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Review

The use of packaging techniques to maintain freshness in fresh-cut fruits and vegetables: a review

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Summary Browning and other discolourations, softening, surface dehydration, water loss, translucency, off-flavour and off-odour development, as well as microbial spoilage are some of the most frequent causes of quality loss in fresh-cut products. Nowadays, the use of innovative modified atmospheres and edible coatings stands out among other techniques in the struggle for maintaining freshness and safety of fresh-cut fruits and vegetables. A few studies have demonstrated the effectiveness of these techniques when applied to different fresh-cut commodities. However, treatment and storage conditions for fresh-cut fruits are still being largely explored to better keep their fresh-like quality attributes. This review discusses the recent advances in the use of innovative modified atmosphere packaging (MAP) systems to maintain freshness of fresh-cut fruits and vegetables. Furthermore, special attention is devoted to the development of coatings that can be used as a complement or alternative to MAP.

Keywords Edible coatings, fresh-cut fruits and vegetables, modified atmosphere packaging.

Introduction

Processing of fresh-cut fruits and vegetables usually involves the induction of wounding stresses in the cut tissues as a result of mechanical injury, leading to an increase in their respiration rate (Watada *et al.*, 1996). Respiration involves the oxidative breakdown of complex substrate molecules, normally present in plant cells such as starch, sugars and organic acids to simpler molecules, in the course of which energy, carbon dioxide and water are given out. Atmospheres low in O_2 (1–5%) and high in CO_2 (5–10%) have been used to extend the shelf-life of fresh-cut fruits and vegetables by reducing respiration, product transpiration and ethylene production, as O_2 is involved in the conversion of 1-amino-cycloprane-1-carboxylic acid to ethylene (Yang & Hoffman, 1984). In general, an inverse relationship has been shown between respiration rates of fruits and vegetables and their postharvest shelf-life. Reduced O_2 and high CO_2 levels have also been proved to effectively control enzymatic browning, firmness and decay of fresh-cut fruits and vegetables. Besides, the proliferation of aerobic spoilage microorganisms can be substantially delayed with reduced O_2 levels. However, under certain conditions, the growth of some anaerobic psychrotrophic pathogens might be allowed or even stimulated (Soliva-Fortuny & Martín-Belloso, 2003a). An adequate O_2 concentration inside packages is required to limit aerobic respiration without triggering anaerobic processes, as too low O_2 and/or excessive CO_2 concentrations may induce the production of undesirable metabolites and the unleashing of several physiological disorders (Soliva-Fortuny & Martín-Belloso, 2003a). In the last few years, the use of elevated O_2 atmospheres (≥70 kPa O_2) has been proposed as an alternative to low O_2 atmospheres to inhibit the growth of naturally occurring spoilage microorganisms, prevent undesired anoxic respirative processes and maintain the fresh-like quality of fresh-cut produce (Amanatidou *et al.*, 1999; Jacxsens *et al.*, 2001; Van der Steen *et al.*, 2002).

On the other hand, edible coatings can be applied as either a complement or an alternative to modified atmosphere packaging (MAP) to improve the shelf-life of fresh-cut fruits. Edible films and coatings may help to reduce the deleterious effects concomitant with minimal processing, not solely retarding food deterioration and enhancing its quality, but also improving its safety because of their natural biocide activity or by incorporating antimicrobial compounds (Petersen *et al.*, 1999). In fact, the application of edible coatings to deliver active substances is one of the major advances reached so far to increase the shelf-life of fresh-cut produce.

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This review highlights some of the most recent findings regarding the use of innovative packaging systems to maintain freshness of fresh-cut fruits and vegetables. An overview of studies on MAP and edible coatings used for preserving fresh-cut fruits and vegetables is provided.

Maintaining the microbiological stability of fresh-cut fruits and vegetables

Packaging under appropriate atmosphere conditions can effectively control the growth of microorganisms on the surface of fresh-cut fruits. The proliferation of aerobic microorganisms can be substantially delayed with reduced O_2 levels. The growth of Gram-negative aerobes such as Pseudomonas is specially inhibited, more than for Gram-positive, microaerophilic species such as Lactobacillus. High CO_2 concentrations are also generally effective in controlling the growth of most aerobic microorganisms, specifically Gram-negative bacteria and moulds, but fail to inhibit most yeasts (Al-Ati & Hotchkiss, 2002). On fresh-cut apples, pears and melon, microbial growth was not inhibited under atmosphere containing moderately high CO_2 concentrations (2.5 kPa O_2 + 7 kPa CO_2); indeed, the growth of fruit bacterial populations appeared to be at least as fast as under atmospheric conditions (Soliva-Fortuny & Martín-Belloso, 2003b; Soliva-Fortuny *et al.*, 2004b; Oms-Oliu *et al.*, 2008b, 2008c). Low O_2 concentrations inhibit the growth of the aerobic microbiota but can also stimulate the proliferation of anaerobic psychrotrophic microorganisms. Too low O_2 concentrations inside packages of fresh-cut vegetables may pose a safety risk, as the growth of anaerobic foodborne pathogens might be allowed or even stimulated (Farber, 1991). Potential foodborne pathogens, such as *Yersinia enterocolitica*, *Aeromonas hydrophila*, *A. caviae* and *Listeria monocytogenes* have been isolated from packaged lettuce (Szabo *et al.*, 2000). Restrictive O_2 atmospheres have also been shown to stimulate the growth of *L. monocytogens* (Conway *et al.*, 2000; Corbo *et al.*, 2005), *E. coli* (Gunes & Hotchkiss, 2002) or *Clostridium botulinum* (Larson & Johnson, 1999). In addition, lactic acid bacteria can grow under moderate CO_2 environments (Al-Ati & Hotchkiss, 2002). Therefore, an appropriate combination of gas composition, package dimensions and permeability adapted to the respiration of the product is critical to reach a sustainable equilibrium of gas concentrations. This equilibrium must ensure that O_2 levels inside the packages are high enough to avoid the triggering of anaerobic fermentative processes (Martín-Belloso *et al.*, 2007).

