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Edible Coatings as Tools to Improve Quality and Shelf-Life of Fresh-Cut Fruits

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ABSTRACT

The current worldwide trend for a healthier lifestyle has triggered a rise in the demand and consumption of minimally processed commodities. Minimal processing operations need to be designed to protect fruits and vegetables against undesirable deleterious consequences of mechanical bruising such as browning, off-flavor development and texture breakdown. The search for methods to retard these negative effects is of great interest to all the stakeholders involved in the production and preservation of fresh-cut fruits. In this sense, edible coatings can be regarded as a strategy to maintain the original properties of intact vegetable tissues. The artificial semipermeable barrier, a polymeric edible coating, contributes to shelf-life extension by reducing migration of moisture and solutes, gas exchange, respiration and oxidative reactions, and the associated physiological disorders. Edible coatings can additionally act as carriers of antibrowning, antimicrobials, colorants, flavouring agents, nutrients or even probiotic organisms. Edible coatings may be composed of polysaccharides, proteins, lipids or a blend of these compounds. Their composition determines the barrier properties of the layer with regard to the transfer of moisture, gases, solutes and/or volatiles when applied on a food system. This review is an update about the state of the art of the development of edible coatings for fresh-cut fruits, as an alternative to the currently used preservation approaches.

Keywords: edible films, minimal processing, novel preservation strategies

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INTRODUCTION

In the last years, there has been an enormous increase in the demand for fresh-cut fruits that has urged the fruit processing industry to develop new and improved methods for maintaining quality and extending shelf-life. It is known, however, that mechanical operations involved in minimal processing, such as peeling, slicing or cutting, can substantially affect the integrity of fruits bringing about negative effects on product quality such as browning, leakage of nutrients, off-flavor development, texture breakdown and weight losses. In addition, the presence of microorganisms on the fruit surface may compromise the safety of fresh-cut fruit. Many techniques have been studied in order to overcome these problems and extend the shelf life of fresh-cut fruits. Control of respiratory pathways is achieved mainly by using adequate modified atmosphere packaging systems (Poubol and Izumi 2005); enzymatic browning reactions are widely slowed down by using specific enzyme/browning inhibitors (Dong *et al.* 2000; Abbott and Buta 2002); and softening and water loss are generally prevented by the use of calcium salts (Poovaiah 1986). In addition, the proliferation of microorganisms on the surface of fresh-cut fruits is currently inhibited by the combined use of antimicrobial dippings, modified atmosphere packaging conditions, and low storage temperatures (Gorny *et al.* 2002). Each technique can be advantageous for certain applications but also has limitations. For this reason, the food industry is currently open to innovative processing technologies in order to meet the consumers' demand for fresh and safe ready-to-eat products. In this sense, edible coatings offer excellent prospects for extending the shelf-life of fresh-cut produce by reducing the deleterious consequences of mechanical bruising. Thus, edible coatings can act as a barrier to moisture and gases, controlling microbial growth and preserving the quality attributes of the cut produce (McHugh and Krochta 1994; Guilbert *et al.* 1996; Park *et al.* 1999). In addition, edible coatings have been recognized for more innovative applications beyond their current use. Indeed, edible coatings exhibit an excellent potential to carry active ingredients such as antibrowning and antimicrobial agents, colorants, flavours, nutrients, and spices. An ideal coating

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should be able to extend the storage life of fresh fruit without causing anaerobiosis and reduce decay without affecting the quality of the fruit (Ghaouth *et al.* 1992). However, the effect of coatings on fruits greatly depends on many intrinsic factors such as temperature, alkalinity, thickness and composition, and extrinsic such as variety and maturity of fruits (Park *et al.* 1990).

This review highlights some of the most recent findings regarding the use of edible coatings as a tool to improve quality and shelf-life of fresh-cut fruits. An update of the information available on the barrier properties of polysaccharide-, protein- and lipid-based edible coatings is discussed, together with their ability to carry other food ingredients such as antioxidants, antimicrobials, and nutraceuticals that help to improve the safety, quality and functionality of fresh-cut fruits.

