7 Advances in Edible Coatings

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CONTENTS

7.1 CONCEPT AND TYPES OF EDIBLE COATINGS

Edible coating can be defined as a thin layer of edible material formed as a coating on a food product and is usually applied by immersing the product in a solution of the coating. This is in contrast to an edible film, which is a preformed, thin layer of edible material that is placed as a wrapping on the food product (Falguera et al., 2011). Food industries and packaging manufacturers have joined in efforts to reduce the amount of food packaging materials, mainly due to environmental and consumer concerns. The development of edible coatings has received much attention in recent years due to advantages such as consumption with the food product, sometimes increasing its organoleptic properties and being produced from agricultural and marine renewable sources, as well as by using several fungal species (ED, 1995, 1998; FDA, 2006; Bourtoom, 2008).

Components of edible coatings can be divided into three categories: hydrocolloids, lipids, and composites. Composites generally contain both hydrocolloid components and lipids and represent a good strategy for enhancing coating properties by taking advantage of the properties of both types of components.

The application of an edible coating onto the fruit surface modifies the internal atmosphere in the same way that do plastic films (Valero and Serrano, 2010), by increasing the carbon dioxide and lowering the oxygen concentrations. Then, the effects of edible coatings on internal gas composition and their interactions on quality parameters must be determined specifically for each fresh produce. The success of edible coatings for fruits depends mainly on selecting the appropriate coating that can give a desirable internal gas composition for each specific product (Cisneros-Zevallos and Krochta, 2002, 2003).

In this chapter, recent trends in edible coatings are summarized with emphasis on their applications on fresh fruit commodities and their effects on physiological behavior, organoleptic quality, nutritive aspects, microbial growth, and levels of bioactive compounds with antioxidant activity.

7.1.1 POLYSACCHARIDES

Polysaccharides are good materials for the formation of edible coating since they show excellent mechanical and structural properties but they are hydrophilic and thus have a poor capacity as a barrier against water vapor and gas diffusion. The principal polysaccharides of interest for edible coatings are cellulose, starch, gums, pectins, alginate, and chitosan. The linear structure of some of these polysaccharides, for example, cellulose, amylose, and chitosan, renders their films tough, flexible, transparent, and resistant to fats and oils (Dhall, 2013). In the future, other complex polysaccharides produced by fungi and bacteria such as xanthan, curdlan, pullan, and hyaluronic acid, will receive more interest.

7.1.1.1 Cellulose

Cellulose is a polymer of D-glucose monomers linked through ß-(1 → 4) glycosidic bonds. It has low water solubility in nature but water solubility can be increased by treating cellulose with alkali to swell the structure, followed by reaction with chloroacetic acid, methyl chloride, or propylene oxide to yield carboxymethyl cellulose (CMC), methyl cellulose (MC), hydroxypropylmethylcellulose (HPMC), or hydroxypropyl cellulose (HPC). All these cellulose derivatives are water-soluble, odorless, tasteless, flexible, and transparent, and exhibit higher barrier capabilities to moisture and oxygen transmission than cellulose itself (Krochta and Mulder-Johnston, 1997).

7.1.1.2 Pectin

Pectins are linear or branched polymers with a high content of galacturonic acid and may contain as many as 17 different monosaccharides. Four main types of pectins have been structurally characterized: homogalacturonan, rhamnogalacturonan I, rhamnogalacturonan II, and xylogalacturonan, which differ in both the structure of the macromolecule backbone and the presence and diversity of side chains. Pectin is a class of complex water-soluble polysaccharides used to form coatings. It is a purified carbohydrate product obtained by aqueous extraction of some edible plant material, usually citrus fruits or apples. Under certain circumstances, pectins form gels, which have made them a very important additive in jellies, jams, marmalades and confectionaries, as well as in edible coatings. Pectin is a high-volume and potentially important food ingredient available in high percentages in agricultural waste. Pectin coatings have been also studied for their ability to retard lipid migration and moisture loss, and to improve appearance and handling of foods (Moalemiyan et al., 2011). Due to their hydrophilic nature, pectin edible coatings have low effectiveness as a water-vapor barrier but good properties as barrier to oxygen and carbon dioxide. Low methoxyl pectins are often used as edible coatings because of their ability to form strong gels upon reactions with multivalent metal cations such as calcium. The incorporation of calcium in polysaccharide edible coatings reduces their water vapor permeability, making the coatings water-insoluble (Ferrari et al., 2013).

7.1.1.3 Chitosan

Chitin is the second most abundant natural biopolymer after cellulose. It is the major structural component of the exoskeleton of arthropods and the cell walls of fungi. The chemical structure of chitin is similar to that of cellulose with 2-acetamido-2-deoxy-ß-D-glucose monomers attached via ß-(1 → 4) linkages. Chitosan is the deacetylated form of chitin which is soluble in acidic solutions, in contrast to chitin (Shahidi et al., 1999). Thus, chitosan is the low acetyl substituted form of chitin and is composed primarily of glucosamine, 2-amino-2-deoxy-ß-D-glucose, known as (1 → 4)-2-amino-2-deoxy-D-glucose. Chitosan, is derived from chitin of marine invertebrates and has been used as an edible coating for its ability to form a good film on the commodity surface and control microbial growth. Chitosan is now widely produced commercially from crab and shrimp shell wastes with different deacetylation grades and molecular weights leading to different functional properties (No et al., 2007). Chitosan is water-insoluble but soluble in weak organic acid solutions. Chitosan derivatives in the form of acetate, ascorbate, lactate, and malate are water-soluble. Water-soluble chitosan can also be produced in the form of oligosaccharide by enzymatic or chemical hydrolysis (No et al., 2007). To date, chitosan has attracted considerable interest due to its antimicrobial activity (Dutta et al., 2009) and has widely been used in antimicrobial films. Chitosan has exhibited antimicrobial activity against a wide variety of pathogenic and spoilage microorganisms, including fungi, and Gram-positive and Gram-negative bacteria.

7.1.1.4 Starch

Starch is in abundance in the plant kingdom and has thermoplastic properties upon disruption of its molecular structure (Tharanathan, 2003). Starch granules contain two types of polymeric molecules: amylose, a linear chain of (1 → 4)-α-D-glucopyranosyl units, and amylopectin, a larger molecule with a backbone of amylose and highly branched side units of D-glucopyranosyl linked by α-(1 → 6)-glycosidic bonds. Starch can form films by the interaction of hydroxyl groups through hydrogen bonds. Since these interactions are weak, films are brittle with poor mechanical properties, although a higher proportion of amylose will improve the film characteristics (Campos et al., 2011). A concentration of amylose over 70% as in amylomaize starches gives stronger and more flexible films. The branched structure of amylopectin generally leads to films with poor mechanical properties (decreased tensile strength and elongation). The substitution of the hydroxyl groups in the molecule weakens the hydrogen binding ability and thereby improves freeze-thaw stability and solution clarity. An ether linkage tends to be more stable than an ester linkage (Tharanathan, 2003).

7.1.1.5 Alginate

Alginate is a polymer isolated from brown seaweed (*Phaeophyceae*) and can form translucent, glossy, and strong films with low water vapor and oxygen permeability and high tensile strength. Alginate is a salt of alginic acid and is composed of D-mannuronic acid and L-guluronic acid, and has the ability to crosslink with divalent ions such as calcium to form strong films (Sime, 1990). Alginate films are poor moisture-barriers as they are hydrophilic films, however, the incorporation of calcium reduces water vapor permeability making alginate films water insoluble. The capacity of hydrocolloid-based films as water vapor barriers increases as their solubility in water decreases.