Recently, some researchers have claimed that superatmospheric O_2 concentrations (≥70 kPa) can be an alternative to low O_2-modified atmospheres to prevent undesired anoxic respiration, inhibit the growth of naturally occurring spoilage microorganisms, and maintain fresh-like sensory quality of fresh-cut produce (Amanatidou *et al.*, 1999; Jacxsens *et al.*, 2001; Van der Steen *et al.*, 2002). Results by Allende *et al.* (2004) are consistent with these claims and show that high O_2 atmospheres (80–100 kPa) alleviated tissue injury, reduced microbial growth and were beneficial in maintaining quality of fresh-cut baby spinach (Allende *et al.*, 2004). However, reports on the effect of high O_2 concentrations on the growth of the aerobic microbiota on fresh-cut mixed salads were inconclusive (Allende *et al.*, 2002). Lactic acid bacteria and *Enterobacteriaceae* 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, whereas psychrotrophic bacteria and *L. monocytogenes* were not affected. Wszelaki & Mitcham (2000) found that 80–100 kPa O_2 inhibited the growth of *Botrytis cinerea* on strawberries. Consistently, an initial atmosphere of ≥70 kPa O_2 has been reported to retard the growth of moulds (Van der Steen *et al.*, 2002) and yeasts (Jacxsens *et al.*, 2003) on strawberries and raspberries. In fresh-cut pears, *Candida parapsilosis* survived on inoculated samples stored under 70 kPa O_2, whereas *Rhodotorula mucilaginosa* was shown to be sensitive to superatmospheric O_2 concentrations (Oms-Oliu *et al.*, 2008b). *Rhodotorula* yeast genera found in fresh-cut 'Piel de Sapo' melon and 'Nam Dokmai' mango cubes were also inhibited when exposed to high O_2 concentrations (Poubol & Izumi, 2005; Oms-Oliu *et al.*, 2008c). The growth of aerobic psychrophilic microorganisms on fresh-cut pear and melon was significantly reduced under 70 kPa O_2 and 2.5 kPa O_2 + 7 kPa CO_2 atmospheres in comparison to passive MAP (Table 1) Oms-Oliu *et al.* (2008b, 2008c). Consistently, Jacxsens *et al.* (2001) could not report differences in the growth of psychrotrophic microorganisms on chicory endives stored for 1 week under conventional atmospheres (3 kPa O_2 and 5 kPa CO_2) and superatmospheric O_2 concentrations (95 kPa O_2 and 5 kPa CO_2). Amanatidou *et al.* (1999) evaluated the potential of high O_2 concentrations to inhibit the growth of a number of microorganisms and pathogenic bacteria typically associated with minimally processed vegetables. They found a more pronounced inhibitory effect on bacterial growth when high O_2 concentrations (80 and 90 kPa) were combined with high CO_2 concentrations (10 and 20 kPa). According to these authors, high O_2 concentrations can generate reactive oxygen species (ROS) that damage vital cell components and thereby reduce microbial growth when oxidative stresses overwhelm cellular antioxidant protection systems. However, the sensitivity of different organisms to O_2 may greatly vary. Some of them could have developed strategies to avoid lethal damage, by inducing enzyme activities that decrease the accumulation of injurious ROS (Kader & Ben-Yehoshua, 2000).

Table 1 Growth of aerobic psychrophilic microorganisms and yeast and moulds on fresh-cut 'Flor de Invierno' pear and 'Piel de Sapo' melon stored under 2.5 kPa O_2 and 7 kPa CO_2, 70 kPa O_2 and passive modified atmosphere packaging over 14 days at 4 °C (*Source*: Oms-Oliu *et al.*, 2008b,c)

	2.5 kPa O_2 + 7 kPa CO_2				**Air**				**70 kPa O_2**			
	PS		**YM**		**PS**		**YM**		**PS**		**YM**	
Day	**Melon**	**Pear**	**Melon**	**Pear**	**Melon**	**Pear**	**Melon**	**Pear**	**Melon**	**Pear**	**Melon**	**Pear**
0	1.2a	2.1a	1.7a	3.2a	1.4a	2.3a	1.5a	3.2a	1.5a	2.1a	1.5a	3.2a
3	2.3b	2.8b	1.6a	3.5b	3.5b	3.6b	2.2b	3.6b	2.2b	2.6b	2.0b	3.1a
7	4.1c	3.9c	2.5b	3.5b	6.2c	4.6c	3.6c	3.4ab	4.2c	3.8c	2.3b	3.1a
10	5.9d	4.3d	2.8b	3.8c	7.3d	6.1d	4.1d	3.6b	6.8d	3.9c	2.7c	2.9a
14	7.8e	5.7e	2.9b	3.7c	7.9d	7.0e	4.7d	4.0c	7.6e	5.1d	2.7c	2.9a

Values within a column followed by the same small setter indicate that mean values are not significantly different by Duncan's multiple-range test ($P < 0.05$).

Pear wedges were dipped into *N*-acetylcysteine (0.75% w/v) and glutathione (0.75% w/v) solution. Aerobic psychrophilic microorganisms (PS); yeast and moulds (YM).

The use of edible coatings with antimicrobial properties or with incorporation of antimicrobial compounds is another potential alternative to enhance the safety of fresh-cut produce. Application of antimicrobial agents directly on the food surface may have limited benefits because the active substances are neutralised on contact with the surface or diffuse rapidly from the surface into the product (Min & Krochta, 2005). Antimicrobial edible films and coatings provide more inhibitory effects against spoilage and pathogenic bacteria by maintaining effective concentrations of the active compounds on the food surfaces (Gennadios & Kurth, 1997). In fact, edible films can be designed to slow down the diffusion of antimicrobial substances from the food surface (Dawson *et al.*, 2002; Sebti *et al.*, 2002). Several types of edible coatings have been used for extending shelf-life of fresh commodities. For instance, chitosan, a film-forming polysaccharide, has been widely used because of their ability of inhibiting the growth of many pathogenic bacteria and fungi (Romanazzi *et al.*, 2002). Chien *et al.* (2007) reported the effectiveness of chitosan in maintaining quality and extending shelf-life of sliced mango. Assis & Pessoa (2004) and Han *et al.* (2005) also proposed chitosan for extending the shelf-life of sliced apples and fresh strawberries respectively. Park *et al.* (2005) reported a reduction of 2.5 and 2 log CFU g^{-1} in the counts of *Cladosporium* sp. and *Rhizopus* sp., respectively, on strawberries coated with a chitosan-based edible film, just after the coating application. A reduction in the counts of aerobic and coliform microorganisms was also observed during storage. Eissa (2007) reported that the application of a chitosan-based coating on fresh-cut mushrooms contributes to the extension of their shelf-life, in maintaining quality and, to some extent, in controlling physiological decay. Durango *et al.* (2006) reported that the use of a coating containing chitosan and yam starch is a viable alternative for controlling microbiological growth on minimally processed carrots. Other edible coatings with antimicrobial properties have been used on fresh-cut produce. Recently, some authors have proposed the use of *Aloe vera* gels as antimicrobial coatings for fruits and vegetables, because of their proven antifungal activity (Martínez-Romero *et al.*, 2003; Jasso de Rodríguez *et al.*, 2005). Valverde *et al.* (2005) and Martínez-Romero *et al.* (2006) proposed *Aloe vera* gel-based edible coatings for preventing moisture loss, reducing texture decay and controlling respiratory rate of table grapes and sweet cherries, respectively, while reducing microbial proliferation. Lee *et al.* (2003) extended the shelf-life of refrigerated apple slices by more than 2 weeks, when using a coating containing carrageenan, ascorbic acid, citric acid and oxalic acid. Amanatidou *et al.* (2000) observed a reduction of at least 2 log CFU g^{-1} in the natural microbiota of minimally processed carrots when calcium chloride and citric acid treatments where combined with a sodium alginate edible coating prior to packaging under modified atmospheres.