DEFINITION AND HISTORICAL BACKGROUND

Edible films and coatings are generally defined as continuous matrices that can be prepared from edible materials such as polysaccharides, proteins and lipids. They can be used as thin wraps or pouches for food, or formed as coatings on food or between food components (Cagri *et al.* 2004).

The application of edible films and coatings to foods with the aim of prolonging their shelf life is not new. Edible films and coatings have been used for centuries to prevent moisture migration, improve food appearance and increase storage time. Wax coatings on whole fruits and vegetables have been used since the 1800s. In fact, coating of citrus fruits (oranges and lemons) with wax to retard desiccation was practiced in China in the 12th and 13th centuries (Hardenburg 1967). Currently, edible coatings are widely used on whole fruits like apple, pear, orange, lemon, grapefruit, with very different purposes, such as water loss reduction, improvement of appearance, incorporation of fungicides or growth regulators, and/or creation of a barrier for gas exchange between the commodity and the external atmosphere.

The use of edible coatings on fresh-cut fruits consists on the application of a layer of edible material on the surface of a cut-fruit with the purpose of providing it with a protection against gas transfer, moisture and aroma loss, decay and overall appearance through storage (Olivas *et al.* 2005). The first documented use of edible coatings on fresh-cut fruits was reported by Bryan (1972) who observed that a carrageenan-based coating applied on cut grapefruit halves resulted in less shrinkage, leakage, and deterioration of taste after two weeks of storage at 4ºC. In the last years, edible coatings have been evaluated in order to improve quality and prolong shelf-life of some fresh-cut fruits regarding their barrier properties. However, edible films and coatings may also be used to improve the structural integrity of fruits (Olivas and Barbosa-Canovas 2005). In addition, they have a great potential to deliver new compounds due to their ability to function as carriers of active compounds (Rojas-Graü *et al.* 2007a).

PROPERTIES OF EDIBLE COATINGS FOR FRESH-CUT FRUITS

Potential properties and applications of edible films and coatings have been extensively reviewed (Min *et al.* 2005; Bravin *et al.* 2006; Jagannath *et al.* 2006; Serrano *et al.* 2006). With regard to fresh-cut fruits, the potential benefits of using edible coatings are shown in **Fig. 1**. Edible coatings may help to improve shelf life and quality of minimally processed foods (Baldwin *et al.* 1995). Consumption with the food, incorporation of additional nutrients, enhancement of sensory characteristics, and/or inclusion of quality enhancing antimicrobials are among the list of potential benefits of an edible coating.

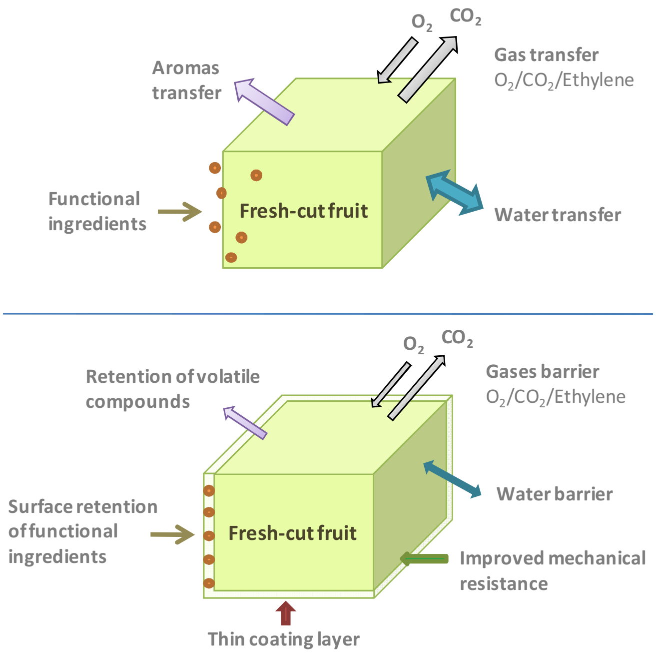

Fig. 1 Potential properties of edible coatings on fresh-cut fruits.

