries. *LWT – Food Science and Technology*. 2017;**77**:517-524. DOI: 10.1016/j.lwt.2016.12.009
- [188] Scholtz V, Pazlarova J, Souskova H, Khun J, Julak J. Nonthermal plasma-A tool for decontamination and disinfection. *Biotechnology Advances*. 2015;**33**:1108-1119. DOI: 10.1016/j.biotechadv.2015.01.002
- [189] Dey A, Rasane P, Choudhury A, Singh J, Maisnam D, Rasane P. Cold plasma processing: A review. *Journal of Chemical and Pharmaceutical Research*. 2016;**9**:2980-2984
- [190] Thirumdas R, Sarangapani C, Annapure US. Cold plasma: A novel non-thermal technology for food processing. *Food Biophysics*. 2015;**10**:1-11. DOI: 10.1007/s11483-014-9382-z
- [191] Ziuzina D, Han L, Cullen PJ, Bourke P. Cold plasma inactivation of internalised bacteria and biofilms for *Salmonella enterica* serovar Typhimurium, *Listeria monocytogenes* and *Escherichia coli*. *International Journal of Food Microbiology*. 2015;**210**:53-61. DOI: 10.1016/j.ijfoodmicro.2015.05.019

- [192] Li X, Farid M. A review on recent development in non-conventional food sterilization technologies. *Journal of Food Engineering*. 2016;**182**:33-45. DOI: 10.1016/j.jfoodeng.2016.02.026
- [193] Ehlbeck J, Schnabel U, Polak M, Winter J, Woedtke T, Brandenburg R, Dem Hagen T, Weltmann K-D. Low temperature atmospheric pressure plasma sources for microbial decontamination. *Journal of Physics D-Applied Physics*. 2011;**44**:1-18. DOI: 10.1088/0022-3727/44/1/013002
- [194] Pignata C, D'Angelo D, Fea E, Gilli G. A review on microbiological decontamination of fresh produce with nonthermal plasma. *Journal of Applied Microbiology*. 2017. DOI: 10.1111/jam.13412
- [195] Tappi S, Berardinelli A, Ragni L, Dalla Rosa M, Guarnieri A, Rocculi P. Atmospheric gas plasma treatment of fresh-cut apples. *Innovative Food Science & Emerging Technologies*. 2014;**21**:114-122. DOI: 10.1016/j.ifset.2013.09.012
- [196] Bußler S, Ehlbeck J, Schlüter OK. Pre-drying treatment of plant related tissues using plasma processed air: Impact on enzyme activity and quality attributes of cut apple and potato. *Innovative Food Science & Emerging Technologies*. 2017;**40**:78-86. DOI: 10.1016/j.ifset.2016.05.007
- [197] Liao X, Liu D, Xiang Q, Ahn J, Chen S, Ye X, Ding T. Inactivation mechanisms of non-thermal plasma on microbes: A review. *Food Control*. 2017;**75**:83-91. DOI: 10.1016/j.foodcont.2016.12.021
- [198] Otto C, Zahn S, Rost F, Zahn P, Jaros D, Rohm H. Physical methods for cleaning and disinfection of surfaces. *Food Engineering Reviews*. 2011;**3**:171-188. DOI: 10.1007/s12393-011-9038-4
- [199] São José JFBd, Andrade NJd, Ramos AM, Vanetti MCD, Stringheta PC, Chaves JBP. Decontamination by ultrasound application in fresh fruits and vegetables. *Food Control*. 2014;**45**:36-50. DOI: 10.1016/j.foodcont.2014.04.015
- [200] Health Protection Agency (HPA). Health Effects of Exposure to Ultrasound and Infrasound, Report of the independent advisory group on non-ionising radiation. London: HPA; 2010. 180. DOI: 978-0-85951-662-4
- [201] Paniwnyk L. Application of ultrasound. In: Sun D-W, editor. *Emerging Technologies for Food Processing*. San Diego CA (USA): Academic Press; 2014. pp. 271-291
- [202] Seymour IJ, Burfoot D, Smith RL, Cox LA, Lockwood A. Ultrasound decontamination of minimally processed fruits and vegetables. *International Journal of Food Science & Technology*. 2002;**37**:547-557. DOI: 10.1046/j.1365-2621.2002.00613.x
- [203] do Rosario DK, da Silva Mutz Y, Peixoto JM, Oliveira SB, de Carvalho RV, Carneiro JC, de Sao Jose JF, Bernardes PC. Ultrasound improves chemical reduction of natural contaminant microbiota and *Salmonella enterica* subsp. *enterica* on strawberries. *International Journal of Food Microbiology*. 2017;**241**:23-29. DOI: 10.1016/j.ijfoodmicro.2016.10.009

- [204] Birmipa A, Sfika V, Vantarakis A. Ultraviolet light and Ultrasound as non-thermal treatments for the inactivation of microorganisms in fresh ready-to-eat foods. *International Journal of Food Microbiology*. 2013;**167**:96-102. DOI: 10.1016/j.ijfoodmicro.2013.06.005
- [205] Kim HJ, Feng H, Kushad MM, Fan X. Effects of ultrasound, irradiation, and acidic electrolyzed water on germination of alfalfa and broccoli seeds and *Escherichia coli* O157:H7. *Journal of Food Science*. 2006;**71**:168-173. DOI: 10.1111/j.1750-3841.2006.00064.x
- [206] Jung S, Samson CT, Lamballerie M. High hydrostatic pressure food processing. In: Proctor A, editor. *Alternatives to Conventional Food Processing*. London, UK: Royal Society of Chemistry Publishing; 2011. pp. 254-306.