Edible films and coatings carrying antimicrobial compounds provide an innovative way to improve the safety and shelf-life of food systems. The incorporation of antimicrobial agents into edible coatings is gaining importance as potential treatments to reduce the populations of deleterious microorganisms. Antimicrobials that are suitable for incorporation into edible films and coatings can be grouped into several categories, including organic acids (acetic, benzoic, lactic, propionic and sorbic), fatty acid esters (glyceryl monolaurate), polypeptides (lysozyme, peroxidase, lactoferrin and nisin), plant essential oils (cinnamon, oregano and lemongrass), nitrites and sulphites (Franssen & Krochta, 2003). Numerous studies have demonstrated that antimicrobial edible films can reduce bacterial levels on many products. Rojas-Graü *et al.* (2007a) reported the efficacy of alginate and gellan edible coatings with the antimicrobial effect of plant essential oils (lemongrass, oregano oil and vanillin) to prolong shelf-life of fresh-cut apples. In line with these studies, Raybaudi-Massilia *et al.* (2008a) observed that the addition of cinnamon, clove or lemongrass oils or their active compounds into an alginate-based coating increased its antimicrobial effect, reduced the population of *E. coli* O157:H7 by more than 4 log CFU g^{-1} and extended the microbiological shelf-life of 'Fuji' apples for at least 30 days. Raybaudi-Massilia *et al.* (2008b) also evaluated the ability of an alginate-based coating carrying malic acid and essential oils (cinnamon, palmarosa and lemongrass) to improve the shelf-life and safety of fresh-cut melon. According to their results, the incorporation of 0.3% palmarosa oil into the coating looks promising, since it was accepted by panelists, maintained the fruit quality parameters, inhibited the growth of the native microbiota and reduced the population of inoculated *Salmonella enteritidis*. Chen *et al.* (1999) developed a methylcellulose edible coating as carrier of benzoic acid to inhibit the growth of osmophilic yeasts on Taiwanese-style fruits (Ten-shing mei and Ching-shuan mei). Yeasts growth was inhibited when both fruits contained 50–100 μg benzoic acid per gram. Zhuang *et al.* (1996) showed that hydroxypropyl methylcellulose coatings containing ethanol were effective in inactivating *Salmonella* Montevideo on the surface of fresh tomatoes. Latter, Franssen & Krochta (2003) studied the effect of the incorporation of citric, sorbic and acetic acid into HPMC coatings cast on tomatoes and observed that the application of the coating alone resulted in a 2 log CFU g^{-1} reduction of *Salmonella* Montevideo, whereas the addition of 0.4% sorbic acid to the coating led to a further significant reduction. Likewise, García *et al.* (1998) reduced the microbial growth and extended the storage life of fresh strawberries using a starch-based coating containing potassium sorbate.

Preserving quality loss of fresh-cut fruits and vegetables

Processing operations can induce undesirable changes in colour and appearance during storage and marketing. Browning, degradation and oxidation of pigments, water loss, translucency, whitening or surface dehydration are likely to occur as a consequence of wounding.

Browning

Most strategies to control cut-edge browning have focused on theoretical approaches to modulate polyphenol oxidase (PPO) enzyme activities (Martinez & Whitaker, 1995). Low O_2 concentrations (0.25–5%) in combination with moderate levels of CO_2 (10–20%) have been used to maintain the visual appearance of several fresh-cut fruits such as peach (Palmer-Wright & Kader, 1997; Gorny *et al.*, 1999), kiwifruit (Agar *et al.*, 1999), mango (Rattanapanone *et al.*, 2001) and melon (Qi *et al.*, 1999; Bai *et al.*, 2001; Oms-Oliu *et al.*, 2007a). The destruction of fruit cellular compartmentation allows the oxidation of phenolic compounds by PPO, thus originating colourless quinones that later on polymerise forming melanins (Gil *et al.*, 2006). Because the O_2 is needed for browning reactions, MAP with low O_2 and high CO_2 levels can contribute positively to avoid browning in fresh-cut produce. However, low O_2 and elevated CO_2 atmospheres can not effectively inhibit browning of fresh-cut fruits and vegetables such as apple, banana, pear, potato or artichoke, because of their high phenolic content. MAP systems in combination with antioxidant treatments have been suggested to delay browning of fresh-cut apples (Rojas-Graü *et al.*, 2007b, 2008a), pears (Oms-Oliu *et al.*, 2008a), mangoes (González-Aguilar *et al.*, 2000) and bananas (Vilas-Boas & Kader, 2006). Among such compounds, ascorbic acid is very effective in inhibiting enzymatic browning, primarily because of its ability to reduce quinones to phenolic compounds before they undergo further reaction to form pigments (Iyengar & McEvil, 1992). Some post-cutting dips of *N*-acetyl-L-cysteine and/or reduced glutathione in combination with a 2.5 kPa O_2 + 7 kPa CO_2 atmosphere have been proved to effectively prevent browning of fresh-cut apples and pears (Rojas-Graü *et al.*, 2007b; Oms-Oliu *et al.*, 2008a). The appearance of browning in some leaf vegetables, e.g. lettuce, can be attributed to the wounding response, which may induce biosynthesis of phenolic compounds, which are substrates of PPO. It has been shown that high CO_2 atmospheres could inhibit the biosynthesis of phenolic compounds (Ke & Saltveit, 1989). However, an excessive restriction of the O_2 levels surrounding a fruit or vegetable in a modified atmosphere package could lead to internal decay and off-flavour formation. The application of high O_2 atmospheres has been suggested as an alternative to low O_2 and high CO_2 concentrations to inhibit enzymatic browning. Day (1996) hypothesised that high O_2 concentrations may cause substrate inhibition of PPO or alternatively, high levels of colourless quinones may cause feedback inhibition of the enzyme. Atmospheres containing 80 kPa O_2 and 20 kPa CO_2 have been recommended to inhibit PPO activity and to control the enzymatic browning in 'Iceberg' lettuce (Heimdal *et al.*, 1994). However, the results achieved in this field are often controversial. In some commodities, high O_2 concentrations alone cannot effectively prevent browning of fresh-cut produce. High O_2 partial pressures (100 kPa) have been shown to have some positive effects on colour only when combined with an adequate dip of ascorbic and citric acids (Limbo & Piergiovanni, 2006). Gorny *et al.* (2002) also found that low-O_2 (0.25 or 0.5 kPa), elevated-CO_2 (4, 10 or 20 kPa CO_2) or high-O_2 (40, 60 or 80 kPa) atmospheres alone did not effectively prevent surface browning of fresh-cut pear slices. Hence, the combined use of a dip of *N*-acetylcysteine and glutathione at 0.75% prior to packaging under 70 kPa O_2 effectively maintained the colour of fresh-cut pears during storage (Oms-Oliu *et al.*, 2008a).

