Section 5p

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Review

Edible coatings to incorporate active ingredients to fresh-cut fruits: a review

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Edible films and coatings are applied on many products to control moisture transfer, gas exchange or oxidation processes. One major advantage of using edible films and coatings is that several active ingredients can be incorporated into the polymer matrix and consumed with the food, thus enhancing safety or even nutritional and sensory attributes. This review discusses the use of edible coatings as carriers of functional ingredients on fresh-cut fruits, including the recent advances in the incorporation of antimicrobials, antibrownings, texture enhancers and nutraceuticals to improve quality and functionality of fresh-cut fruits. Sensory implications, regulatory status and future trends are also reviewed.

Introduction

Consumers usually judge the quality of fresh-cut fruit on the basis of appearance and freshness at the time of purchase (Kader, 2002). However, minimal processing operations alter the integrity of fruits bringing about negative effects on product quality such as browning, off-flavour development and texture breakdown. Also, the presence of microorganisms on the fruit surface may compromise the safety of fresh-cut fruit. The search for methods that aim to retard these negative effects is of great interest to all the stakeholders involved in the production and distribution of fresh-cut fruits. Traditionally, edible coatings have been used in the fresh-cut industry as a strategy to reduce the deleterious effects that minimal processing imposes on intact vegetable tissues. Edible coatings may contribute to extend the shelf-life of fresh-cut fruits by reducing moisture and solute migration, gas exchange, respiration and oxidative reaction rates, as well as by reducing or even suppressing physiological disorders (Baldwin, Nisperos, Chen, & Hagenmaier, 1996; Park, 1999). Nevertheless, edible films and coatings have been recognized for more innovative uses beyond their current uses. Edible coatings have a high potential to carry active ingredients such as antibrowning agents, colorants, flavours, nutrients, spices and antimicrobial compounds that can extend product shelf-life and reduce the risk of pathogen growth on food surfaces (Pranoto, Salokhe, & Rakshit, 2005). However, specific studies on fresh-cut fruits are rather limited and their industrial implementation is still incipient. In this sense, the main goal of this article is to review and update the information available on the use of edible coatings as carriers of food ingredients (antimicrobials, antibrownings, texture enhancers and nutraceuticals) to improve the safety, quality and functionality of fresh-cut fruits. Finally, an update of the sensory implications, regulatory status and future perspectives is provided. In this review, an attempt is made to identify the state of the art of this relevant topic which is considered as an innovative food preservation approach.

Potential active ingredients to be carried by edible coatings

Applications of some edible films and coatings as support of active ingredients for improving the quality and extending the shelf-life of fresh-cut fruits are summarized in Table 1 and discussed in the following section.

Antimicrobial agents

Fresh-cut fruits are more perishable than their corresponding whole uncut commodities due to wounding during preparation (Brecht, 1995). The physical and chemical barrier provided by the epidermis, which prevents the development of microbes on the fruit surface, is removed during processing (Martín-Belloso, Soliva-Fortuny, & Oms-Oliu, 2006). Dipping of aqueous solutions containing antimicrobials is the most practical way to extend the microbial stability of fresh-cut fruits. However, application

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Table 1. Application of edible coatings containing functional ingredients for improving the quality and extending the shelf-life of fresh-cut fruits.