7.1.1.6 Aloe Gel

Aloe vera gel has been identified as a novel coating agent to extend the shelf-life of perishable food crops with good antimicrobial properties, especially as natural antifungal compound (Valverde et al., 2005). *Aloe* spp. are perennial succulents plants characterized by stemless large, thick, fleshy leaves that are lance-shaped and have a sharp apex and a spiny margin. *Aloe* leaves have yellow latex, which is referred to as *Aloe* juice or sap and has a bitter taste. The leaf pulp is the innermost portion of the leaf and is composed of the parenchyma cells that contain the gel (Steenkamp and Stewart, 2007). *Aloe* gel contains polysaccharides, primarily of ß–(1,4)-linked, polydispersed, highly acetylated mannans (acemannan). Many of the medicinal effects of *Aloe* leaf extracts have been attributed to the polysaccharides found in the inner leaf parenchymatous tissue but it is believed that these biological activities should be assigned to a synergistic action of the compounds contained therein rather than a single chemical substance (Eshun and He, 2004; Hamman, 2008). Recently, the leaf characteristics and gel chemical composition of eight *Aloe* species as well as their possible use as edible coatings have been described by Zapata et al. (2013).

7.1.1.7 Gum Arabic

Gum Arabic or gum acacia is a dried, gummy exudate from the stems or branches of the *Acacia* species. It is the least viscous and most soluble of the hydrocolloids (Nisperos-Carriedo, 1994) and is used extensively in the industrial sector because of its emulsification, film-forming, and encapsulation properties. More than half of the world supply is used in confectionary to retard sugar crystallization and to thicken candies, jellies, glazes, and chewing gums, although evidences exist as edible coating for fruits. The main gum to be used commercially is derived from *Acacia senegal* because of its good emulsification properties (Elmanan et al., 2008).

7.1.2 PROTEINS

Proteins have received great attention in edible coating research because of their abundance as agricultural byproducts and food processing residuals. The presence of reactive amino acid residuals enables proteins to be modified and cross-linked through physical and chemical treatments to produce novel polymeric structures (Gennadios, 2002). Protein-based coatings have more interesting mechanical and barrier properties than polysaccharides. Many protein materials have been tested including collagen, corn zein, wheat gluten, SPI, fish proteins, ovalbumin, whey protein isolate and casein (Khwaldia et al., 2004).

7.1.2.1 Whey Protein

Whey proteins from bovine milk have been studied to a great extent because of their ability to form transparent and flexible coatings that exhibit good barrier and mechanical properties (Krochta, 2002). Whey proteins are globular proteins that remain soluble after precipitation of casein at pH 4.6 during cheese making. In bovine milk, these thermolabile proteins consist of mainly α-lactalbumin, β-lactoglobulin, and other proteins present in smaller fractions (e.g., bovine serum albumin, immunoglobulins, and proteasepeptones). Whey proteins are commercially available as whey protein isolates or whey protein concentrates, which have protein content of >90 and 20%–85%, respectively (Reinoso et al., 2008). However, whey protein has a hydrophilic nature and lipids need to be added to the film-forming solution to reduce the water-sensitivity of films.

7.1.2.2 Gelatine

Gelatine is obtained by controlled hydrolysis of the fibrous insoluble protein, collagen, which is the major constituent of animal skin, bones, and connective tissue. The characteristic features of gelatine are high content of amino-acids, such as glycine, proline, and hydroxyproline (Dhall, 2013). Gelatine films can be formed from 20%–30% gelatine, 10%–30% plasticizer (glycerine or sorbitol), and 40%–70% water followed by drying the gelatine gel.

7.1.2.3 Zein

Zein includes a group of alcohol-soluble proteins (prolamines) found in corn endosperm and accounts for 50%+ of the total endosperm protein. Zein has been used intermittently in a number of industrial applications since becoming commercially available in 1938 but is currently limited to formulations of coating agents for the food and pharmaceutical industries. Zein has long been recognized for its film-forming ability and its use as a bioplastic material is of interest because of its environmental and renewable qualities. Zein is a mixture of several peptides of different molecular weight, solubility, and charge that are named as zein fractions and classified according to their relative mass and solubility as α, γ, ß, and δ-zein. α-Zein, the major fraction (85% of total zein), is soluble in 50%–95% isopropyl alcohol (Wang et al., 2005). The utilization of corn zein as a structural polymer has been actively investigated in the last decades (Park and Chinnan, 1995). Zein films cast from aqueous ethanol solutions were rated as moderately good with respect to mechanical properties and moisture and oxygen barrier properties. Zein films plasticized with oleic acid have exhibited tensile and moisture-barrier properties that make them potentially useful as biodegradable packaging materials (Rakotonirainy et al., 2001).

7.1.2.4 Soy Protein

Since the 1960s, soy protein products have been used as nutritional and functional food ingredients in every food category available to the consumer. Recently, soy protein is being used as an ingredient for elaborating edible coatings. The content of protein from soybeans (38%–44%) is much higher than the protein content of cereal grain (8%–15%). Most of the protein in soybeans is insoluble in water but soluble in dilute-neutral salt solutions (Dhall, 2013). Soy protein consists of two major protein fractions referred to as the 7S (conglycinin, 35%) and 11S (glycinin, 52%) fraction. Edible coatings based on soy protein can be produced in either of two ways: surface film-formation on heated soymilk or film-formation from solutions of soy protein isolates (SPIs) (Gennadios, 2002).

7.1.3 Lipids

Because of their apolar nature, hydrophobic lipidic substances are used in fruit coatings mainly as a barrier against moisture migration and to improve surface appearance (Lin and Zhao, 2007). Lipid components commonly used in coatings include natural waxes (e.g., carnauba wax, beeswax, candelilla wax), acylglycerols, and fatty acids. Additionally, some authors include shellac, which is a natural resin, as an ingredient of natural coatings for fruits that are not consumed with peel such as citrus fruits, even though it is not included in the GRAS ingredient list, to provide gloss to food surfaces. Each hydrophobic substance has its own physicochemical properties, and, thus, edible films based on lipids have variable behavior against moisture transfer (Morillon et al., 2002). Lipid compounds include neutral lipids of glycerides, which are esters of glycerol and fatty acids, and the waxes, which are esters of long-chain monohydric alcohols and fatty acids.

Wax was the first edible coating used on fruits, with the Chinese applying wax coatings to oranges and lemons in the 12th and 13th centuries. Although the Chinese did not realize that the full function of edible coatings was to slow down respiratory gas exchange, they found that wax-coated fruits could be stored longer than non-waxed fruits (Park, 1999).

7.2 EFFECTS OF EDIBLE COATINGS ON FRUIT PROPERTIES

7.2.1 Effect on Fruit Physiology

The quality of fruit is determined by a wide range of characteristics such as nutritional value, organoleptic quality, processing, and shelf-life. Fruits are classified as climacteric and nonclimacteric, with climacteric fruits characterized by an increased rate of respiration and ethylene production early in the ripening process, while in nonclimacteric fruits those changes do not occur. However, in both types of fruits, parameters related to fruit quality change during postharvest storage and marketing, leading to limited storability and shelf-life. The main postharvest changes are in taste, aroma, skin color, firmness, as well as weight-loss due to transpiration. The physiological and biochemical activities involved in fruit-ripening and senescence can be delayed by a range of postharvest treatments (Valero and Serrano, 2010), including the use of edible coatings. Edible coatings maintain the quality of fruit and vegetables by forming a film over the produce, which then serves as a partial barrier to gas transmission and, thereby, creates a modified atmosphere around the commodity that affects fruit physiology and biochemistry.

