14 Edible Coatings

Henriette Monteiro Cordeiro de Azeredo

CONTENTS

14.1 INTRODUCTION

Considerable attention has been given to edible food packaging, which is intended to be an integral part of and to be eaten with the food product; thus, they are also inherently biodegradable (Krochta, 2002). The increasing interest and research activity in edible packaging have been motivated by both increasing consumer demand for safe, convenient, and stable foods and also awareness of the negative environmental impacts of nonbiodegradable packaging waste. Although the terms *edible films* and *edible coatings* are sometimes referred to as synonyms, there is a difference in that films are preformed separately and then applied to food surface or sealed into edible pouches, whereas coatings are formed directly onto food surfaces.

Edible films and coatings have similar functions as those of conventional packaging, acting as barriers against water vapor, gases, and flavor compounds and improving structural integrity and mechanical-handling properties of foods. Although edible films and coatings are not meant to entirely replace conventional packaging, the efficiency of food protection can be enhanced by combining primary edible packaging and secondary nonedible packaging. Although the basic functions of edible coatings are similar to those of conventional packaging, their use requires

an external packaging because of handling and hygienic reasons (Debeaufort et al., 1998). In this context, edible coatings can reduce conventional packaging requirements and waste, since they are able to improve overall food quality, to extend shelf life, and to improve economic efficiency of packaging materials.

Materials used for edible coatings are usually not as effective as petroleum-derived polymers in terms of mechanical and barrier properties. However, such properties are not especially important for fruits and vegetables, since a moderate gas permeation is required in order to allow the product to maintain respiration rates at a minimum but not negligible level.

According to Guilbert and Biquet (1986), wax coatings have been used to delay dehydration of citrus fruits in China since the twelfth century. However, only in the 1930s have emulsions of oils or waxes in water been developed to be spread on fruit surfaces to improve their appearance, as well as control the ripening process, and to retard water loss (Debeaufort et al., 1998).

Coating fruits is not yet a common process in the food industry. Industrial fruit coating consists mostly in keeping fruits in motion (e.g., by vibration or rolling) and simultaneously applying the coating dispersion so that the fruits are exposed to it. Spray coating is the most commonly used technique for applying food coatings, including a batch tank and spraying nozzles to deposit the coating dispersion on food pieces as they move over a conveyor roller (Debeaufort and Voilley, 2009), which should drive them to a drying step. For coating dispersions with high viscosities, screw or drum coaters are more indicated.

This chapter presents a review of developments in edible coatings and their applications for fresh and minimally processed (fresh-cut) fruits.

14.2   REQUIREMENTS FROM A COATING MATERIAL

The characteristics required from an edible coating depend on the specific requirements of the product to be coated, including the primary degradation modes to which it is most susceptible. Fresh and minimally processed fruits have complex requirements concerning packaging systems, since such products are still metabolically active. The main requirements for a fruit coating are described in the following:

1. Moderately low permeability to oxygen and carbon dioxide in order to slow down respiration and overall metabolic activity, retarding ripening and its related changes. On the other hand, the metabolic activity must not be reduced to a degree that creates anaerobic conditions, which promote physiological disorders and accelerate quality loss (Kester and Fennema, 1986; Debeaufort et al., 1998). Edible coatings for fruits should control the ripening by reducing oxygen penetration in the fruit rather than by decreasing CO_2 and ethylene evaporation rates, that is to say, the CO_2/O_2 permeability ratio (related to selectivity) should be as high as possible. Proteins and polysaccharide coatings present much higher ratios (from 10 to 25) than those of conventional plastic films (lower than 5.73) (Debeaufort et al., 1998). The decreased metabolic activity provided by edible coatings has also been known to retard softening changes (Conforti and Zinck, 2002;
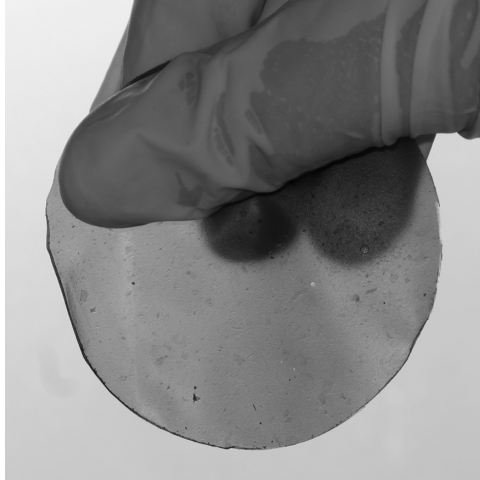
FIGURE 14.1 Sample of an edible film from acerola puree and alginate.

Zhou et al., 2011), which result from the loss of turgor pressure and degrada-
tion of cell walls, contributing to a decrease in fruit brittleness and firmness
(Zhou et al., 2008). The degradation of cell wall structure has been attrib-
uted to activity of enzymes such as pectin methylesterase, cellulase, and
polygalacturonase on polysaccharides present in the cell wall (Goulao and
Oliveira, 2008).