Moisture-barrier properties

Water loss leads to a loss of turgor and crispness, and occurs rapidly in fresh-cut products due to the absence of a cuticle and sub-epidermal layers and the exposure of internal tissues (Shackel *et al.* 1991). However, water loss can be greatly retarded by appropriate packaging (Toivonen and Brummell 2008). In this sense, edible coatings have the potential to provide moisture barrier on the surface of cut produce reducing the moisture loss; in fact, edible coatings may help to reduce dehydration of the cut surface by maintaining a moisture-saturated environment (Watada *et al.* 1996). Edible coatings have been extensively used to protect fresh-cut fruit from surface dehydration. Avena-Bustillos *et al.* (1997) reduced water loss of apples 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. 2**). McHugh and Senesi (2000) significantly reduced moisture loss of fresh-cut apples when applying wraps made from apple puree containing lipids. Similarly, Wong *et al.* (1994) reduced the water loss of apple slices by 12 and 14-fold

Fig. 2 Effect of an alginate edible coating on the juice leakage volume of fresh-cut pineapple pieces stored at 5ºC.

when coating them with a cellulose/lipid bilayer edible film. Likewise, Olivas *et al.* (2003) found that the incorporation of stearic acid into methylcellulose-based coatings played an important role in avoiding weight loss of pear wedges, while methylcellulose-only coatings showed poor moisture barrier. 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.

Gas-barrier properties

Edible coatings are also used as a protective barrier to reduce respiration and transpiration rates through the fruits surface. The coatings act as a gas barrier around each fruit piece creating a modified atmosphere inside each coated piece (Rojas-Graü *et al*. 2008). The coatings can restrict gas exchange between the tissues and the surrounding atmosphere, leading to a decrease in respiration and stress-mediated deteriorative response (Lin and Zhao 2007). They may also help to prevent the volatile compounds from escaping the product during its storage. However, although reduction of gas transfer from the fruit to the environment is desirable, extremely impermeable coatings may induce anaerobic conditions that could eventually lead to a decrease in the production of characteristic aroma volatile compounds (Mattheis and Fellman, 2000; Perez-Gago *et al*. 2003a). Lee *et al.* (2003) reported a reduction of the initial respiration rate of fresh-cut Fuji apples coated with whey protein concentrate. This effect was attributed to the calcium ions contained in the film forming solution and to the oxygen barrier properties inherent to the film. Wong *et al.* (1994) employed a bilayer of acetylated monoglyceride and ascorbate buffer containing calcium ions for controlling the gas diffusion through coated cut apples, and obtained a large reduction in the rates of gas evolution. Rojas-Graü *et al.* (2008) observed an increase of ethanol and acetaldehyde formation from the second week of storage in apple wedges coated with alginate or gellan-based coating, while in uncoated apples the production of these gases was comparatively lower. Lin and Zhao (2007) indicated that the modification of internal atmosphere by the use of edible coatings can develop ethanol and alcoholic flavours as a result of anaerobic fermentation associated with too high carbon dioxide or too low oxygen concentrations. The appearance of fermentative metabolites as a result of anaerobic respiration is often associated to off-flavours and its presence might be detrimental to quality (Day 1994). The selection of an edible coating material with appropriate gas permeability as well as the control of environmental conditions such as temperature and relative humidity is of capital importance when determining the conditions to be created inside the coated products, since coating permeability and produce respiration are both affected by these parameters (Lin and Zhao 2007).