The data in Table 7.1 summarizes the findings from a wide range of published studies on the effect of various edible coatings on ethylene production, respiration

TABLE 7.1
Effects of Edible Coatings on Ethylene Production, Respiration Rate and Weight Loss in Climacteric Fruit

Climacteric Fruit	Edible Coating	C_2H_4	Respir	Wt. Loss	Reference
Sapote	Wax	↑	↑	↓	Ergun et al. (2005)
Apple–Fuji	Shellac	↓	↓	↓	Hagenmaier (2005)
Red delicious	Shellac	o	↓	↓	Hagenmaier (2005)
Gala	Alginate	ND	ND	↓	Olivas et al. (2007)
Avocado	Methylcellulose	ND	↓	↓	Maftoonazad and Ramaswamy (2005)
Plum	HPMC—Lipid	ND	ND	o	Pérez-Gago et al. (2002)
	Whey Protein	ND	ND	↓	Reinoso et al. (2008)
	Aloe spp.	↓	↓	↓	Guillén et al. (2013)
	Versasheen™	↓	↓	↓	Eum et al. (2009)
	Alginate	↓	↓	↓	Valero et al. (2013)
	A. vera + Rosehip oil	↓	↓	↓	Paladines et al. (2014)
Mango	Semperfresh™	↓	o	↓	Dang et al. (2008)
	A. vera	↓	o	o	Dang et al. (2008)
	Carnauba	↓	↓	↓	Dang et al. (2008)
Tomato	Zein, Alginate	↓	↓	↓	Zapata et al. (2008)
	Gum Arabic	ND	ND	↓	Ali et al. (2010)
	Gum Arabic	↓	↓	↓	Ali et al. (2013)
	A. vera	ND	ND	↓	Athmaselvi et al. (2013)
	A. vera, Shellac	↓	↓	↓	Chauhan et al. (2013)
Nectarine	*A. vera*	↓	↓	↓	Ahmed et al. (2009)
	A. vera	↓	↓	↓	Navarro et al. (2011)
	A. vera + Rosehip oil	↓	↓	↓	Paladines et al. (2014)
Peach	*Aloe* spp.	↓	↓	↓	Guillén et al. (2013)
	A. vera + Rosehip oil	↓	↓	↓	Paladines et al. (2014)

Note: Attribute was decreased (↓), increased (↑), unaffected (o), or was not determined (ND) in each study.

TABLE 7.2
Effects of Edible Coatings on Respiration Rate and Weight Loss in Nonclimacteric Fruit

Nonclimacteric Fruit	Edible Coating	Respir	Wt. Loss	Reference
Strawberry	Wheat gluten	ND	↓	Tanada-Palmu and Grosso (2005)
	Starch	ND	↓	García et al. (1998), Mali and Grossmann (2003)
	Chitosan	ND	↓	Han et al. (2004), Gol et al. (2013)
	CMC, HPMC	ND	↓	Gol et al. (2013)
Bell pepper	Candelilla wax	o	↓	Hagenmaier (2005)
Raspberry	Chitosan	↓	↓	Han et al. (2004)
Sweet cherry	Chitosan acetate	↓	↓	Dang et al. (2010)
	Alginate	↓	↓	Díaz-Mula et al. (2012)
	A. vera	↓	↓	Martínez-Romero et al. (2006)
	A. vera + Rosehip oil	↓	↓	Paladines et al. (2014)
Sour cherry	*Aloe vera*	↓	↓	Ravanfar et al. (2014)
Mandarin	HPMC - Lipid	↓	↓	Pérez-Gago et al. (2002)
Pomegranate	Starch	↓	↓	Oz and Ulukanli (2012)
Table grape	*A. vera*	↓	↓	Valverde et al. (2005), Castillo et al. (2010)
	Chitosan	↓	↓	Shiri et al. (2013)

Note: Attribute was decreased (↓), unaffected (o), or was not determined (ND) in each study.

rate and weight loss in a wide range of climacteric fruit. It is clear that the different coatings with polysaccharide, protein, or lipid constituents induced a reduction in ethylene production and respiration rate, as well as a delay in ripening during storage. In addition, the edible coatings were effective in reducing weight loss, resulting in net benefit from an economic perspective. Similarly, Table 7.2 shows the effect of different coatings on reducing respiration rate and weight loss in nonclimacteric fruits, which also achieved maintenance of quality attributes during storage.

7.2.2 EFFECT ON ORGANOLEPTIC QUALITY

In recent years, there is an increasing consciousness of quality, particularly in relation to the effect of eating fruit on the health of consumers; this greatly demands research activities with regard to the production of defined quality, the preservation of quality during marketing, as well as the evaluation of quality parameters and integrating this into the production processes (Valero and Serrano, 2010). The term “quality” is related to the degree of excellence and absence of defects of a fresh produce, which implies either sensory attributes (appearance, color, texture, flavor, and aroma), nutritive (chemical components used to obtain energy), and functional properties (vitamins and other nonnutrient phytochemicals). Shewfelt (1999) suggested that the inherent produce characteristics determine quality, but consumer acceptability is determined by their perception and satisfaction. Thus, quality can be oriented to the produce or to the consumer point of view. It is well documented that during postharvest storage, there is deterioration in fruit quality, primarily affecting the following traits: color, firmness, content of total soluble solids (TSS), and total acidity (TA). The application of edible coatings could modulate changes in these above mentioned parameters and, in turn, extend the marketability and shelf-life of these perishable commodities.

With respect to firmness, Figure 7.1 shows published data on the effect of different edible coatings on a range of fruit species stored at different temperatures. In general, fruit with edible coatings showed higher retention of firmness as compared with control fruit, although the effect was dependent on fruit type, storage temperature, and type of coating. For example, in strawberries that were stored at 11°C for eight days, hydroxypropylmethylcellulose (HPMC) was more effective than carboxymethyl cellulose (CMC) on retaining firmness (Gol et al., 2013). Similarly, in tomato, the most effective coating was gum Arabic followed by zein, while smaller differences were observed when *A. vera* and starch were used as coatings (Zapata et al., 2008; Ali et al., 2010, 2013; Chauhan et al., 2013). However, *A. vera* was very effective in reducing loss of firmness in nectarine, sweet cherry, and table grape (Valverde et al., 2005; Martínez-Romero et al., 2006; Ahmed et al., 2009; Navarro

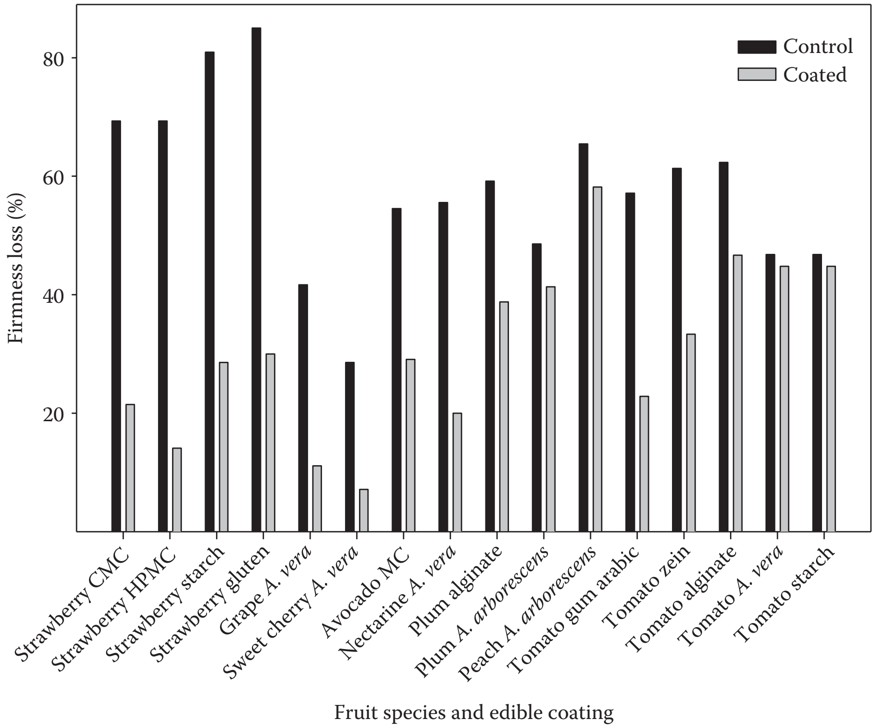

FIGURE 7.1 Firmness loss in fruit with an edible coating and control and after storage. (Charts were prepared from data given in references cited in Tables 7.1 and 7.2.)

et al., 2011). It is well-known that cell-wall hydrolytic enzymes cause dramatic loss of firmness in fruit tissues, the most important being polygalacturonase (PG), cellulase (CL), pectinmethylesterase (PME), and α and β-galactosidases (GAL), among others (Valero and Serrano, 2010), and, thus, reduction in activity of these enzymes would lead to reduced postharvest softening. For example, chitosan, as an edible coating, becomes bound to pectin and thus prevents access of PG to the substrate and maintains firmness in papaya (González-Aguilar et al., 2009). Cellulase activity has been also reduced in carambola fruit treated with chitosan, gum Arabic, and alginate, as well as PME and β-GAL activities (Gol et al., 2013). On the other hand, edible coatings can be used to modify the internal atmosphere of fruits and, in turn, delay senescence (Rojas-Grau et al., 2009). Edible coatings create a passive modified atmosphere that can influence various changes in fresh fruits, such as firmness, and, in the case of climacteric fruit, inhibit ethylene production (Falguera et al., 2011).