Functional ingredients	Amount incorporate (%)	Coating materials	Fresh-cut fruits	Effect	References
Antimicrobials					
Potassium sorbate	0.2 (w/v)	Starch	Strawberries	Inhibited the growth of mesophilic aerobes, mold and yeast counts.	Garcia *et al.* (2001)
Citric acid	Not reported				
Lemongrass	1.0–1.5 (v/v)	Alginate, apple puree	Apples	Reduced native psychrophilic aerobes, moulds and yeast. Lemongrass (1.0–1.5%) and oregano (0.5%) reduced >4 log CFU/g of inoculated *Listeria innocua*.	Rojas-Graü, Raybaudi-Massilia, *et al.* (2007)
Oregano	0.1–0.5 (v/v)				
Vanillin	0.3–0.6 (v/v)				
Cinnamon	0.7 (v/v)	Alginate	Apples	Inhibited native microbiota during 30 days and reduced >4 log CFU/g of *E. coli* O157:H7 in the first week of storage.	Raybaudi-Massilia, Rojas-Graü, *et al.* (2008)
Clove	0.7 (v/v)				
Lemongrass	0.7 (v/v)				
Cinnamaldehyde	0.5 (v/v)				
Eugenol	0.5 (v/v)				
Citral	0.5 (v/v)				
Malic acid	2.5 (w/v)	Alginate	Melon	Inhibited the microbial growth and reduced up to 3.1 log CFU/g after 30 days of storage.	Raybaudi-Massilia, Mosqueda-Melgar, *et al.* (2008)
Cinnamon	0.7 (v/v)				
Palmarosa	0.7 (v/v)				
Lemongrass	0.7 (v/v)				
Chitosan	0.1–2.0 (w/v)	Methylcellulose	Melon	Reduced the growth of mesophilic aerobes, psychrotrophs, yeast and moulds and maintained the growth of *E. coli*, *Staphylococcus aureus*, *Salmonella* sp. <10 CFU/g	Krasaekoopt and Mabumrung (2008)
Antioxidants					
Ascorbic acid	1.0 (w/v)	Carrageenan, whey protein concentrate	Apples	Maintained the original colour during storage without changes in sensory properties.	Lee *et al.* (2003)
Citric acid	1.0 (w/v)				
Oxalic acid	0.05 (w/v)				
Ascorbic acid	0.5–1.0 (w/v)	Whey protein concentrate–beeswax	Apples	Reduced surface browning. 4-Hexylresorcinol showed the least effectiveness at reducing browning.	Perez-Gago *et al.* (2006)
Cysteine	0.1–0.5 (w/v)				
4-Hexylresorcinol	0.005–0.02 (w/v)				
Ascorbic acid	Not reported	Maltodextrin, methylcellulose	Apples	Reduced surface discoloration.	Brancoli and Barbosa-Cánovas (2000)
Ascorbic acid	0.5 (w/v)	Carboxymethyl cellulose, soy protein	Apples	Delayed browning more effectively when was applied in an edible coating than in an aqueous solution.	Baldwin *et al.* (1996)
Ascorbic acid	0.5 (w/v)	Pectin, apple puree	Apples	Preserved colour for 12 days at 5 °C.	McHugh and Senesi (2000)
Citric acid	0.5 (w/v)				
N-acetylcysteine	1.0 (w/v)	Alginate, gellan	Apples	Maintained the original colour by 2 weeks of storage.	Rojas-Graü, Tapia, *et al.* (2008)
N-acetylcysteine	1.0–2.0 (w/v)	Alginate, gellan	Apples	Prevented surface discoloration.	Rojas-Graü, Tapia, *et al.* (2007)
Glutathione	1.0–2.0 (w/v)				
Ascorbic acid	1.0 (w/v)	Methylcellulose	Pear	Prolonged shelf-life by retarding browning.	Olivas *et al.* (2003)
N-acetylcysteine	0.75 (w/v)	Alginate, gellan	Pear	Prevented browning for 2 weeks.	Oms-Oliu *et al.* (2008a)
Glutathione	0.75 (w/v)				
Texture enhancers					
Calcium chloride	2.0 (w/v)	Alginate, gellan	Apples	Maintained firmness by 2 weeks.	Rojas-Graü, Tapia, *et al.* (2008)
Calcium chloride	1.0 (w/v)	Whey protein concentrate	Apples	Inhibited the loss of firmness.	Lee *et al.* (2003)
Calcium chloride	10.0 (w/v)	Alginate	Apples	Maintained firmness during storage.	Olivas *et al.* (2007)
Calcium chloride	2.0 (w/v)	Alginate	Pineapple	Helped to retain internal liquids.	Montero-Calderón, Rojas-Graü, and Martin-Belloso (2008)

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Table 1 (*continued*)

Functional ingredients	**Amount incorporate (%)**	**Coating materials**	**Fresh-cut fruits**	**Effect**	**References**
Calcium chloride	2.0 (w/v)	Alginate, gellan, pectin	Melon	Helped to maintain fruit firmness during 15 days.	Oms-Oliu *et al.* (2008b)
Calcium lactate	2.0 (w/v)	Alginate	Melon	Maintained firmness in coated samples.	Raybaudi-Massilia, Mosqueda-Melgar, *et al.* (2008)
Calcium gluconate	1.0 (w/v)	Chitosan	Strawberries	Did not improve the firmness retention.	Hernández-Muñoz *et al.* (2008)
Calcium gluconate	5.0 (w/v)	Chitosan	Raspberries	Helped to maintain textural quality.	Han *et al.* (2004)
Calcium lactate	2.0 (w/v)	Alginate	Apples	Maintained the initial texture by more than 30 days.	Raybaudi-Massilia, Rojas-Graü, *et al.* (2008)
Nutraceuticals					
Calcium gluconate	5.0 (w/v)	Chitosan	Strawberries, raspberries	Increased the content of these nutrients in both fruits.	Han *et al.* (2004)
Vitamin E	0.2 (w/v)				
Ascorbic acid	1.0 (w/v)	Alginate	Papaya	Preserved the natural ascorbic acid content of the fruit.	Tapia *et al.* (2008)
Calcium gluconate	1.0 (w/v)	Chitosan	Strawberries	Increased nutritional value of the strawberries.	Hernández-Muñoz *et al.* (2008)
Bifidobacterium lactis	2.0 (w/v)	Alginate, gellan	Apple, papaya	Maintained values of *B. lactis* $>10^6$ CFU/g by 10 days during storage.	Tapia *et al.* (2007)