Coatings based on edible compounds from several sources have been evaluated to maintain the visual appearance of fresh-cut fruits and vegetables. Brancoli & Barbosa-Cánovas (2000) decreased surface discolouration of apple slices by coating slices with maltodextrin, methylcellulose ascorbic acid and calcium chloride. Le Tien *et al.* (2001) achieved reduced browning rates in apple and potato slices coated with a combination of whey protein and carboxymethyl cellulose. Perez-Gago *et al.* (2003b, 2005) inhibited browning of apple slices by using composite coatings prepared from whey protein isolate or concentrate and beeswax or carnauba wax. Sonti *et al.* (2003) coated apple cubes with whey protein concentrate and whey protein isolate, obtaining a delay in browning and texture decay. With this same purpose, McHugh & Senesi (2000) proposed a coating made of a mixture of apple purée, pectin and vegetable oils. The addition of a lipid in the coating formulation remarkably restricted the gas transfer through the forming matrix and improved protection against the outer atmosphere. Shon & Haque (2007) observed a decrease in browning of cut apples and potatoes when using an edible coating containing sour whey flour. They also concluded that the coating effect was not at all beneficial in preventing browning of onion slices. Pen & Jiang (2003) reported that a chitosan edible coating applied on fresh-cut Chinese water chestnuts retarded the development of browning, maintained sensory quality and retained levels of total soluble solids, acidity and ascorbic acid in coated slices.

In addition, antioxidants can be added into the coating matrix to protect the cut surface against oxidative rancidity, degradation and enzymatic browning. Olivas *et al.* (2003) preserved fresh-cut pear wedges from surface browning by applying a methylcellulose-based coating containing ascorbic and citric acids. Similar results were obtained by Nisperos-Carriedo *et al.* (1992) who incorporated ascorbic acid into edible coatings to reduce enzymatic browning in whole and sliced mushrooms. Rojas-Graü *et al.* (2007c) and Tapia *et al.* (2005) applied alginate- and gellan-based coatings with the addition of cysteine, glutathione and ascorbic acid to fresh-cut apples and papayas, proving that such coatings are good carriers of antioxidant agents. Likewise, Perez-Gago *et al.* (2006) reduced browning of cut apples by using a whey protein concentrate-beeswax coating containing ascorbic acid, cysteine, or 4-hexylresorcinol. Lee *et al.* (2003) studied the effect of carrageenan and whey protein concentrate edible coatings in combination with anti-browning agents on fresh-cut apple slices and observed that the incorporation of ascorbic, citric and oxalic acids was advantageous in maintaining colour during 2 weeks.

Discolouration

Discolouration is a particular problem in vegetable products such as onion, garlic and leek, which can develop pink, red, green, bluegreen or blue tonalities as a consequence of cell disruption (Toivonen & Brummell, 2008). This kind of quality loss is more frequent in fresh produce than in fresh-cut commodities, but can develop in cases where cutting operations or handling lead to significant tissue damage (Howard *et al.*, 1994). For instance, pink discolouration, which is one of the major causes of quality loss in fresh-cut lettuce, was effectively controlled by flushing lettuce pieces with $\geq$2.5 kPa O_2 concentrations (Kim *et al.*, 2005). However, CO_2 accumulation (5–15 kPa) has been shown to cause the development of brown stain (Lipton, 1987), which appears first on the midrib surfaces of some leafy vegetables as a variable-sized sunken or yellowed area that can later become more delineated and brown (López-Gálvez *et al.*, 1996). In fresh-cut carrots or tomatoes, a whitish surface appearance has been attributed to an enzyme-stimulated reaction related to dehydration of surfaces or formation of the wound-induced lignin barrier (Cisneros-Zevallos *et al.*, 1995; Artés *et al.*, 1999). Neither 1% O_2 + 10% CO_2 nor 50% O_2 + 30% CO_2 atmospheres avoided the development of white discolouration on fresh-cut carrots after 12 days (Amanatidou *et al.*, 2000). These authors combined the use of an alginate-based coating with MAP to avoid this disorder. In green vegetables, the senescence process usually leads to a yellow colouration of the tissue, because of the degradation of chlorophylls and the formation of pheophytins. The maintenance of refrigeration temperatures and a high relative humidity, combined with atmospheres lowered in O_2 and moderately enriched in CO_2, are shown to delay chlorophylls degradation (Artés *et al.*, 2007). In shredded Galega kale, yellow discolouration because of chlorophylls degradation was much higher in air than under low O_2 atmospheres (1–3 kPa O_2) (Fonseca *et al.*, 2005).

Edible coatings may be effectively used to maintain the bright orange colour of fresh-cut carrots during storage, by reducing the incidence of ‘‘white blush’’ as consequence of the surface dehydration of cut surfaces (Bolin & Huxsoll, 1991). White discolouration in carrots can be avoided with the use of an appropriate edible coating. Howard & Dewi (1995) and Li & Barth (1998) highlighted the positive effect of an edible cellulose-based coating on the development of white surface discolouration in minimally processed carrots. Avena-

Bustillos *et al.* (1994a) and Mei *et al.* (2002) reported similar results when coating carrots with an emulsion of sodium caseinate/stearic acid emulsion and a xanthan gum solution respectively.

Translucency

Another factor with a great impact on the appearance of fresh-cut products is the change in homogeneity of the tissue that results in the development of translucency after processing. This physiological disorder, characterised by dark and glassy flesh, seems to be of particular importance in tomatoes (Artés *et al.*, 1999; Gil *et al.*, 2002; Lana *et al.*, 2006), melons (Aguayo *et al.*, 2004a; Saftner *et al.*, 2005), papayas (O'Connor-Shaw *et al.*, 1994) pears (Soliva-Fortuny *et al.*, 2002b) and pineapples (Chen & Paull, 2001; Montero-Calderón *et al.*, 2008). Development of translucency has been found to be the principal visual sign of deterioration in MAP-packaged fresh-cut 'Piel de Sapo' melon (Aguayo *et al.*, 2003, 2004a; Bai *et al.*, 2001, 2003). It has been reported that 15 kPa CO_2 reduced decay and translucency in 'Honeydew' and 'Cantaloupe' melon pieces (Portella & Cantwell, 1998). A 2.5 kPa O_2 + 7 kPa CO_2 atmosphere best maintained the visual quality of fresh-cut 'Piel de Sapo' melon compared with passive MAP and 70 kPa O_2 atmospheres for 2 weeks at 4 °C. Translucency of watersoaked areas is also the most frequent disorder in fresh-cut tomatoes stored under MAP (Gil *et al.*, 2002), even observed at low temperatures, and has been considered a chilling injury symptom (Hong & Gross, 2000). Fresh-cut pepper and cucumber were sensitive to chilling injury during storage at 5 °C (Kang & Lee, 1997). Fresh-cut tomato also exhibited slight symptoms of chilling injury when stored at 0 °C (Aguayo *et al.*, 2004b).