Color change is another important parameter related to organoleptic quality; and loss of quality can be measured objectively by increases in HunterLab a/b parameter and decreases in b, Chroma, and Hue angle. Figure 7.2 shows some examples of change in these color parameters and its relation to coating type and fruit species during postharvest storage. From Figure 7.2 it can be inferred that, in general, the application of

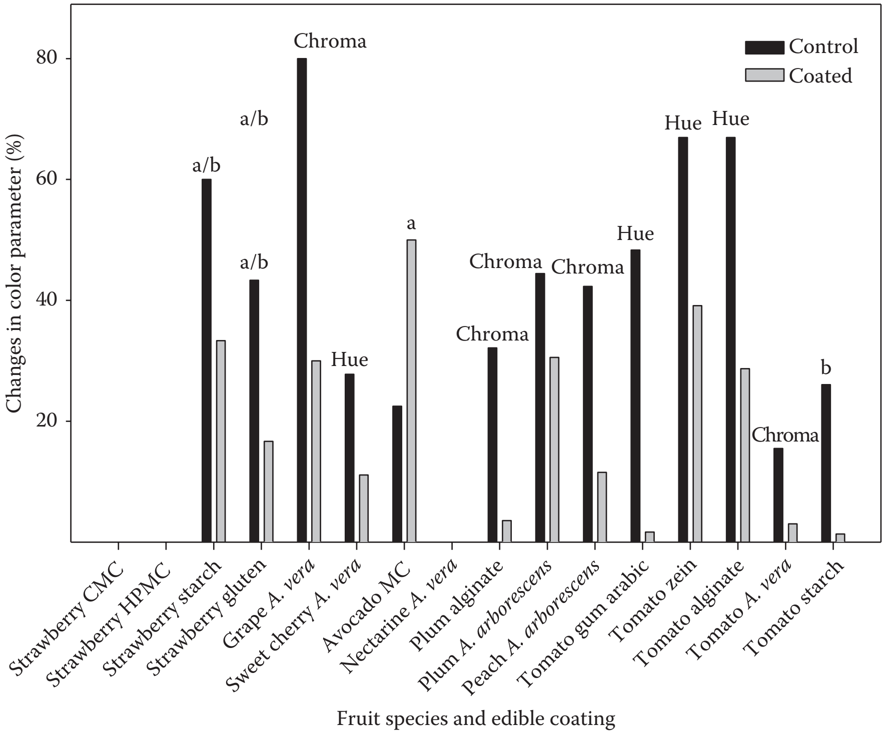

FIGURE 7.2 Color changes as Hunter Lab parameters in fruit with an edible coating and control and after storage. (Charts were prepared from data given in references cited in Tables 7.1 and 7.2.)

different edible coatings led to less changes in the color parameter, although efficacy depended on type of coating, fruit species, and storage conditions. For instance, the Chroma index increased a 80% in control table grapes, and ≅40% in plum and peach and only 18% in tomato, while these increases were much lower in fruits treated with different coatings such as *Aloe vera* or *A. arborescens* gel or alginate (Valverde et al., 2005; Athmaselvi et al., 2013; Guillén et al., 2013; Valero et al., 2013).

The levels of sugars and organic acids are important in determining the taste of ripe fleshy fruit, and the relative content of these constituents depends on the activity and the interaction of sugar and acid metabolism (Valero and Serrano, 2010). TA usually decreases in the fruit flesh during postharvest storage; this is attributed to organic acids being substrates for the respiratory metabolism in detached produce. As can be seen in Figure 7.3, all fruit experienced acidity losses during storage, the magnitude being dependent on fruit species, ranging from 10% in tomato to 70% in peach. However, in general, the different coatings led to reductions in acidity losses, the higher effect being found in tomato and plum coated with alginate and also in plum and peach coated with *A. arborescens* (Zapata et al., 2008; Guillén et al., 2013; Valero et al., 2013).

During postharvest, there is also a general increase in the content of TSS, as has been reported for nectarines, apricots, kiwifruits, and strawberries (Valero and

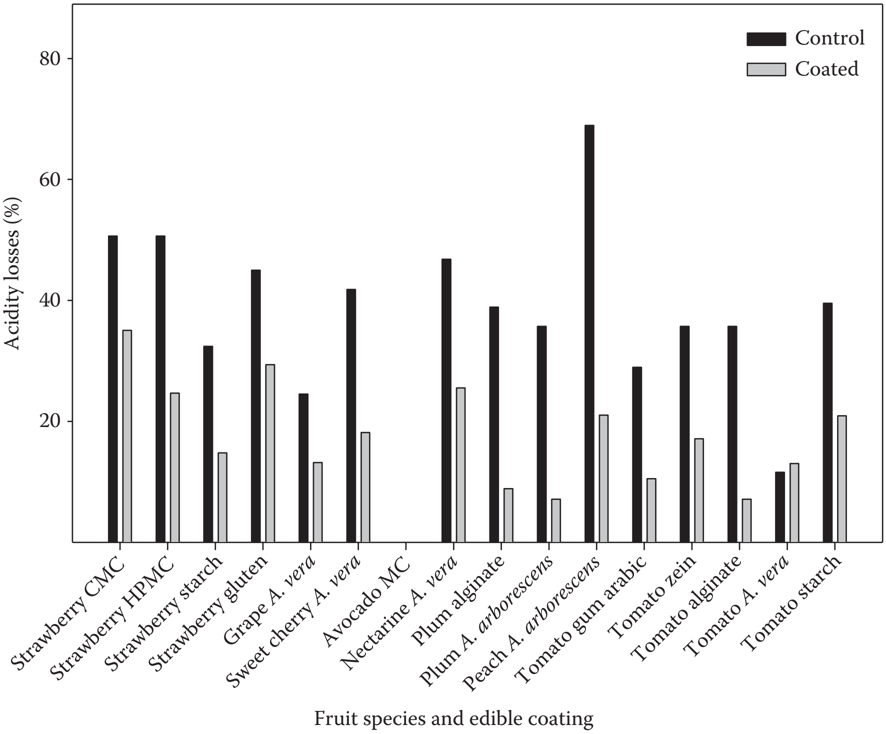

FIGURE 7.3 Acidity loss in fruit with an edible coating and control and after storage. (Charts were prepared from data given in references cited in Tables 7.1 and 7.2.)

Serrano, 2010). This increase in soluble solids is much higher in fruits that accumulate larger amounts of starch during development on the plant, such as mango or bananas. The application of edible coatings on fruit generally leads to lower increases in TSS, such as in strawberry coated with starch, CMC or HPMC (García et al., 1998; Mali and Grossmann, 2003; Gol et al., 2013) and in tomato coated with gum Arabic or starch (Ali et al., 2010; Das et al., 2013), as a consequence of a delay in the postharvest ripening process. However, in other reports, higher increases in TSS have been found in coated fruit than in controls, such as in wax-coated sapote fruits (Ergun et al., 2005) and in zein, alginate or *A. vera* gel-coated tomatoes (Zapata et al., 2008; Athmaselvi et al., 2013).

7.2.3 Effect on Fruit Bioactive Compounds and Antioxidant Activity

Fruits contain hundreds of nonnutrient constituents with significant biological activity, generally called "bioactive compounds" or phytochemicals, which have antioxidant activity and protective effects against several chronic diseases associated to aging, including atherosclerosis, cardiovascular diseases, cancer, cataracts, increased blood pressure, ulcerous, neurodegenerative diseases, brain and immune dysfunction, and even against bacterial and viral diseases. These bioactive compounds vary widely in chemical structure and function in plant tissues and are grouped in vitamins (C and E), carotenoids, phenolics, and thiols (Asensi-Fabado and Munné-Bosch, 2010; Baldrick et al., 2011; Brewer, 2011; Serrano et al., 2011; Li et al., 2012; Valero and Serrano, 2013).