of antimicrobial agents directly on the food surface may have limited benefits because the active substances are rapidly neutralized or diffuse from the surface into the food product, thus limiting the effect of the antimicrobial compound (Min & Krochta, 2005). In this sense, antimicrobial edible films and coatings may provide increased inhibitory effects against spoilage and pathogenic bacteria by maintaining effective concentrations of the active compounds on the food surfaces (Gennadios & Kurth, 1997).

There are several categories of antimicrobials that can be potentially incorporated into edible films and coatings, including organic acids (acetic, benzoic, lactic, propionic, sorbic), fatty acid esters (glyceryl monolaurate), polypeptides (lysozyme, peroxidase, lactoferrin, nisin), plant essential oils (EOs) (cinnamon, oregano, lemongrass), nitrites and sulphites, among others (Franssen & Krochta, 2003). While their actual mechanisms of action are not well understood, the antibacterial effectiveness of organic acids is thought to stem from the fact that protonated acids are membrane soluble, and can enter the cytoplasm by simple diffusion (Ricke, 2003). Lee, Park, Lee, and Choi (2003) reported that apple slices coated with carrageenan containing ascorbic acid, citric acid, and oxalic acid extended shelf-life by 2 weeks when packaged in trays at 3 °C. Garcia, Martino, and Zaritzky (2001) reduced microbial growth below 6 log CFU/g at the maximum storage time assayed (28 days) and extended storage life of fresh strawberries using a starch-based coating containing potassium sorbate and citric acid. However, in the last years there has been a considerable pressure by consumers to reduce or eliminate chemically synthesized additives in foods.

Essential oils outstand as an alternative to chemical preservatives and their use in foods meets the demands of consumers for natural products, as reviewed by Burt (2004). The activity of EOs and their active constituents have been widely studied against many microorganisms, including several pathogens (Delaquis, Stanich, Girard, & Mazza, 2002; Karatzas, Bennik, Smid, & Kets, 2000; Vázquez, Fente, Franco, Vázquez, & Cepeda, 2001), although their mechanism of action has not been studied in great detail (Lambert, Skandamis, Coote, & Nychas, 2001). In this sense, Burt (2004) reported that hydrophobicity is an important characteristic of EOs, which makes them able to pass through cell membranes and enter mitochondria, disturbing the internal structures and rendering the membranes more permeable.

The application of EOs in foods is yet limited due to their impact on organoleptic food properties, variability of their composition, and their variable activity in foods due to interactions with food components (Gutierrez, Barry-Ryan, & Bourke, 2008). Nevertheless, the use of EOs to control microbial growth in foods has been proposed for several products including fresh-cut fruits and vegetables. For instance, Roller and Seedhar (2002) observed that carvacrol and cinnamaldehyde were very effective at reducing the natural flora on kiwifruit when used at

$0.15\ \mu l\ ml^{-1}$ in dipping solution, but less effective on honeydew melon, probably due to the difference in pH between fruits. In addition, Min and Krochta (2005) indicated that the application of antimicrobial agents directly on the food surface may have limited benefits because the active substances could be neutralized in direct contact with the product.

Many factors must be considered in developing an antimicrobial edible coating, including the properties of the food, the coating and the effectiveness of the antimicrobial agents incorporated into the coating. Because of this, basic preliminary studies must be carried out to evaluate the antimicrobial effect of a compound incorporated into an edible film matrix before it is applied on the surface of a real food system. Rojas-Graü, Avena-Bustillos, *et al.* (2006) and Rojas-Graü, Olsen, *et al.* (2007) have studied the effects of oregano, cinnamon, and lemongrass oils and their active compounds (carvacrol, cinnamaldehyde and citral) incorporated into apple puree and alginate—apple puree edible films against *Escherichia coli* O157:H7. The effectiveness of these antimicrobial agents was evaluated using an agar diffusion method, which is commonly used to evaluate the antimicrobial activity of films. In these works, oregano oil or their active compound, carvacrol, showed the bigger effectiveness against *E. coli* O157:H7, as reflected in greater surrounding clear zone (Fig. 1). Both studies demonstrated that films made from fruits have the potential to be used as carriers of antimicrobial compounds and constitute a feasible approach for incorporating EOs onto fresh food surfaces.