Carrier properties

One of the distinctive functions of edible coatings is the ability of incorporating active ingredients into the matrix to enhance its functionality. In fact, quality, shelf-life stability, and safety of fresh-cut fruits can be significantly improved with the incorporation of antioxidants, antimicrobials, and functional ingredients, with a certain limitation, that is determined at the level where the additives could dramatically interfere with the mechanical and barrier properties of the coating (Kester *et al.* 1986; Gennadios and Weller 1990; Guilbert and Gontard 1995).

Antioxidants can be added into the coating matrix to protect the cut surface against oxidative rancidity and enzymatic browning. Rojas-Graü *et al.* (2007a) and Tapia *et al.* (2008) applied alginate- and gellan-based coatings incorporating cysteine, glutathione and ascorbic acid to fresh-cut apples and papayas, thus 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) 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.

On the other hand, the use of edible coatings as carriers of antimicrobial compounds is another potential alternative to enhance the safety of fresh-cut produce. The incorporation of antimicrobial agents into the edible matrix may be used to limit diffusion phenomena. According to Min and Krochta (2005) when antimicrobial agents are directly applied, the active substances are neutralized in contact with the surface or diffuse rapidly from the surface into the product. However, antimicrobial edible films and coatings could contribute to the maintenance of effective concentrations of the active compounds on the food surfaces (Gennadios and Kurth, 1997). Several types of antimicrobials incorporated into edible coatings have been used for extending shelf-life of fresh commodities, but their use in fresh-cut fruits is yet limited. At the moment, organic acids and plant essential oils are the main antimicrobial agents incorporated into edible coatings for fresh-cut fruits. Garcia, Martino and Zaritzky (2001) extended the storage life of fresh strawberries and maintained microbial loads below 6 log CFU/g for 28 days of storage using a starch-based coating containing potassium sorbate and citric acid. Likewise, Lee *et al.* (2003) reported that the shelf-life of apple slices coated with a carrageenan-based layer containing ascorbic acid, citric acid, and oxalic acid was extended by at least 2 weeks at 3°C. Krasaekoopt and Mabumrung (2008) observed that the incorporation of 1.5 and 2% (w/v) chitosan in a methylcellulose coating applied on fresh-cut cantaloupe produced a better microbiological quality in the final product. Rojas-Graü *et al.* (2007b) observed a 4 log reduction in the inoculated population of *L. innocua* in fresh-cut apples when lemongrass or oregano oils were incorporated into an apple puree-alginate edible coating. Raybaudi-Massilia *et al.* (2008a) demonstrated 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 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. Later, Raybaudi-Massilia *et al.* (2008b) reported that the incorporation of 0.3% (v/v) palmarosa oil into the alginate coating inhibited the growth of the native microbiota and reduced the population of inoculated *Salmonella* Enteritidis in fresh-cut melon.

Edible films and coatings are also an excellent vehicle to enhance the nutritional value of fruits and vegetables by carrying basic nutrients that lack or are present in low amounts in fruits and vegetables. Chien *et al.* (2007) maintained the ascorbic acid content of sliced red pitayas (dragon-fruit) coated with low molecular weight chitosan. Tapia *et al.* (2008) reported that the addition of ascorbic to the alginate edible coating helped to preserve the natural ascorbic acid content in fresh-cut papaya, thus helping to maintain its nutritional quality throughout storage. Hernández-Muñoz *et al.* (2006) indicated that chitosan-coated strawberries retained more calcium gluconate (3079 g/kg dry matter) than strawberries dipped into calcium solutions (2340 g/kg). Likewise, Han *et al.* (2004) observed that chitosan-based coatings had the ability of holding high concentrations of calcium gluconate or vitamin E in fresh and frozen strawberries and red raspberries, thus significantly increasing their content in both fruits. Tapia *et al.* (2007) maintained counts of *Bifidobacterium lactis* Bb-12 above 10^6 cfu/g on papaya and apple pieces coated with alginate or gellan film-forming solutions containing the probiotic microorganims during refrigerated storage (10 days), thus demonstrating the feasibility of these polysaccharide coatings to carry and support viable probiotics on fresh-cut fruit.