2. Low water vapor permeability in order to retard desiccation (Garcia and
Barret, 2002). In the case of minimally processed fruits, this is espe-
cially difficult, since the product surface usually has a very high water
activity, which tends to decrease the performance of hydrophilic coatings
(Hagenmaier and Shaw, 1992).

3. Sensory inertness or compatibility. Edible coatings were traditionally sup-
posed to be tasteless so would not interfere with the flavor of the product
(Contreras-Medellin and Labuza, 1981). Alternatively, they may have sensory
properties compatible with those of the food. For instance, fruit purees have
been studied as film-forming edible materials (McHugh et al., 1996; Senesi
and McHugh, 2002; Rojas-Graü et al., 2006, 2007a; Azeredo et al., 2009)
which can be used as edible coatings for fruits due to the presence of film-
forming polysaccharides in their compositions. Figure 14.1 presents a photo-
graph of an edible film elaborated with acerola puree and alginate.

14.3 CHEMICAL COMPOSITION OF EDIBLE COATINGS AND THEIR APPLICATIONS TO FRUITS

Edible films and coatings may be classified according to the kind of material from
which they are derived. Each chemical class has its inherent properties, advantages,
and limitations for being used as films.

14.3.1 Polysaccharide-Based Coatings

Polysaccharides are long-chain biopolymers formed from mono- or disaccharide repeating units linked by glycosidic bonds. They are widely available and usually have low cost. Most polysaccharides are neutral, although some gums are negatively charged. As a consequence of the large number of hydroxyl and other polar groups in their structure, hydrogen bonds play important roles in film formation and characteristics. Negatively charged gums, such as alginate, pectin, and carboxymethyl cellulose (CMC), tend to present some different properties depending on the pH (Han and Gennadios, 2005).

Polysaccharide films are usually formed by disrupting interactions among polymer segments during coacervation and forming new intermolecular hydrophilic and hydrogen bonds upon evaporation of the solvent (Janjarasskul and Krochta, 2010). Because of their hydrophilicity, polysaccharide films provide a good barrier to CO_2 and O_2; hence, they retard respiration and ripening of fruits (Cha and Chinnan, 2004). On the other hand, similarly to other hydrophilic materials, their polarity determines their poor barrier to water vapor (Park and Chinnan, 1995) as well as their sensitivity to moisture, which may affect their functional properties (Janjarasskul and Krochta, 2010).

14.3.1.1 Starches

Starches are polymers of D-glucopyranosyl, consisting of a mixture of the predominantly linear amylose and the highly branched amylopectin (Figure 14.2). Native starch molecules arrange themselves in semicrystalline granules in which amylose and amylopectin are linked by hydrogen bonding. When heat is applied to native starch in presence of water, the granules swell and hydrate, which triggers the "gelatinization" process, characterized by the loss of crystallinity and molecular order, followed by a dramatic increase in viscosity (Kramer, 2009).

Amylose responds to the film-forming capacity of starches, since it forms cohesive and relatively strong films (Han et al., 2006). On the other hand, amylopectin films are brittle and noncontinuous, since its branch-to-branch structure interferes with intermolecular associations, disrupting film formation (Peressini et al., 2003).
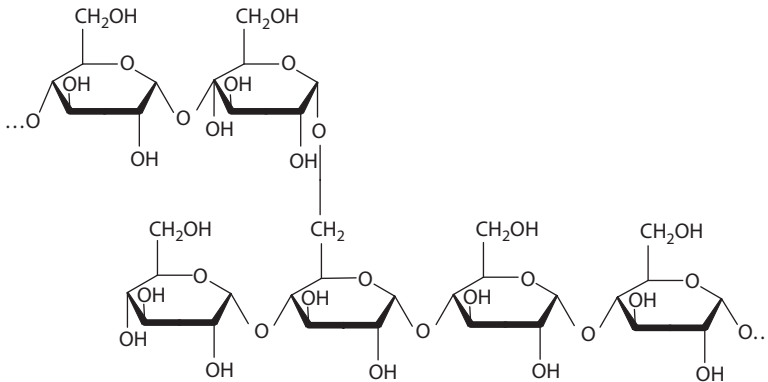

FIGURE 14.2 Chemical structure of a starch fragment.

Indeed, García et al. (1998), comparing quality of strawberries coated with starches from different sources, observed a significant effect of amylose content on color, weight loss, and firmness of coated strawberries.

Application of starch films is limited by two major drawbacks. The films are often very brittle, requiring the presence of plasticizers to improve their flexibility (Peressini et al., 2003; Mali et al., 2004). Moreover, the high hydrophilicity of starch causes its barrier properties to decrease with increasing relative humidity; therefore, starch is not the best option when working with minimally processed fruits (Olivas and Barbosa-Cánovas, 2009).