In line with these preliminary studies, Rojas-Graü, Raybaudi-Massilia, *et al.* (2007) combined the efficacy of alginate and gellan edible coatings with the antimicrobial effect of EOs (lemongrass, oregano oil and vanillin) to prolong shelf-life of fresh-cut apples. They observed a 4 log reduction the inoculated population of *Listeria innocua* in fresh-cut apple when lemongrass or oregano oils were incorporated into an apple puree—alginate edible coating. Raybaudi-Massilia, Rojas-Graü, Mosqueda-Melgar, and Martín-Belloso (2008) indicated that the addition of cinnamon, clove or lemongrass oils at 0.7% (v/v) or their active compounds (citral, cinnamaldehyde and eugenol) at 0.5% (v/v) into an alginate-based coating increased their antimicrobial effect, reduced the population of *E. coli* O157:H7 by more than 4 log CFU/g and extended the microbiological shelf-life of Fuji apples for at least 30 days. However, they observed that lemongrass and citral acted faster against *E. coli* O157:H7 at day 0 than the other compounds, suggesting that both EOs entered into the bacteria more easily (higher rate of diffusion), causing irreversible damage and cell death. Later, the same authors evaluated the effect of an alginate coating as carrier of malic acid and EOs (cinnamon, palmarosa and lemongrass) to improve the shelf-life and safety of fresh-cut melon. According to their results, the incorporation of 0.3% v/v palmarosa oil into the coating looks promising, since it inhibited growth of the native microbiota and reduced the population of inoculated *Salmonella enteritidis* (Raybaudi-Massilia, Mosqueda-Melgar, & Martín-Belloso, 2008).

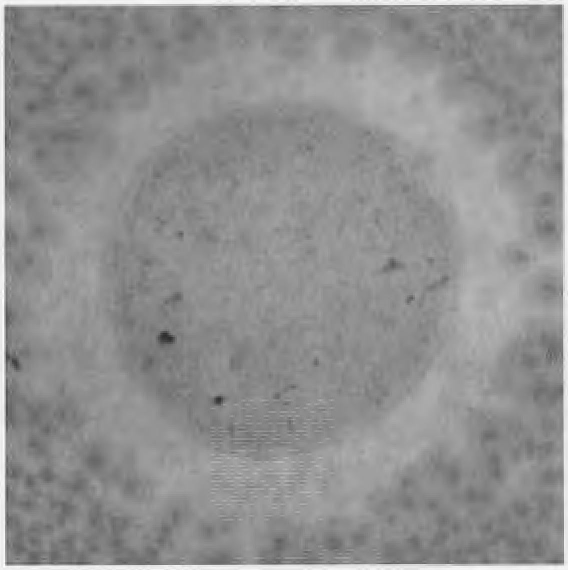

Fig. 1. Inhibitory zone (*E. coli* O157:H7 colony-free perimeter) of alginate—apple puree edible film containing 0.1% v/v carvacrol oil.

Despite the good results achieved so far with the incorporation of EOs into edible films and coatings, the major drawback is their strong flavour which could change the original taste of foods. The implications on sensory characteristics of fresh-cut fruits will be revised in another section.

Antibrowning agents

Fresh-cut fruits processing operations can induce undesirable changes in colour and appearance of these products during storage and marketing. The phenomenon is usually caused by the enzyme polyphenol oxidase (PPO), which in presence of oxygen, converts phenolic compounds into dark colored pigments (Zawistowski, Biliaderis, & Eskin, 1991). Application of antioxidant treatments as dipping after peeling and/or cutting is the most common way to control browning of fresh-cut fruits.

Ascorbic acid is the most extensively used to avoid enzymatic browning of fruit due to the reduction of the *o*-quinones, generated by the action of the PPO enzymes, back to the phenolic substrates (McEvily, Iyengar, & Otwell, 1992). However, ascorbic acid is oxidized to dehydroascorbic acid after a certain time (Luo & Barbosa-Canovas, 1997; Rojas-Graü, Soliva-Fortuny, & Martín-Belloso, 2008), thus allowing the accumulation of *o*-quinones (Sapers, 1993).