No general tendency has been found for the changes in bioactive compounds during fruit storage. Thus, loss of compounds beneficial to health, such as phenolics and ascorbic acid, has been found in apples, table grapes, and pomegranates, while increases in phytochemicals have been observed in sweet cherry and plum cultivars (Díaz-Mula et al., 2009; Serrano et al., 2009, 2011). Figure 7.4 shows published examples in which the content of total phenolics decreased during storage, and the beneficial effects of the different coatings reduced these phenolic losses. Interestingly, tomato coated with gum Arabic showed increases in total phenolics while they decreased in control fruit (Ali et al., 2010, 2013).

Similar behavior was found for total antioxidant activity (Figure 7.4) with lower losses in chitosan-coated pomegranate, pear and blueberry than in controls (Duan et al., 2011; Ghasemnezhad et al., 2013; Kou et al., 2014) and even TAA increased in sweet cherry and tomato coated with alginate and gum Arabic, respectively, more than in control fruits (Díaz-Mula et al., 2012; Ali et al., 2013).

7.3 EDIBLE COATINGS WITH NATURAL ANTIMICROBIAL COMPOUNDS

In recent years, new edible films and coatings are being formulated with the addition of natural antimicrobial compounds for application onto fresh and minimally processed fruit commodities. This system constitutes an environment-friendly technology and improves the mechanical handling properties that may enhance food quality, safety, stability, by providing a semi-permeable barrier to water vapor, oxygen, and

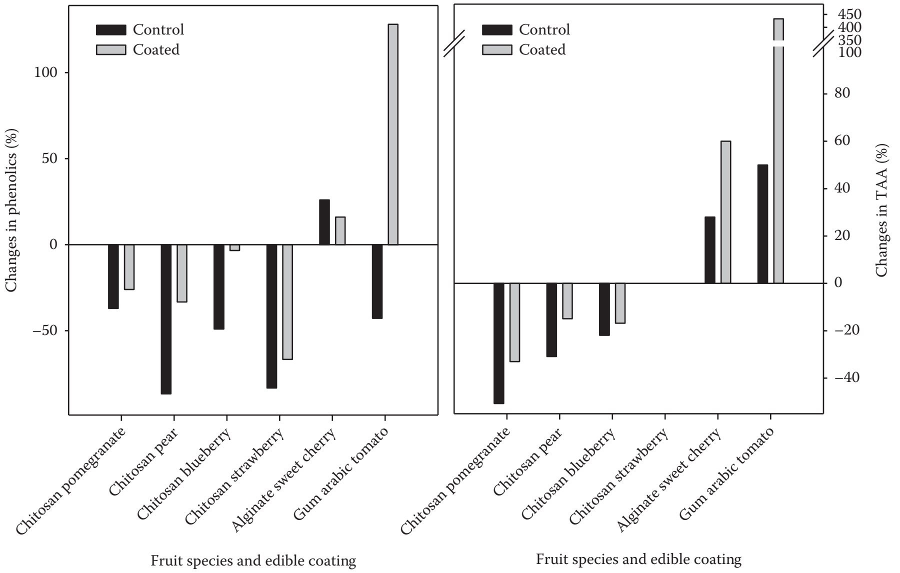

FIGURE 7.4 Changes in total phenolics or total antioxidant activity (TAA) in fruit with an edible coating and control, and after storage. (Charts were prepared from data given in references cited in Tables 7.1 and 7.2.)

carbon dioxide, between the fruit and the surrounding atmosphere, with increased antimicrobial properties (Valencia-Chamorro et al., 2011). There is a wide range of naturally-occurring compounds that exhibit antimicrobial activity, including chitosan, polypetides, and essential oils or spice extracts. As already stated, chitosan is a polysaccharide that shows antimicrobial activity, which has been attributed to its positive charges that would interfere with the negatively charged residues of macromolecules on the cell surface, rendering membrane leakage (Sebti et al., 2007). Most of the antimicrobials proposed to be used in the formulation of coatings must inhibit the spoilage microorganisms (bacteria and fungi) and reduce the food-borne pathogens. In recent years, there is a trend to select the antimicrobials from natural sources and to use generally GRAS compounds, in order to satisfy consumer demands for healthy foods, free of chemical additives (Campos et al., 2011).

The essential oils (EOs) have these characteristics. EOs or the so called volatile or ethereal oils are aromatic oily liquids obtained from plant organs: flower, bud, seed, leave, twig, bark, herb wood fruit, and root (Serrano et al., 2008). Natural compounds that also possess antioxidant effects have been extracted from plants that belong to genus *Thymus*, *Origanum*, *Syzygium*, *Mentha*, and *Eucalyptus* (Burt, 2004). Chemical composition of EOs is complex and strongly dependent on the part of the plant considered (e.g., seed vs. leaves), the moment of harvest (before, during, or after flowering), the harvesting season and the geographical sources. Major components in EOs are phenolic substances, which are thought to be responsible for the antimicrobial properties, and many of them are classified as GRAS (Campos et al., 2011). The antimicrobial activity of the EOs can be attributed to their content of monoterpenes that, due to their lipophilic character, act by disrupting the integrity of microbial cytoplasmic membrane. Lipophilic compounds accumulate in the lipid bilayer according to its specific partition coefficient, leading to disruption of the membrane structure (Liolios et al., 2009).

Table 7.3 gives some examples of different coatings on several whole fruits, in which improvement of coating efficacy was achieved by the incorporation of some natural antimicrobial compounds, such as EOs from different plant origin. The most studied parameter was the contamination of different microorganisms such as bacteria (*E.coli*, *Salmonella* spp. and *S. aureus*) and fungal species (*Penicillium*, *Rhizopus* and *Botrytis*). Apart from the antimicrobial activity, the combined use of the edible coatings with natural antimicrobials was also effective in improving the parameters related to organoleptic and functional quality. As an example, tomato coated with zein at 10% plus the addition of EO_S (thymol, carvacrol, and eugenol at 75 µL/L) exhibited a reduced rate of color-change than control tomatoes coated with zein alone after nine days of storage at 10°C (Figure 7.5). The effect was attributed to the reported antioxidant properties of EOs leading to a delay of the postharvest ripening process (Serrano et al., 2008). Accordingly, the addition

TABLE 7.3
Improvement of Coating Efficacy with the Addition of Natural Antimicrobial Compounds

Fruit	Edible Coating	Natural Antimicrobial	Effects	Reference
Blueberry	Chitosan 2%	Phenolics from blueberry extracts	Reduced decay and increased phenolics	Yang et al. (2014)
Pepper, Apple	Pullulan 10%	Summer savory herb	Inhibited growth of Gram-positive and Gram-negative bacteria and *P. expansum*	Kraśniewska et al. (2014)
Strawberry	Alginate 2%	Carvacrol, Methyl Cinnamate	Inhibited *E. coli* and *B. cinerea*	Peretto et al. (2014)
Apple	Cassava starch 2%	Cinnamom or fennel	Inhibited *S. aureus* and *Salmonella*	Oriani et al. (2014)
Plum	Carnauba wax	Lemongrass oil	Inhibited *Salmonella* and *E. coli*, reduced ethylene and improved quality	Kim et al. (2013)
Orange	Chitosan	Tea tree oil	Reduced *P. italicum* growth	Cháfer et al. (2012)
Tomato	Chitosan (1%)	Lime essential oil	Inhibited *Rhizopus stolonifer* and *E. coli*	Ramos-García et al. (2012)
Table grape	Chitosan or HPMC	Bergamot oil	Reduced microbial counts	Sánchez-González et al. (2011)
Lemon	Wax	Carvacrol or thymol	Reduced *P. digitatum*, respiration and acidity loss	Pérez-Alfonso et al. (2012), Castillo et al. (2014)