### 14.3.1.2   Cellulose and Its Derivatives

Together with starch, cellulose and its derivatives (such as ethers and esters) are the most important raw materials for elaboration of edible films (Peressini et al., 2003). Cellulose, the most abundant natural polymer on earth, is an essentially linear natural polymer of (1→4)-β-D-glucopyranosyl units (Figure 14.3). Its tightly packed polymer chains and highly crystalline structure make it insoluble in water. Water solubility can be conferred by etherification; the water-soluble cellulose ethers, including methyl cellulose (MC), hydroxypropyl cellulose (HPC), hydroxypropyl-methyl cellulose (HPMC), and CMC, have good film-forming properties (Cha and Chinnan, 2004; Janjarasskul and Krochta, 2010). An MC coating has been demonstrated to retard softening and to reduce respiration rates of avocados (Maftoonazad and Ramaswamy, 2005).

14.3.1.3   Anionic Polysaccharides

Pectins are water-soluble anionic heteropolysaccharides composed mainly of (1→4)-α-D-galactopyranosyluronic acid units, in which some carboxyl groups of galacturonic acid are esterified with methanol (Figure 14.4). High-methoxyl pectins (HMPs) have a degree of esterification (DE) above 50%, whereas low-methoxyl
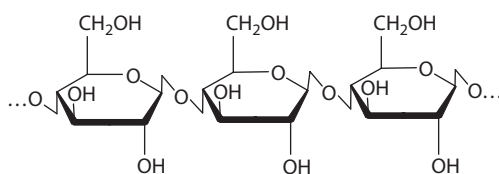
FIGURE 14.3   Chemical structure of cellulose.
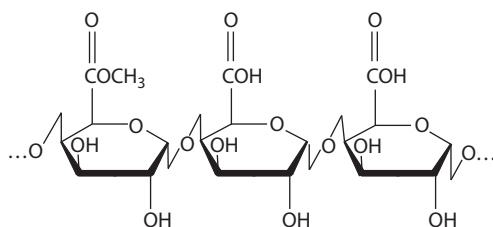
FIGURE 14.4   A fragment of pectin containing esterified and nonesterified carboxyl groups of galacturonic acid.
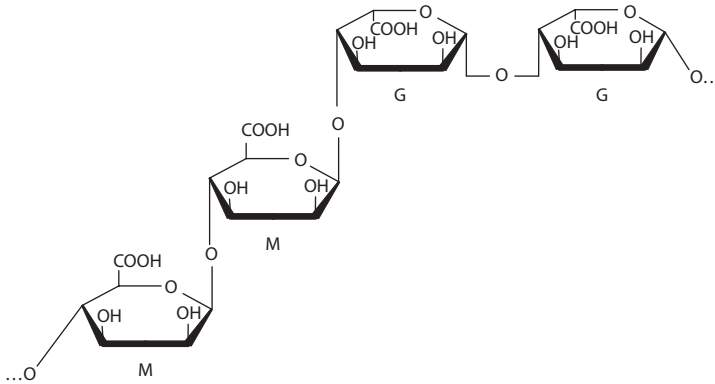
FIGURE 14.5 Basic structure of alginates, containing units of *mannuronic* (M) and *guluronic* (G) acids.

pectin (LMP) has a DE below 50%. The ratio of esterified to nonesterified galacturonic acid determines the behavior of pectin in food applications, since it affects solubility and gelation properties of pectin (Baldwin et al., 1995). HMP forms gels with sugar and acid, whereas LMP forms gels in the presence of divalent cations such as Ca^{2+}, which links adjacent LMP chains via ionic interactions, forming a tridimensional network (Janjarasskul and Krochta, 2010).

Alginates, which are extracted from brown seaweeds, are salts of alginic acid, a linear copolymer of D-mannuronic and L-guluronic acid monomers (Figure 14.5), containing homogeneous poly-*mannuronic* and poly-*guluronic* acid blocks (M and G blocks, respectively) and MG blocks containing both uronic acids. These highly anionic polysaccharides suffer instantaneous gel formation by reacting with di- or trivalent cations, similarly to LMP. Calcium ions, especially effective, have been applied as gelling agents (Cha and Chinnan, 2004). Calcium ions pull alginate chains together via ionic interactions, after which interchain hydrogen bonding occurs (Kester and Fennema, 1986). Films can be formed either from evaporating water from an alginate gel or by a two-step procedure involving drying of alginate solution followed by treatment with a calcium salt solution to induce cross-linking (Janjarasskul and Krochta, 2010). The strength and permeability of films may be altered by changing calcium concentration and temperature, among other factors (Kester and Fennema, 1986). Apples previously immersed in calcium chloride and coated with alginate presented lower weight loss, softening, and browning when compared to untreated fruits (Olivas et al., 2007).