As an alternative to ascorbic acid, several thiol-containing compounds such as cysteine, N-acetylcysteine, and reduced glutathione have been investigated as inhibitors of enzymatic browning (Gorny, Hess-Pierce, Cifuentes, &

Kader, 2002; Son, Moon, & Lee, 2001). These compounds react with quinones formed during the initial phase of enzymatic browning reactions to yield colorless addition products or to reduce *o*-quinones to *o*-diphenols (Richard, Goupy, & Nicolas, 1992). Furthermore, carboxylic acids (citric acid and oxalic acid) have been also suggested as effective antioxidant agents in fresh-cut fruits (Jiang, Pen, & Li, 2004; Pizzocaro, Torregiani, & Gilardi, 1993; Son *et al.*, 2001).

The incorporation of antibrowning agents into edible coatings applied on fresh-cut fruits has been studied by various authors. Perez-Gago, Serra, and del Rio (2006) reported a substantial reduction in browning of fresh-cut apples when using a whey protein concentrate–beeswax coating containing ascorbic acid, cysteine or 4-hexylresorcinol. They observed a significant improvement of the efficiency of antioxidant agents when incorporated into the coating formulation, being the most effective treatment with 0.5% cysteine (Fig. 2). Brancoli and Barbosa-Cánovas (2000) decreased surface discoloration of apple slices with maltodextrin and methylcellulose coatings including ascorbic acid. Baldwin *et al.* (1996) found that a carboxymethyl cellulose-based coating with addition of several antioxidants, including ascorbic acid, reduced browning and retarded water loss of cut apple more effectively than an aqueous solution of antioxidants. Rojas-Graü, Tapia, Rodríguez, Carmona, and Martín-Belloso (2007) proved that alginate (2% w/v) and gellan (0.5% w/v) edible coatings can be used to deliver antioxidant agents such as cysteine or glutathione to the surface of fresh-cut apples. Indeed, Rojas-Graü, Tapia, and Martín-Belloso (2008) observed that both alginate and gellan edible coatings containing N-acetylcysteine prevented apple wedges from browning during 21 days of storage (Fig. 3). McHugh and Senesi (2000) delayed browning of fresh-cut apples coated with a mixture of apple purée, pectin and vegetable oils containing ascorbic acid (1.5% w/w) and citric acid (1.5% w/w). Olivas, Rodriguez, and Barbosa-Cánovas (2003) preserved fresh-cut "Anjou" pear wedges of surface browning using a methylcellulose-based coating containing ascorbic acid and citric acid. Similar results were obtained by Lee *et al.* (2003), who studied the effect of carrageenan and whey protein concentrate edible coatings in combination with antibrowning 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. Oms-Oliu, Soliva-Fortuny, and Martín-Belloso (2008a) observed that the incorporation of N-acetylcysteine (0.75% w/v) and glutathione (0.75% w/v) into gellan, alginate or pectin formulations helped to control enzymatic browning of fresh-cut "Flor de Invierno" pears, maintaining the initial h° values during 2 weeks of storage.

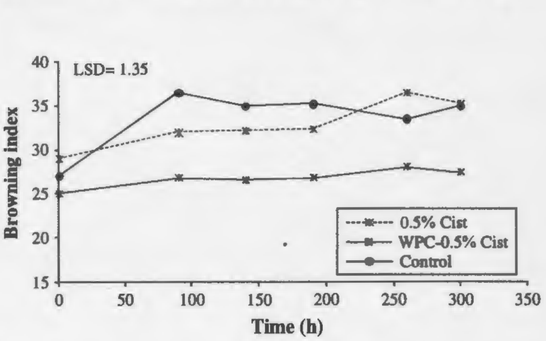

Fig. 2. Effect of cysteine incorporation on whey protein concentrate (WPC) edible coating or in dipping solution on browning index of fresh-cut apples (adapted from Perez-Gago *et al.*, 2006).

Fig. 3. Effect of N-acetylcysteine addition into alginate edible coating on the colour of fresh-cut apple after 21 days of refrigerate storage.

Texture enhancers

Processing operations may result in a dramatic loss of firmness in fruit tissues due to the action of pectic enzymes. Subcellular compartmentalization is disrupted at the cut surfaces, and the mixing of substrates and enzymes, which are normally separated, can initiate reactions that normally do not occur (Toivonen & Brummell, 2008). The most common way of controlling softening phenomena in fresh-cut fruits is the use of treatments with calcium salts (García, Herrera, & Morilla, 1996). Calcium ions interact with pectic polymers to form a crosslinked network that increases mechanical strength, thus delaying senescence and controlling physiological disorders in fruits and vegetables (Poovaiah, 1986).