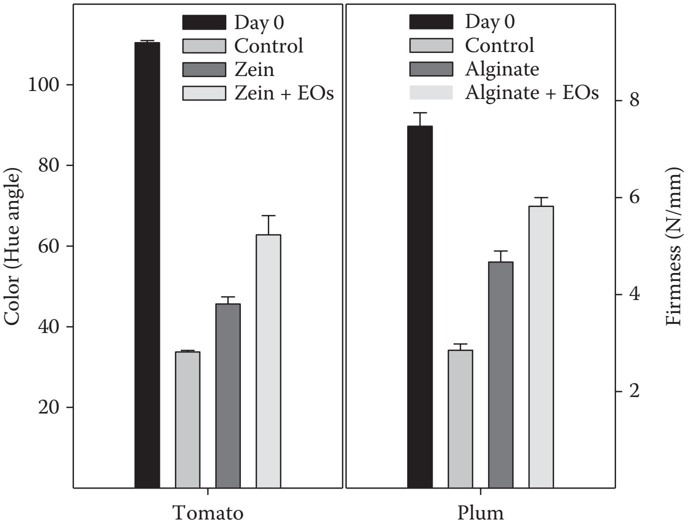

FIGURE 7.5 Color (Hue angle) after nine days' storage of tomatoes coated with zein at 10% or zein + essential oils (EOs), and fruit firmness of plums coated with 3% or alginate + EOs (Serrano and Valero, unpublished data). Data are the mean ± SE.

of these EOs to alginate led to reduced softening, since firmness of plums after 15 days of storage at 2°C was significantly higher in alginate + EOs coated plums compared with alginate alone or controls, for which an accelerated softening process occurred (Figure 7.5).

7.4 CONCLUDING REMARKS

The use of edible coatings for preservation of whole fruit is a matter of high interest taking into account the increasing number of research reports on this issue. For each particular fruit, the design of an appropriate coating formulation is essential for assuring the quality and safety during postharvest storage. The proper selection of an edible coating will depend on the respiration and transpiration rates of the commodity and on the environmental conditions of the storage area. Edible coatings can protect perishable fruits from deterioration during storage by retarding weight loss, reducing respiration rate and ethylene production, improving texture and other quality parameters, and reducing microbial contamination. Many of the polysaccharide-based and protein-based coatings, especially those with inherent antimicrobial or antifungal activities such as chitosan, are attracting more interest as substitutes for traditional lipid coatings.

Edible coatings are effective as a barrier to respiratory gas exchange and water vapor. The efficacy of edible coatings depends on the coating, type and characteristics of the fruit, type of coating, and storage conditions (temperature and duration). More research is needed in order to get a better understanding of the relationship between the internal atmosphere produced by the edible coating and the physiological changes in fruits during storage that will influence the final quality of the coated product. The coatings used for one fruit cultivar may not be appropriate for another since each fruit is different in peel resistance, gas diffusion, and fruit respiration rate among other attributes. One advantage of using edible coatings is that several active compounds can be incorporated into the polymer matrix and consumed with the food, such as the use of natural antimicrobial compounds. In this sense, a new generation of edible coatings is being currently developed allowing the incorporation of EOs for controlling spoiling microorganism and thus enhancing the safety of coated fresh fruits. Finally, sensory evaluation and consumer acceptability tests need to be conducted during the storage of coated fruit.

REFERENCES

Ahmed MJ, Singh Z, Khan AS. 2009. Postharvest *Aloe vera* gel-coating modulates fruit ripening and quality of ‘Arctic Snow’ nectarine kept in ambient and cold storage. *Int J Food Sci Technol* 44: 1024–1033.

Ali A, Maqbool M, Alderson PG, Zahid N. 2013. Effect of gum Arabic as an edible coating on antioxidant capacity of tomato (*Solanum lycopersicum* L.) fruit during storage. *Postharv Biol Technol* 76: 119–124.

Ali A, Maqbool M, Ramachandran S, Alderson PG. 2010. Gum Arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruit. *Postharv Biol Technol* 58: 42–47.

Asensi-Fabado MA, Munné-Bosch S. 2010. Vitamins in plants: Occurrence, biosynthesis and antioxidant function. *Trends Plant Sci* 15: 582–592.

Athmaselvi KA, Sumitha P, Revathy B. 2013. Development of *Aloe vera*-based edible coating for tomato. *Int Agrophys* 27: 369–375.

Baldrick FR, Woodside JV, Elborn S, Young IS, Mckinley MC. 2011. Biomarkers of fruit and vegetable intake in human intervention studies: A systematic review. *Crit Rev Food Sci Nutrit* 51: 795–815.

Bourtoom T. 2008. Edible films and coatings: Characteristics and properties. *Int Food Res J* 15: 237–248.

Brewer MS. 2011. Natural antioxidants: Sources, compounds, mechanisms of action, and potential applications. *Comprehensive Rev Food Sci Food Safety* 10: 221–247.

Burt S. 2004. Essential oils: Their antibacterial properties and potential applications in foods—A review. *Int J Food Micro* 94: 223–253.

Campos CA, Gerschenson LN, Flores SK. 2011. Development of edible films and coatings with antimicrobial activity. *Food Bioprocess Technol* 4: 849–875.

Castillo S, Navarro D, Zapata PJ, Guillén F, Valero D, Serrano M, Martínez-Romero D. 2010. Antifungal efficacy of *Aloe vera in vitro* and its use as a preharvest treatment to maintain postharvest table grape quality. *Postharv Biol Technol* 57: 183–188.

Castillo S, Pérez-Alfonso CO, Martínez-Romero D, Guillén F, Serrano M, Valero D. 2014. The essential oils thymol and carvacrol applied in the packing lines avoid lemon spoilage and maintain quality during storage. *Food Control* 35: 132–136.

Cháfer M, Sánchez-González L, González-Martínez C, Chiralt A. 2012. Fungal decay and shelf-life of oranges coated with chitosan and bergamot, thyme, and tea tree essential oils. *J Food Sci* 77: E182–E187.

Chauhan OP, Nanjappa C, Ashok N, Ravi N, Roopa N, Raju PS. 2013. Shellac and *Aloe vera* gel-based surface coating for shelf-life extension of tomatoes. *J Food Sci Technol* (in press).

Cisneros-Zevallos L, Krochta JM. 2002. Internal modified atmospheres of coated fresh fruits and vegetables: Understanding relative humidity effects. *J Food Sci* 67: 1990–1995.

Cisneros-Zevallos L, Krochta JM. 2003. Dependence of coating thickness on viscosity of coating solution applied to fruits and vegetables by dipping method. *J Food Sci* 68: 503–510.

Dang KTH, Singh Z, Swinny EE. 2008. Edible coatings influence fruit ripening, quality, and aroma biosynthesis in mango fruit. *J Agric Food Chem* 56: 1361–1370.

Dang QF, Yan JQ, Li Y, Cheng XJ, Liu CS, Chen XG. 2010. Chitosan acetate as an active coating material and its effects on the storing of *Prunus aviu*m L. *J Food Sci* 75: S125–S131.

Das DK, Dutta H, Mahanta CL. 2013. Development of a rice starch-based coating with antioxidant and microbe-barrier properties and study of its effect on tomatoes stored at room temperature. *LWT Food Sci Technol* 50: 272–278.

Dhall RK 2013 Advances in edible coatings for fresh fruits and vegetables: A Review. *Crit Rev Food Sci Nutrit* 53: 435–450.

Díaz-Mula HM, Serrano M, Valero D. 2012. Alginate coatings preserve fruit quality and bioactive compounds during storage of sweet cherry fruit. *Food Bioprocess Technol* 5: 2990–2997.

Díaz-Mula HM, Zapata PJ, Guillén F, Martínez-Romero D, Castillo S, Serrano M, Valero D. 2009. Changes in hydrophilic and lipophilic antioxidant activity and related bioactive compounds during postharvest storage of yellow and purple plum cultivars. *Postharv Biol Technol* 51: 354–363.

Duan J, Wu R, Strik BC, Zhao Y. 2011. Effect of edible coatings on the quality of fresh blueberries (Duke and Elliott) under commercial storage conditions. *Postharv Biol Technol* 59: 71–79.