14.3.1.4 Chitosan

Chitosan, a linear polysaccharide consisting of β (1→4) linked residues of *N*-acetyl-2-amino-2-deoxy-D-glucose (glucosamine) and 2-amino-2-deoxy-D-glucose (*N*-acetylglucosamine) (Figure 14.6), produced by partial deacetylation of chitin, presents a cationic character which confers unique properties on this polysaccharide, such as antimicrobial activity and the ability to carry and slow-release functional ingredients (Coma et al., 2002). Chitosan coatings were effective in extending shelf life of
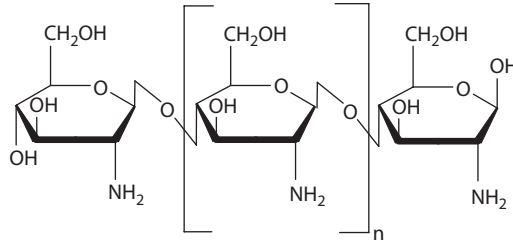
FIGURE 14.6   Chemic structure of chitosan.

several fruits; reducing rates of water loss (Dong et al., 2004; Hernández-Muñoz et al., 2006; Chien et al., 2007; Lin et al., 2011), ascorbic acid loss (Dong et al., 2004; Chien et al., 2007), softening (Ali et al., 2011), and enzymatic browning (Dong et al., 2004; Jiang et al., 2005); and delaying the ripening process by decreasing respiration rates (Ali et al., 2011; Lin et al., 2011). Moreover, they were reported to have retarded microbial growth in fruit surfaces (Hernández-Muñoz et al., 2006; Chien et al., 2007; Campaniello et al., 2008). The polycationic structure of chitosan probably interacts with the predominantly anionic components (lipopolysaccharides, proteins) of microbial cell membranes, especially Gram-negative bacteria (Helander et al., 2001).

14.3.1.5   Some Novel Polysaccharide Coatings

Ali et al. (2010) evaluated the performance of a novel coating based on gum arabic on tomato fruits. When compared to uncoated fruits, tomatoes coated with 10% gum arabic presented significant lower rates of changes in weight, color, firmness, titratable acidity, soluble solids content, ascorbic acid content, and decay percentage. Maqbool et al. (2010) observed that, although gum arabic alone has not presented antifungal effects against *Colletotrichum musae* (the causal agent of anthracnose) in bananas, composite coatings obtained from combining gum arabic with chitosan presented better antifungal effects when compared to chitosan alone. However, the authors did not present an explanation for the observed synergistic effect of gum arabic and chitosan.

Some new edible coatings have been obtained from mucilages, which are heteropolysaccharides obtained from plant stems. Prickly pear cactus mucilage as an edible coating was demonstrated to have extended shelf life of strawberries, retarding their softening (Del-Valle et al., 2005). *Aloe vera* mucilage, composed mainly by polysaccharides, has been used as a coating for grapes (Valverde et al., 2005) and sweet cherries (Martínez-Romero et al., 2006), retarding their respiration and ripening rates, softening, weight loss, and color changes.

14.3.2   PROTEIN-BASED COATINGS

Proteins are linear, random copolymers built from up to 20 different monomers. The main mechanism of formation of protein films involves denaturation of the protein initiated by heat, solvents, or change in pH, followed by association of peptide chains through new intermolecular interactions (Janjarasskul and Krochta, 2010).

While hydroxyl is the only reactive group in polysaccharides, proteins may be involved in several possible interactions and chemical reactions (Hernandez-Izquierdo and Krochta, 2008), such as chemical reactions through covalent (peptide and disulfide) bonds and noncovalent (ionic, hydrogen, and van der Waals) interactions. Moreover, hydrophobic interactions may occur between nonpolar groups of amino acid chains (Kokini et al., 1994).

The most peculiar properties of proteins compared to other film-forming materials are denaturation, electrostatic charges, and amphiphilic character. Protein conformation can be affected by many factors, such as charge density and hydrophilic–hydrophobic balance (Han and Gennadios, 2005). Proteins have good film-forming properties and good adherence to hydrophilic surfaces (Baldwin et al., 1995). Protein-derived films provide good barriers to O_2 and CO_2 but not to water (Cha and Chinnan, 2004). Their barrier and mechanical properties are impaired by moisture owing to their inherent hydrophilic nature (Janjarasskul and Krochta, 2010).

Gelatin is a substantially pure protein food ingredient, obtained by a mild heat treatment of collagen under acidic or alkaline conditions, when collagen is partially denatured, but recovers part of its triple helix structure upon cooling. On dehydration, films are formed with irreversible conformational changes (Badii and Howell, 2006; Dangaran et al., 2009).

Total bovine milk proteins consist of about 80% casein and 20% whey proteins. Edible films and coating from casein, whey proteins, and total milk proteins have been reported. Simple milk protein films provide good barriers to gases because of their complex intermolecular bindings (Chen, 1995). Caseinate films are water soluble, although the use of a buffer solution at the pI of casein results in water-insoluble films (Krochta et al., 1990). Avena-Bustillos and Krochta (1993) observed that barrier properties of casein may be enhanced by cross-linking with calcium ions or by adjusting its pH to the isoelectric point. Coatings from both calcium caseinate (Le Tien et al., 2001) and whey proteins (Le Tien et al., 2001; Pérez-Gago et al., 2003) delayed browning of apples, which was attributed to the oxygen barrier of the coatings and/or to its antioxidative properties (Pérez-Gago et al., 2003). Whey protein coatings enhanced the appearance of plums by creating glossy surfaces and improved their firmness (Reinoso et al., 2008).

