[Ghidelli, C., & Pérez-Gago, M. B. (2018). Recent advances in modified atmosphere packaging and edible coatings to maintain quality of fresh-cut fruits and vegetables. Critical reviews in food science and nutrition, 58(4), 662-679.]

ivia
Institut Valencià
d'Investigacions Agràries

[https://doi.org/10.1080/10408398.2016.1211087]

Critical Reviews in Food Science and Nutrition, 58:4, 662-679

Recent advances in modified atmosphere packaging and edible coatings to maintain quality of fresh-cut fruits and vegetables

CHRISTIAN GHIDELLI [1,2] AND MARÍA B. PÉREZ-GAGO [1*].

[1] Centro de Tecnología Poscosecha, Instituto Valenciano de Investigaciones Agrarias (IVIA), 46113 Moncada, Valencia, Spain.

[2] R & D Department, Advanced Technologies Inspiralia, 28049 Madrid, Spain

Running title: Advances in MAP and Edible Coatings for Fresh-Cut Products

*Author to whom correspondence should be addressed:
Telephone: (+34) 963424000
Fax number: (+34) 963424001
e.mail: perez_mbe@gva.es

Critical Reviews in Food Science and Nutrition, 58:4, 662-679

ABSTRACT

Processing of fruits and vegetables generates physiological stresses in the still living cut tissue, leading to quality deterioration and shorter shelf-life as compared with fresh intact produces. Several strategies can be implemented with the aim to reduce the rate of deterioration of fresh-cut commodities. Such strategies include low temperature maintenance from harvest to retail and the application of physical and chemical treatments such as modified atmosphere packaging (MAP) with low O_2 and high CO_2 levels and antioxidant dips. Other technologies such as edible coatings with natural additives, new generation of coatings using nanotechnological solutions such as nanoparticles, nanoencapsulation, and multilayered systems, and non-conventional atmospheres such as the use of pressurized inert/noble gases and high levels of O_2 have gained a lot of interest as a possibility to extend the shelf life of minimally processed fruits and vegetables. However, the high perishability of these products challenges in many cases their marketability by not achieving sufficient shelf life to survive the distribution system, requiring the combination of treatments to assure safety and quality. This review reports the recent advances in the use of MAP, edible coatings, and the combined effect of both technologies to extend the shelf life of fresh-cut fruits and vegetables.

Keywords: Minimally processed fruits and vegetables, edible coating, modified atmosphere packaging, hurdle technologies.

INTRODUCTION

Minimally processed or fresh-cut products are ready-to-eat or ready-to-use fresh fruits and vegetables that have been washed, chopped and packed in sealed polymeric films or trays. This trading form was developed in the 1980s to respond to the emerging consumer demand for convenient, high quality and preservative-free products that maintain fresh appearance, while being less severely processed than canned or frozen products. The demand for fresh-cut fruits and vegetables has continuously increased during the last few years, being the convenience factor the main reason for the growth, although now the healthy eating trend is helping to make this sector even stronger.

Contrary to other food processing techniques such as drying, freezing or canning, fresh-cut processing does not extend the shelf-life of the product. In fact, processing and packaging of fresh-cut fruits and vegetables generates physiological stresses in the still living cut tissues leading to quality deterioration and a shorter shelf-life as compared to intact fruits and vegetables (Gil et al., 2006; Rojas-Graü et al., 2009). The greatest hurdle to the commercial marketing of fresh-cut fruits and vegetables is their higher susceptibility to enzymatic browning, tissue softening, increasing of respiration, microbial growth, and environmental factors. Among them, temperature, humidity, atmospheric composition and ethylene concentration directly influence the deterioration process. Mechanical damage during harvesting, handling, storage and transportation before processing also reduces the shelf-life of the fresh-cut products.

There is no single technology that limits the overall quality deterioration. Several strategies can be implemented with the aim to reduce the rate of deterioration of fresh-cut commodities. These include the use of high quality raw produce harvested at optimum maturity, sanitation during handling and processing, reduction of mechanical damage during processing, and post-processing treatments such as low temperature and low oxygen atmosphere packaging to reduce respiration rate and ethylene production. Other technologies such as edible coatings with natural additives and non-conventional atmospheres have gained a lot of interest as a way to extend the shelf life of minimally processed fruits and vegetables.

Successful applications of modified atmosphere packaging (MAP) with low O_2 and high CO_2 for minimally processed fruits and vegetables have been extensively reported in the literature (Rojas-Graü et al., 2009; Caleb et al., 2013; Zhang et al., 2015). The effect of low O_2 and high CO_2 MAP to reduce quality deterioration of fresh-cut products during storage is related to a reduction in respiration rate, ethylene biosynthesis, water loss, phenolic oxidation, and aerobic microbial count. However, the beneficial quality effects of MAP on the packaged fresh-cut fruits and vegetables depend upon a number of uncontrollable factors, such as the species, cultivar, cultural practices, stage of development, postharvest handling, as well as controllable factors, including packaging material gas permeability, respiration rate, and storage conditions (Kader and Ben-Yehosua, 2000). Exposure of fresh-cut produce to too low O_2 and excessive CO_2 levels may lead to anaerobic respiration and fermentation with the production of undesirable metabolites and other physiological disorders. Therefore, the range of O_2 and CO_2 in the package must be defined for each product and handling/processing characteristic (e.g. processed form, package format, storage conditions, etc.).

Innovative MAP such as the use of pressurized inert/noble gases and high levels of O_2 (>70 kPa) have also been reported as effective in extending shelf life of minimally processed fruits and vegetables (Kader and Ben-Yehoshua, 2000). The main benefits of superatmospheric O_2 and noble gases atmospheres are related to the prevention of microbiological spoilage and anaerobic fermentation, as observed in fresh-cut melon, cabbage, baby spinach, green peppers, broccoli, and lettuce (Jamie and Saltveit, 2002; Allende et al., 2004; Oms-Oliu et al., 2008a; Lee et al., 2011; Meng et al., 2012). Moreover, inert gases and high O_2 concentrations have been found to be particularly effective at inhibiting enzymatic reactions and maintaining firmness of fresh-cut iceberg lettuce, mushrooms, potatoes, apples, green pepper, and melons (Amanatidou et al., 2000; Day, 2001; Jacxsens et al., 2001; Jamie and Saltveit, 2002; Limbo and Piergiovanni, 2006; Oms-Oliu et al., 2008a; Meng et al., 2012). Nevertheless, the effect of innovative MAP is dependent on similar factors as with conventional MAP (i.e. type of commodity, temperature, storage duration, etc.) (Kader and Ben-Yehoshua, 2000).

Another approach to extend the shelf life of fresh-cut fruits and vegetables is the use of edible coatings alone or combined with MAP. Edible coatings can provide a semipermeable barrier to gases and water vapor, which might translate in a reduction in respiration rate, enzymatic browning and water loss and their protective function may be also enhanced with the addition of ingredients such as antioxidants, antimicrobials, flavors, etc. (Pérez-Gago et al., 2005). Several reviews present the beneficial effect of edible coatings to maintain the quality properties of fresh-cut fruits and vegetables (Dea et al., 2012; Dhall, 2013). Considering the importance of these technologies in horticultural products, this paper provides a critical review about the most recent works in the literature regarding MAP and edible coating application, alone or in combination, to extend the shelf life of fresh-cut fruits and vegetables. The most recent studies on these technologies are summarized in Table 1.

MODIFIED ATMOSPHERE PACKAGING

MAP of fresh-cut products consists of enclosing the commodity in polymeric films in which the gas composition is modified from normal air to provide an atmosphere for increasing shelf life and maintaining the quality. Because of the respiration process, the fresh-cut product consumes O_2 and produces CO_2, therefore the O_2 and the CO_2 concentration within the package is reduced and increased, respectively. The steady state of equilibrium is reached when the amount of O_2 consumed and CO_2 produced inside the package equals the O_2 and CO_2 amount permeating through the film. Therefore, the specific gas composition at equilibrium is determined by the product weight and physiology (e.g. respiration rate, maturity stage, etc), environmental conditions (e.g. temperature, relative humidity), and properties of the packaging material (e.g. film thickness, permeability, perforation density and surface area) (Caleb et al., 2013). The modified atmospheres can be achieved passively or actively. The passive MAP relies on the natural process of produce respiration and film permeability. While, active MAP is achieved by displacing the air within the package with a known mixture of gases to create an atmosphere that evolves during storage according to the produce respiration rate, the storage conditions and film permeability.

Passive MAP for fresh-cut fruits and vegetables

There is scarce information in literature about the effect of passive MAP on fresh-cut products compared to active MAP. Gil-Izquierdo et al. (2002) and Giménez et al. (2003) studied the effect of packaging films of different permeability (polyvinylchloride (PVC), low density polyethylene (LDPE) and polypropylene (PP)) on the quality (weight losses, color, texture and sensory acceptability) and microbial growth (mesophiles, psychrotrophs, anaerobic micro-organisms, sporeformers, faecal coliforms, *Salmonella* and *Escherichia coli*) of minimally processed artichoke and observed that the highest permeability reached equilibrium rapidly and the highest atmosphere modification was detected with PP film. The atmosphere reached within the package affect the vitamin C and phenolic content (Gil-Izquierdo et al., 2002) and the microbial quality (Giménez et al., 2003) of minimally processed artichokes. Microbial counts were below the legal limit in those batches where the equilibrium atmosphere was anaerobic, whereas some batches with an acceptable sensory quality had microbial counts higher than those allowed by the legislation. Similarly, Palma et al. (2013) reported lower microbial load in minimally processed cactus pear packed with low permeability PP films than in those packed with high permeability polyethylene (PE) films. Furthermore, fruits packed with micro-perforated films showed the highest microbial load. This was attributed in part to in-package gas composition and in part to a continuous contamination of microorganisms through micro-holes.

Escalona et al. (2007) studied the effect of passive MAP on quality attributes and shelf life of kohlrabi sticks during 14 days of storage at 0 ºC. Two commercial films were tested (oriented polypropylene (OPP) and amide-polyethylene (amide-PE)) and compared to microperforated OPP film as control. On day 14 only sticks stored in MAP conditions scored above the limit of marketability; meanwhile, a poor appearance and slight tissue dehydration were observed in control sticks. The use of passive MAP helped maintaining firmness and induced a good fresh quality of sticks, especially when those were placed in amide-PE bags. Sticks packaged in this polymeric material reached an equilibrium atmosphere of 7 kPa O_2 and 9 kPa CO_2 after 6 days of storage and under these conditions the product presented an acceptable sensorial quality for 14 days.

Allende et al. (2004) studied the effect of PE film bags with two different O_2 permeabilities on plant metabolism, sensory quality and microbial growth of minimally processed baby spinach. Spinaches packaged in the higher barrier film (16.2 kPa CO_2) exhibited a more rapid accumulation of CO_2 than those in the permeable film (6.1 kPa CO_2) package at the end of 12 days of storage at 5 ºC. Fresh-cut spinach packed with the barrier film exhibited a significant reduction in the growth of aerobic mesophilic bacteria compared to control conditions, but induced a strong off-odor and loss of tissue integrity due to the combination of extremely low O_2 and high CO_2 concentrations inside the packaging.

The application of antibrowning agents such as hexylresorcinol, potassium sorbate, and ascorbic acid in combination with passive MAP obtained with Cryovac LDX-5406 film reduced enzymatic browning and maintained the sensory quality of fresh-cut mangoes stored at 10 °C for 14 days (González-Aguilar et al., 2000). In any of the antioxidant treatments the O_2 and CO_2 concentrations at the end of the 14 days of storage were below 5 kPa or higher than 10 kPa, respectively. On the other hand, Beltrán et al. (2005) reported that the respiratory activity of potato strips packaged in LDPE in response to different sanitizers (traditional and non-traditional sanitizers) was similar for all treatments. After 5 days of storage at 4 ºC, the steady state within packages was reached with O_2 and CO_2 levels of about 0.3–1.4 and 6.3–8.3 kPa, respectively. The sanitizing treatments in vacuum packaging increased the lag phase of mesophilic bacteria up to 11 days, being the best packaging method to preserve the sensory quality of fresh-cut 'Monalisa' potatoes up to 14 days at 4 ºC. In fresh-cut green bell pepper the application of 2% calcium propionate and subsequent packaging in Cryovac PD961 film maintained an equilibrium modified atmosphere of 13-14 kPa O_2 and 7 kPa CO_2, which helped to extend the microbial quality till 6 days storage at 8 ºC (Ranjitha et al., 2015).

Packaging fresh-cut cantaloupe in passive MAP by sealing with Cryovac LDX-5406 film maintained its commercial shelf life for 9 days at 5 ºC, whereas in similar perforated films (10 1.5-mm holes) shelf life was only 5 to 7 days, mainly due to tissue translucency and/or off-odor development (Bai et al., 2001). Similar results were found in fresh-cut honeydew melon harvested in two different seasons and packaged in a similar packaging system. Passive MAP extended the shelf life of honeydew melon by 1.3-3.7 days, depending on storage temperature, compared to those packaged in perforated films. Although quality attributes differed between cubes of fruit harvested in winter and summer, the shelf-life was similar for both winter and summer cubes stored under passive MAP (Bai et al., 2003). In a more recent work, Jayathunge et al. (2014) determined the optimum maturity stage and micro-perforation level of PVC trays for fresh-cut papaya based on physico-chemical properties, and reported that packages with five and seven micro-perforations created anaerobic conditions and the accumulation of ethylene that negatively affected the overall quality of papaya cubes, whereas in packages with ten micro-perforations the concentrations of O_2 and CO_2 reached the equilibrium with 4 kPa and 6 kPa, respectively, and helped to maintain a storage shelf life of 19 days at 4 ºC.

Low oxygen atmosphere-active MAP for fresh-cut fruits and vegetables (LOA)

MAs requirements for fresh-cut fruits and vegetables is low O_2 (1–5 kPa) and⁄or elevated CO_2 (5–10 kPa) levels to maintain quality and consequently extend shelf life of many products. In some cases, displacing the air within the package with a known mixture of gases close to the recommended atmospheres helps to extend the shelf life of the cut product by reducing the metabolism, delaying browning reactions, and inhibiting microbial growth as soon as the product is cut. Thus for example, fresh-cut honeydew and cantaloupe packaged in active MAP with 5 kPa O_2 + 5 kPa CO_2 and 4 kPa O_2 + 10 kPa CO_2, respectively, had better color retention, reduced respiration rate and microbial population, and longer shelf-life than those in passive MAP (Bai et al., 2001, 2003). In fresh-cut pears and melon, packaging under 2.5 kPa O_2 + 7 kPa CO_2 inhibited ethylene synthesis (Soliva-Fortuny et al., 2007; Oms-Oliu et al., 2008a, 2008b, 2009). However, O_2 consumption and CO_2 production rates of just-packaged fresh-cut pears were stimulated in a greater extend under 2.5 kPa O_2 and 7 kPa CO_2 atmospheres than under initial 21 kPa O_2 (Oms-Oliu et al., 2008b). This phenomenon was attributed to a possible effect of the vacuum created in the package before flushing the gas mixture, promoting changes in the pear tissue structure, as well as a dramatic modification of the internal atmosphere. On the contrary, fresh-cut pears packaged in 21 kPa O_2 did not suffer such stress due to vacuum. This effect was only observed at early storage and decreased with storage time.