Texture enhancers may also be added to edible coatings to minimize softening during storage of fresh-cut fruits and vegetables. Following the addition of calcium ions, some carbohydrates undergo conformational changes, giving rise to the well known "egg box" model of gelation. This is based on chain dimerization and eventually further aggregation of the dimmers (Moe, Draget, Skjåk-Broek, & Smidsrød, 1995). Rojas-Graü, Tapia, *et al.* (2008) observed that apple wedges coated with alginate and gellan edible coatings crosslinked with calcium salts outstandingly maintained their initial firmness during refrigerated storage.

Similar results were obtained by Oms-Oliu, Soliva-Fortuny, and Martín-Belloso (2008b) on fresh-cut melon coated with different calcium-crosslinked polysaccharide-based edible coatings (alginate, gellan and pectin). Hernández-Muñoz, Almenar, Valle, Velez, and Gavara (2008) observed that the addition of calcium gluconate to the chitosan (1%) coating formulation increased the firmness of strawberries during refrigerated storage. Lee *et al.* (2003) indicated that incorporating 1% of calcium chloride within the whey protein concentrate coating formulation helped to maintain firmness of fresh-cut apple pieces. Han, Zhao, Leonard, and Traber (2004) observed that a chitosan-based coating containing 5% calcium (Gluconal CAL) increased the firmness of frozen-thawed raspberries by roughly a 25% in comparison with uncoated fruits. Olivas, Mattinson, and Barbosa-Cánovas (2007) maintained firmness of fresh-cut "Gala" apples practically constant using alginate edible coatings. In the latter study, apple wedges were immersed in a calcium chloride solution and subsequently coated with different alginate coating formulations.

Nutraceuticals

Despite the growing interest in incorporating nutraceutical compounds into food products, few studies have suggested their integration into edible films or coatings.

In this sense, the concentration of nutrients added to the films/coatings must be carefully studied since it is important to know the effects on their basic functionality, namely on their barrier and mechanical properties. Some studies have reported the effect of the addition of active compounds in the functionality of edible films. For instance, Mei and Zhao (2003) evaluated the feasibility of milk protein-based edible films to carry high concentrations of calcium (5 or 10% w/v) and vitamin E (0.1% or 0.2% w/v). They concluded that protein-based edible films can carry active compounds, although the film functionality can be compromised. In contrast, Park and Zhao (2004) reported that the water barrier property of the chitosan-based films was improved by increasing the concentration of mineral (5–20% w/v zinc lactate) or vitamin E in the film matrix. Nevertheless, the tensile strength of the films was affected by the incorporation of high concentrations of calcium or vitamin E, although other mechanical properties, such as film elongation, puncture strength, and punctures deformation, were not affected.

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, where these micronutrients are present in low quantities. Tapia *et al.* (2008) reported that the addition of ascorbic (1% w/v) to the alginate and gellan-based edible coatings helped to preserve the natural ascorbic acid content in fresh-cut papaya, thus helping to maintain its nutritional quality throughout storage (Fig. 4). Han *et al.* (2004) indicate that chitosan-based coatings had capability to hold high concentrations of calcium or vitamin E, thus significantly increasing their content in fresh and frozen strawberries and red raspberries. 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, Almenar, Ocio, and Gavara (2006) observed that chitosan-coated strawberries retained more calcium gluconate (3079 g/kg dry matter) than strawberries dipped into calcium solutions (2340 g/kg). 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 *Bifidobacterium lactis* Bb-12 were maintained for 10 days during refrigerated storage of both papaya and apple pieces, demonstrating the feasibility of these polysaccharide coatings to carry and support viable probiotics on fresh-cut fruit. 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.

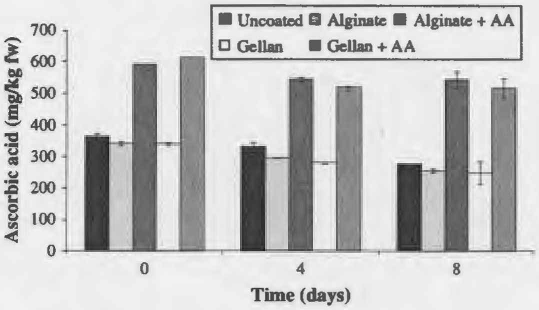

Fig. 4. Effect of alginate and gellan edible coatings with or without addition of ascorbic acid (AA-1% w/v) on total ascorbic acid content of fresh-cut papaya stored at 4 °C (adapted from Tapia *et al.*, 2008).

Sensory implications

Edible films and coatings are usually consumed with the coated products. Therefore, the incorporation of compounds such as antimicrobials, antioxidants and nutraceuticals should not affect consumer acceptance.