Finally, texture enhancers such as calcium chloride can be incorporated into the formulation of edible coatings to better maintain quality during storage of fresh-cut produce. The use of calcium chloride for crosslinking some polymers, could minimize softening phenomena. Perez-Gago *et al.* (2006) indicated that the incorporation of 1% calcium chloride within a whey protein concentrate coating formulation helped to maintain firmness of fresh-cut apple pieces. Oms-Oliu *et al.* (2008a) reported that the use of calcium chloride, as a crosslinker of polysaccharide chains (alginate, gellan, and pectin), helped to maintain firmness of fresh-cut melon during storage. Similar results were obtained by Rojas-Graü *et al.* (2008) who observed that apple wedges coated with alginate or gellan edible coatings and calcium chloride solution, maintained their initial firmness during refrigerated storage. Hernández-Muñoz *et al.* (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% calcium chloride within a whey protein concentrate coating formulation helped to maintain firmness of fresh-cut apple pieces. Olivas *et al.* (2007) maintained firmness of fresh-cut "Gala" apples using a dip in a calcium chloride solution and subsequently applying an alginate-based coating. Similarly, Ribeiro *et al.* (2007) observed a decrease in firmness loss of fresh strawberries coated with a calcium-enriched carrageenan coating with respect to the non-coated fruit.

Despite the good results achieved so far with the incorporation of active compounds into edible films and coatings, the incorporation of certain antibrowning or antimicrobial agents into formulations may have detrimental consequences on the flavor of the coated product. 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 (Richard *et al*. 1992; Iyidogan and Bayindirli 2004; 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. In the case of essential oils, the major drawback is their strong flavour which could change the original taste of foods. Rojas-Graü *et al*. (2007b) 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 antimicrobial purpose. By contrast, Raybaudi-Massilia *et al.* (2008b) 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.

EDIBLE COATINGS USED TO IMPROVE QUALITY OF FRESH-CUT FRUITS

There is a very wide range of compounds that can be used in the formulation of edible coatings. Protein, polysaccharides and lipids are the most common film-forming materials that can be used alone or combined. Usually, other minor components can be included to enhance coating properties, such as plasticizers, emulsifiers, and/or surfactants (Baldwin 1999). Their presence and quantity determine the barrier properties of the material with regard to water vapour, oxygen, carbon dioxide and lipid transfer in food systems (Guilbert *et al.* 1996). Both polysaccharide and protein edible coatings are regarded as good oxygen barriers due to their hydrogen-bonded network structure, which is very tightly packed and ordered (McHugh and Krochta 1994). The major drawbacks of such films and coatings are their relatively low water resistance and poor vapour barrier properties resulting from their hydrophilic nature (Yang and Paulson 2000). The incorporation of lipids, either in an emulsion or as a layer coating into the films formulations, greatly improves their water vapour barrier properties (García *et al.* 2000; Yang and Paulson 2000). Nonetheless, none of the three constituents can provide the needed protection by themselves and so they are usually combined for an optimal performance (McHugh and Krochta 1994; Guilbert *et al.* 1996). Coatings based on edible compounds from several sources have been evaluated in order to maintain the quality and improve the shelf-life of fresh-cut fruits and vegetables.

Polysaccharide-based coatings

Polysaccharides are the most widely used components found in edible coatings for fruits, as they are present in most commercially available formulations (Krochta and de-Mulder-Johnston 1997). Polysaccharides exhibit effective gas barrier properties despite their high hydrophobicity and show high water vapour permeability in comparison with commercial plastic films. Nevertheless, the oxygen and moisture barrier properties of these substances can be enough to protect fresh-cut fruit and vegetables from dehydration and in some cases retard their respiration rate. In fact, these coatings may retard ripening and increase shelf-life of coated produce, without creating severe anaerobic conditions (Baldwin *et al.* 1995). Polysaccharides that have been used for coating applications in fresh-cut fruits include cellulose and derivatives, starch, alginates, gums, chitosan, pectin, carrageenan, and some mucilage compounds.