Effectiveness of LOA active MAP to control enzymatic browning, preserve visual appearance and extend the shelf life has also been reported in other fresh-cut products such as Galega kale (Fonseca et al., 2005) or pineapple (Marrero and Kader, 2006). However, in products rich in antioxidant compounds such as artichoke, pear, banana, persimmon, mango, papaya, nectarine, etc. the only use of LOA may be insufficient to prevent browning and provide sufficient shelf life to the cut product. Therefore, most of the works in the literature report the combine effect of antibrowning agents such as citric and ascorbic acid, cystene, hexylresorcinol and MAP to control enzymatic browning and extend the shelf life of various fresh-cut produces as mango (González-Aguilar et al., 2000), pear (Gorny et al., 2002), banana (Vilas-Boas and Kader, 2006), and nectarine (Cefola et al., 2014). Thus in fresh-cut papaya, whereas LOA active MAP alone (5 kPa O_2 + 10 kPa CO_2) or the antioxidant dip ($CaCl_2$ and citric acid) were not effective in preserving quality, the combination improved color, maintained firmness and reduced microbial count, which extended the shelf life of this product up to 25 days at 5 ºC. Furthermore, the combination of antioxidants and active MAP showed a significantly lower decrease in O_2 concentration in the package and correspondingly lower increase in CO_2, than untreated samples avoiding off-flavor development (Waghmare and Annapure, 2013).

Excessive low O_2 concentrations surrounding the fresh-cut product obtained by either passive or active MAP may accelerate the decay and the accumulation of fermentative metabolites leading to off-flavor and odors. Tudela et al. (2013) described severe off-odor development caused by ammonia accumulation in spinach after 10 days at 7 ºC when exposed to low O_2 and high CO_2 (stabilizing near 1 kPa O_2 and 11 kPa CO_2). Nevertheless, senescence of spinach occurred more rapidly in samples stored under higher O_2 (stabilizing near 10 kPa O_2 + 9 kPa

CO_2) concentrations. Soliva-Fortuny et al. (2007) observed that storage of fresh-cut pears under low O_2 and high CO_2 concentrations (2.5 kPa O_2/7 kPa CO_2) in low permeability PE bags was detrimental to flavor perception and even harmful to the fruit tissue after 3 weeks at 5 ºC. The increase in tissue softening and fermentative metabolites due to excessively low O_2 (<1 kPa) and high CO_2 (10-15 kPa), and ethanol accumulation in packages has also been observed in fresh-cut pears and melon (Oms-Oliu et al., 2008b, 2008c). However, Gunes et al. (2001) reported that elevated CO_2 (15 kPa) had an inhibitory effect on the accumulation of fermentation products in fresh-cut apples stored under 1 kPa O_2 atmospheres, resulting in about a 50% reduction in acetaldehyde, ethanol and ethyl acetate concentrations compared with 1 kPa O_2 in the absence of CO_2.

The effect of low O_2 and high CO_2 concentrations on the growth of Gram negative bacteria, moulds, and aerobic microorganisms, as *Pseudomonas* is well known. For example, packaging under active and passive LOA significantly inhibited the growth of spoilage microorganism in fresh-cut pears, melon, honey pomelo, nectarine, and mushroom slices, among others (Simón et al., 2005; Oms-Oliu et al., 2008b; Li et al., 2012a, Cefola et al., 2014) and reduced the development of aerobic psycrhrotrophic bacteria and *Pseudomonas* in leaf spinach (Tudela et al., 2013). The effect of MAP on microbial quality depends on the type and concentration of the microorganism, as well as the ripeness stage of the commodity and gas concentration at packaging. Oms-Oliu et al. (2009) observed that active MAP (2.5 kPa O_2 + 7 kPa CO_2) inhibited bacterial growth, yeast and mould proliferation in mature-green pears, but did not control microbial growth in partially ripe and ripe pears. On the other hand, mild abuse temperatures during storage of fresh-cut products under LOA can negatively affect their microbial quality. Thus, O’Beirne et al. (2015) observed the growth of *Listeria monocytogenes* on fresh-cut Iceberg lettuce during storage at a constant temperature of 7 ºC was enhanced at the lower oxygen MAP of 0.25 kPa O_2 + 12 kPa CO_2 by day 10, compared to a MAP of 2 kPa O_2 + 6 kPa CO_2.

Postharvest losses in nutritional quality, particularly vitamin C content, can be substantial and might be enhanced by physical damage, extended storage duration, high temperatures, low relative humidity, and chilling injury of chilling-sensitive commodities (Lee and Kader, 2000). Although the influences of processing and storage on the nutritional content of fresh-cut fruits seemed to depend on the commodity, storage under either passive or active MAP might reduce the rate of nutritional losses (Gil et al., 2006). In general, the range of O_2 availability is the main factor affecting antioxidant properties of fresh-cut products, whereas high CO_2 concentrations appear to have a significant effect on ascorbic acid, phenolic compounds and carotenoids. Fonseca et al. (2005) reported higher ascorbic acid degradation of shredded Galega kale in air than under 1–3 kPa O_2 atmospheres. Packaging of fresh-cut tomatoes under 2.5 kPa of O_2 and 5 kPa of CO_2 reduced the formation of carotenoids and maintained vitamin C during 21 days at 4 ºC (Odriozola-Serrano et al., 2009). Aguayo et al. (2010) reported that passive MAP significantly reduced the loss of antioxidant activity and ascorbic acid concentrations of fresh-cut apples during storage at 4 ºC, specially when apple slices were treated with calcium ascorbate. Others authors have reported that high concentrations of CO_2 (more than 5 kPa) had a negative effect on ascorbic acid maintenance of apple slices (Cocci et al., 2006) and fresh-cut pear (Oms-Oliu et al., 2007), especially when hypoxic conditions were reached in the packages. Similarly, total anthocyanin content in pomegranate arils was higher in clamshell packages than in MAP in low barrier bi-axial oriented polyester films (Banda et al., 2015). However, this was attributed to enhanced moisture loss in the clamshell package compared to MAP.

High oxygen atmosphere for fresh-cut fruits and vegetables (HOA)

The application of O_2 concentrations higher than 70 kPa has been found to be particularly effective at controlling aerobic and anaerobic microorganisms, preventing anaerobic fermentation and controlling enzymatic browning (Kader and Ben-Yehoshua, 2000). However, the effect greatly depends on the commodity, cultivar, physiological stage, and storage conditions.

The effect of high O_2 concentrations reducing microbial growth has been related to the accumulation of reactive oxygen species that damage vital cell components, affecting cellular antioxidant protection systems of cell metabolism (Kader and Ben-Yehoshua, 2000). O_2-enriched MAP (>85 kPa) reduced the growth of psychrotrophic microorganisms in fresh-cut Red Chard stored up to 8 days at 5 °C with 100 kPa O_2 (Tomás-Callejas et al., 2011) and fresh-cut pear and melon packaged in 70 kPa O_2 during storage at 4 ºC (Oms-Oliu et al., 2008a, 2008b). Allende et al. (2004) also reported a reduced growth of mesophilic aerobes in fresh-cut baby spinach packaged in 80-100 kPa O_2 for 12 days at 5 ºC. However, reports on the effect of high O_2 concentrations on the growth of aerobic microbiota on fresh-cut mixed salads were inconclusive (Allende et al., 2002). Lactic acid bacteria and Enterobacteriaceae bacteria appeared to be inhibited under high O_2 concentrations but, on the other hand, the growth of yeasts and *Aeromonas caviae* was stimulated under high O_2 levels, and psychrotrophic bacteria and *L. monocytogenes* were not affected. An inhibitory effect on some spoilage microorganisms such as *Rhodotorula mucilaginosa* yeast has also been observed in fresh-cut pears, 'Piel de Sapo' melons, mango cubes and honey pomelo when exposed to high O_2 concentrations (Poubol and Izumi, 2005; Oms-Oliu et al., 2008a; Li et al., 2012a). Whereas, *Candida parapsilosis* survived on inoculated cut pears stored under 70 kPa O_2 during 21 days at 4 ºC (Oms-Oliu et al., 2008b). In strawberries, 80-100 kPa O_2 atmospheres inhibited the growth of *Botrytis cinerea* (Wszelaki and Mitcham, 2000) and an initial atmosphere of 70 kPa O_2 retarded the growth of molds and yeasts on strawberries and raspberries stored 14 days at 5-7 ºC (Van der Steen et al., 2002).

The inhibitory effect on bacterial growth has been noticed to be greater when the high O_2 is combined with high CO_2 concentrations (10 to 20 kPa) rather than when the individual gas is used alone. Lee et al. (2011) suggested that high O_2 combined with CO_2 could give a bacteriostatic and bactericidal effect through suppression of aerobes by high CO_2 and anaerobes by high O_2. Particularly, the antibacterial effect was evidently shown on *E. coli* and *S. aureus* among other inoculated strains (*P. fluorescence, S. Typhimurioum, L. monocytogenes*) in fresh-cut cabbage. Amanatidou et al. (2000) also reported that packaging carrots slices under 50 kPa O_2 and 30 kPa CO_2 significantly inhibited the growth of Enterobacteriaceae bacteria, *Pseudomonas* and lactic acid bacteria and shelf life was extended up to 15 days at 8 ºC. In fresh-cut bell peppers, MAP with 50 or 80 kPa O_2 and 15 kPa CO_2 controlled the growth of mesophilic, psycrhrotrophic bacteria and Enterobacteriaceae family up to 8-9 days at 5ºC and maintained the sensory quality attributes; however, high O_2 alone did not prevent microbial growth (Conesa et al., 2007). In fresh-cut honeydew melon cubes, MAPs consisting of 50 kPa O_2 + 50 kPa CO_2 and 70 kPa O_2 + 30 kPa CO_2 had little effect on color and firmness, however samples packed in 50 kPa O_2 + 50 kPa CO_2 had appreciably lower populations of yeasts and lactic acid bacteria, and lower quantities of volatile organic compounds after 5 days of storage at 7 ºC (Zhang et al., 2013).

Beside the effect on microbial growth control, the application of superatmospheric O_2 may stimulate, have no effect, or lower the respiration rate of fresh-cut produces, depending on the commodity, cultivar, physiological stage, storage conditions, etc. (Kader and Ben-Yehoshua, 2000). Poubol and Izumi (2005) studied the physiological behavior of two fresh-cut mango cultivars held in high O_2 atmospheres (60 kPa) for 42 h at 5 ºC. The authors observed that the 60 kPa O_2 atmosphere reduced the respiration rate of 'Carabao' mango cubes slightly during storage at 5 °C, whereas the same high O_2 concentrations did not affect the respiration rate of 'Nam Dokmai' mango cubes. Escalona et al. (2006) observed that the application of 70-80 kPa O_2 concentrations combined with 10-20 kPa CO_2 successfully reduced respiration rate and prevented anaerobic fermentation of fresh-cut butter lettuce. In fresh-cut melon, active MAP with initial low O_2 levels (2.5 kPa) reduced in-package ethylene concentration, whereas superatmospheric O_2 levels (70 kPa) avoided anaerobic metabolism by reducing CO_2 production rate and preventing ethanol production during 3 weeks of storage at 4 ºC (Oms-Oliu et al., 2008a, 2008c). Similarly, high oxygen partial pressures (55 to 100 kPa) had an inhibitory effect on the anaerobic volatiles production in potato slices stored 10 days at 5 ºC (Limbo and Piergiovanni, 2006) and helped to maintain the overall sensory quality of pomegranate arils during 18 days at 5 ºC (Ayhan and Esturk, 2009). However, other works have shown contradictory results regarding the effect of high O_2 levels on respiration rate and volatile production. Thus, 'Mollar de Elche' pomegranate arils packed under HOA (≈90 kPa) or 'Wonderful' pomegranate arils packed under high O_2-high CO_2 atmospheres (30 kPa O_2 + 10-40 kPa CO_2) presented higher respiration rate than those packed under passive MAP or air conditions (Maghoumi et al., 2013; Banda et al., 2015). In fresh-cut pear, superatmospheric O_2 did not prevent the production of acetaldehyde and ethanol during storage at 4 ºC due to a stress response related at the same time with the highly oxidative environment and the accumulation of CO_2 within the package (Oms-Oliu et al., 2008b).

The application of high O_2 atmospheres has also been suggested as an alternative to low O_2 and moderate CO_2 concentrations to inhibit enzymatic browning. It has been hypothesized that high O_2 levels may cause substrate inhibition of the enzyme polyphenol oxidase (PPO), or alternatively, that high levels of colorless quinones formed in the oxidation reaction may cause a feedback inhibition of the PPO (Day, 2001). In sliced mushrooms and fresh-cut melon, high oxygen atmospheres (70-95 kPa O_2) were particularly effective for inhibiting enzymatic browning as compared with low-oxygen atmosphere MAP (Jacxsens et al., 2001; Oms-Oliu et al., 2008a). Allende et al. (2004) reported lower tissue damage to spinach leaves in high O_2 packages (80 and 100 kPa) stored at 5 ºC for 12 days. However, although high O_2 atmospheres (50 to 90 kPa) reduced enzymatic browning of minimally processed Iceberg lettuce compared with low O_2 (3 kPa), it promoted russet spotting development (López-Gálvez et al., 2015). This was related to an increase in ethylene production in the high O_2 MAP which intensifies some of the effects of this plant hormone on lettuce heads, such as russet spotting. In some commodities, high O_2 concentrations alone cannot effectively prevent browning of fresh-cut produce and required the combination with other hurdle technologies. Limbo and Piergiovanni (2006) showed the positive effect of high-oxygen partial pressures combined with dipping in acid solutions to control enzymatic browning of fresh-cut potato for 10 days at 5 ºC. Gómez di Marco et al. (2012) reported that the best combination to reduce artichoke heads browning was the application of 80 kPa O_2 and lemon juice as antioxidant. However, Poubol and Izumi (2005) reported that the application of superatmospheric O_2 concentrations (60 kPa) to fresh-cut mango showed a similar or higher degree of browning than the use of ambient air conditions at 5 ºC. Similarly, Gorny et al. (2002) reported that high O_2 (40, 60, 80 kPa) did not effectively prevent surface browning of fresh-cut pears.