Zein, the prolamin (alcohol-soluble) fraction of corn protein, has been used in coating formulations (Cha and Chinnan, 2004). Zein coatings are usually prepared by dissolving zein in aqueous ethyl alcohol (Ghanbarzadeh et al., 2007). Zein is rich in nonpolar amino acids, with low proportions of basic and acidic amino acids. Its consequent water insolubility favors the water vapor barrier of its films (Dangaran et al., 2009).

Wheat gluten is composed mainly of gliadins and glutenins (alkali- and acid-soluble) fractions. Gliadin, the viscous component, constitutes a heterogeneous protein group characterized by single polypeptide chains associated by hydrogen bonding and hydrophobic interactions, having intramolecular disulfide bonds. Glutenins form an extensive network of intermolecular disulfide bonds (Hernández-Muñoz et al., 2003). Because gluten is water insoluble, a complex solvent system with basic or acidic conditions in the presence of alcohol and disulfide bond-reducing agents is required to prepare casting solutions (Cuq et al., 1998). Strawberries with gluten coatings presented lower weight loss and softening when compared to uncoated ones (Tanada-Palmu and Grosso, 2005).

14.3.3 Lipid Coatings

Unlike other macromolecules, lipids are not biopolymers, being not able to form cohesive, self-supporting films. So, they are either used as coatings or incorporated into biopolymers to form composite films, providing a good water vapor barrier, thanks to their low polarity (Greener and Fennema, 1989).

Lipid-based edible films have variable behavior against moisture transfer, depending on their particular properties. Polarity of lipids depends on the distribution of chemical groups, the length of aliphatic chains, and the presence and degree of unsaturation (Morillon et al., 2002). Unsaturated fatty acids are less efficient to control moisture transfer because of their higher polarity when compared to saturated ones. Indeed, Hagenmaier and Baker (1997) observed that coatings containing stearic or palmitic acids were more efficient to reduce desiccation of oranges than those with oleic acid.

Waxes are esters of long-chain aliphatic acids with long-chain aliphatic alcohols (Rhim and Shellhammer, 2005). They are more resistant to water diffusion than most other edible film materials because of their very low content of polar groups (Kester and Fennema, 1986) and their high content in long-chain fatty alcohols and alkanes (Morillon et al., 2002). There are a variety of naturally occurring waxes, derived from vegetables (e.g., carnauba, candelilla, and sugar cane waxes), minerals (e.g., paraffin and microcrystalline waxes), or animals—including insects (e.g., beeswax, lanolin, and wool grease)—while some other waxes are synthetically produced, such as carbowaxes and polyethylene wax (Rhim and Shellhammer, 2005).

Triglycerides or neutral lipids are esters of fatty acids with glycerol. Mono- and ditriglycerides (partial esters) can also be used as coating materials. Their functional properties, especially water vapor permeability, are dependent on their chemical structures. Long-chain triglycerides are insoluble in water, whereas short-chain molecules are partially water soluble. Unsaturated fatty acids have significantly lower melting points and increased moisture transfer rates than the corresponding saturated ones (Rhim and Shellhammer, 2005). Branching of acyl chain also results in increased water vapor permeability because of the increased mobility of hydrocarbon chains and less efficient lateral packing of acyl chains (Janjarasskul and Krochta, 2010).

Acetic acid esters of monoglycerides, called acetylated monoglycerides, have been also used as food-coating materials. Their moisture barrier tends to improve with increasing degree of acetylation, possibly because of removal of hydrophilic hydroxyl groups. According to Bourlieu et al. (2008), there are certain inconveniences about their use, such as undesirable aftertaste and the tendency of highly saturated acetylated monoglycerides to crack and flake during storage.

14.3.4 Composite Coatings

Multicomponent or composite coatings are usually made to explore the complementary advantages of each component as well as to minimize their disadvantages. Most composite coatings associate a hydrophobic compound (often lipids) and a hydrophilic structural matrix (Guilbert and Biquet, 1986). Since polysaccharides

and proteins are less permeable than lipids to gases, their presence in coatings is useful to reduce respiration rates and to retard fruit senescence, while lipids reduce desiccation.

Composite films and coatings can be produced as either bilayers or stable emulsions. In bilayer composite films, the lipid forms a second layer over the polysaccharide or protein layer. On the other hand, in emulsion composite films, the lipid is dispersed and entrapped in the supporting biopolymer matrix (Pérez-Gago and Krochta, 2005).

García et al. (2000) demonstrated that lipid addition to starch films decreased their crystalline-amorphous ratio, which is expected to increase film diffusibility and, consequently, permeability. On the other hand, lipid addition also reduces the hydrophilic–hydrophobic ratio of films, which decreases their water solubility and therefore water vapor permeability.