As far as we know, there is little information about the application of edible coatings to prevent translucency in fresh-cut produce. Recently, Oms-Oliu *et al.* (2008e) reported a substantial decrease in the whiteness index of fresh-cut melon coated with a gellan-based coating, which could be linked to an increase in translucency. In the same way, Sothornvit & Rodsamran (2006) observed an important increase in translucency of fresh-cut mango coated with a mango edible film, which was higher when cut fruits were stored at room temperature.

Softening

Many of the changes occurring in fresh-cut products are influenced by the effect of processing operations, which often result in a dramatic firmness loss. O_2 and CO_2 concentrations do not usually have much effect on the texture of fresh-cut fruits. Atmospheres of 2 kPa O_2, 4 kPa O_2, 4 kPa CO_2 and 10 kPa CO_2 did not affect the softening rate of fresh-cut banana slices stored for 3 days at 10 ºC. However, when low O_2 levels (2 and 4 kPa O_2) were combined with high CO_2 concentrations (5 and 10 kPa) softening was slightly enhanced (Vilas-Boas & Kader, 2006). Similarly, Gorny *et al.* (2002) reported that low O_2 (0.25 or 0.5 kPa) and elevated CO_2 (5, 10 or 20 kPa) atmospheres alone did not effectively prevent softening of fresh-cut pear slices. On the other hand, kiwifruit slices exhibited delayed softening when stored in an ethylene-free atmosphere of 2–4 kPa O_2 and/or 5–10 kPa CO_2 (Agar *et al.*, 1999). However, the use of dips, containing calcium salts, is usually more effective than MAP in preserving fresh-cut fruits from softening (Oms-Oliu *et al.*, 2007a). Oms-Oliu *et al.* (2008b) related firmness loss in fresh-cut pears to excessively low O_2 and high CO_2 concentrations. Soliva-Fortuny *et al.* (2002b, 2002c) showed that high CO_2 concentrations induce tissue breakdown and formation of important amounts of exudates, evidenced as droplets on the cellular surface and flooded intercellular spaces of fresh-cut pear and apple tissues (Soliva-Fortuny *et al.* (2002b, 2002c). The use of high O_2 levels to prevent anaerobic processes was shown to have a positive effect on maintaining firmness of fresh-cut 'Piel de Sapo' melon (Oms-Oliu *et al.*, 2008c).

Texture loss can also be prevented with the use of an appropriate edible coating. Del-Valle *et al.* (2005) improved the texture of strawberries using a cactus-mucilage edible coating. Maftoonazad & Ramaswamy (2004) observed improved firmness in avocados coated with methylcellulose-based edible coating during storage. Texture enhancers such as calcium chloride may be added to edible coatings to improve quality during storage of fresh-cut produce. Hence, the use of calcium chloride for crosslinking some polymers, could minimise softening phenomena. Rojas-Graü *et al.* (2007c) observed that apple wedges coated with alginate and gellan edible coatings maintained their initial firmness during refrigerated storage, corroborating that both coatings are good carriers of firming agents such as calcium chloride, which is used for crosslinking the polymers. Similar results were obtained by Lee *et al.* (2003) who indicated that incorporating 1% of calcium chloride within the whey protein concentrate coating formulation helped to maintain firmness of fresh-cut apples pieces. Olivas *et al.* (2007) maintained firmness of fresh-cut 'Gala' apples during storage by using an alginate-based coating after immersion into a calcium dip. Likewise, Han *et al.* (2004) reported that a chitosan-based coating containing calcium resulted in at least a 24% reduction in the drip loss of frozen-thawed raspberries and increased their firmness by about 25% in comparison with uncoated fruits.

The other major factors affecting texture are water loss and osmotic changes (Saladié *et al.*, 2007). Water loss can be greatly retarded by appropriate packaging

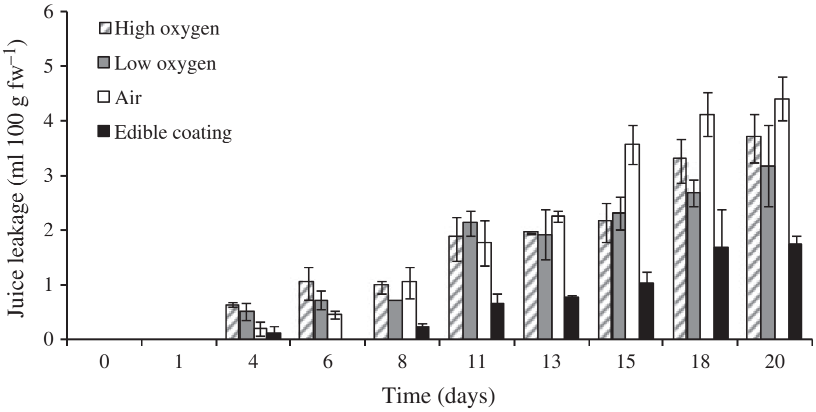

Figure 1 Effect of packaging conditions on juice leakage volume of fresh-cut pineapple stored at 5 °C. High O_2: 38–40%; low O_2: 10–12%; edible coating: alginate (2%). Data shown are mean ± standard deviation. Duncan's test at $P \leq 0.05$ (*Source*: Montero-Calderón *et al.*, 2008).

(Toivonen & Brummell, 2008). For instance, edible coatings have been extensively used to protect fresh-cut fruit from surface dehydration. The coating acts as a gas barrier around each fruit piece and creates a modified atmosphere inside each coated piece (Rojas-Graü & Martín-Belloso, 2008b). Avena-Bustillos *et al.* (1994b, 1997) reduced water loss of apples, celery sticks and zucchini using an emulsion containing calcium caseinate and an acetylated monoglyceride. Montero-Calderón *et al.* (2008) reported that the use of alginate coatings significantly improved shelf-life of fresh-cut pineapple, as reflected in higher juice retention in contrast with the substantial juice leakage observed in other evaluated packaging conditions (Fig. 1). McHugh & Senesi (2000) significantly reduced moisture loss of fresh-cut apples when applying wraps made from apple puree containing various concentrations of lipids. Similarly, Wong *et al.* (1994) reduced between 12 and 14 times water loss of apple slices by coating them with a cellulose/lipid bilayer edible film.