The use of high oxygen concentrations has been shown to reduce firmness loss in several fresh-cut products such as sliced carrot (Amanatidou et al., 2000), shredded iceberg lettuce (Day, 2001), and fresh-cut melon (Oms-Oliu et al., 2008a, 2008c). According to Amanatidou et al. (2000), the effect of high O_2 atmospheres on firmness may be related to an inhibition on the proliferation of pectolytic *Pseudomonas*. However, pear slices kept in air, 40, 60 or 80 kPa O_2 (balance N_2) all softened at similar rates (Gorny et al., 2002).

Few works have been published on the effect of high O_2 concentrations on the nutritional content of fresh-cut fruits and vegetables. Day (2001) described that high O_2 atmospheres had a beneficial effect on ascorbic acid retention on prepared lettuce. However, vitamin C content of fresh-cut pears packaged in 70 kPa O_2 was rapidly lost in comparison with those packaged in low O_2 atmosphere and reached the lowest concentrations after 35 days at 5 ºC (Oms-Oliu et al., 2007). Similarly, ascorbic acid content and antioxidant capacity underwent a significant depletion in ready-to-eat honey pomelo slices packaged under high O_2 (75 kPa) atmosphere in comparison with low O_2 active (3 kPa 5 O_2 + kPa CO_2) and passive MAP (Li et al., 2012a). Li et al. (2012b) also reported the highest decrease in vitamin C in fresh-cut pears stored in 80 kPa O_2 packaging with more than 50% loss in vitamin C content after 12 days of storage at 4 ºC; whereas, phenolic and anthocyanin contents of the samples packed in 80 kPa O_2 were 2.5 and 12 times higher, respectively, than those in the passive package, and 3 and 2 times higher than those in low O_2 package after 12 days of storage at 4 ºC. Higher production of phenolic compounds was also observed by Odriozola-Serrano et al. (2009) in tomato slices packed under high O_2 (60-80 kPa) and passive MAP and stored at 4 ºC, whereas vitamin C was decreased in high O_2 atmospheres. According to these authors, the increase on phenolic compounds in fresh-cut products under both passive MAP and high O_2 concentrations active MAP could be directly associated with a physiological response to stress conditions. The fresh-cut tomatoes stored in 80 kPa of O_2 atmospheres also scored higher on flavonols, lycopene, β-carotene, chlorogenic acid, and total antioxidant capacity than those packed under lower O_2 concentrations (2.5 or 10 kPa). Furthermore, lower hydrophilic antioxidant capacity was obtained in tomato slices stored in 80 kPa of O_2, whereas the antioxidant capacity of the lipophilic fraction was enhanced with oxygen availability inside headspace packages. These results indicate that the effect of high O_2 on the nutritional content of fresh-cut products may vary depending on the commodity, O_2 concentration, storage time and temperature.

Noble gases and other non-conventional atmospheres for fresh-cut fruits and vegetables

The use of noble gases such as Helium (He), Argon (Ar), and Xenon (Xe) to replace N_2 as the balancing gas in MAP is considered one of the major advances to preserve and extend the shelf life of fresh and minimally processed fruits and vegetables. He, Ar and Xe have been successfully applied in MAP and controlled atmosphere storage to reduce microbial growth and maintain the quality of fresh products (Jamie and Saltveit, 2002; Meng et al., 2012; Wu et al., 2012a, 2012b). The beneficial effect of noble gases Ar and He have been related to their solubility and diffusivity characteristics (Day, 2001; Jamie and Saltveit, 2012). The similar atomic size to molecular O_2 and higher solubility in water than N_2 and O_2 make probably inner gases more effective at displacing O_2 from cellular sites and enzymatic O_2 receptors with the consequence that oxidative deterioration reactions are likely to be inhibited (Day et al., 2001). Furthermore, replacing the N_2 with He/Ar may modify the diffusion of O_2, CO_2, and C_2H_4 in fresh commodities. These changes allow fresh commodities that experience internal low O_2 deficiencies at lower O_2 storage to tolerate the low O_2 environment better than they could tolerate in the presence of N_2 atmospheres (Jamie and Saltveit, 2002). Similarly, several studies have explored the use of nitrous oxide (N_2O) and pure N_2, alone or in combination with Ar, to maintain fresh produce quality because of the ability to reduce ethylene emission, inhibit fungal growth, and slow down sensory quality deterioration of fresh-cut commodities (Cocci et al., 2006; Banda et al., 2015; Cortellino et al., 2015).

Rocculi et al. (2005) reported that the use of 90 kPa Ar on fresh-cut kiwifruit was significantly effective at maintaining firmness values and slowing down respiration, but not at controlling color browning. Better results were obtained by packaging of kiwifruits under 90 kPa N_2O, limiting firmness loss and maintaining color values during 12 days of storage at 4 ºC. Tomás-Callejas et al. (2011) investigated the antimicrobial and quality effect of 100 kPa O_2-, He-, N_2-, or N_2O-enriched active MAP compared to a passive MAP on fresh-cut red chard baby leaves at 5 ºC during 8 days of storage. No differences in microbial growth were observed between He-, N_2-, and N_2O-enriched MAPs and the passive MAP. The active MAP helped to retain better the vitamin C content compared with the passive MAP; whereas, total phenolics content drastically increased during storage in samples under O_2-, He-, and N_2-enriched MAP. Among the treatments tested in active MAP, He preserved the total chlorophyll content throughout the shelf life. In fresh broccoli, however, atmospheres containing 90 kPa Ar and 2 kPa O_2 (balance N_2) did not delay the loss of chlorophyll (Jamie and Saltveit, 2002). In a recent work, Cortellino et al. (2015) highlighted that the Ar and N_2O mixture (65 kPa N_2O + 25 kPa Ar + 5 kPa O_2 + 5 kPa CO_2) was less effective at inhibiting ethylene production of 'Golden Delicious' apple slices than the conventional MAP (90 kPa N_2 + 5 kPa O_2 + 5 kPa CO_2), even though both atmospheres were characterized by the same percentage of O_2 (5 kPa), whereas the Ar and CO_2 mixture (80 kPa Ar + 20 kPa CO_2) completely inhibit ethylene production during 11 days of cold storage at 4 ºC. The latest atmosphere (Ar + CO_2) was also the most effective to maintain fruit firmness, although the beneficial effect was significantly reduced by dipping fruit in antibrowning agents (ascorbic and citric acids). However, any of the MAP tested could effectively prevent browning in absence of the antibrowning treatment and the atmosphere with 80 kPa Ar displayed a contradictory behavior as it controlled browning in antibrowning-dipped samples but enhanced it in undipped ones. On the contrary, Rocculi et al. (2004) reported positive results at inhibiting enzymatic browning of apple slices packed in atmospheres containing Ar-N_2O (65 kPa N_2O + 25 kPa Ar + 5 kPa CO_2 + 5 kPa O_2) and N_2O (90 kPa N_2O + 5 kPa CO_2 + 5 kPa O_2) compared to air and conventional MAP (90 kPa N_2 + 5 kPa CO_2 + 5 kPa O_2), which was related to a higher solubility these gases compared to N_2.

Under appropriate temperature and pressure conditions inner gases can form ice-like crystals called clathrate hydrates, in which molecules are trapped within cage-like structure of water molecules, lowering water activity in fresh-cut produce, thereby reducing the leaching of organic material from fresh-cuts and movement of microbes into deeper tissues in comparison to other pretreatments (Caleb et al., 2013). Based on this behaviour, Meng et al. (2012) reported that the application of pressurized Ar (2, 4 and 6 MPa) on fresh-cut green pepper packed with 5 kPa O_2 and 8 kPa CO_2 were able to maintain the cell integrity of the produce by inhibiting the production of malondialdehyde, as well as the activities of catalase and peroxidase. The treatments were also reported to reduce the proliferation of spoilage microorganisms such as coliforms, yeast and moulds. Wu et al. (2012a) studied the effect of high pressure Ar (150 MPa) on preserving fresh-cut apples at 4 ºC. The pressurized Ar reduced the respiration rate and ethylene production of fresh-cut apples. However, it caused some negative effects on color and firmness, which were overwhelmed by combining the pressurized Ar and antioxidant treatments with calcium chloride, citric and ascorbic acid. This combination reduced color change and firmness loss and maintained the sensory quality of fresh-cut apples for 12 days at 4 ºC. Similarly, fresh-cut pineapple treated with pressurized Ar (1.8 MPa) effectively maintained the quality and delayed the microbial growth of the product, reaching 6 days of shelf life at 4 ºC (Wu et al., 2012b). The shelf life of fresh-cut pineapple was further extended to 20 days at 4 ºC by treating the samples with high pressure Ar or N_2 (10 MPa) (Wu et al., 2012c). These treatments effectively reduced respiration rate, ethylene production, browning and loss of total phenols and ascorbic acid, while did not cause a significant decline in fruit firmness. These authors completed the study comparing the effect of high pressure (1.8 MPa absolute) versus normal atmosphere pressure of a combination of Ar and Xe (Ar:Xe = 2:9 partial pressure) on wound healing and microbial growth in fresh-cut apples and pineapples inoculated with *E. coli* and *Saccharomyces cerevisiae* and stored at 4 ºC (Wu et al., 2013). The results showed that samples under high pressure Ar + Xe mixed treatment exhibited a positive wound healing response due probably to the increase in H_2O_2 production and the accumulation of phenolics and lignin during storage. The enhanced wound healing ability provided by the high pressure Ar + Xe mixed treatment was also found to contribute at the inhibition of the growth of *E. coli* or *S. cerevisiae* in tested apple and pineapple samples. In a similar way, the application of Ar or a mixture of compressed noble gases (Ar and Krypton) helped to maintain a better quality on fresh-cut green peppers compared to untreated peppers. The noble gases reduced the respiration rate and vitamin C loss of fresh-cut peppers compared to the untreated samples, but did not inhibit the PPO activity. Overall, mixed Argon-Krypton samples presented lower mass loss and cell membrane permeability than the Ar treatment alone (Raymond et al., 2013).

EDIBLE COATINGS FOR FRESH-CUT FRUITS AND VEGETABLES

Traditionally, edible coatings have been used as a tool to reduce the deleterious effects of processing on fruit and vegetable tissues. An edible coating is a thin layer of edible material formed on the surface of a fruit and vegetable that provides a semipermeable barrier to gases, water vapor, and volatile compounds between the product and the surrounding atmosphere. Therefore, edible coatings can contribute to extend the shelf life of fresh-cut fruits and vegetables by reducing respiration rate, enzymatic browning, and water loss.

Compounds most commonly used to form edible coatings include polysaccharides as chitosan, alginate, cellulose, carrageenan, pectin, starch; proteins as whey, casein, soy protein; and lipids as carnauba, beeswax and fatty acids (Dea et al., 2012). Several works have described the beneficial effect of polysaccharide and protein-based edible coatings on reducing the respiration rate of fresh-cut produces, which has been attributed to their good oxygen barrier. Hence, lower CO_2 production has also been observed in fresh-cut apples, melons, and pears coated with an alginate-based edible (Rojas-Graü et al., 2007; Oms-Oliu et al., 2008d; Raybaudi-Massilia et al., 2008a, 2008b) and in apple slices coated with whey protein (Lee et al., 2003).

The hydrophilic nature of proteins and polysaccharides usually requires the addition of lipids to improve the moisture barrier of the edible coatings. Lipids such as sunflower oil added to alginate, gellan or pectin-based coatings and stearic acid incorporated to methyl cellulose-based edible coatings have been proven to significantly reduce weight loss of fresh-cut apple, papaya and pear (Tapia et al., 2007; Olivas et al., 2003). However, some works have also reported that edible coatings based on gellan and carragennan with no lipid incorporated also reduced water loss of fresh-cut apples, papaya and banana (Lee et al., 2003; Tapia et al., 2007; Bico et al., 2009). On the other hand, studies to optimize the performance of whey protein isolate coatings on fresh-cut apples prior to the incorporation of additives such as antioxidants showed that lipid and solid content also affected the degree of browning of the samples (Pérez-Gago et al., 2003). As beeswax and solid content of the formulation increased the browning index of the samples decreased. However, high beeswax or solid content imparted a whitish appearance to the coated apples that negatively affected the visual quality.

The functional properties of edible coatings for fresh-cut fruits and vegetables are usually enhanced by the incorporation of active ingredients such as antioxidants, texture enhancers, and antimicrobials to reduce enzymatic browning, texture loss, and the risk of pathogen growth on food surfaces. Thus, fresh-cut pears were preserved from surface browning by a methyl cellulose coating containing ascorbic acid (Olivas et al., 2003) or alginate and gellan coatings containing N-acetylcysteine and glutathione (Oms-Oliu et al., 2008d). Browning of fresh-cut apples has also been controlled or reduced by carrageenan and whey protein-based coatings containing ascorbic acid, citric acid, cysteine or oxalic acid (Lee et al., 2003; Pérez-Gago et al., 2006), alginate and gellan coatings containing N-acetylcysteine (Rojas-Graü et al., 2008; Raybaudi-Massilia et al., 2008a) and chitosan coatings containing ascorbic acid (Qi et al., 2011). In carrot slices, artichoke heads and fresh-cut mangoes, alginate coatings with ascorbic or citric acid were also effective to control browning (Amanatidou et al., 2000; Del Nobile et al., 2009; Robles-Sánchez et al., 2013) and banana slices maintained a better visual quality with a carrageenan coating containing ascorbic acid and cysteine (Bico et al., 2009).

Calcium and its salts have been used as firming agents of a great variety of fresh-cut fruits and vegetables by helping to maintain cell wall integrity. Furthermore, the addition of calcium as a gelling agent to alginate, gellan and pectin-based edible coatings have also shown to be effective at maintaining firmness in several fresh-cut products such as apple (Rojas-Graü et al., 2007, 2008; Freitas et al., 2013; Pan et al., 2013), pineapple (Azarakhsh et al., 2014) and melon (Raybaudi-Massilia et al., 2008b). A recent study also shows that the combined treatment of chitosan and calcium chloride was the most effective treatment for fresh-cut honeydew melon, leading to less weight loss and increase in firmness as compared to the application of the individual treatments. Nanostructural analysis indicated that firmness retention was closely related to an improvement in the sodium carbonate-soluble pectin integrity via interactions between the pectin and calcium ions or protonated chitosan groups (Chong et al., 2015).