1. Cellulose and derivatives

Cellulose is the most abundant natural polymer on earth. It is highly crystalline, fibrous, and insoluble. Cellulose derivatives such as methylcellulose (MC), hydroxypropyl-methyl-cellulose (HPMC) and the ionic carboxymethyl-cellulose (CMC) are commonly found in the formulation of edible coatings, especially in commercial products. Baldwin *et al.* (1996) enhanced the storage life of cut apples with a CMC-based edible coating. Brancoli and Barbosa-Cánovas (2000) decreased surface discoloration of apple slices by coating slices with MC, maltodextrin, ascorbic acid, and calcium chloride. Similarly, Olivas *et al*. (2003) preserved fresh-cut pear wedges from surface browning by applying a MC-based coating containing ascorbic and citric acids. Plotto *et al.* (2004) coated fresh-cut mangoes with several edible coatings and they observed that a CMC-based coating containing maltodextrin presented the highest scores for visual quality and flavor.

2. Chitosan

Another polysaccharide commonly used in the formulation of edible coatings is chitosan, which is mainly obtained from crab and shrimp shells (Hirano 1999). This coating material has excellent film-forming properties, broad antimicrobial activity, and compatibility with other substances, such as vitamins, minerals, and antimicrobial agents (Li *et al.* 1992; Shahidi *et al.* 1999; Park and Zhao 2004; Durango *et al.* 2006; Chien *et al.* 2007; Ribeiro *et al.* 2007). Chitosan has been extensively studied for application as a film or coating due to its ability to inhibit 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 and 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 in the counts of *Cladosporium* sp. and *Rhizopus* sp., respectively, on strawberries coated with a chitosan-based edible film. A reduction in the counts of aerobic and coliform microorganisms was also observed during storage. Pen and 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. The main drawback of chitosan is that it can affect the taste and odor of the coated products. In fact, the use of chitosan-based coatings may generate slight flavour modifications because of its typical astringent/bitter taste.

3. Alginates and gellan gum

Alginate is a generic term for the salts of alginic acid. Commercial alginates are extracted from brown seaweeds of the *Phaephyceae* class. Their structure consists of a linear copolymer of D-mannuronic and L-guluronic acid monomers. Alginates possess good film-forming properties and produce uniform, transparent, and water soluble films. The gel forming properties of alginates can be attributed to their capacity to bind divalent ions like calcium and are strongly correlated with the proportion and length of the guluronic acid blocks (G-blocks) in their polymeric chains. On the other hand, gellan gum is a microbial polysaccharide secreted by the bacterium *Sphingomonas elodea* (formerly known as *Pseudomonas elodea*). The functionality of gellan gum depends on its degree of acylation. High acyl gellan gums form soft, very elastic, transparent and flexible gels, while low acyl gellan gums form hard, non-elastic, brittle gels (Sworn 2000). The mechanism of gelation involves the formation of a three-dimension network, which in turn is formed by double helical junction segments that are complexated with cations and hydrogen bonds (Takahashi *et al.* 2004). Both polysaccharides are increasingly finding applications in the food industry as texturizing and gelling agents (Yang and Paulson 2000). Olivas *et al.* (2007) reportted that alginate coatings extended the shelf-life of fresh-cut 'Gala' apples without causing anaerobic respiration. Rojas-Graü *et al.* (2008) observed that fresh-cut apple coated with alginate and gellan edible coatings effectively prolonged the shelf-life of apple wedges by two weeks of storage. Rojas-Graü *et al.* (2007a) also reported the effectiveness of alginate and gellan edible coatings as carriers of antibrowning agents to prolong shelf-life of fresh-cut apples. In line with these studies, Raybaudi-Massilia *et al*. (2008b) evaluated the ability of an alginate-based coating carrying malic acid and essential oils to improve the shelf-life and safety of fresh-cut melon. Oms-Oliu *et al*. (2008b) maintained the vitamin C and total phenolic content in pear wedges coated with alginate, gellan or pectin edible coatings. Oms-Oliu *et al*. (2008a) also observed that the use of alginate coating may contribute to reduce the wounding stress induced in fresh-cut `Piel de Sapo´ melon. Tapia *et al*. (2008) extended the shelf-life of fresh-cut papaya pieces using alginate and gellan-based edible coatings containing ascorbic acid.