The optimum lipid concentration in the preparation of composite edible coatings should be determined by considering both the effect of decreasing the moisture transfer rate and the physical strength of the films, since excessive levels of some lipid materials can result in the coating becoming brittle (Shellhammer and Krochta, 1997).

A gluten coating reduced softening and weight loss of strawberries, especially when lipids (beeswax, stearic, and palmitic acids) were incorporated. However, the lipid addition impaired the acceptance of the strawberries in terms of appearance and flavor (Tanada-Palmu and Grosso, 2005). Similarly, Vargas et al. (2006) observed that, although the addition of a lipid component (oleic acid) has improved the water vapor resistance of chitosan-coated strawberries, it has decreased their acceptance.

14.4 COATING/FRUIT SURFACE SUITABILITY

Film formation as a coating depends on two types of interaction: cohesion and adhesion. Cohesion is related to attractive forces between molecules of film components, influencing the mechanical strength of films (Guilbert et al., 1996; Sothornvit and Krochta, 2005). The presence of ingredients incompatible with the main biopolymer in the film-forming dispersion causes the cohesion and the film strength to decrease (Han and Gennadios, 2005). Excessive cohesive forces result in brittleness, which may be overcome by addition of plasticizers. Adhesion, by its turn, is related to attractive forces between film and substrate; it is important for film casting and coating processes (Sothornvit and Krochta, 2005). A poor adhesion results in incomplete coating or easy peel-off of a film from the surface (Han and Gennadios, 2005).

For the optimization of a coating solution, the control of adhesion and cohesion coefficients is very important since the former promotes spreading of the liquid whereas the later promotes its contraction (Ribeiro et al., 2007).

The coating procedure involves wetting the fruit surface with a coating solution. An adequate coating solution spreads spontaneously on the fruit surface (Mittal, 1997). However, it is hardly possible to have a coating solution/dispersion perfectly suited to the surface in terms of polarity and surface tension. Then, efforts should be made in order to find the best formulation possible in terms of compatibility with the surface. The interfacial tension between the coating solution and the fruit surface

must be estimated, based on the surface tension of both the surface and the coating solution and the contact angle between both.

Finding a suited coating solution can be a challenge. The lower the surface (or interfacial) tension of a solution, the higher its surface (or interfacial) activity (Gaonkar, 1991). Most solutions are water based, and water has a high surface tension ($72.8 \, \text{dyn cm}^{-1}$), whereas most solid surfaces have lower surface tension (Nussinovitch, 2009). Since an adequate coating involves compatibility between the coating solution and the solid surface, the surface tension of the coating solution must be reduced in order to adjust it to the lower surface tension of the surface, thus lowering the interfacial tension and enhancing adhesion.

Surface-active agents, such as emulsifiers and other amphiphilic chemicals in the film-forming solution, reduce the surface tension of the coating solution, thus decreasing the difference between the solid surface energy and the surface tension of the coating solution and ultimately increasing the work of adhesion (Han and Gennadios, 2005). The surfactant Tween 80 was added to a chitosan coating solution in order to reduce its surface tension and enhance its wettability, improving its adhesion to apple skin (Choi et al., 2002).

Another strategy which can be used to improve compatibility of hydrophilic coatings with fruit surfaces is by means of chemical modification of biopolymers, by introducing hydrophobic groups into their structure. Hydrophobization has been successfully used by Vu et al. (2011) to enhance compatibility of a chitosan coating to strawberry surface.

14.5   ACTIVE COATINGS FOR FRUITS

Besides their function as inert barriers to extend fruit stability, edible coatings can also interact with the coated fruit and/or the surrounding environment in a desirable way, thus constituting an active coating. Active properties of coatings may be related to release of compounds (e.g., antimicrobials and antibrowning agents) which can retard fruit degradation or to absorption/scavenging of undesirable compounds (e.g., ethylene) which might accelerate degradation. Edible coatings have been presented as excellent way to carry additives since they are able to maintain effective concentrations of the additives on the fruit surfaces, where they are mostly needed, reducing the impact of such chemicals on overall acceptability of the fruit (Oms-Oliu et al., 2010).

Incorporating antimicrobial compounds into edible coatings help preserve the quality of fresh-cut fruits, which are more perishable than the corresponding whole fruits, because of the skin removal, favoring microorganisms to invade and grow on product. Since antimicrobials are mostly needed on the product surface, their application on a coating helps minimize antimicrobial usage (Vodjani and Torres, 1990). Antimicrobials most commonly used include organic acids and their salts. Incorporation of malic and lactic acid into soy protein coatings retarded microbial growth on fresh-cut melon (Eswaranandam et al., 2006). Alginate-based edible coatings incorporated with essential oils of cinnamon, palmarosa, and lemongrass have been reported to be more effective to extend the microbiological stability of melons when compared to coatings without the essential oils (Raybaudi-Massilia et al., 2008). On the other hand, the acceptance of melons was decreased by addition of cinnamon oil.

The incorporation of the sulfur-containing amino acids *N*-acetylcysteine and gluta-thione into edible coatings has been shown to reduce microbial growth (Oms-Oliu et al., 2008; Rojas-Graü et al., 2008).