The use of edible coatings with antimicrobial properties has been considered a potential tool to improve the safety of fresh-cut products. Among the different coatings, chitosan has been widely tested in fresh-cut fruits and vegetables for their antimicrobial properties. González-Aguilar et al. (2009) reported that dipping fresh-cut papaya in a chitosan coating suppressed mesophilic plate count, and the growth of molds and yeast. Moreira et al. (2011) also reported a significant reduction in total mesophilic and psychrotrophic bacteria counts, the inhibition of total coliforms and a decrease of inoculated *E. coli* O157:H7 counts of fresh-cut broccoli during cold storage. Furthermore, chitosan coatings have also been effective to avoid color change during storage of fresh-cut products such as litchi, mushrooms, and apples (Dong et al., 2004; Eissa et al., 2007; Qi et al., 2011), reduce weight loss and maintain ascorbic acid and total phenolic content in fresh-cut litchi and shredded carrots (Dong et al., 2004; Pushkala et al., 2012), and delay texture changes in fresh-cut mushrooms (Eissa et al., 2007).

Incorporating antimicrobial compounds into edible coatings has been another approach to enhance the safety and extend the shelf life of ready-to-eat products. Several antimicrobial compounds have been investigated as for incorporation into edible coatings, including organic acids (acetic, benzoic, lactic, propionic, sorbic), polypeptides (lysozyme, peroxidase, lactoferrin, nisin) and plant essential oil (cinnamon, oregano, lemongrass, etc.). Among them, essential oils are the most studied antimicrobial ingredients incorporated into edible coatings against pathogenic microorganisms in fresh-cut products. However, in many cases effective concentrations adversely affected the sensory properties of coated produce, making necessary an optimization to achieve microbial control, while preserving overall quality. Thus, alginate-based coatings with 0.1% eugenol or 0.15% citral plus 0.1% eugenol and pectin-based coatings with 0.15% citral or 0.2% eugenol best maintained the overall acceptability and reduced microbial growth of fresh-cut apples (Guerreiro et al., 2016). Combination of lemongrass at 0.3 and 0.5% with an alginate-based edible coating (sodium alginate and sunflower oil) significantly reduced yeast, molds and total plate counts in fresh-cut pineapple (Azarakhsh et al., 2014). In other study, the addition of palmarosa oil (0.3%) to a similar alginate-based coating inhibited the native flora and reduced *S. enteritidis* population while maintained the fresh-cut melon quality parameters (Raybaudi-Massilia et al., 2008b). Chitosan, alone or combined with essential oils or bioactive compounds (propolis, resveratrol and tea tree essential oil), also inhibited the growth of mesophilic and psychrotrophic bacteria, and controlled *E. coli* and *L. monocytogenes* survival, avoiding deleterious effects on the sensory attributes of fresh-cut broccoli (Álvarez et al., 2012).

On the other hand, organic acid salts, such as potassium sorbate or sodium benzoate, and peptides, such as nisin, which are widely used by the food industry as safe antimicrobial food additives, have been less studied as edible coating ingredients to control microbial growth in fresh-cut fruit. A recent work on fresh-cut persimmon reported the beneficial effect of apple pectin-based coatings amended with antioxidant (1% citric acid plus 1% $CaCl_2$) and antimicrobial agents (0.2 and 0.4% potassium sorbate, 0.4% sodium benzoate or 500 IU mL^{-1} nisin) to control enzymatic browning and microbial growth (Sanchís et al., 2016a). These coatings effectively reduced the populations of artificially inoculated *E. coli* and *S. enteritidis*, nisin-coating being the most effective, while for *L. monocytogenes*, only the nisin coating effectively reduced the bacterial population. Similarly, the application of cellulose films containing 7500 IU mL^{-1} nisin inhibited the growth of *Staphylococcus aureus* and *L. monocytogenes* in processed mangoes (Teixeira-Barbosa et al., 2013). Narsaiah et al. (2015) also reported that a 2% alginate coating incorporated with 20% bacteriocin could be used to store minimally processed papaya for 3 weeks by reducing microbial counts compared to uncoated samples without compromising the physico-chemical quality.

Combination of chitosan with other polysaccharides has also shown to improve its functional properties. For example, a chitosan-methyl cellulose film applied as food wrapper inhibited the growth of inoculated *E. coli* and *S. cerevisiae* on fresh-cut melon and pineapple as compared to un-wrapped fruit, or fruit wrapped in a commercial stretch film (Sangsuwan et al., 2008). In a comparative study between chitosan, *Aloe vera* and sodium alginate edible coatings on preserving quality and extending shelf life of minimally processed kiwifruit, only *Aloe vera* and chitosan formulated with acetic acid were effective to reduce microbial growth trough 12 days at 4 ºC; however chitosan coated slices were not accepted by the sensory panelists (Benítez et al., 2015).

A new generation of edible coatings is under development, which aims to incorporate and/or control release of active compounds using nanotechnological solutions such as nanoparticles and nanoencapsulation (Dhall, 2013). The most commonly nanomaterials studied in edible films and coatings are metal and metal oxides such as silver (Ag), zinc oxide (ZnO), titanium dioxide (TiO_2) and magnesium oxide (MgO), which are known by their antimicrobial properties. These have been successfully incorporated to edible films such as chitosan, alginate, carrageenan and gellan to improve mechanical and barrier properties. However, few works can be found about the use of edible coatings containing nanoparticles for fresh-cut fruits and vegetables. Costa et al. (2012) studied the effect of an active alginate based-coating loaded with silver-montmorillonite (Ag-MMT) in shelf life and microbiological quality of fresh-cut carrots. Enterobacteriaceae bacteria and mesophilic bacteria in the active-coated sample were found below 10^4 and 5×10^7 CFU/g, respectively, that were set as the threshold for these microbial groups. Reduced cell loads by one or two log cycles of psychrotrophic bacteria, *Pseudomonas* spp. and yeasts were also observed in fresh-cut coated carrots. This coating also resulted effective at controlling dehydration and extended the shelf life of the carrots packaged in OPP films to more than 45 days. In fresh-cut kiwifruit, the combined application of ultrasound treatment and nano-ZnO incorporated to a chitosan-based edible coating slowed down ethylene and carbon dioxide production, reduced the water loss and softening, delayed the senescence and significantly extend the storage life of the product (Meng et al., 2014).

On the other hand, micro- and nano-encapsulation consists in the incorporation of active compounds into edible coatings with the aim to control their release under specific conditions (e.g., changes of pH, temperature, irradiation, osmotic shock). This technology protects the encapsulated active compounds from moisture, heat or other extreme conditions and enhances their stability and viability (Dea et al., 2012). Among the different active compounds, essential oils are the most widely encapsulated materials. Hence, Alikhani-Koupaei (2015) successfully encapsulated rosemary essential oil into liposome to form liposomal oil, which was later incorporated into a mucilage edible coating to extend the shelf life of fresh-cut banana. This coating reduced weight loss and maintained the overall quality of the product for up to 9 days after processing without affecting sensory quality.

The potential of chitosan as edible coating for fruits and vegetables has also attracted the interest for the study of colloidal particles at the nano level to enhance its effectiveness. Luo et al. (2013) studied the effect of chitosan coating, alone or in combination with nano-chitosan (40-50 nm) on browning and lignification of fresh-cut *Zizania latifolia* stored at 1 ºC for 12 days. The results showed that nano-chitosan coating was more effective than chitosan to retard browning and lignification of fresh-cut *Z. latifolia* by inhibiting browning and lignification-related enzyme activity. Similarly, chitosan nanoparticles of 110nm had higher antimicrobial activity against moulds and yeasts, and mesophilic and psychrotrophic bacteria than the conventional chitosan coating, while not affecting other quality attributes of fresh-cut apples (Pilon et al., 2015).

In some cases, the dipping of fresh-cut fruits and vegetables into an edible coating is limited by the difficult adhesion to the hydrophilic surface of the cut product. The multilayer coating technique has been used as a good alternative to overcome these problems. The preparation of multilayer structures consists of consecutive dipping of the cut product into two or more coating solutions containing oppositely charged polyelectrolytes. Coatings prepared with this technique have been applied in fresh-cut produces as papaya (Brasil et al., 2012), pear (Medeiros et al., 2012), pineapple (Mantilla, 2013), watermelon (Sipahi et al., 2013), and melon (Poverenov et al., 2014a, 2014b). By using this technique, microencapsulated β-cyclodextrin and trans-cinnamaldehyde complex have been successfully incorporated into a multilayered edible coating made of chitosan and pectin (Brasil et al., 2012). This multilayered edible coating was very effective at inhibiting aerobic and psychrotrophic bacteria, yeast and mold growth of fresh-cut papaya and helped to extend the shelf life of the product up to 15 days at 4 ºC. This coating maintained firmness, color, vitamin C and β-carotene content and had no negative impact on flavor of coated papaya, being more accepted by the panelists than control samples. Similarly, the application of a multilayered edible coating composed of 2% trans-cinnamaldehyde, 2% chitosan and 1% pectin helped extend the shelf life of fresh-cut cantaloupe up to 9 days at 4 ºC (Martiñon et al., 2014).

Similar systems have been prepared with sodium alginate and microencapsulated β-cyclodextrin and trans-cinnamaldehyde for fresh-cut watermelon (Sipahi et al., 2013) and pineapple (Mantilla et al., 2013). The multiplayer edible coatings were prepared by layer by layer deposition of sodium alginate coating with pectin and calcium ion (calcium chloride or calcium lactate). The order was chosen based on the polyetrolyte interaction among opposite charges to obtain a stable and uniform coating and consisted of five steps (Calcium-antimicrobial coating-Calcium-Pectin-Calcium). The multilayered edible coating extended the shelf-life of fresh-cut pineapple and watermelon stored at 4 ºC for 15 days. The coating effectively reduced the growth of psychrotrophic bacteria, yeasts and molds, and also helped to maintain color, pH, total soluble solids, and firmness values without affecting odor and flavor attributes of the fruit. Medeiros et al. (2012) also optimized nanolayered coatings based on carrageenan and lysozyme. The coating was successfully applied to fresh-cut 'Rocha' pear and controlled weight loss and maintained high and low values of the total soluble solids and the tritable acidity, respectively, after 7 days of storage at 4 ºC.

Comparing a layer by layer alginate-chitosan with single-layer coatings on fresh-cut melon, the multilayer coating was found to possess the beneficial properties of both ingredients, combining good adhesion to melon matrix of the inner alginate layer with antimicrobial activity of the outer chitosan layer, thereby reducing the bacteria, yeast, and fungi counts by 1-2 log CFU. Furthermore, the by-layer coating slowed down tissue softening compared to single-layer coatings, so that after 14 days of storage only these samples maintained an appreciable firmness. An unexpected benefit of the by-layer coating was that it prevented an increase in headspace CO_2 and ethanol concentrations compared to monolayer coatings and even of the non-coated control, which are the signs of hypoxic stress and off-flavor development in coated samples when the gas barrier is too high. This phenomenon was presumably related to swelling behavior of the chitosan layer in the humid atmosphere of the fresh-cut melon package, enhancing gas-exchange properties of the by-layer coating, but at the same time reducing water vapor resistance (Poverenov et al., 2014a). Similarly, layer by layer gelatine-chitosan coatings also demonstrated superior performance than mono-layer and blended coatings in maintaining fruit firmness of fresh-cut melon. However, while the by-layer formulation demonstrated the most effective inhibition of the total microbial growth especially after 5-7 days of storage, the blended formulation demonstrated high antifungal activity after 11 days of storage (Poverenov et al., 2014b).

As regards the commercial coatings tested on fresh-cut fruits and vegetables, most of them are based on cellulose derivatives combined or not with sucrose fatty acid esters such as Semperfresh (AgriCoat Industries Ltd., Berkshire, UK) and Nature-Seal (Ecoscience Product System Divison, Orlando, FL). These have been applied to fresh-cut mango (González-Aguilar et al., 2008), carrots disks and mushroom slices (Farber et al., 2003; Cliffe-Byrness and O'Beirne, 2007) among others. However, recent works have applied commercial formulations of Nature-Seal to fresh-cut fruits such as apples as natural antibrowning solutions based on blends of vitamins and mineral salts (Alegre et al., 2013; Altisent et al., 2014). Another commercial coating that has been applied to fresh-cut pears and apples is the chitosan derivative Nutrisave (Nova Chem, Halifax, NS, Canada), which resulted effective reducing respiration rate and weight loss, and delaying microbial decay (Baldwin et al., 1995).

COMBINATION MAP AND EDIBLE COATING FOR FRESH-CUT FRUITS AND VEGETABLES

The use of MAP or edible coatings in association with low temperature storage represent two of the main approaches to preserve the quality of minimally processed fruits and vegetables. However, the high perishability of these products challenges in many cases their marketability by not achieving sufficient shelf life to survive the distribution system. Therefore, some attempts have been focused to extend the shelf life of fresh-cut commodities by combining both edible coatings and MAP technologies.

Mastromatteo et al. (2011) studied the effect of a sodium alginate edible coating enriched with active compounds (hydro-alcoholic solution and grape seed extract) and two MAP conditions (passive and LOA with 10 kPa O_2 + 10 kPa CO_2) on the quality of minimally processed kiwifruits and observed that the alginate-based coating increased the shelf life of the samples up to 14 and 12 days when packed in LOA and passive MAP, respectively, compared to 8 days for the control samples. Similarly, the quality of minimally processed carrots was extended from 12 to 15 days when the product was treated with 0.1% citric acid and coated with alginate prior to storage at 8 ºC under active MAP (50 kPa O_2 + 30 kPa CO_2) (Amanatidou et al., 2000).

Sothornvit and Rodsamran (2010) studied the effect of a mango-based film to wrap fresh-cut mango in combination with LOA packaging (10 kPa O_2). The MAP, with or without the mango film wrap, extended the shelf life of fresh-cut mango to 6 days when stored at 5 ºC. Whereas, at room conditions the combination of the LOA and the edible mango wrap significantly reduced off-flavor and extended the shelf life from 2-3 days to 4 days.