4. Starch

Starch is one of the most abundant natural polysaccharides. It has been widely used as food hydrocolloid (Narayan 1994) because it is inexpensive, abundant, biodegradable, and easy to use. Coatings made from starch are often transparent or translucent, odourless, tasteless, and colourless, and have low permeability to oxygen at low-to-intermediate relative humidity (Myllarinen *et al.* 2002). Garcia *et al.* (1998) found a significant effect of a starch-based coating on the colour, weight loss, firmness and shelf-life of coated strawberries. Latter, Garcia *et al.* (2001) observed that a starch-based coating containing potassium sorbate, a plasticizer and sunflower oil, improved the moisture barrier properties, reduced microbial growth and exhibited a selective permeability to oxygen and carbon dioxide, thus extending the storage life of strawberries.

5. Fruit purees

Some researchers have reported that edible coatings made from fruit purees can be used to extend the shelf life of fresh-cut fruits and vegetables, as well as to enhance their nutritional value and increase their consumer appeal. The incorporation of hydrocolloids such as pectin may improve the properties of fruit-based coatings (Mancini and McHugh 2000). Pectins are a common type of gelling agents, which have the ability to form gels in the presence of calcium ions or sugar makes them an important ingredient of many food products. McHugh and Senesi (2000) extended the shelf-life and significantly reduced moisture loss and browning rates of fresh-cut apples wrapped with a coating made from apple puree containing various concentrations of fatty acids, fatty alcohols, beeswax, vegetal oil and high methoxyl pectin. Rojas-Graü *et al.* (2008) applied a coating containing a mixture of apple puree and alginate to preserve the quality of apple slices. By contrast, Sothornvit and Rodsamran (2008) observed an important increase in translucency of fresh-cut mango coated with an edible film based on mango. Development of translucency was found to increase with temperature.

6. Mucilages

Mucilages generally are hetero-polysaccharides obtained from plant stems (Trachtenberg and Mayer 1981). McGarvie and Parolis (1979) determined that the mucilage extracted from the stems contains residues of D-galactose, D-xylose, L-arabinose, L-rhamnose and D-galacturonic acid. This complex polysaccharide is part of dietary fibre and has the capacity to absorb large amounts of water, dissolving and dispersing itself and forming viscous or gelatinous colloids (Dominguez-López 1995). Recently, some authors have proposed the use of mucilage gels as coatings for fruits and vegetables. Del-Valle *et al.* (2005) improved the shelf-life of strawberries using a cactus-mucilage edible coating, maintaining physical and sensorial properties. 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. In addition, 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. Furthermore, Serrano *et al.* (2006) maintained total phenolics, ascorbic acid and high retention of total antioxidant activity in table grapes coated with *Aloe vera* gel coatings.

Protein-based coatings

Proteins that can be used in the formulation of edible coatings for fresh fruits include those derived from animal sources, such as casein and whey protein, or obtained from plant sources like zein, wheat gluten, soy protein, and peanut protein (Gennadios 1994). Like polysaccharides, protein edible films and coatings also exhibit excellent oxygen, carbon dioxide, and lipid-barrier properties, particularly at low relative humidity, and provide mechanical strength and structural integrity. However, protein films and coatings exhibit relatively poor water-barrier characteristics, attributed to the inherent hydrophilicity of proteins and the hydrophilic plasticizers incorporated into the film matrix to impart adequate flexibility (Kester and Fennema 1986; Gennadios *et al.* 1994; McHugh and Krochta 1994; Sothorvit and Krochta 2000; Baldwin and Baker 2002).