- [207] Rendueles E, Omer MK, Alvseike O, Alonso-Calleja C, Capita R, Prieto M. Microbiological food safety assessment of high hydrostatic pressure processing: A review. *LWT – Food Science and Technology*. 2011;**44**:1251-1260. DOI: 10.1016/j.lwt.2010.11.001
- [208] Préstamo G, Arroyo G. High hydrostatic pressure effects on vegetable structure. *Journal of Food Science*. 1998;**63**:878-881. DOI: 10.1111/j.1365-2621.1998.tb17918.x
- [209] Oey I, Lille M, Van Loey A, Hendrickx M. Effect of high-pressure processing on colour, texture and flavour of fruit- and vegetable-based food products: A review. *Trends in Food Science and Technology*. 2008;**19**:320-328. DOI: 10.1016/j.tifs.2008.04.001
- [210] Vázquez-Gutierrez JL, Quiles A, Vonasek E, Jernstedt JA, Hernando I, Nitin N, Barrett DM. High hydrostatic pressure as a method to preserve fresh-cut Hachiya persimmons: A structural approach. *Food Science and Technology International*. 2016;**22**:688-698. DOI: 10.1177/1082013216642049
- [211] Denoya GI, Polenta GA, Apóstolo NM, Budde CO, Sancho AM, Vaudagna SR. Optimization of high hydrostatic pressure processing for the preservation of minimally processed peach pieces. *Innovative Food Science & Emerging Technologies*. 2016;**33**:84-93. DOI: 10.1016/j.ifset.2015.11.014
- [212] Spilimbergo S, Komes D, Vojvodic A, Levaj B, Ferrentino G. High pressure carbon dioxide pasteurization of fresh-cut carrot. *The Journal of Supercritical Fluids*. 2013;**79**:92-100. DOI: 10.1016/j.supflu.2012.12.002
- [213] Ferrentino G, Komes D, Spilimbergo S. High-power ultrasound assisted high-pressure carbon dioxide pasteurization of fresh-cut coconut: A microbial and physico-chemical study. *Food and Bioprocess Technology*. 2015;**8**:2368-2382. DOI: 10.1007/s11947-015-1582-0
- [214] Kader AA, Ben-Yehoshua S. Effects of superatmospheric oxygen levels on postharvest physiology and quality of fresh fruits and vegetables. *Postharvest Biology and Technology*. 2000;**20**:1-13. DOI: 10.1016/S0925-5214(00)00122-8
- [215] Escalona VH, Geysen S, Verlinden BE, Nicolai BM. Microbial quality and browning of fresh-cut butter lettuce under superatmospheric oxygen condition. *European Journal of Horticultural Science*. 2007;**72**:130-137

- [216] Geysen S, Escalona VH, Verlinden BE, Aertsen A, Geeraerd AH, Michiels CW, Van Impe JF, Nicolai BM. Validation of predictive growth models describing superatmospheric oxygen effects on *Pseudomonas fluorescens* and *Listeria innocua* on fresh-cut lettuce. *International Journal of Food Microbiology*. 2006;**111**:48-58. DOI: 10.1016/j.ijfoodmicro.2006.04.044
- [217] Zheng Y, Yang Z, Chen X. Effect of high oxygen atmospheres on fruit decay and quality in Chinese bayberries, strawberries and blueberries. *Food Control*. 2008;**19**:470-474. DOI: 10.1016/j.foodcont.2007.05.011
- [218] Allende A, Luo Y, McEvoy JL, Artés F, Wang CY. Microbial and quality changes in minimally processed baby spinach leaves stored under super atmospheric oxygen and modified atmosphere conditions. *Postharvest Biology and Technology*. 2004;**33**:51-59. DOI: 10.1016/j.postharvbio.2004.03.003
- [219] Van der Steen C, Jacxsens L, Devlieghere F, Debevere J. Combining high oxygen atmospheres with low oxygen modified atmosphere packaging to improve the keeping quality of strawberries and raspberries. *Postharvest Biology and Technology*. 2002;**26**:49-58. DOI: 10.1016/S0925-5214(02)00005-4
- [220] Heimdal H, Kühn BF, Poll L, Larsen LM. Biochemical changes and sensory quality of shredded and MA-packaged iceberg lettuce. *Journal of Food Science*. 1995;**60**:1265-1268. DOI: 10.1111/j.1365-2621.1995.tb04570.x