Campaniello et al. (2008) studied the possible use of chitosan coating to improve the safety and quality on fresh-cut strawberries packaged in high (80 kPa) or low (5 kPa) oxygen MAP at different temperature (4, 8, 12, 15 °C) of storage. The combination of coating and MAP resulted in a sensible improvement on the microbial quality, particularly at the highest temperatures. Conventional MAP contributed to better control psychrotrophic bacteria; whereas high O_2 MAP had a beneficial effect on sensorial characteristics, color and mesophilic bacteria inhibition. On the contrary, Simões et al. (2009) reported that microbial populations of carrots sticks were not influenced by chitosan-yam starch or passive MAP during 12 days at 4 ºC. However, the coating preserved the overall quality by reducing whiteness and the combined application of the chitosan coating and moderate MAP conditions (10 kPa O_2 +10 kPa CO_2) enhanced phenolic content in carrot sticks, which was attributed to chitosan acting as an exogenous elicitor. The observed accumulation was suppressed by low O_2 and high CO_2 levels (2 kPaO_2 + 15-25 kPaCO_2) reached by the less permeable film, probably related to low PAL activity or induction of enzymatic systems responsible of PAL inactivation. Similarly, a starch coating reinforced with natural smectite montmorillonite nanoparticles and passive MAP (15 kPaO_2 + 20 kPaCO_2 steady state) led to the preservation of the total antioxidant activity, the volatile and organic acids of minimally processed carrots (Guimarães et al., 2016).

The application of gamma irradiation and high O_2 - high CO_2 (60 kPa O_2 + 30 kPa CO_2) MAP significantly reduced the growth of aerobic microorganism on minimally processed carrots. The combination of these treatments with a calcium caseinate and whey protein isolated-based edible coating did not affect the microbial growth of the samples; however, the coating was needed to protect carrots against dehydration and whitening (Lafortune et al., 2005). Caillet et al. (2006) also evaluated the effect of an antimicrobial edible coating based on calcium caseinate containing trans-cinnamaldehyde, combined with high oxygen (60 kPa O_2 + 30 kPa CO_2) or air and gamma irradiation at 0.25 or 0.5 kGy on peeled carrots inoculated with *L innocua.* The use of HOA contributed to completely inhibit the growth of *L. innocua* and lowered the radiation dose required for that purpose. The antimicrobial edible coating was needed to reduce the *L. innocua* growth when minimally processed carrots were packed under air.

The combination of optimized soy protein isolate-based antioxidant edible coatings and MAP has been evaluated on fresh-cut artichoke, eggplant and persimmon during storage at 5 ºC (Ghidelli et al., 2010, 2014, 2015). MAP conditions included active conventional MAP (5 kPa O_2 + 15 kPa CO_2), passive MAP, and high O_2 MAP (>50 kPa, balanced with N_2) and they were compared to atmospheric conditions as control. Minimally processed eggplants and artichokes were susceptible to tissue damage when packaged under active or passive MAP with low O_2 and high CO_2 levels, whereas high O_2 MAP (>30-50 kPa) resulted detrimental for the storage of fresh-cut persimmons. The combination of the soy protein coating with the different MAP did not extend the shelf life of artichoke slices, but helped maintain the antioxidant capacity of the product as compared to control packaging conditions during the 4-day commercial period reached (Ghidelli et al., 2015). Similarly, the coating in atmospheric conditions provided the best and cheapest approach for extending the shelf life of fresh-cut eggplants up to 9 days of storage (Ghidelli et al., 2014). On the contrary, the combination of the soy protein isolate-based coating with the active MAP packaging (5 kPa O_2 + 15 kPa CO_2) showed a synergic effect in controlling tissue browning of fresh-cut 'Rojo Brillante' persimmon and maintain the visual quality above the limit of marketability up to 8-10 days of storage at 5 ºC (Ghidelli et al., 2010). Sanchís et al. (2016b) reported that the combination of a pectin-based coating formulated with antibrowning and antimicrobial agents (1% citric acid + 1% $CaCl_2$ + 500 IU mL^{-1} nisin) and active MAP (5 kPa O_2, balance N_2) improved the visual quality of 'Rojo Brillante' persimmon slices compared to single treatments, being evaluated as very good at the end of the 9-day storage period at 5 ºC. The antimicrobial pectin coating also reduced the growth of total aerobic mesophilic bacteria during storage at 5 ºC and effectively stunted the growth of *E. coli*, *S. enteritidis* and *L. monocytogenes* in artificially inoculated fresh-cut persimmon. The effect of the antimicrobial coating towards Gram-positive and Gram-negative bacteria was attributed to the combination of nisin and the low pH achieved by citric acid.

FINAL REMARKS

This review presents several studies about MAP and edible coatings with promising results to improve the safety and extend the shelf life of fresh-cut fruits and vegetables. The higher susceptibility of these products to enzymatic browning, tissue softening, microbial growth, and loss of nutrients makes in many cases necessary to continue looking for alternatives to reach sufficient shelf life for commercial distribution of the product. Depending on the MAP conditions, much research is still required to avoid or retard fermentative reactions, off-flavor and loss of nutritional compounds. Innovative MAP such as the use of pressurized inert/noble gases and high levels of O_2 have resulted effective in extending shelf life of different fresh-cut fruits and vegetables, being the main benefits the prevention of microbiological spoilage and anaerobic fermentation. Nevertheless, the effect of innovative MAP is dependent on similar factors as with conventional MAP, i.e. type of commodity, temperature, storage duration, packaging material, etc. Some of the promising area for development to improve quality of fresh-cut commodities could be the use of active MAP able to deliver active compounds and new packaging material to better match the respiration of fresh-cut fruits and vegetables.

On the other hand, the application of edible coatings with active compounds and the use of nanotechnological solutions, such as nanoparticles, nanoencapsulation, and multilayered systems, to improve the quality of fresh-cut products require more research to understand the interactions among active compounds and coating materials to avoid sensory and physiological disorders in the product.

New combinations of MAP with edible coatings can be a feasible way for improving microbial stability and quality of fresh-cut fruits and vegetables, thus extending their shelf-life. Exploration of these technologies in highly perishable fruits and vegetables (i.e. high susceptibility to enzymatic browning, loss of integrity, microbial spoilage) that have received little or no attention is also required to increase the offer of fresh-cut fruits and vegetables, providing producers and consumer’s products with sufficient shelf life and the maximal safety and quality.

ACKNOWLEDGEMENTS

The authors thank the Spanish “Instituto Nacional de Investigación y Tecnología Agraria y Aliementaria” (INIA) and the European Union FEDER program for funding research in this topic (projects RTA-2006-00114-00-00, RTA-2009-00135-00-00, and RTA-2012- -00061-00-

00). The doctorate program of Christian Ghidelli was supported by the Valencian Institute of Agricultural Research (IVIA).

References

Aguayo, E., Requejo-Jackman, C., Stanley, R., and Woolf, A. (2010). Effects of calcium ascorbate treatments and storage atmosphere on antioxidant activity and quality of fresh-cut apple slices. *Postharvest Biol. Technol.* **57**: 52-60.

Alegre, I., Vinas, I., Usall, J., Anguera, M., Altisent, R., and Abadias, M. (2013). Antagonistic effect of Pseudomonas graminis CPA-7 against foodborne pathogens in fresh-cut apples under simulated commercial conditions. *Food Microbiol.* **33**: 139-148.

Allende, A., Jacxsens, L., Devlieghere, F., Debevere, J., and Artés, F. (2002). Effect of superatmospheric oxygen packaging on sensorial quality, spoilage, and *Listeria monocytogenes* and *Aeromonas caviae* growth in fresh processed mixed salads. *J. Food Prot.* **65**: 1565-1573.

Allende, A., Luo, Y., McEvoy, J. L., Artés F., and Wang, C. Y. (2004). Microbial and quality changes in minimally processed baby spinach leaves stored under super atmospheric oxygen and modified atmosphere conditions. *Postharvest Biol. Technol.* **33**: 51-59.

Alikhani-Koupaei, M. (2015). Liposomal and edible coating as control release delivery systems for essential oils: comparison of application on storage life of fresh-cut banana. *Qual. Assur. Safety Crops Foods.* **7**: 175-185.

Altisent, R., Plaza, L., Alegre, I., Vinas, I., and Abadias, M. (2014). Comparative study of improved vs. traditional apple cultivars and their aptitude to be minimally processed as 'ready to eat' apple wedges. *LWT-Food Sci. Technol.* **58**: 541-549.

Álvarez, M. V., Ponce, A. G., and Moreira, M. R. (2012). Antimicrobial efficiency of chitosan coating enriched with bioactive compounds to improve the safety of fresh-cut broccoli. *LWT-Food Sci.Technol.* **50**: 78-87.

Amanatidou, A., Slump, R. A., Gorris, L. G. M., and Smid, E. J. (2000). High oxygen and high carbon dioxide modified atmospheres for shelf-life extension of minimally processed carrots. *J. Food Sci.* **1**: 61-66.

Ayhan, Z. and Esturk, O. (2009) Overall quality and shelf life of minimally processed and modified atmosphere packaged 'ready-to-eat' pomegranate arils. J. Food Sci. 74: C399-C405.

Azarakhsh, N., Osman, A., Ghazali, H. M., Tan, C. P., and Adzahan, N. M. (2014). Lemongrass essential oil incorporated into alginate-based edible coating for shelf-life extension and quality retention of fresh-cut pineapple. *Postharvest Biol. Technol.* **88**: 1-7.

Bai, J. H., Saftner, R. A., Watada, A. E., and Lee, Y. S. (2001). Modified atmosphere maintains quality of fresh-cut cantaloupe (*Cucumis melo* L.). *J. Food Sci.* **66**: 1207-1211.

Bai, J. H., Saftner, R. A., and Watada, A. E. (2003). Characteristics of fresh-cut honeydew (*Cucumis melo* L.) available to processors in winter and summer and its quality maintenance by modified atmosphere packaging. *Postharvest Biol. Technol.* **28**: 349-359.

Baldwin, E. A., Nisperos-Carriedo, M. O., and Baker, R. A. (1995). Use of edible coatings to preserve quality of lightly (and slightly) processed products. *Crit. Rev. Food Sci. Nutr.* **35**: 509-24.

Banda, K., Caleb, O. J., Karin, J., and Opara U. L. (2015). Effect of active-modified atmosphere packaging on the respiration rate and quality of pomegranate arils (cv. Wonderful). *Postharvest Biol. Technol.* **109**: 97-105.

Beltrán, D., Selma, M. V., Tudela, J. A., and Gil, M. I. (2005). Effect of different sanitizers on microbial and sensory quality of fresh-cut potato strips stored under modified atmosphere or vacuum packaging. *Postahervest Biol. Technol.* **37**: 37-46.

Benítez, S., Achaerandio, I., Pujola, M., and Sepulcre, F. (2015). *Aloe vera* as an alternative to traditional edible coatings used in fresh-cut fruits: A case of study with kiwifruit slices. *LWT-Food Sci. Technol.* **61**: 184-193.

Bico, S. L. S., Raposo, M. F. J., Morais, R. M. S. C., and Morais, A. M. M. B. (2009). Combined effect of chemical dip and/or carrageenan coating and/or controlled atmosphere on quality of fresh-cut banana. *Food Control.* **20**: 508-514.

Brasil, I. M., Gomes, C., Puerta-Gomez, A., Castell-Perez, M. E., and Moreira R. G. (2012). Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya. *LWT–Food Sci. Technol.* **47**: 39-45.

Caillet, S., Millette, M., Salmieri, S., and Lacroix, M. (2006). Combined effects of antimicrobial coating, modified atmosphere packaging, and gamma irradiation on *Listeria innocua* present in ready-to-use carrots (*Daucus carota*). *J. Food Prot.* **69**: 80-85.

Caleb, O. J., Mahajan, P. V., Al-Said, F. A., and Opara, U. L. (2013). Modified atmosphere packaging technology of fresh and fresh-cut produce and the microbial consequences - A review. *Food Biol. Technol.* **6**: 303-329.

Campaniello, D., Bevilacqua, A., Sinigaglia, M., and Corbo, M. R. (2008). Chitosan: antimicrobial activity and potential applications for preserving minimally processed strawberries. *Food Microbiol.* **25**: 992-1000.

Cefola, M., Pace, B., Sergio, L., Baruzzi, F., Gatto, M. A., Carito, A., Linsalata, V., Cascarano, N. A., and Di Venere, D. (2014). Postharvest performance of fresh-cut 'Big Top' nectarine as affected by dipping in chemical preservatives and packaging in modified atmosphere. *Int. J. Food Sci. Technol*. **49**: 1184-1195.

Chong, J. X., Lai, S., and Yang, H. (2015). Chitosan combined with calcium chloride impacts fresh-cut honeydew melon by stabilising nanostructures of sodium-carbonate-soluble pectin. *Food Control.* **53**: 195-205.

Cliffe-Byrnes, V., and O'Beirne, D. (2007). The effects of modified atmospheres, edible coating and storage temperatures on the sensory quality of carrot discs. *Int. J. Food Sci. Technol. 42*: 1338-1349.

Cocci, E., Rocculi, P., Romani, S., and Dalla Rosa, M. (2006). Changes in nutritional properties of minimally processed apples during storage. *Postharvest Biol. Technol.* **39**: 265-271.

Conesa, A., Artés-Hernandez, F., Geysen, S., Nicolaï, B., and Artés, F. (2007). High oxygen combined with high carbon dioxide improves microbial and sensory quality of fresh-cut peppers. *Postharvest Biol. Technol.* **43**: 230-237.

Cortellino, G., Gobbi, S., Bianchi, G., and Rizzolo, A. (2015). Modified atmosphere packaging for shelf life extension of fresh-cut apples. *Trends Food Sci. Technol*. **46**: 320-330.

Costa, C., Conte, A., Buonocore, G. C., Lavorgna, M., and Del Nobile, M. A. (2012). Calcium-alginate coating loaded with silver-montmorillonite nanoparticles to prolong the shelf-life of fresh-cut carrots. *Food Res. Int.* **48**: 164-169.

Day, B. (2001). Modified atmosphere packaging for fresh fruit and vegetable – an overview. *Acta Hort.* **553**: 585-590.

Dea, S., Ghidelli, C., Pérez-Gago, M. B., and Plotto, A. (2012). Coatings for minimally processed fruits and vegetables. **In**: Edible Coatings and Films to Improve Food Quality, pp. 243-289. Baldwin, E. A., Hagenmaier, R., and Bai, J., Eds., CRC Press, Boca Raton, FL, USA.

Del Nobile, M. A., Conte, A., Scrocco, C., Laverse, J., Brescia, I., Conversa, G., and Elia, A. (2009). New packaging strategies to preserve fresh-cut artichoke quality during refrigerated storage. *Innovative Food Sci. Emerging Technol.* **10**: 128-133.