Fresh-cut fruits can also be benefitted by the incorporation of antibrowning agents into edible coatings in order to retard color changes caused by oxidation of phenolic compounds by polyphenol oxidase (PPO) in presence of oxygen. The incorporation of ascorbic acid into edible coatings has been reported to retard enzymatic brown-ing of fruits (Brancoli and Barbosa-Cánovas, 2000; McHugh and Senesi, 2000; Pérez-Gago et al., 2006). The thiol-containing amino acids, *N*-acetylcysteine and glutathione, incorporated into edible coatings, besides reducing microbial growth in fruit surfaces, were also effective to inhibit browning of fresh-cut fruits (Pérez-Gago et al., 2006; Rojas-Graü et al., 2007b, 2008; Oms-Oliu et al., 2008), since they react with quinones formed during the initial phase of enzymatic browning to yield colorless products or to reduce *o*-quinones back to *o*-diphenols (Richard et al., 1992). Edible coatings containing sour whey have been demonstrated to be effective in reducing oxidative browning of cut apples, when compared to other coatings based on milk proteins (Shon and Haque, 2007).

14.6 FINAL CONSIDERATIONS

Edible coatings have demonstrated to be effective to increase stability of a vari-ety of fresh and minimally processed fruits. Despite the great benefits from using edible coatings, commercial applications of this technology on a broad range are still very limited. Enhancement of the water resistance of polysaccharide films is still required, which can be obtained by chemical modification of the biopolymer matrix or incorporation of hydrophobic ingredients. Moreover, mechanical and bar-rier properties of biopolymer films still need improvement. Several studies have tried to improve performance of biopolymers by incorporation of nanostructures such as nanocellulose (Azeredo et al., 2009, 2010) and nanoclays (Mangiacapra et al., 2006; Olabarrieta et al., 2006; Petersson and Oksman, 2006). However, the use of nano-structures in edible coatings still requires careful investigation about their safety, since their size may allow them to penetrate into cells and eventually remain in the human body. Considering evidences supporting that nanoparticles can exhibit differ-ent properties from the corresponding bulk materials, the need for accurate informa-tion on their effects to human health is imperative.

REFERENCES

Ali, A., Maqbool, M., Ramachandran, S., and Alderson, P.G. 2010. Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technology* 58: 42–47.

Ali, A., Muhammad, M.T., Sijam, K., and Siddiqui, Y. 2011. Effect of chitosan coatings on the physicochemical characteristics of Eksotika II papaya (*Carica papaya* L.) fruit during cold storage. *Food Chemistry* 124: 620–626.

Avena-Bustillos, R.J. and Krochta, J.M. 1993. Water vapor permeability of caseinate-based edible films as affected by pH, calcium crosslinking and lipid content. *Journal of Food Science* 58(4): 904–917.

Azeredo, H.M.C., Mattoso, L.H.C., Avena-Bustillos, R.J., Ceotto Filho, G., Munford, M.L., Wood, D., and McHugh, T.H. 2010. Nanocellulose reinforced chitosan composite films as affected by nanofiller loading and plasticizer content. *Journal of Food Science* 75(1): N1–N7.

Azeredo, H.M.C., Mattoso, L.H.C., Wood, D., Williams, T.G., Avena-Bustillos, R.J., and McHugh, T.H. 2009. Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. *Journal of Food Science* 74(5): N31–N35.

Badii, F. and Howell, N.K. 2006. Fish gelatin: Structure, gelling properties and interaction with egg albumen proteins. *Food Hydrocolloids* 20: 630–640.

Baldwin, E.A., Nisperos-Carriedo, M.O., and Baker, R.A. 1995. Edible coatings for lightly processed fruits and vegetables. *HortScience* 30(1): 35–38.

Bourlieu, C., Guillard, V., Vallès-Pamiès, B., and Gontard, N. 2008. Edible moisture barriers for food product stabilization. In *Food Materials Science*, eds. J.M. Aguilera and P.J. Lillford, pp. 547–575. New York: Springer.

Brancoli, N. and Barbosa-Cánovas, G.V. 2000. Quality changes during refrigerated storage of packaged apple slices treated with polysaccharide films. In *Innovations in Food Processing*, eds. G.V. Barbosa-Cánovas and G.W. Gould, pp. 243–254. Lancaster, PA: Technomic.

Campaniello, D., Bevilacqua, A., Sinigaglia, M., and Corbo, M.R. 2008. Chitosan: Antimicrobial activity and potential applications for preserving minimally processed strawberries. *Food Microbiology* 25: 992–1000.

Cha, D.S. and Chinnan, M.S. 2004. Biopolymer-based antimicrobial packaging—A review. *Critical Reviews in Food Science and Nutrition* 44(4): 223–237.

Chen, H. 1995. Functional properties and applications of edible films made of milk proteins. *Journal of Dairy Science* 78: 2563–2583.