Keeping the nutritional composition and antioxidant potential of fresh-cut fruits and vegetables

Currently, there are a few works reporting the effect of MAP on nutritional composition and bioactive compounds of fresh-cut fruit and vegetables. Some of these works have reported the effect of MAP on the sugar and organic acids content of fresh-cut fruits and vegetables. Namely, Carlin *et al.* (1990) found good retention of D-sucrose in fresh-cut carrots stored under 10% to 40% CO_2 with 2% or 10% O_2. Depletion of D-sucrose concentrations was also significantly retarded when an alginate-based coating was combined with 20% or 30% CO_2 (Amanatidou *et al.*, 2000). However, González-Aguilar *et al.* (2000) did not find any significant effect of packaging conditions on the sugars and organic acids content of fresh-cut mangoes. On the other hand, an appropriate combination of MAP with refrigeration temperatures may help to maintain vitamin C concentrations by limiting ascorbic acid oxidation. Lamikanra *et al.* (2000) concluded that storage temperature is the most influential factor affecting the organic acids content in fresh-cut melon. Ascorbic acid of fresh-cut bell peppers stored under MAP for 15 days was better maintained at 5 °C than at 10 °C (González-Aguilar *et al.*, 2004). Furthermore, the O_2 availability in the package headspace has a dramatic effect on the vitamin C decrease throughout storage. According to Soliva-Fortuny & Martín-Belloso (2003b), the vitamin C content of fresh-cut pears was kept almost constant throughout storage in the absence of O_2. Barth *et al.* (1993) reported significantly higher amounts of ascorbic acid in broccoli stored in MAP than in unpacked broccoli. Ascorbic acid degradation of shredded Galega kale was also more pronounced in air than under hypoxic environments, although almost no differences were found between 1, 2 and 3 kPa O_2 atmospheres (Fonseca *et al.*, 2005). Consistently, the vitamin C content of fresh-cut spinach was found to be better maintained for 7 days under 6% O_2 + 14% CO_2 than in air. However, Gil *et al.* (1999) found that ascorbic acid was transformed to DHA, its concentration being higher in MAP-stored fresh-cut spinach than in air-stored samples after 1 week storage.

There is scarce information about the effects of high O_2 concentrations on the antioxidant content of fresh-cut produce. Results by different authors are somewhat contradictory. Day (2001) reported that high O_2 atmospheres did not result in a further decrease in ascorbic acid contents in prepared lettuce. However, it has been shown that the vitamin C content in fresh-cut pears packaged under 70 kPa O_2 is rapidly lost in comparison with a 2.5 kPa O_2 + 7 kPa CO_2 atmosphere (Oms-Oliu *et al.*, 2007b). Although the availability of O_2 is the main factor affecting vitamin C degradation, high CO_2 levels appeared to have a negative effect on the vitamin C content of fresh-cut pears and apples (Soliva-Fortuny & Martín-Belloso, 2003b; Soliva-Fortuny *et al.*, 2004b).

Agar *et al.* (1999) reported that high CO_2 levels stimulated ascorbic acid oxidation and inhibited the reduction of DHA to ascorbic acid. In fresh-cut pears stored under a 2.5 kPa O_2 + 7 kPa CO_2 atmosphere, a substantial loss of vitamin C after 1 week could be related to anoxic conditions reached inside the packages (Oms-Oliu *et al.*, 2008a). According to Tudela *et al.* (2002), high CO_2 levels in fresh-cut potatoes increased vitamin C loss by accelerating ascorbate peroxidase-catalysed oxidation processes. According to this claim, an important increase in peroxidase activity was shown during storage of fresh-cut 'Piel de Sapo' melon packaged under a 2.5 kPa O_2 + 7 kPa CO_2 atmosphere (Oms-Oliu *et al.*, 2008d).

The effect of MAP on other antioxidant constituents of fruits and vegetables has been also studied. Odriozola-Serrano *et al.* (2008) reported a good retention of lycopene in fresh-cut tomatoes stored under 5 kPa O_2 + 5 kPa CO_2 atmospheres for at least 14 days at 5 °C (Fig. 2). These authors indicated that lycopene synthesis because of ripening processes, together with low oxidation of carotenoids as a result of the low availability of O_2 in the package headspace, contributed to the higher levels of lycopene throughout storage. Such results were similar to those observed by Perkins-Veazie & Collins (2004) for fresh-cut watermelon stored under similar conditions for 7 days at 5 °C. In addition, no losses in the total flavonoids content of fresh-cut spinach were reported throughout storage regardless of the packaging atmosphere (Gil *et al.*, 1999). These results were consistent with those previously reported on Swiss chard (Gil *et al.*, 1998a). The stability of flavonoids contrasts with that of hydroxycinnamic acids and anthocyanins (Gil *et al.*, 1998b). High O_2 atmospheres induced the loss of certain phenolic compounds in fresh-cut prepared lettuce compared with air or low O_2-modified atmospheres (Day, 2001). Cocci *et al.* (2006) also reported that the O_2 availability in the package headspace of air-stored fresh-cut apples could have led to a stronger degradation of phenolic compounds on the cut surface, which is directly exposed to molecular O_2 from the package headspace. A substantial loss of chlorogenic acid was reported in fresh-cut pears stored under high O_2 atmospheres compared with low O_2 environments and was associated with enzymatic browning reactions (Oms-Oliu *et al.*, 2008a). According to these authors, the increase in other phenolic compounds such as epicatechin and quercetin in fresh-cut pears packaged under both passive modified atmospheres and high O_2 concentrations could be directly associated with a physiological response to stress conditions. Physiological stress may stimulate phenylalanine ammonia-lyase (PAL, EC 4.3.1.5) activity with a consequent further production of phenolic compounds, which in turn participate in subsequent tissue browning (Saltveit, 1997; Cantos *et al.*, 2002). Research has shown that wounding increases the phenolic content of carrots (Heredia & Cisneros-Zevallos, 2002), lettuce (Kang & Saltveit, 2002) and purple-flesh potatoes (Reyes & Cisneros-Zevallos, 2003). Wound response of fresh-cut vegetables can be reduced by MAP storage. Some researchers have indicated that the use of modified atmospheres could prevent accumulation of phenolic compounds in fresh-cut produce. Beltrán *et al.* (2005) reported a reduction of phenolic compounds in shredded iceberg lettuce stored under reduced O_2 and elevated CO_2 (4 kPa O_2 + 12 kPa CO_2). They indicated a high accumulation of phenolic compounds when fresh-cut lettuce was stored in air, whereas CO_2 levels of > 10 kPa led to a reduced phenolic content (Table 2). According to Mateos *et al.* (1993), exposure of fresh-cut lettuce to 20% CO_2 reduced total phenolic content