Dhall, R. K. (2013). Advances in edible coatings for fresh fruits and vegetables: a review. *Crit. Rev. Food Sci. Nutr.* **53**: 435-450.

Dong, H., Cheng, L., Tan, J., Zheng, K., and Jiang, Y. (2004). Effects of chitosan coating on quality and shelf life of peeled litchi fruit. *J. Food Eng.* **64**: 355-358.

Eissa, H. A. A. (2007). Effect of chitosan coating on shelf life and quality of fresh-cut mushroom. *J. Food Qual*. **30**: 623-645.

Escalona, V. H., Verlinden, B. E., Geysen, S., and Nicolai, B. M. (2006). Changes in respiration of fresh-cut butterhead lettuce under controlled atmospheres using low and superatmospheric oxygen conditions with different carbon dioxide levels. *Postharvest Biol. Technol.* **39**: 48-55.

Escalona, V. H., Aguayo, E., and Artés, F. (2007). Quality changes of fresh-cut kohlrabi sticks under modified atmosphere packaging. *J. Food Sci.* **72**: S303-S307.

Farber, J. N., Harris, L. J., Parish, M. E., Beuchat, L. R., Suslow, T.V.,Gorney, J. R.,Garrett, E. H., and Busta, F. F. (2003).Microbiological safety of controlled and modified atmosphere packaging of fresh and fresh-cut produce. *Compr. Rev. Food Sci. Food Saf.* **2**:142-160.

Fonseca, S. C., Oliveira, F. A. R., Brecht, J. K, and Chau, K. V. (2005). Influence of low oxygen and high carbon dioxide on shredded Galega kale quality for development of modified atmosphere packages. *Postharvest Biol. Technol*. **35**: 279-292.

Freitas, I. R., Cortez-Vega, W. R., Pizato, S., Prentice-Hernandez, C., and Borges, C. D. (2013). Xanthan gum as a carrier of preservative agents and calcium chloride applied on fresh-cut apple. *J. Food Sci*. **33**: 229-238.

Ghidelli, C., Mateos, M., Sanchís, E, Rojas-Argudo, C., del Río, M. A., and Pérez-Gago, M. B. (2010). Effect of edible coating and modified atmopshere packaging on enzymatic browning of fresh-cut persimmons cv. Rojo Brillante. *Acta Hort*. **876**: 341-348.

Ghidelli, C., Mateos, M., Rojas-Argudo, C., and Pérez-Gago, M. B. (2014). Extending the shelf life of fresh-cut eggplant with a soy protein-cysteine based edible coating and modified atmosphere packaging. *Postharvest Biol. Technol*. **95**: 81-87.

Ghidelli, C., Mateos, M., Rojas-Argudo, C., and Pérez-Gago, M. B. (2015). Novel approaches to control enzymatic browning of fresh-cut artichoke: Effect of a soy protein-based edible coating and modified atmosphere packaging. *Postharvest Biol. Technol*. **99**: 105-113.

Gil, M. I, Aguayo, E., and Kader, A. A. (2006). Quality changes and nutrient retention in fresh-cut versus whole fruits during storage. *J. Agric. Food Chem*. **54**: 4284-4296.

Gil-Izquierdo, A., Conesa, M. A., Ferreres, F., and Gil, M. I. (2002). Influence of modified atmosphere packaging on quality, vitamin C and phenolic content of artichokes (C*ynara scolymus* L.). *Eur. Food Res. Technol*. **215**: 21-27.

Giménez, M., Olarte, C., Sanz, S., Lomas, C., Echávarri, J. F., and Ayala, F. (2003). Relation between spoilage and microbiological quality in minimally processed artichoke packaged with different films. *Food Microbiol*. **20**: 231-242.

Gómez di Marco, P., Robles, P., Braun, J., Artés Hernández, F., Fernández, J. A., and Artés, F. (2012). Combined technologies to inhibit enzymatic browning and preserve quality of fresh-cut artichoke hearts. *Acta Hortic*. **942**: 385-390.

González-Aguilar, G. A., Wang, C. Y., and Buta, J. G. (2000). Maintaining quality of fresh-cut mangoes using antibrowning agents and modified atmosphere packaging. *J. Agric. Food Chem*. **48**: 4204-4208.

González-Aguilar, G. A., Celis, J., Sotelo-Mundo, R. R., de la Rosa, L. A., Rodrigo-Garcia, J., and Alvarez-Parrilla, E. (2008). Physiological and biochemical changes of different fresh-cut mango cultivars stored at 5 ºC. *Int. J. Food Sci. Technol.* **43**: 91-101

González-Aguilar, G. A., Valenzuela-Soto, E., Lizardi-Mendoza, J., Goycoolea, F., Martínez-Téllez, M. A., Villegas-Ochoa, M. A., Monroy-García, I. N., and Ayala-Zavala, J. F. (2009). Effect of chitosan coating in preventing deterioration and preserving the quality of fresh-cut papaya 'Maradol'. *J. Sci. Food Agr.* **89**: 15-23.

Gorny, J. R., Hess-Pierce, B., Cifuentes, R. A., and Kader, A. A. (2002). Quality changes in fresh-cut pear slices as affected by controlled atmospheres and chemical preservatives. *Postharvest Biol. Technol.* **24**: 271-278.

Guimarães, I. C., dos Reis, K. C., Tavares Menezes, E. G., Siriano Borges, P. R., Costa Rodrigues, A., Leal, R., Hernandes, T., Nunes de Carvalho, E. H., and Vilas-Boas, E. V. B. (2016). Combined effect of starch/montmorillonite coating and passive MAP in antioxidant activity, total phenolics, organic acids and volatile of fresh-cut carrots. *Int. J. Food Sci. Nutr.* **67**: 141-152

Guerreiro, A. C., Gago, C. M. L., Faleiro, M. L., Miguel, M. G. C., and Antunes, M. D. C. (2016). Edible coatings enriched with essential oils for extending the shelf-life of 'Bravo de Esmolfe' fresh-cut apples. *Int. J. Food Sci. Technol.* **51**: 87-95.

Gunes, G., Watkins, C. B., and Hotchkiss, J. H. (2001). Physiological responses of fresh-cut apple slices under high CO_2 and low O_2 partial pressures. *Postharvest Biol. Technol.* **22**: 197-204.

Jacxsens, L., Devlieghere, F., Van der Steen, C., and Debevere, J. (2001). Effect of high oxygen modified atmosphere packaging on microbial growth and sensorial qualities of fresh-cut produce. *Int. J. Food Microbiol.* **71**: 197-210.

Jamie, P., and Saltveit, M. E. (2002). Postharvest changes in broccoli and lettuce during storage in argon, helium, and nitrogen atmospheres containing 2% oxygen. *Postharvest Biol. Technol.* **26**: 113-116.

Jayathunge, K. G. L. R., Gunawardhana, D. K. S. N., Illeperuma, D. C. K., Chandrajith, U. G., Thilakarathne, B. M. K. S., Fernando, M. D., and Palipane, K. B. (2014). Physico-chemical and sensory quality of fresh cut papaya (*Carica papaya*) packaged in micro-perforated polyvinyl chloride containers. *J. Food Sci. Technol.* **51**: 3918-3925.

Kader, A.A., and Ben-Yehoshua, S. (2000). Effects of superatmospheric oxygen levels on postharvest physiology and quality of fresh fruits and vegetables. *Postharvest Biol. Technol.* **20**: 1-13.

Lafortune, R., Caillet, S., and Lacroix, M. (2005). Combined effects of coating, modified atmosphere packaging, and gamma irradiation on quality maintenance of ready-to-use carrots (*Daucus carota*). *J. Food Prot.* **68**: 353-359.

Lee, S.K. and Kader, A.A. (2000). Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* **20**: 207-220.

Lee, J. Y., Park, H. J., Lee, C. Y., and Choi, W. Y. (2003). Extending shelf-life of minimally processed apples with edible coatings and antibrowning agents. *LWT-Food Sci.Technol.* **36**: 323-329.

Lee, H. H., Hong, S. I., and Kim, D. (2011). Microbiological and visual quality of fresh-cut cabbage as affected by packaging treatments. *Food Sci. Biotechnol.* **20**: 229-235.

Li, L., Ban, Z., Li, X., Wang, X., and Guan, J. (2012a). Phytochemical and microbiological changes of honey pomelo (*Citrus grandis* L.) slices stored under super atmospheric oxygen, low-oxygen and passive modified atmospheres. *Int. J. Food Sci. Technol.* **47**: 2205-2211.

Li, W. L., Li, X. H., Fan, X., Tang, Y., and Yun, J. (2012b). Response of antioxidant activity and sensory quality in fresh-cut pear as affected by high O_2 active packaging in comparison with low O_2 packaging. *Food Sci. Technol. Int.* **18**: 197-205.

Limbo, S. and Piergiovanni, L. (2006). Shelf life of minimally processed potatoes. Part 1. Effects of high oxygen partial pressures in combination with ascorbic and citric acids on enzymatic browning. *Postharvest Biol. Technol.* **39**: 254-264.

López-Gálvez, F., Ragaert, P., Azizul Hague, Md., and Eriksson, M., van Labeke, M. C., and Devlieghere, F. (2015). High oxygen atmospheres can induce russet spotting development in minimally processed iceberg lettuce. *Postharvest Biol. Technol.* **100**: 168-175.

Luo, H., Jiang, L.I., Bao, Y., Wang, L., and Yu, Z. (2013). Effect of chitosan/nano-chitosan composite coating on browning and lignification of fresh-cut *Zizania latifolia*. *J. Food Qual.* **36**: 426-431.

Maghoumi, M., Gómez, P. A., Artés-Hernández, F., Mostofi, Y., Zamani, Z., and Artés, F., (2013). Hot water, UV-C and superatmospheric oxygen packaging as hurdle techniques for maintaining overall quality of fresh-cut pomegranate arils. *J. Sci. Food Agric.* **93**: 1162-1168.

Mantilla, N., Castell-Pérez, M. E., Gomes, C., and Moreira, R. G. (2013). Multilayered antimicrobial edible coating and its effect on quality and shelf-life of fresh-cut pineapple (*Ananas comosus*). *LWT-Food Sci. Technol.* **51**: 37-43.

Marrero, A., and Kader, A. A. (2006). Optimal temperature and modified atmosphere for keeping quality of fresh-cut pineapples. *Postharvest Biol. Technol.* **39**: 163-168.

Martiñon, M. E., Moreira, R. G., Castell-Pérez, M. E., and Gomes, C. (2014). Development of a multilayered antimicrobial edible coating for shelf-life extension of fresh-cut cantaloupe (*Cucumis melo* L.) stored at 4 ºC. *LWT-Food Sci. Technol.* **56**: 341-350.

Mastromatteo, M., Mastromatteo, M., Conte, A., and Del Nobile, M. A. (2011). Combined effect of active coating and MAP to prolong the shelf life of minimally processed kiwifruit (*Actinidia deliciosa* cv. Hayward). *Food Res. Int.* **44**: 1224-1230.

Medeiros, B. G. D., Pinheiro A. C., Teixeira J. A., Vicente A. A., and Carneiro-da-Cunha, M. G. (2012). Polysaccharide/protein nanomultilayer coatings: construction, characterization and evaluation of their effect on 'Rocha' pear (*Pyrus communis* L.) shelf-life. *Food Bio. Technol.* **5**: 2435-2445.

Meng, X., Zhang, M., and Adhikari, B. (2012). Extending shelf-life of fresh-cut green peppers using pressurized argon treatment. *Postharvest Biol. Technol.* **71**: 13-20.

Meng, X., Zhang, M., and Adhikari, B. (2014). The effects of ultrasound treatment and nano-zinc oxide coating on the physiological activities of fresh-cut kiwifruit. *Food Bioprocess Technol.* **7**: 126-132.

Moreira, M. R., Roura, S. I., and Ponce, A. (2011). Effectiveness of chitosan edible coatings to improve microbiological and sensory quality of fresh cut broccoli. *LWT-Food Sci. Technol.* **44**: 2335-2341.

Narsaiah, K., Wilson, R. A., Gokul, K., Mandge, H. M., Jha, S. N., Bhadwal, S., Anurag, R. K., Malik, R. K., and Vij, S. (2015). Effect of bacteriocin-incorporated alginate coating on shelf-life of minimally processed papaya (*Carica papaya* L.). *Postharvest Biol. Technol.* **100**: 212-218.

O'Beirne, D., Gomez-Lopez, V., Tudela, J. A., Allende, A., and Gil, M. I. (2015). Effects of oxygen-depleted atmospheres on survival and growth of *Listeria monocytogenes* on fresh-cut Iceberg lettuce stored at mild abuse commercial temperatures. *Food Microbiol.* **48**: 17-21.

Odriozola-Serrano, I., Oms-Oliu, G., Soliva-Fortuny, R., and Martín-Belloso, O. (2009). Effect of high-oxygen atmospheres on the antioxidant potential of fresh-cut tomatoes. *J. Agric. Food Chem*. **57**: 6603-6610.

Olivas, G. I., Rodriguez, J. J., and Barbosa-Cánovas, G. V. (2003). Edible coatings composed of methylcellulose, stearic acid, and additives to preserve quality of pear wedges. *J. Food Proces. Preserv*. **27**: 299-320.

Oms-Oliu, G., Soliva-Fortuny, R., and Martín-Belloso, O. (2007). Respiratory rate and quality changes in fresh-cut pears as affected by superatmospheric oxygen. *J. Food Sci*. **72**: E456-E463.

Oms-Oliu, G., Raybaudi-Massilia, R. M., Soliva-Fortuny, R., and Martín-Belloso, O. (2008a). Effect of superatmospheric and low oxygen modified atmospheres on shelf-life extension of fresh-cut melon. *Food Control*. **19**: 191-199.

Oms-Oliu, G., Soliva-Fortuny, R., and Martín-Belloso, O. (2008b). Physiological and microbiological changes in fresh-cut pears stored in high oxygen active packages compared with low oxygen active and passive modified atmosphere packaging. *Postharvest Biol. Technol*. **48**: 295-301.

Oms-Oliu, G., Soliva-Fortuny, R., and Martín-Belloso, O. (2008c). Modeling changes of headspace gas concentrations to describe the respiration of fresh-cut melon under low or superatmospheric oxygen atmospheres. *J. Food Eng*. **85**: 401-409.

Oms-Oliu, G., Soliva-Fortuny R., and Martín Belloso, O. (2008d). Edible coatings with antibrowning agents to maintain sensory quality and antioxidant properties of fresh-cut pears. *Postharvest Biol. Technol*. **50**: 87-94.