Dutta PK, Tripathi S, Mehrotra GK, Dutta J. 2009. Perspectives for chitosan-based antimicrobial films in food applications. *Food Chem* 114: 1173–1182.

ED. 1995. Directiva 95/2/CE del Parlamento Europeo y del Consejo de 20 de febrero de 1995 relativa a aditivos alimentarios distintos de los colorantes y edulcorantes (http://ec.europa.eu/food/fs/sfp/addit_flavor/flav11_en.pdf, Accessed 06-10-2014).

ED. 1998. Directiva 98/72/CE del Parlamento Europeo y del Consejo de 15 de octubre de 1998 relativa a aditivos alimentarios distintos de los colorantes y edulcorantes (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1998:295:0018:0030:EN:PDF, Accessed 06-10-2014).

Elmanan M, Al-Assaf S, Philips GO, Williams PA. 2008. Studies of Acacia exudates gums: Part IV. Interfacial rheology of *Acacia senegal* and *Acacia seyal*. *Food Hydrocolloids* 22: 682–689.

Ergun M, Sargent SA, Fox AJ, Crane JH, Huber DJ. 2005. Ripening and quality responses of mamey sapote fruit to postharvest wax and 1-methylcyclopropene treatments. *Postharv Biol Technol* 36: 127–134.

Eshun K, He Q. 2004. Aloe vera: A valuable ingredient for the food, pharmaceutical and cosmetic industries: A review. *Critic Rev Food Sci Nutrit* 44: 91–96.

Eum HL, Hwang DK, Linke M, Lee SK, Zude M. 2009. Influence of edible coating on quality of plum (*Prunus salicina* Lindl. cv. ‘Sapphire’). *Eur Food Res Technol* 229: 427–434.

Falguera V, Quintero JP, Jiménez A, Aldemar Muñoz J, Ibarz A. 2011. Edible films and coatings: Structures, active functions and trends in their use. *Trends Food Res Technol* 22: 292–303.

FDA 21CFR172. 2006. Food additives permitted for direct addition to food for human consumption, Subpart C. Coatings, Films and Related Substances (http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfCFR/CFRSearch.cfm?CFRPart=172, Accessed 06-10-2014).

Ferrari CC, Sarantópoulos CIGL, Carmello-Guerreiro SM, Hubinger MD. 2013. Effect of osmotic dehydration and pectin edible coatings on quality and shelf-life of fresh-cut melon. *Food Bioprocess Technol* 6: 80–91.

García MA, Martino MN, Zaritzky NE. 1998. Starch-based coatings: Effect on refrigerated strawberry (*Fragaria ananassa*) quality. *J Sci Food Agric* 76: 411–420.

Gennadios A. 2002. *Protein-based Films and Coatings*. CRC, Boca Raton FL.

Ghasemnezhad M, Zareh S, Rassa M, Sajedi RH. 2013. Effect of chitosan coating on maintenance of aril quality, microbial population and PPO activity of pomegranate (*Punica granatum* L. cv. Tarom) at cold storage temperature. *J Sci Food Agric* 93: 368–374.

Gol NB, Patel PR, Rao TVR. 2013. Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. *Postharv Biol Technol* 85: 185–195.

González-Aguilar GA, Valenzuela-Soto E, Lizardi-Mendoza J, Goicoolea F, Martínez-Telez MA, Villegas-Ochoa MA, Monory-García I, Ayala-Zabala JF. 2009. Effect of chitosan coating in preserving deterioration and preserving quality of fresh cut papaya “Maradol”. *J Sci Food Agric* 89: 15–23.

Guillén F, Díaz-Mula HM, Zapata PJ, Valero D, Serrano M, Castillo S, Martínez-Romero D. 2013. *Aloe arborescens* and *Aloe vera* gels as coatings in delaying postharvest ripening in peach and plum fruit. *Postharv Biol Technol* 83: 54–57.

Hagenmaier RD. 2005. A comparison of ethane, ethylene and CO_2 peel permeance for fruit with different coatings. *Postharv Biol Technol* 37: 56–64.

Hamman JH. 2008. Composition and applications of *Aloe* vera leaf gel. *Molecules* 13: 1599–1616.

Han C, Zhao Y, Leonard SW, Traber MG. 2004. Edible coatings to improve storability and enhance nutritional value of fresh and frozen strawberries (*Fragaria x ananassa*) and raspberries (*Rubus ideaus*). *Postharv Biol Technol* 33: 67–78.

Khwaldia K, Pérez C, Banon S, Desobry S, Hardy JS. 2004. Milk proteins for edible films and coatings. *Crit Rev Food Sci Nutrit* 44: 239–251.

Kim IH, Lee H, Kim JE, Song KB, Lee YS, Chung DS, Min SC. 2013. Plum coatings of lemongrass oil-incorporating carnauba wax-based nanoemulsion. *J Food Sci* 78: E1551–E1559.

Kou XH, Guo WL, Guo RZ, Li XY, Xue ZH. 2014. Effects of chitosan, calcium chloride, and pullulan coating treatments on antioxidant activity in pear cv. “Huang Guan” during storage. *Food Bioprocess Technol* 7: 671–681.

Kraśniewska K, Gniewosz M, Synowiec A, Przybył JL, Baczek K, Weglarz Z. 2014. The use of pullulan coating enriched with plant extracts from *Satureja hortensis* L. to maintain pepper and apple quality and safety. *Postharv Biol Technol* 90: 63–72.

Krochta JM. 2002. Proteins as raw materials for films and coatings: Definitions, current status and opportunity. In: *Protein-Based Films and Coatings* ed. A Gennadios. CRC, Boca Raton, FL, pp. 1–42.

Krochta JM, Mulder-Johnston CD. 1997. Edible and biodegradable polymer films: Challenges and opportunities. *Food Technol* 51: 61–74.

Li H, Tsao R, Deng Z. 2012. Factors affecting the antioxidant potential and health benefits of plant foods. *Can J Plant Sci* 92: 1101–1111.

Lin D, Zhao Y. 2007. Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables. *Comprehensive Rev Food Sci Food Safety* 6: 60–75.

Liolios CC, Gortzi O, Lalas S, Tsaknis J, Chinou I. 2009. Liposomal incorporation of carvacrol and thymol isolated from the essential oil of *Origanum dictamnus* L. and *in vitro* antimicrobial activity. *Food Chem* 112: 77–83.

Maftoonazad N, Ramaswamy HS. 2005. Postharvest shelf-life extension of avocados using methyl cellulose-based coating. *LWT Food Sci Technol* 38: 617–624.

Mali S, Grossmann MVE. 2003. Effects of yam starch films on storability and quality of fresh strawberries (*Fragaria ananassa*). *J Agric Food Chem* 51: 7005–7011.

Martínez-Romero D, Alburquerque N, Valverde JM, Guillén F, Castillo S, Valero D, Serrano M. 2006. Postharvest sweet cherry quality and safety maintenance by *Aloe vera* treatment: A new edible coating. *Postharv Biol Technol* 39: 93–100.

Moalemiyan M, Ramaswamy HS, Maftoonazad N. 2011. Pectin-based edible coating for shelf-life extension of Ataulfo mango. *J Food Process Eng* 35: 572–600.

Morillon V, Debeaufort F, Blond G, Capelle M, Voilley A. 2002. Factors affecting the moisture permeability of lipid-based edible films: A Review. *Crit Rev Food Sci Nutrit* 42: 67–89.

Navarro D, Díaz-Mula HM, Guillén F, Zapata PJ, Castill S, Serrano M, Valero D, Martínez-Romero D. 2011. Reduction of nectarine decay caused by *Rhizopus stolonifer*, *Botrytis cinerea* and *Penicillium digitatum* with *Aloe vera* gel alone or with the addition of thymol. *Int J Food Micro* 151: 241–246.

Nisperos-Carriedo MO. 1994. Edible coatings and films based on polysaccharides. In: *Edible Coatings and Films to Improve Food Quality* eds. JM Krochta, EA Baldwin, MO Nisperos-Carriedo, Technomic Publishing, Lancaster, PA, pp. 322–323.