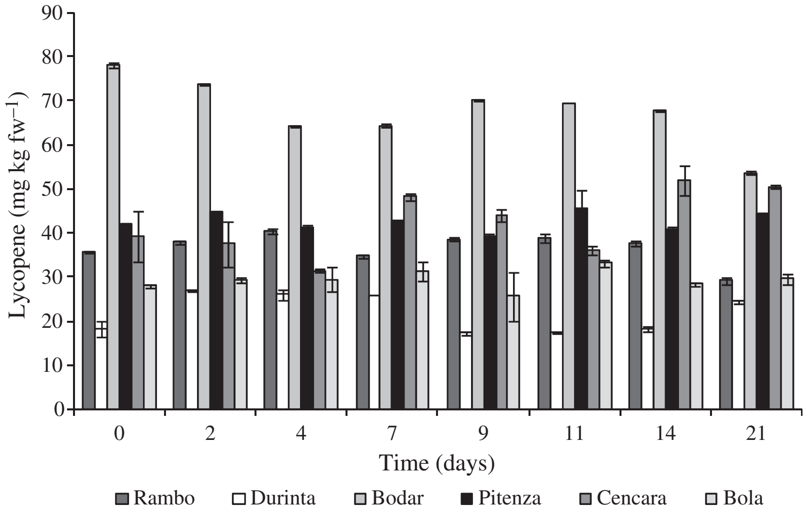

Figure 2 Changes in lycopene content of fresh-cut tomato from different cultivars stored under 5 kPa O_2 and 5 kPa CO_2 atmospheres for 21 days at 4 °C. Data shown are mean ± standard deviation. Least significant difference at $P \leq 0.05$ (*Source*: Odriozola-Serrano *et al.*, 2008).

Table 2 Changes on caffeic acid derivatives, flavonoids and total polyphenols of shredded iceberg lettuce stored in air and active modified atmosphere packaging (MAP) for 13 days at 4 °C (*Source*: Beltrán *et al.*, 2005)[a]

Storage days	Caffeic acid derivatives Air	Caffeic acid derivatives MAP	Flavonoids Air	Flavonoids MAP	Total polyphenols Air	Total polyphenols MAP
0	17.7		3.4		21.1	
5	22.2	23.5	4.8	2.4	26.9	25.9
9	19.0	8.7	3.3	3.1	22.3	11.8
13	17.5	8.5	3.6	3.4	21.1	11.8

[a]Mean values (three replicates) in milligram per 100 g of fresh weight. Fresh-cut lettuce was pretreated with a chlorine solution (80 mg L^{-1}). MAP: 4 kPa of O_2 + 12 kPa of CO_2 balanced with N_2.

because of a decrease in PAL activity as a result of the decrease in cytoplasmatic pH. Nevertheless, Oms-Oliu *et al.* (2008d) reported a higher production of phenolic compounds in fresh-cut melon stored under 2.5 kPa O_2 and 7 kPa CO_2 compared with 10 kPa O_2 + 7 kPa CO_2, air, 20 and 70 kPa O_2 atmospheres, which may be related to an enhanced oxidative stress induced by too-low O_2 and high CO_2 concentrations (Oms-Oliu *et al.*, 2008d).

Edible coatings offer the potential to improve the nutritional quality and antioxidant properties of fresh-cut produce. Chien *et al.* (2007) maintained the ascorbic acid content of sliced red pitayas (dragon-fruit) coated with low molecular weight chitosan. Li & Barth (1998) improved carotene retention on minimally processed carrots using a cellulose-based edible coating. Oms-Oliu *et al.* (2008f) maintained the vitamin C and total phenolic content in pear wedges coated with alginate, gellan or pectin edible coatings containing antioxidant agents, which contributed to maintain their antioxidant potential. It was also observed that the use of pectin or alginate coatings may contribute to reduce the wounding stress induced in fresh-cut ‘Piel de Sapo’ melon (Oms-Oliu *et al.*, 2008e). Serrano *et al.* (2006) maintained total phenolics, ascorbic acid and high retention of total antioxidant activity in table grape coated with *Aloe vera* gel coatings.

Edible coatings are also an excellent vehicle to enhance the nutritional value of fruits and vegetables by carrying basic nutrients that are lacking or present in low amounts in fruits and vegetables (Lin & Zhao, 2007). Despite the growing interest in incorporating nutraceutical compounds into food products, few studies have been reported suggesting the integration of bioactive ingredients into edible films or coatings to improve their functional properties. The concentration of nutrients added to the coatings must be carefully studied to know the effects on their basic functionality, namely on their barrier and mechanical properties.

Several researchers have endeavoured to incorporate minerals, vitamins and fatty acids into edible film and coating formulations to enhance the nutritional value of some fruits and vegetables. Tapia *et al.* (2008) formulated alginate and gellan-based edible coatings containing ascorbic acid for fresh-cut papaya pieces. They observed that alginate coatings appeared to perform better on ascorbic acid retention, probably because of slightly better gas barrier properties. Authors also reported that the incorporation of ascorbic acid to the coatings resulted in a substantial increase in the ascorbic acid content of the fresh-cut product, thus helping to preserve the naturally occurring amounts of this compound throughout storage. Similar results have been obtained by Ayranci & Tunc (2004) who reported that antioxidants such as citric or ascorbic acids, incorporated as an additive into a methylcellulose coating, extensively reduced ascorbic acid losses in whole apricot and peppers. Han *et al.* (2004) incorporated calcium and vitamin E to chitosan-based coatings to improve storability and nutritional properties of fresh and frozen strawberries and red raspberries. Their results demonstrate the capability of chitosan-based coatings to hold high concentrations of calcium or vitamin E, thus increasing significantly the content of these nutrients in both fresh and frozen fruits. For one serving (100 g), coated fruits contained about 34–59 mg of calcium and 1.7–7.7 mg of vitamin E, depending on the type of fruit and the time of storage, whereas uncoated fruits contained only 19–21 mg of calcium and 0.25–1.15 mg of vitamin E. Similarly, Hernández-Muñoz *et al.* (2006) observed that chitosan-coated strawberries retained more calcium (3079 g kg^{-1} dry matter) than strawberries dipped into calcium solutions (2340 g kg^{-1}). The addition of 1% calcium gluconate to the chitosan coating formulation (1.5% in 0.5% acetic acid) did not further extend the shelf-life of strawberries. Mei *et al.* (2002) developed xanthan gum coatings containing high concentrations of calcium and vitamin E (5% Gluconal Cal® and 0.2% α-tocopheryl acetate) with the purpose of enhancing nutritional and sensory qualities of fresh baby carrots. The results of this study showed that calcium and vitamin E contents in the coated samples increased from 2.6% to 6.6% and from 0 to about 67% of the Dietary Reference Intake values per serving (85 g) respectively, without affecting the carrots fresh aroma and flavour, sweetness, crispness and β-carotene levels. Because peeled baby carrots are a poor source of calcium and vitamin E, the incorporation of both into an edible coating formulation can be excellent system for enhancing the nutritional quality of this type of product. On the other hand, the addition of probiotics to obtain functional edible films and coatings has been scarcely studied. Tapia *et al.* (2007) developed the first edible films for probiotic coatings on fresh-cut apple and papaya, observing that both fruits were successfully coated with alginate or gellan film-forming solutions containing viable bifidobacteria. In fact, values higher than 10^6 cfu g^{-1} *Bifidobacterium lactis Bb*-12 were maintained for 10 days during refrigerated storage of both papaya and apple pieces. According to Samona & Robinson (1991) the count of viable bifidobacteria at the time of consumption should be of at least 10^6 cfu g^{-1} to confer health benefits to the product. This work represents a promising advance in the search for new applications of edible films and coatings as carriers of diverse food additives, and opens new possibilities for the development of probiotic products.