Oms-Oliu, G., Aguiló-Aguayo, I., Soliva-Fortuny, R., and Martín-Belloso, O. (2009). Effect of ripeness at processing on fresh-cut 'Flor de Invierno' pears packaged under modified atmosphere conditions. *Int. J. Food Sci. Technol.* **44**: 900-909.

Palma, A., Mangia, N. P., Fadda, A., Barberis, A., Schirra, M., and D'Aquino, S. (2013). Effect of different film packaging on microbial growth in minimally processed cactus pear (*Opuntia ficus-indica*). *Commun. Agric. Appl. Biol. Sci.* **78**: 73-82.

Pan, S.-Y., Chen, C.-H., and Lai, L.-S. (2013). Effect of tapioca starch/decolorized hsian-tsao leaf gum-based active coatings on the qualities of fresh-cut apples. *Food Bioprocess Technol.* **6**: 2059-2069.

Pérez-Gago M. B., Serra M., Alonso M., Mateos M., and del Río M. A. (2003). Effect of solid content and lipid content of whey protein isolate-beeswax edible coatings on color change of fresh-cut apples. *J. Food Sci.* **68**: 2186-2191.

Pérez-Gago M. B., Serra M., Alonso M., Mateos M., and del Río M. A. (2005). Effect of whey protein and hydroxypropyl methylcellulose-based edible composite coatings on color change of fresh-cut apples. *Postharvest Biol. Tech.* **36**: 77-85.

Pérez-Gago, M. B., Serra, M., and del Río, M. A. (2006). Color change of fresh-cut apples coated with whey protein concentrate-based edible coatings. *Postharvest Biol. Technol.* **39**: 84-92.

Pilon, L., Spricigo, P. C., Miranda, M., de Moura, M. R., Assis, O. B. G., Mattoso, L. H. C., and Ferreira, M. D. (2015). Chitosan nanoparticle coatings reduce microbial growth on fresh-cut apples while not affecting quality attributes. *Int. J. Food Sci. Technol.* **50**: 440-448.

Poubol, J, and Izumi, H. (2005). Physiology and microbiological quality of fresh-cut mango cubes as affected by high-O_2 controlled atmospheres. *J. Food Sci.* **70**: M286-M291.

Poverenov, E., Danino, S., Horev, B., Granit, R., Vinokur, Y., and Rodov, V. (2014a). Layer-by-layer electrostatic deposition of edible coating on fresh cut melon model: Anticipated and unexpected effects of alginate-chitosan combination. *Food Bioprocess Technol*. **7**: 1424-1432.

Poverenov, E., Rutenberg, R., Danino, S., Horev, B., and Rodov, V. (2014b). Gelatin-chitosan composite films and edible coatings to enhance the quality of food products: Layer-by-layer vs. blended formulations. *Food Bioprocess Technol*. **7**: 3319-3327.

Pushkala, R., Parvathy, K. R., and Srividya, N. (2012). Chitosan powder coating, a novel simple technique for enhancement of shelf life quality of carrot shreds stored in macro perforated LDPE packs. *Inn. Food Sci. Emerg. Technol*. **16**: 11-20.

Qi, H., Hu, W., Jiang, A., Tian, M., and Li, Y. (2011). Extending shelf-life of fresh-cut ‘Fuji’ apples with chitosan-coatings. Innovative Food Sci. Emerging Technol. **12**: 62-66.

Ranjitha, K., Rao, Sudhakar D. V., Shivashankara, K. S., and Roy, T. K. (2015). Effect of pretreatments and modified atmosphere packaging on the shelf life and quality of fresh-cut green bell pepper. *J. Food Sci. Technol.-Mysore*. **52**: 7872-7882.

Raybaudi-Massilia, R. M., Rojas-Graü, M. A., Mosqueda-Melgar, J., and Martín-Belloso, O. (2008a). Comparative study on essential oil incorporated into an alginate-based edible coating to assure the safety and quality of fresh-cut Fuji apples. *J. Food Protect*. **71**: 1150-1161.

Raybaudi-Massilia, R. M., Mosqueda-Melgar, J., and Martín-Belloso, O. (2008b). Edible alginate-based coating as carrier of antimicrobials to improve shelf-life and safety of fresh-cut melon. *Int. J. Food Microbiol*. **121**: 313-327.

Raymond, L. V., Zhang, M., Karangwa, E., and Chesereka, M. J. (2013). Mixed noble gas effect on cut green peppers. *Int. Agroph*. **27**: 75-79.

Rocculi, P., Romani, S., and Dalla Rosa, M. (2004). Evaluation of physico-chemical parameters of minimally processed apples packed in non-conventional modified atmosphere. *Food Res. Int.* **37**: 329-335.

Rocculi, P., Romani, S., and Dalla Rosa, M. (2005). Effect of MAP with argon and nitrous oxide on quality maintenance of minimally processed kiwifruit. *Postharvest Biol. Technol.* **35**: 319-328.

Robles-Sánchez, R. M., Rojas-Graü, M. A., Odriozola-Serrano, I., González-Aguilar, G., and Martín-Belloso, O. (2013). Influence of alginate-based edible coating as carrier of antibrowning agents on bioactive compounds and antioxidant activity in fresh-cut Kent mangoes. *LWT-Food Sci. Technol.* **50**: 240-246.

Rojas-Graü, M. A., Tapia, M. S., Rodríguez, F. J., Carmona, A. J., and Martín-Belloso, O. (2007). Alginate and gellan based edible coatings as carrier of antibrowning agents applied on fresh-cut Fuji apple. *Food Hydrocolloid.* **21**: 118-127.

Rojas-Graü, M. A., Tapia, M. S., and Martín-Belloso, O. (2008). Using polysaccharide-based edible coatings to maintain quality of fresh-cut Fuji apples. *LWT-Food Sci.Technol.* **41**: 139-147.

Rojas-Graü, M. A., Oms-Oliu, G., Soliva-Fortuny, R., and Martín-Belloso, O. (2009). The use of packaging techniques to maintain freshness in fresh-cut fruits and vegetables: a review. *Int. J. Food Sci. Technol.* **44**: 875-889.

Sanchís, E., González, S., Ghidelli, C., Sheth, C. C., Mateos, M., Palou, L., and Pérez-Gago, M. B. (2016a). Browning inhibition and microbial control in fresh-cut persimmon (*Diospyros kaki* Thunb. cv. Rojo Brillante) by apple pectin-based edible coatings. *Postharvest Biol. Technol.* **112**: 186-193.

Sanchís, E., Ghidelli, C., Sheth, C. C., Mateos, M., Palou, L., and Pérez-Gago, M. B. (2016b). Integration of antimicrobial pectin-based edible coating and active modified atmosphere packaging to preserve the quality and microbial safety of fresh-cut persimmon (*Diospyros kaki* Thunb. cv. Rojo Brillante). *J. Sci. Food Agric*. In press

Sangsuwan, J., Rattanapanone, N., and Rachtanapun, P. (2008). Effect of chitosan/methyl cellulose films on microbial and quality characteristics of fresh-cut cantaloupe and pineapple. *Postharvest Biol. Technol*. **49**: 403-410.

Simões, A. D. N., Tudela, J. A., Allende, A., Puschmann, R., and Gil, M. I. (2009). Edible coatings containing chitosan and moderate modified atmosphere maintain quality and enhance phytochemicals of carrot sticks. *Postharvest Biol. Technol*. **51**: 364-370.

Simón, A., González-Fandos, E., and Tobar, V. (2005). The sensory and microbiological quality of fresh sliced mushroom (*Agaricus bisporus* L.) packaged in modified atmospheres. *Int. J. Food Sci. Technol*. **40**: 943-952.

Sipahi, R. E., Castell-Pérez, M. E., Moreira, R. G., Gomes C., and Castillo A. (2013). Improved multilayered antimicrobial alginate-based edible coating extends the shelf life of fresh-cut watermelon (*Citrullus lanatus*). *LWT-Food Sci. Technol*. **51**: 9-15.

Soliva-Fortuny, R. C., Ricart-Coll, M., Elez-Martínez, P., and Martín-Belloso, O. (2007). Internal atmosphere, quality attributes and sensory evaluation of MAP packaged fresh-cut Conference pears. *Int. J. Food Sci. Technol*. **42**: 208-213.

Sothornvit, R., and Rodsamran, P. (2010). Mango film coated for fresh-cut mango in modified atmosphere packaging. *Int. J. Food Sci. Technol*. **45**: 1689-1695.

Tapia, M. S., Rojas-Graü, M. A., Rodríguez, F. J., Ramírez, J., Carmona, A., and Martín-Belloso, O. (2007). Alginate- and gellan-based edible films for probiotic coatings on fresh-cut fruits. *J. Food Sci*. **72**: E190-E196.

Teixeira-Barbosa, A. A., Silva, H. S., Nogueira-Matos, P., Guitierrez Carnelossi, M. A., and de Castro, A. A. (2013). Effects of nisin-incorporated films on the microbiological and physicochemical quality of minimally processed mangoes. *Int. J. Food Microbiol.* **164**: 135-140.

Tomás-Callejas, A., Boluda, M., Robles, P. A., Artés, F, and Artés-Hernandez, F. (2011). Innovative active modified atmosphere packaging improves overall quality of fresh-cut red chard baby leaves. *LWT-Food Sci.Technol.* **44**: 1422-1428.

Tudela, J. A., Marin, A., Garrido, Y., Cantwell, M., Medina-Martínez, M. S., and Gil, M. I. (2013). Off-odour development in modified atmosphere packaged baby spinach is an unresolved problem. *Postharvest Biol. Technol.* **75**: 75-85.

Van der Steen, C., Jacxsens, L., Devlieghere, F., and Debevere, J. (2002). Combining high oxygen atmospheres with low oxygen modified atmosphere packaging to improve the keeping quality of strawberries and raspberries. *Postharvest Biol. Technol.* **26**: 49–58.

Vilas-Boas, E. V. B., and Kader A. A. (2006). Effect of atmospheric modification, 1-MCP and chemicals on quality of fresh-cut banana. *Postharvest Biol. Technol.* **39**: 155-162.

Waghmare, R. B., and Annapure, U. S. (2013). Combined effect of chemical treatment and/or modified atmosphere packaging (MAP) on quality of fresh-cut papaya. *Postharvest Biol. Technol.* **85**: 147-153.

Wszelaki, A. L., and Mitcham, E. J. (2000). Effects of superatmospheric oxygen on strawberry fruit quality and decay. *Postharvest Biol. Technol.* **20**: 125–133.

Wu, Z. S., Zhang, M., and Wang, S. (2012a). Effects of high pressure argon treatments on the quality of fresh-cut apples at cold storage. *Food Control.* **23**: 120-127.

Wu, Z. S., Zhang, M., and Adhikari, B. (2012b). Application of high pressure argon treatment to maintain quality of fresh-cut pineapples during cold storage. *J. Food Eng.* **110**: 395-404.

Wu, Z. S., Zhang, M., and Adhikari, B. (2012c). Effects of high-pressure argon and nitrogen treatments on respiration, browning and antioxidant potential of minimally processed pineapples during shelf life. *J. Sci. Food Agric.* **92**: 2250-2259.

Wu, Z. S., Zhang, M., and Adhikari, B. (2013). Effects of high pressure argon and xenon mixed treatment on wound healing and resistance against the growth of *Escherichia coli* or *Saccharomyces cerevisiae* in fresh-cut apples and pineapples. *Food Control*. **30**: 265-271.

Zhang, M., Meng, X., Bhandari, B., Fang, Z., and Chen, H. (2015). Recent application of modified atmosphere packaging (MAP) in fresh and fresh-cut foods. *Food Rev. Int*. **31**: 172-193.

Zhang, B. Y., Samapundo, S., Pothakos, V., Sürengil, G., and Devlieghere, F. (2013). Effect of high oxygen and high carbon dioxide atmosphere packaging on the microbial spoilage and shelf-life of fresh-cut honeydew melon. *Int. J. Food Microbiol*. **166**: 378-390.

Table 1. Modified atmosphere packaging (MAP) and/or edible coating application, alone or in combination for fresh-cut fruits and vegetable.

Commodity	**Atmosphere conditions**	**Coating material**	**Additives**	**Benefits**	**References**
Apple	0-10 kPa O_2 + 0-30 kPa CO_2	—	AA, CA, $CaCl_2$	Reduce respiration rates Reduce ethylene production Control browning Preserve visual appearance	Gunes et al., 2001
	—	Carragennan, WPC	CA, OA	Reduce CO_2 production Inhibit browning Reduce water loss	Lee et al., 2003
	—	WPC, BW	AA, Cys, 4-HR	Inhibit browning	Pérez-Gago et al., 2006
	—	Alginate, gellan, sunflower oil, fatty acids	N-acetylcysteine, glutathione, $CaCl_2$	Maintain texture Reduce water loss	Rojas-Graü et al., 2007
	—	Alginate, gellan, sunflower oil	N-acetylcysteine, AA, CA	Reduce weight loss	Tapia et al., 2007
	—	Alginate, gellan, sunflower oil	N-acetylcysteine, $CaCl_2$	Inhibit browning Maintain texture	Rojas-Graü et al., 2008
	—	Alginate	N-acetylcysteine, glutathione, cinnamon, clove, lemongrass, citral, cynnamaldehyde, eugenol, calcium lactate, malic acid	Prevent microbiological growth Reduce CO_2 production Inhibit browning	Raybaudi-Massilia et al., 2008a
	Passive MAP	—	CaAsc	Control browning Preserve visual appearance Maintain antioxidants and vit C content	Aguayo et al., 2010
	—	Chitosan	AA	Inhibit browning	Qi et al., 2011
	Pressurized Ar (150Mpa)	—	$CaCl_2$, AA, CA	Reduce respiration rate and ethylene production. Reduced color change and	Wu et al., 2012a

				firmness loss Maintain sensory quality for 12 days at 4 ºC.	
	—	Sodium alginate, pectin	Eugenol, citral	Maintain the overall acceptability and reduce microbial growth at the optimum essential oil concentration	Guerreiro et al., 2016
Artichoke	Passive MAP	—	—	Reduce weight loss Maintain vit C and phenolic compounds content	Gil-Izquierdo et al., 2002
	—	Alginate	CA, $CaCl_2$	Inhibit browning	Del Nobile et al., 2009
	80 kPa O_2	—	Lemon juice	Inhibit browning	Gómez di Marco et al., 2012
	—	SPI-BW	Cys	Inhibit enzymatic browning	Ghidelli et al., 2015
	80 kPa O_2	SPI-BW	Cys	Mantain visual quality Mantain actioxidant capacity	
	5 kPa O_2 + 15 kPa CO_2	SPI-BW	Cys	Induce tissue browning	
Banana	2-4 kPa O_2 + 5-10 kPa CO_2	—	AA, Cys, $CaCl_2$	Control browning	Vilas-Boas and Kader, 2006
	—	Carragennan	AA, Cys, $CaCl_2$	Inhibit browning Reduce water loss	Bico et al., 2009
	—	Mucilage	Encapsulated rosmary oil	Reduce weight loss Maintain the overall quality of the product for up to 9 days	Alikhani-Koupaei, 2015
Broccoli	—	Chitosan	—	Reduce total mesophilic and psychrotrophic bacteria growth Inhibition of total coliform growth Decrease of *E.coli* growth	Moreira et al., 2011
	—	Chitosan	Propolis, resveratrol, tea tree essential oil	Inhibit mesophilic and phsychrotrophic bateria growth Control *E. coli* and *L monocytogenes* growth	Álvarez et al., 2012
Cabbage	70 kPa O_2 +	—	—	Inhibit microbial growth	Lee et al., 2011