Proteins have been explored less extensively than polysaccharides for their use on fresh-cut fruits. Only whey proteins have been the subject of intense investigation over the past decade. Sonti *et al.* (2003) coated apple cubes with whey protein concentrate and whey protein isolate, obtaining a delay in browning and texture decay. LeTien *et al.* (2001) achieved reduced browning rates in apple slices coated with a combination of whey protein and CMC. Lee *et al*. (2003) studied the effect of whey protein and carrageenan 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. Shon and Haque (2007) observed a decrease in browning of cut apples and potatoes when using an edible coating containing sour whey flour. Eswaranandam *et al.* (2006) extended the shelf-life of fresh-cut cantaloupe melon using a soy protein coating containing malic and lactic acids.

Bilayer coatings and emulsions

As mentioned before, polysaccharides and proteins are polymeric and hydrophilic in nature, thus good film-formers with excellent oxygen, aroma, and lipids barriers at low relative humidity, though they are poor moisture barriers. In fact, each individual coating material has some unique, but limited, functions. The integration of proteins, polysaccharides and/or lipids together can improve functionality of the coating; in fact they are more effective when used in a combination (Lin and Zhao 2007). Owing to the presence of microscopic pores and elevated solubility and diffusivity, lipids offer limited oxygen barrier properties. However, lipid films and coatings have good water vapour barrier properties, due to their low polarity (Kester and Fennema 1986), but are usually opaque and relatively inflexible (Guilbert *et al.* 1996). Generally, lipids contribute to the improvement of the water vapour resistance whereas hydrocolloids confer selective permeability to O_2 and CO_2, as well as durability, structural cohesion, and integrity (Krochta 1997).

Composite coatings or films can be categorized as bilayer or stable emulsions. According to Lin and Zhao (2007), for bilayer composite film/coatings, lipid generally forms an additional layer over the polysaccharide or protein layer, while the lipid in the emulsion composite layer is dispersed and entrapped in the matrix of protein or polysaccharide. Some authors have reported that emulsified coatings are less efficient than bilayer coatings due to the non homogeneous distribution of the lipid substance. Nonetheless, they have the advantage of requiring only one application step instead of the two needed for bilayer coatings. The improved moisture-barrier properties of composite coatings have made them promising candidates for coating fresh-cut fruits and vegetables. Tanada-Palmu and Grosso (2005) reported that wheat gluten with lipid (beeswax, stearic acid, and palmitic acid) based bilayer-coatings significantly retained firmness and reduced weight loss of fresh strawberries. Baldwin *et al.* (1995) indicated that a coating composed of a milk protein (casein) and a lipid (acetylated monoglyceride) effectively provided protection against moisture loss and oxidative browning for up to 3 days in fresh-cut apples. Wong *et al.* (1994) coated apple cubes with double layers of polysaccharides (cellulose, carrageenan, pectin, or alginate) and acetylated monoglyceride. Pennisi (1992) observed a reduction of browning and water loss of fresh-cut apple slices covered with a chitosan-lauric acid composite coating. 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.

FINAL REMARKS

This review highlights the beneficial effects of edible coatings to reduce loss of quality and increase the shelf-life of fresh-cut fruits. Nevertheless, further research should focus on the characterization of new materials and coating formulations that allow obtaining coatings with selective gas barrier properties, without leading to the unleashing of fermentative processes due to excessive modification of the internal atmosphere of the fruit tissues. In addition, new methods of application of edible coatings to fruit surfaces need to be developed. Finally, scientific research must be conducted in order to identify safety issues related to the potential toxicity or allergenicity of the some edible coating materials.

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