No HK, Meyers SP, Prinyawiwatkul W, Xu Z. 2007. Applications of chitosan for improvement of quality and shelf-life of foods: A review. *J Food Sci* 72: R87–R100.

Olivas GI, Mattinson DS, Barbosa-Cánovas GV. 2007. Alginate coatings for preservation of minimally processed 'Gala' apples. *Postharv Biol Technol* 45: 89–96.

Oriani VB, Molina G, Chiumarelli M, Pastore GM, Hubinger M. 2014. Properties of cassava starch-based edible coating containing essential oils. *J Food Sci* 79: E189–E194.

Oz AT, Ulukanli Z. 2012. Application of edible starch-based coating including glycerol plus oleum Nigella on arils from long-stored whole pomegranate fruits. *J Food Process Preserv* 36: 81–95.

Paladines D, Valero D, Valverde JM, Díaz-Mula HM, Serrano M, Martínez-Romero D. 2014. The addition of rosehip oil improves the beneficial effect of *Aloe vera* gel on delaying ripening and maintaining postharvest quality of several stone fruit. *Postharv Biol Technol* 92: 23–28.

Park HJ. 1999. Development of advanced edible coatings for fruits. *Trends Food Res Technol* 10: 254–260.

Park HJ, Chinnan MS. 1995. Gas and water vapor barrier properties of edible films from protein and cellulosic materials. *J Food Eng* 25: 497–507.

Peretto G, Du WX, Avena-Bustillos RJ, Berrios JDJ, Sambo P, McHugh TH. 2014. Optimization of antimicrobial and physical properties of alginate coatings containing carvacrol and methyl cinnamate for strawberry application. *J Agric Food Chem* 62: 984–990.

Pérez-Alfonso CO, Martínez-Romero D, Zapata PJ, Serrano M, Valero D, Castillo S. 2012. The effects of essential oils carvacrol and thymol on growth of *Penicillium digitatum* and *P. italicum* involved in lemon decay. *Int J Food Micro* 158: 101–106.

Pérez-Gago MB, Rojas C, Del Río MA. 2002. Effect of lipid type and amount of edible hydroxypropyl methylcellulose-lipid composite coatings used to protect postharvest quality of mandarins cv. fortune. *J Food Sci* 67: 2903–2910.

Rakotonirainy AM, Wang Q, Padua GW. 2001. Evaluation of zein films as modified atmosphere packaging for fresh broccoli. *J Food Sci* 66: 1108–1111.

Ramos-García M, Bosquez-Molina E, Hernández-Romano J, Zavala-Padilla G, Terrés-Rojas E, Alia-Tejacal I, Barrera-Necha L, Hernández-López M, Bautista-Baños S. 2012. Use of chitosan-based edible coatings in combination with other natural compounds, to control *Rhizopus stolonifer* and *Escherichia coli* DH5α in fresh tomatoes. *Crop Prot* 38: 1–6.

Ravanfar R, Niakousari M, Maftoonazad N. 2014. Postharvest sour cherry quality and safety maintenance by exposure to Hot-water or treatment with fresh Aloe vera gel. *J Food Sci Technol* (in press)

Reinoso E, Mittal GS, Lim LT. 2008. Influence of whey protein composite coatings on plum (*Prunus domestica* L.) fruit quality. *Food Bioprocess Technol* 1: 314–325.

Rojas-Grau MA, Soliva-Fortuny R, Martín-Belloso O. 2009. Edible coatings to incorporate active ingredients to fresh cut fruits: A review. *Trends Food Res Technol* 20: 438–447.

Sánchez-González L, Pastor C, Vargas M, Chiralt A, González-Martinez C, Chafer M. 2011. Effect of hydroxypropylmethylcellulose and chitosan coatings with and without bergamot essential oil on quality and safety of cold-stored grapes. *Postharv Biol Technol* 60: 57–63.

Sebti I, Chollet E, Degraeve P, Noel C, Peyrol E. 2007. Water sensitivity, antimicrobial, and physicochemical analyses of edible films based on HPMC and/or chitosan. *J Agric Food Chem* 55: 693–699.

Serrano M, Díaz-Mula HM, Valero D. 2011. Antioxidant compounds in fruits and vegetables and changes during postharvest storage and processing. *Stewart Postharv Rev* 2011: 1:1.

Serrano M, Díaz-Mula HM, Zapata PJ, Castillo S, Guillén F, Martínez-Romero D, Valverde JM, Valero D. 2009. Maturity stage at harvest determines the fruit quality and antioxidant potential after storage of sweet cherry cultivars. *J Agric Food Chem* 57: 3240–3246.

Serrano M, Martínez-Romero D, Guillén F, Valverde JM, Zapata PJ, Castillo S, Valero D. 2008. The addition of essential oils to MAP as a tool to maintain the overall quality of fruits. *Trends Food Res Technol* 19: 464–471.

Shahidi F, Arachchi JKV, Jeon YJ. 1999. Food applications of chitin and chitosans. *Trends Food Res Technol* 10: 37–51.

Shiri MA, Ghasemnezhad M, Bakhshi D, Sarikhani H. 2013. Effect of postharvest putrescine application and chitosan coating on maintaining quality of table grape cv. "shahroudi" during long-term storage. *J Food Process Preserv* 37: 999–1007.

Shewfelt RL. 1999. What is quality? *Postharv Biol Technol* 15: 197–200.

Sime WJ. 1990. Alginates. In: *Food Gels* ed. P Harris, Elsevier, London pp. 53–58.

Steenkamp V, Stewart MJ. 2007. Medicinal applications and toxicological activities of *Aloe* products. *Pharmaceut Biol* 45: 411–420.

Tanada-Palmu PS, Grosso CRF. 2005. Effect of edible wheat gluten-based films and coatings on refrigerated strawberry (*Fragaria ananassa*) quality. *Postharv Biol Technol* 36: 199–208.

Tharanathan RN. 2003. Biodegradable films and composite coatings: Past, present and future. *Trends Food Res Technol* 14: 71–78.

Valencia-Chamorro SA, Palou L, Del Río MA, Pérez-Gago MB. 2011. Antimicrobial edible films and coatings for fresh and minimally processed fruits and vegetables: A Review. *Crit Rev Food Sci Nutrit* 51: 872–900.

Valero D, Díaz-Mula M, Zapata PJ, Guillén F, Martínez-Romero D, Castillo S, Serrano M. 2013. Effects of alginate edible coating on preserving fruit quality in four plum cultivars during postharvest storage. *Postharv Biol Technol* 77: 1–6.

Valero D, Serrano M. 2010. *Postharvest Biology and Technology for Preserving Fruit Quality*. CRC-Taylor & Francis, Boca Raton, FL.

Valero D, Serrano M. 2013. Growth and ripening stage at harvest modulates postharvest quality and bioactive compounds with antioxidant activity. *Stewart Postharv Rev* 3: 7.

Valverde JM, Valero D, Martínez-Romero D, Guillén F, Castillo S, Serrano M. 2005. Novel edible coating based on *Aloe vera* gel to maintain table grape quality and safety. *J Agric Food Chem* 53: 7807–7813.

Wang Y, Lopes Filho F, Geil P, Padua GW. 2005. Effects of processing on the structure of zein/oleic acid films investigated by X-ray diffraction. *Mol Biosci* 5: 1200–1208.

Yang G, Yue J, Gong X, Qian B, Wang H, Deng Y, Zhao Y. 2014. Blueberry leaf extracts incorporated chitosan coatings for preserving postharvest quality of fresh blueberries. *Postharv Biol Technol* 92: 46–53.

Zapata PJ, Guillén F, Martínez-Romero D, Castillo S, Valero D, Serrano M. 2008. Use of alginate or zein as edible coatings to delay postharvest ripening process and to maintain tomato (*Solanum lycopersicon* Mill) quality. *J Sci Food Agric* 88: 1287–1293.

Zapata PJ, Navarro D, Guillén F, Castillo S, Martínez-Romero D, Valero D, Serrano M. 2013. Characterisation of gels from different *Aloe* spp. as antifungal treatment: Potential crops for industrial application. *Indust Crops Products* 42: 223–230.