	15 kPa CO_2			Inhibit *E. coli* and *S. aureus* growth	
Carrot	50 kPa O_2 + 30 kPa CO_2	Alginate	CA, $CaCl_2$	Inhibit browning Inhibit Enterobacteriacea, *Pseudomonas*, lactic acid bacteria grrowth Reduce firmness loss	Amanatidou et al., 2000
	60 kPa O_2 + 30 kPa CO_2	CC, WPI	—	Reduce microbial growth Retard whitening	Lafortune et al., 2005
	60 kPa O_2 + 30 kPa CO_2	CC	Cynnamaldehyde	Inhibit *L. innocua* growth	Caillet et al., 2006
	Passive MAP	Chitosan, yam starch	—	Prevent surface whitening Maintain sensory quality Enhanced phenolic content	Simões et al., 2009
	—	Chitosan	—	Reduce weight loss Preserve phenolic content	Pushkala et al., 2012
	Passive MAP	Alginate	Ag-montmorillonite	Control dehydration and extend the shelf life Reduce mesophilic and psychrotrophic bacteria, Enterobacteriaceae, *Pseudomonas* spp., and yeasts	Costa et al., 2015
	Passive MAP	Cassava strach	Smectite montmorillonite nanoparticles	Preserve the total antioxidant activity, the volatile and organic acids	Guimarães et al., 2016
Eggplant	—	SPI-BW	Cys	Inhibit enzymatic browning	Ghidelli et al., 2014
	80 kPa O_2	SPI-BW	Cys	Mantain visual quality	
	5 kPa O_2 + 15 kPa CO_2	SPI-BW	Cys	Induce tissue browning	
Galega kale	1-2 kPa O_2 + 15-20 kPa CO_2	—	—	Control browning Preserve visual appearance	Fonseca et al., 2005
Kiwi	10 kPa O_2 + 10 kPa CO_2	Alginate	Hydro-alcoholic solution, grape seed extract	Control dehydration Reduce respiration rate Maintain sensory quality	Mastromatteo et al., 2011
	—	Chitosan and	Nano-ZiO	Slow down ethylene and carbon	Meng et al., 2015

		ultrasounds		dioxide production Reduce the water loss and softening Delay senescence and extend shelf life	
	—	Chitosan, *Aloe vera* or alginate	Acetic acid or CA	Maintain quality and extend shelf life *Aloe vera* and chitosan with acetic acid: reduce microbial growth Chitosan: negative effect on sensory quality	Benítez et al., 2015
Kohlrabi	Passive MAP	—	—	Maintain sensory quality	Escalona et al. 2007
Lettuce	80 kPa O_2	—	—	Reduce firmness loss Maintain vit C content	Day, 2001
	70-80 kPa O_2 + 10-20 kPa CO_2	—	—	Reduce respiration rate Prevent anaerobic fermentation	Escalona et al., 2006
	50 to 90 kPa 3 kPa	—	—	Reduce enzymatic browning by high O_2 atmosphere, but russet spotting was induced	López-Gálvez et al., 2015
Litchi	—	Chitosan	—	Inhibition PPO activity Reduce weigh loss Maintain vit C content	Dong et al., 2004
Mango	Passive MAP	—	AA, 4-HR, PS	Inhibit browning Maintain sensory quality	González-Aguilar et al., 2000
	60 kPa O_2	—	—	Inhibit *Rhodotorula mucilaginosa* yeast growth Reduce respiration rate Maintain/increase browning	Poubol and Izumi, 2005
	10 kPa O_2 + 0 kPa CO_2	Mango film	—	Reduce off flavor	Sothornvit and Rodsamran, 2010
	—	Alginate, sunflower oil	AA, CA, $CaCl_2$	Inhibit browning	Robles-Sánchez et al., 2013
Melon	2.5 kPa O_2 + 7 kPa CO_2	—	AA, $CaCl_2$	Control browning Preserve visual appearance	Oms-Oliu et al., 2007

	2.5 kPa O_2 + 7 kPa CO_2	—	$CaCl_2$	Inhibit ethylene syntesis Decrease CO_2 emission	Oms-Oliu et al., 2008a
	70 kPa O_2	—	$CaCl_2$	Reduce psychrotrophic growth Inhibit *Rhodotorula mucilaginosa* yeast growth Reduce CO_2 production Prevent anaerobic fermentation Inhibit browning Reduce firmness loss	
	—	Alginate	Cinnamon, palmarosa, lemongrass, eugenol, geraniol, citral, malic acid, calcium lactate	Inhibit microbial growth Inhibition native flora growth Reduce *S. enteritidis* growth	Raybaudi-Massilia et al., 2008b
	70 kPa O_2	—	$CaCl_2$	Reduce CO_2 production Prevent anaerobic fermentation Reduce firmness loss	Oms-Oliu et al., 2008c
	—	Chitosan, MC	Vanillin	Control microbial growth	Sangsuwan et al., 2008
	—	LbL alginate-chitosan	—	Improve adhesion Slow down tissue softening Enhance gas exchange properties Reduce bacteria, yeast, and fungi counts	Poverenov et al., 2014a, 2014b
	—	Chitosan	$CaCl_2$	Reduce weight loss and increase firmness Maintain color Inhibit mesophilic and psychrotropic growth	Chong et al., 2015
Mixed salad	95 kPa O_2	—	—	Inhibit lactic acid bacteria, Enterobacteriaceae bacteria growth	Allende et al., 2002
Mushroom	95 kPa O_2	—	—	Inhibit browning	Jacxsen et al., 2001
	< 0.1 kPa O_2 + 15 kPa CO_2	—	—	Inhibition of microbial growth	Simón et al., 2005
	—	Chitosan	—	Inhibit PPO activity Maintain texture	Eissa, 2007

Nectarine	10 kPa O_2 + 10 kPa CO_2	—	2% AA + 1% calcium lactate	Control brwoning Reduce microbial load	Cefola et al., 2014
Papaya	—	Alginate, gellan, sunflower oil	N-acetylcysteine, AA, CA	Reduce water loss	Tapia et al., 2007
	—	Chitosan	—	Inhibit microbial growth	González-Aguilar et al.,2009
	—	LbL Chitosan-Pectin	β-cyclodextrin and trans-cinnamaldehyde	Maintained firmness, color, vitamin C and β-carotene content Inhibit aerobic and psychrotrophic bacteria, yeast and mold growth Extend shelf life to 15 d at 4 ºC	Brasil et al., 2012
	5 kPa O_2 + 10 kPa CO_2	—	CA, $CaCl_2$	Reduce microbial growth Control browning Maintain texture	Waghmare and Annapure, 2013
	Passive MAP	—	—	Optimum O_2 and CO_2 concentrations of 4 kPa and 6 kPa, respectively, helped to maintain a storage shelf life of 19 days at 4 ºC	Jayathunge et al., 2014
	—	Alginate	Bacteriocin	Reduce microbial counts without compromising physico-chemical quality	Narsaiah et al., 2015
Pear	0.25-0.5 kPa O_2 + 5-10-20 kPa CO_2	—	AA, Cys, calcium lactate	Control browning	Gorny et al., 2002
	40, 50, 60 kPa O_2 (balance N_2)	—	—	Neither control browning, nor firmness loss	
	—	MC, stearic acid	AA, PS, $CaCl_2$	Inhibit browning Reduce weigh loss	Olivas et al., 2003
	2.5 kPa O_2 + 7 kPa CO_2	—	AA, $CaCl_2$	Inhibit ethylene syntesis Decrease CO_2 emission Control browning Preserve visual appearance	Soliva-Fortuny et al., 2007
	2.5 kPa O_2 + 7 kPa CO_2	—	N-acetylcysteine, glutathione	Inhibit microbial growth Inhibit ethylene syntesis	Oms-Oliu et al., 2008b

				Decrease CO_2 production Control browning Preserve visual appearance	
	70 kPa O_2	—	N-acetylcysteine, glutathione	Reduce psychrotrophic growth Inhibit *Rhodotorula mucilaginosa* yeast growth	
	—	Alginate, gellan, pectin	N-acetylcysteine, glutathione, $CaCl_2$	Reduce CO_2 production Inhibit browning	Oms-Oliu et al., 2008d
	2.5 kPa O_2 + 7 kPa CO_2	—	—	Inhibit ethylene syntesis Decrease CO_2 production Control browning	Oms-Oliu et al., 2009
	80 kPa O_2	—	—	Increase production of phenolics compounds and anthocyanin	Li et al., 2012b
Pepper	50-80 kPa O_2 + 15 kPa CO_2	—	—	Control mesophilic and psychrotrophic bacteria, Enterobacteriaceae bacteria growth	Conesa et al., 2007
	Ar+Krypton (2 MPa) Ar (2 MPa)			Reduce respiration rate and vitamin C loss Mixed Ar-Krypton samples presented lower mass loss and cell membrane permeability	Raymond et al., 2013
Persimmon	—	SPI	CA, $CaCl_2$	Reduce browning	Ghidelli et al., 2010
	5 kPa O_2 + 15 kPa CO_2	SPI	CA, $CaCl_2$	Synergic effect to reduce browning	
	>30 kPa O_2	SPI	CA, $CaCl_2$	Damage the tissue	
	—	Pectin	CA, $CaCl_2$, PS, SB, nisin	Control browning and extended shelf life Inhibit growth of mesophilic aerobic bacteria Reduce the populations of artificially inoculated *E. coli* and *S. enteritidis*, while for *L. monocytogenes*, only the nisin coating was effective	Sanchís et al., 2016a

	5 kPa O_2, balance N_2	Pectin	CA, $CaCl_2$, nisin	Improve visual quality Reduce the growth of total aerobic mesophilic bacteria Stunt the growth of *E. coli*, *S. enteritidis* and *L. monocytogenes* in artificially inoculated fruit.	Sanchís et al., 2016b
Pineapple	< 8 kPa O_2 + 10 kPa CO_2	—	—	Control browning Preserve visual appearance	Marrero and Kader, 2006
	—	Chitosan, MC	Vanillin	Control microbial growth	Sangsuwan et al., 2008
	Pressurized Ar (1.8 and 10 MPa) Pressurized N_2 (10 MPa)	—	—	Reduce respiration rate, ethylene production, browning and loss of total phenols and ascorbic acid. Delay microbial growth	Wu et al., 2012b, 2012c
	Pressurized Ar + Xe (Ar:Xe = 2:9)	—	—	Positive wound healing response. Inhibit the growth of *E. coli* and *S. cerevisiae* in tested apple and pineapple samples.	Wu et al., 2013
	—	LbL sodium alginate - pectin with Ca^{+2}	β-cyclodextrin and trans-cinnamaldehyde	Reduce psychrotrophic bacteria, yeasts and molds growth Maintain color, pH, total soluble solids, and firmness	Mantilla et al., 2013
	—	Alginate, sunflower oil	Lemongrass, $CaCl_2$	Reduce microbial growth Reduce firmness loss	Azarakhsh et al., 2014
Pomegranate arils	>30 kPa O_2	—	—	Reduce anthocyanin content Extend shelf life base on sensory scores and microbial load	Banda et al., 2015 Ayhan and Esturk, 2009
	100 kPa N_2			Reduce aerobic mesophilic bacteria	Banda et al., 2015
Pomelo	3 kPa O_2 + 5 kPa CO_2	—	—	Inhibit microbial growth	Li et al., 2012a
	75 kPa O_2	—	—	Inhibit *Rhodotorula mucilaginosa* yeast growth	
Potato	55-100 kPa O_2	—	AA, CA	Prevent anaerobic fermentation	Limbo and Piergiovanni, 2006
Red Chard	> 85 kPa O_2	—	—	Inhibit psychrotrophic growth	Tomás-Calleja et al., 2011

Spinach	Passive MAP	—	—	Reduce aerobic mesophilic bacteria growth	Allende et al., 2004
	100 kPa O_2	—	—	Reduce mesophilic bacteria growth	
	Passive MAP	—	—	Reduce psychrotrophic bacteria growth and *Pseudomonas* growth Control browning Preserve visual appearance	Tudela et al., 2013
Strawberry	80-100 kPa O_2	—	—	Inhibit the growth of *Botrytis cinerea*	Wszelaki and Mitcham, 2000
	70 kPa O_2	—	—	Retard the growth of molds and yeasts	Van der Steen et al., 2002
	80 kPa O_2 + 20 kPa CO_2	Chitosan	—	Inhibit growth of mesophilic and psychrotropic bacteria and yeast	Campaniello et al., 2008
	5 kPa O_2 + 30 kPa CO_2	Chitosan	—	Inhibit growth of mesophilic, psychrotropic bacteria and yeast Maintain color	
Tomato	2.5 kPa O_2 +5 kPa CO_2	—	—	Maintain vitamin C Increase of phenolics, flavonoids and carotenoids	Odriozola-Serrano et al., 2009
	60 and 80 kPa O_2	—	—	Increase of phenolics compounds Decrease vitamin C Decrease hydrophilic antioxidant capacity	

AA = ascorbic acid, BW = beeswax, CaAsc = calcium ascorbate, CC = calcium caseinate, $CaCl_2$ = calcium chloride, CA = citric acid, Cys = cystein, 4-HR = hexylresorcinol, LbL = layer by layer coating, MC = methylcellulose, OA = oxalic acid, PPO = polyphenol oxidase, PS = potassium sorbate, SB = sosium benzoate, SPI = soy protein isolate, WPC = whey protein concetrate, WPI = whey protein isolate.