Some authors have indicated that the incorporation of antimicrobial agents into edible coatings could impart undesirable sensorial modifications in foods, especially when EOs are used (Burt, 2004). At the moment, little is known about the influence of the incorporation of EOs into edible coatings on sensory properties of coated fresh-cut fruits. Rojas-Graü, Raybaudi-Massilia, *et al.* (2007) evaluated the sensory quality of fresh-cut apples coated with alginate coatings containing EOs. Coated fresh-cut apples containing vanillin (0.3% w/w) were the most acceptable in terms of flavour quality, whereas coated apple pieces containing 0.1% v/v oregano oil exhibited the lowest overall preference due to a residual aromatic herbal taste detected on cut apples. Lately, Raybaudi-Massilia, Mosqueda-Melgar, *et al.* (2008) reported that the incorporation of 0.3% v/v palmarosa oil into alginate coatings for fresh-cut melon looks promising, since it was well accepted by sensory panellists.

Good results have also been reported for other antimicrobial compounds. Eswaranandam, Hettiarachchy, and Meullenet (2006) concluded that organic acids (malic and lactic acid) incorporated into soy protein coatings did not adversely impact the sensory properties of fresh-cut cantaloupe melon cubes.

Sometimes the incorporation of certain antibrowning agents into edible coatings can yield an unpleasant odour, particularly when high concentrations of sulphur-containing compounds such as N-acetylcysteine and glutathione are used as dipping agents (Iyidogan & Bayindirli, 2004; Richard *et al.*, 1992; Rojas-Graü, Sobrino-López, Tapia, & Martín-Belloso, 2006). Perez-Gago *et al.* (2006) detected a smell of sulphur compounds in fresh-cut apples coated with whey protein concentrate/beeswax containing cysteine as antioxidant agent into the coating formulation. However, no differences were found between coated and uncoated samples containing ascorbic acid, indicating that this compound can be incorporated in whey protein concentrate coatings without a substantial effect on the organoleptic properties. Recently, Oms-Oliu *et al.* (2008a) reported that sulphur-containing compounds (N-acetylcysteine and glutathione) incorporated into alginate or pectin coating formulations did not appear to be detected by panellists when applied on fresh-cut pears. It was also reported that these substances are perceived with less intensity when incorporated into an edible coating formulation. Lee *et al.* (2003) indicated that whey protein concentrate coatings (5% w/v) containing ascorbic acid (1% w/v) and calcium chloride (1% w/v) were the most effective in preserving the sensory quality of cut apples.

Not many studies have reported the sensory characteristics of coated fresh-cut fruits when nutraceutical ingredients are incorporated. The taste of these ingredients has been regarded as a particularly important aspect, since many nutraceutical compounds have natural bitter, astringent, or other off-flavours (Drewnowski & Gomez-Carneros, 2000) that can lead to rejection of the product by consumers (LeClair, 2000). Han, Lederer, McDaniel, and Zhao (2005) evaluated the sensory quality of fresh strawberries coated with chitosan-based films, with or without addition of vitamin E. Results from consumer testing at day 1 and 1 week after coating application indicated that chitosan coatings increased the visual acceptance of strawberries; however, coatings containing vitamin E produced a decrease in the product acceptability. In addition, results from trained panel after 1 week of storage showed that chitosan-coated strawberries have similar sensory descriptors as those of fresh berries, whereas coatings containing vitamin E developed the waxy-and-white surface of the samples. However, the incorporation of vitamin E reduced the glossiness of coated strawberries which could affect consumer acceptance.

Regulatory status

According to the European Directive (ED, 1995, 1998) and USA regulations (FDA, 2006), edible films and coatings can be classified as food products, food ingredients, food additives, food contact substances, or food packaging materials. Nevertheless, because they are an integral part of the edible portion of food products, they should observe all regulations required for food ingredients (Guilbert & Gontard, 1995). To maintain edibility, all film-forming components, as well as any functional additives in the film-forming materials, should be food-grade non toxic materials, and all process facilities should meet high standards of hygiene (Guilbert & Gontard, 1995; Guilbert, Gontard, & Gorris, 1996; Han, 2002; Nussinovitch, 2003).

The foremost governmental regulations concerning food additives are the Food and Drug Act (FDA), the European Union standards, and the Codex Alimentarius, which constitutes the FAO/WHO joint regulatory body (Raju & Bawa, 2006). The US Food and Drug Administration (FDA) stated that any compound to be included in the formulation should be generally recognized as safe (GRAS) or regulated as food additive, and used within specified limitations (FDA, 2006). In Europe, the ingredients that can be incorporated into edible coating formulations are majorly regarded as food additives and are listed within the list of additives for general purposes, although pectins, Acacia and karaya gums, beeswax, polysorbates, fatty acids, and lecithin are mentioned apart for coating applications (ED, 1995). In any case, the use of these coating forming substances is permitted, provided that the 'quantum satis' principle is observed. This Directive was complemented recently by the introduction of specific purity criteria for food additives (ED, 2008). Since edible coatings could have ingredients with a functional effect, inclusion of these compounds should be mentioned on the label. In Europe, the use of food additives must always be labelled on the packaging owing to their category (antioxidant, preservative, colorant, and so on) with either their name or E-number.