Effects on flavour of fresh-cut fruits and vegetables: a possible drawback?

Modified atmosphere packaging systems can severely modify the fruit volatiles profile. Fresh-cut fruits and vegetables can develop undesirable off-odours under low O_2 and elevated CO_2 atmospheres (Soliva-Fortuny *et al.*, 2002a, 2004a; Rojas-Graü *et al.*, 2007b; Oms-Oliu *et al.*, 2007a, 2007b). The beneficial effect of MAP can be attributed to a decrease of the overall metabolic activity of plant tissues. However, if O_2 partial pressure in MAP decreases below the fermentation threshold limit, the tissue will initiate anaerobic respiration, with the corresponding production of off-flavours and off-odours (Oms-Oliu *et al.*, 2007b). Bett *et al.* (2001) studied the influence of passive MAP on the flavour profile of fresh-cut 'Gala' apples. Their results indicate that overall flavour increased during the first few days after processing and then dramatically declined establishing a period of marketability of 9 days. Kim *et al.* (2005) found that fresh-cut lettuce packaged in films with lower O_2 transmission rate developed stronger off-odours and more atmosphere modification than corresponding samples packages with higher O_2 transmission rate. Thus, perforated and micro-perforated polymeric packages reduce off-odour formation (Izumi *et al.*, 1996). High O_2 atmospheres have been also used to prevent anaerobic conditions and reduce production of fermentative metabolites (Day, 1996). However, ethanol accumulation throughout storage was detected in fresh-cut melon and pears packaged under 70 kPa O_2 (Oms-Oliu *et al.*, 2008b, 2008c), which was attributed to a stress response caused by the highly oxidative environment, together with the accumulation of carbon dioxide into the packages. The most accepted explanation for O_2 toxicity is the formation of superoxide radicals (O_2^-), which are destructive to cell metabolism (Fridovitch, 1975). According to Wszelaki & Mitcham (2000), the volatiles content (acetaldehyde, ethanol and ethyl acetate) of strawberry fruits stored under high O_2 treatments ($\geq$60 kPa) for 14 days substantially increased compared with that observed in air-stored fruit.

Edible coatings are used as a protective barrier to reduce respiration and transpiration rates through the fruits surface. However, although reduction of gas transfer from the fruit to the environment is desirable, extremely impermeable coatings may induce anaerobic conditions that can lead to a decrease in the production of characteristic fruit aroma volatile compounds (Mattheis & Fellman, 2000; Perez-Gago *et al.*, 2003a). Martínez-Romero *et al.* (2006) maintained sweet cherries coated with an Aloe vera-based coating without any detrimental effect on taste, aroma or flavours during storage.

On the other hand, it is important to highlight that many compounds used in the development of edible films and coatings, including edible matrixes, plasticisers and other active ingredients, can affect the taste and odour of coated products. These compounds have their own characteristic flavour and colour, and interaction between ingredients may generate some changes in the sensory profile. For instance, the use of chitosan-based coatings may generate slight flavour modifications because of its typical astringent/bitter taste. Although, Han *et al.* (2005) reported that the application of a chitosan-based coating resulted in no perception of astringency in fresh strawberries. In the same way, Chien *et al.* (2007) observed that a chitosan coating did not influence the natural taste of sliced red pitayas. Their results contrast with those reported by Vargas *et al.* (2006), who observed that chitosan led to a significant decrease in the aroma and flavour of strawberries, especially when high concentrations of oleic acid were used with the purpose of increasing the moisture barrier properties.

On the other hand, the incorporation of certain anti-browning or antimicrobial agents into edible coating formulations may have detrimental consequences on the flavour of the coated product. Rojas-Graü *et al.* (2007a) detected a residual aromatic herbal taste in fresh-cut apples coated with an apple puree-alginate film containing a low concentration of oregano oil, which had been added with an antimicrobial purpose. Some authors have indicated that high concentrations of sulphur-containing compounds such as *N*-acetylcysteine and glutathione may produce an unpleasant odour in fruits and vegetables (Iyidogan & Bayindirli, 2004; Richard *et al.*, 1992; Rojas-Graü *et al.*, 2006). In this regard, Perez-Gago *et al.* (2006) detected a smell of sulphur compounds in fresh-cut apples coated with a whey protein concentrate/beeswax formulation containing cysteine as an antioxidant agent.

Final remarks

Traditional MAP atmospheres are rarely sufficient to ensure safety and achieve high-quality products. Most currently used MAP systems alone do not effectively prevent wounding-induced browning and deteriorative processes, which are triggered when tissue integrity is damaged as a consequence of minimal processing operations. In addition, polymeric films used in MAP have some limitations because of their structure and permeation characteristics. They may promote water loss, which results in texture changes, translucency and/or surface dehydration, or, oppositely, they can even increase the formation of water condensates that favour microbiological proliferation. Furthermore, combination of MAP systems with edible coatings can be a feasible way of improving microbial stability and quality of fresh-cut fruits and vegetables, thus extending their shelf-life. In addition, edible films and coatings offer opportunities to reduce the need for synthetic packaging materials and improve their recyclability. A new generation of edible coatings is being currently developed, allowing the incorporation and/or controlled release of active compounds using nanotechnological solutions. Nowadays, nanotechnologies are being used to enhance the nutritional aspects of food by means of nanoscale additives and nutrients and nanosised delivery systems for bioactive compounds. Incorporation of active ingredients into edible coatings for fresh-cut fruits is feasible through microencapsulation solutions or the use of novel multilayer systems (nanolaminates). These nanolaminate coatings could include various functional agents such as antimicrobials, anti-browning agents, antioxidants, enzymes, flavourings and colourants, to increase shelf-life and maintain quality of the coated foods.

Acknowledgments

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