- [221] Jacxsens L, Devlieghere F, Van der Steen C, Debevere J. Effect of high oxygen modified atmosphere packaging on microbial growth and sensorial qualities of fresh-cut produce. *International Journal of Food Microbiology*. 2001;**71**:197-210. DOI: 10.1016/S0168-1605(01)00616-X
- [222] Oms-Oliu G, Soliva-Fortuny R, Martín-Belloso O. Modeling changes of headspace gas concentrations to describe the respiration of fresh-cut melon under low or superatmospheric oxygen atmospheres. *Journal of Food Engineering*. 2008;**85**:401-409. DOI: 10.1016/j.jfoodeng.2007.08.001
- [223] Lu C, Toivonen PMA. Effect of 1 and 100 kPa O<sub>2</sub> atmospheric pretreatments of whole 'Spartan' apples on subsequent quality and shelf life of slices stored in modified atmosphere packages. *Postharvest Biology and Technology*. 2000;**18**:99-107. DOI: 10.1016/S0925-5214(99)00069-1
- [224] Amanatidou A, Slump RA, Gorris LGM, Smid EJ. High oxygen and high carbon dioxide modified atmospheres for shelf-life extension of minimally processed carrots. *Journal of Food Science*. 2000;**65**:61-66. DOI: 10.1111/j.1365-2621.2000.tb15956.x
- [225] Formica-Oliveira AC, Martínez-Hernández GB, Aguayo E, Gómez PA, Artés F, Artés-Hernández F. A functional smoothie from carrots with induced enhanced phenolic content. *Food and Bioprocess Technology*. 2017;**10**:491-502. DOI: 10.1007/s11947-016-1829-4
- [226] Gorny J, Agar I. Are argon-enriched atmospheres beneficial? *Perishables Handling Newsletter*. 1998;**94**:7-8

- [227] Jamie P, Saltveit ME. Postharvest changes in broccoli and lettuce during storage in argon, helium, and nitrogen atmospheres containing 2% oxygen. *Postharvest Biology and Technology*. 2002;**26**:113-116. DOI: 10.1016/S0925-5214(02)00006-6
- [228] Zhang M, Zhan ZG, Wang SJ, Tang JM. Extending the shelf-life of asparagus spears with a compressed mix of argon and xenon gases. *LWT – Food Science and Technology*. 2008;**41**:686-691. DOI: 10.1016/j.lwt.2007.04.011
- [229] Tomás-Callejas A, Boluda M, Robles PA, Artés F, Artés-Hernández F. Innovative active modified atmosphere packaging improves overall quality of fresh-cut red chard baby leaves. *LWT – Food Science and Technology*. 2011;**44**:1422-1428. DOI: 10.1016/j.lwt.2011.01.020
- [230] Gouble B, Fath D, Soudain P. Nitrous oxide inhibition of ethylene production in ripening and senescing climacteric fruits. *Postharvest Biology and Technology*. 1995;**5**:311-321. DOI: 10.1016/0925-5214(94)00030-V
- [231] Rodríguez-Hidalgo S, Artés-Hernández F, Gómez PA, Fernández JA, Artés F. Quality of fresh-cut baby spinach grown under a floating trays system as affected by nitrogen fertilisation and innovative packaging treatments. *Journal of the Science of Food and Agriculture*. 2010;**90**:1089-1097. DOI: 10.1002/jsfa.3926
- [232] Ansah FA, Amodio ML, Colelli G. Evaluation of the impact of nitrous oxide use on quality and shelf life of packaged fresh-cut 'iceberg' lettuce and wild rocket. *Chemical Engineering Transactions*. 2015;**44**:319-324. DOI: 10.3303/CET1544054
- [233] Silveira AC, Araneda C, Hinojosa A, Escalona VH. Effect of non-conventional modified atmosphere packaging on fresh cut watercress (*Nasturtium officinale* R. Br.) quality. *Postharvest Biology and Technology*. 2014;**92**:114-120. DOI: 10.1016/j.postharvbio.2013.12.012
- [234] Inestroza-Lizardo C, Silveira AC, Escalona VH. Metabolic activity, microbial growth and sensory quality of arugula leaves (*Eruca vesicaria* Mill.) stored under non-conventional modified atmosphere packaging. *Scientia Horticulturae*. 2016;**209**:79-85. DOI: 10.1016/j.scienta.2016.06.007