In the regulation of most countries, chemical substances added as antimicrobials are regarded as food additives if the primary purpose of the substances is shelf-life extension. However, each country has its own regulations defining a list of approved additives (ED, 1995; USDA, 2006). For instance, according to US regulations, organic acids including acetic, lactic, citric, malic, propionic, tartaric and their salts are GRAS for miscellaneous and general purpose usage (Doores, 1993). On the other hand, many EOs are used widely in the food, health and personal care industries and are also classified as GRAS substances or permitted as food additives (Kabara, 1991).

Another important topic within regulatory status is the presence of allergens. Many edible films and coatings are made with ingredients that could cause allergic reactions. Within these allergens, milk, soybeans, fish, peanuts, nuts and wheat are the most important. Several edible films and coatings are formed from milk protein (whey, casein), wheat protein (gluten), soy protein and peanut protein. Therefore, the presence of a coating with a known allergen on a food must be also clearly labelled (Franssen & Krochta, 2003).

Future trends

A new generation of edible coatings is under development, with the aim of allowing the incorporation and/or controlled release of active compounds using nanotechnological solutions such as nanoencapsulation and multilayered systems. Nowadays, nanotechnologies are being used to enhance the nutritional aspects of food by means of nanoscale additives and nutrients and nanosized delivery systems for bioactive compounds (Bouwmeester *et al.*, 2007).

Micro- and nanoencapsulation of active compounds with edible coatings may help to control their release under specific conditions (López-Rubio, Gavara, & Lagarón, 2006), thus protecting them from moisture, heat or other extreme conditions and enhancing their stability and viability (Jimenez, García, & Beristain, 2004). Alginate is the most widely used material for encapsulation, but materials from other sources can be used. Enzymes, probiotic, prebiotic, marine oils (omega-3-fatty acids) are among the most suitable functional substances to be encapsulated.

On the other hand, the use of nanolaminate layer-by-layer (LbL) multilayered systems, in which the charged surfaces are coated with interfacial films consisting of multiple nanolayers offers promising prospects (Decher, 2003; Weiss, Takhistov, & McClements, 2006). The preparation of multilayer structures consists of consecutive immersion of the substrate into two or more coating solutions containing oppositely charged species (Guzey & McClements, 2006). According to Krzemiski *et al.* (2006) and Marudova, Lang, Brownsey, and Ring (2005) poly-L-lysine, alginate, pectin and chitosan are the most common biopolymers that can be used to form these multilayered structures. However, it is also possible to utilize other charged species to assemble the multilayered structures, including charged lipid droplets, solid particles, micelles, or surfactants (Vargas, Pastor, Chiralt, McClements, & González-Martínez, 2008).

Coating foods with nanolaminates involves either dipping them into a series of solutions containing substances that would adsorb to a food's surface or spraying substances onto the food surface (McClements, Decker, & Weiss, 2005). These nanolaminate coatings could be elaborated entirely from food-grade ingredients (proteins, polysaccharides, lipids) and could include various functional agents such as antimicrobials, antibrowning agents, antioxidants, enzymes, flavourings, and colorants (Weiss *et al.*, 2006). In fact, the LbL electrodeposition technique could be used to coat highly hydrophilic food systems such as fresh-cut fruits and vegetables including further vitamins and antimicrobial agents (Vargas *et al.*, 2008).

Final remarks

The development of new technologies to improve the delivery properties of edible films and coatings is a major issue for future research. At the moment, most studies on food applications have been conducted at a laboratory scale. However, further research should be focused on a commercial scale with the purpose of providing more realistic information that can be used to commercialize fresh-cut products coated with edible films or coatings. In spite of these limitations, food industries are looking for edible films and coatings that could be used on a broad spectrum of foods and add value to their products, while increasing their shelf-life.

Lastly, more studies are necessary to understand the interactions among active ingredients and coating materials when developing new edible film and coating applications. When active ingredients (antimicrobials, antioxidants, and nutrients) are added to edible films and coatings, mechanical, sensory and even functional properties can be dramatically affected. Studies on this subject are rather limited, and more information is required in order to develop new coating applications with improved functionality and high sensory performance.

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