Chien, P.J., Sheu, F., and Yang, F.H. 2007. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *Journal of Food Engineering* 78: 225–229.

Choi, W.Y., Park, H.J., Ahn, D.J., Lee, J., and Lee, C.Y. 2002. Wettability of chitosan coating solution on 'Fuji' apple skin. *Journal of Food Science* 67: 2668–2672.

Coma, V., Martial-Gros, A., Garreau, S., Copinet, A., Salin, F., and Deschamps, A. 2002. Edible antimicrobial films based on chitosan matrix. *Journal of Food Science* 67: 1162–1169.

Conforti, F.D. and Zinck, J.B. 2002. Hydrocolloid-lipid coating affect on weight loss, pectin content, and textural quality of green bell peppers. *Journal of Food Science* 67(4): 1360–1363.

Contreras-Medellin, R. and Labuza, T.P. 1981. Prediction of moisture protection requirements for foods. *Cereal Food World* 26(7): 335–343.

Cuq, B., Gontard, N., and Guilbert, S. 1998. Proteins as agricultural polymers for packaging production. *Cereal Chemistry* 75(1): 1–9.

Dangaran, K., Tomasula, P.M., and Qi, P. 2009. Structure and formation of protein-based edible films and coatings. In *Edible Films and Coatings for Food Applications*, eds. M.E. Embuscado and K.C. Huber, pp. 25–56. New York: Springer.

Debeaufort, F., Quezada-Gallo, J.A., and Voilley, A. 1998. Edible films and coatings: Tomorrow's packagings: A review. *Critical Reviews in Food Science* 38: 299–313.

Debeaufort, F. and Voilley, A. 2009. Lipid-based edible films and coatings. In *Edible Films and Coatings for Food Applications*, eds. M.E. Embuscado and K.C. Huber, pp. 135–168. New York: Springer.

Del-Valle, V., Hernández-Muñoz, P., Guarda, A., and Galotto, M.J. 2005. Development of a cactus-mucilage edible coating (*Opuntia ficus indica*) and its application to extend strawberry (*Fragaria ananassa*) shelf-life. *Food Chemistry* 91: 751–756.

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

Eswaranandam, S., Hettiarachchy, N.S., and Meullenet, J.F. 2006. Effect of malic and lactic acid incorporated soy protein coatings on the sensory attributes of whole apple and fresh-cut cantaloupe. *Journal of Food Science* 71: S307–S313.

Gaonkar, A.G. 1991. Surface and interfacial activities and emulsion of some food hydrocolloids. *Food Hydrocolloids* 5: 329–337.

Garcia, E. and Barret, D.M. 2002. Preservative treatments for fresh cut fruits and vegetables. In *Fresh-Cut Fruits and Vegetables*, ed. O. Lamikanra, pp. 267–304. Boca Raton, FL: CRC Press.

García, M.A., Martino, M.N., and Zaritky, N.E. 1998. Starch-based coatings: Effect on refrigerated strawberry (*Fragaria ananassa*) quality. *Journal of the Science of Food and Agriculture* 76(3): 411–420.

García, M.A., Martino, M.N., and Zaritky, N.E. 2000. Lipid addition to improve barrier properties of edible starch-based films and coatings. *Journal of Food Science* 65(6): 941–947.

Ghanbarzadeh, B., Musavi, M., Oromiehie, A.R., Rezayi, K., Razmi, E., and Milani, J. 2007. Effect of plasticizing sugars on water vapour permeability, surface energy and microstructure properties of zein films. *LWT-Food Science and Technology* 40: 1191–1197.

Goulao, L.F. and Oliveira, C.M. 2008. Cell wall modifications during fruit ripening: When a fruit is not the fruit. *Trends in Food Science and Technology* 19(1): 4–25.

Greener, I.K. and Fennema, O. 1989. Barrier properties and surface characteristics of edible, bilayer films. *Journal of Food Science* 54(6): 1393–1399.

Guilbert, S. and Biquet, B. 1986. Technology and application of edible protective films. In *Food Packaging and Preservation*, ed. M. Mathlouthi, pp. 371–394. London, U.K.: Elsevier.

Guilbert, S., Gontard, N., and Gorris, L.G.M. 1996. Prolongation of the shelf life of perishable food products using biodegradable films and coatings. *LWT-Food Science and Technology* 29: 10–17.

Hagenmaier, R.D. and Baker, R.A. 1997. Edible coatings from morpholine-free wax microemulsions. *Journal of Agricultural and Food Chemistry* 45: 349–352.

Hagenmaier, R.D. and Shaw, P.E. 1992. Gas permeability of fruit coating waxes. *Journal of the American Society for Horticultural Science* 117: 105–109.

Han, J.H. and Gennadios, A. 2005. Edible films and coatings: A review. In *Innovations in Food Packaging*, ed. J.H. Han, pp. 239–262. London, U.K.: Elsevier.

Han, J.H., Seo, G.H., Park, I.M., Kim, G.N., and Lee, D.S. 2006. Physical and mechanical properties of pea starch edible films containing beeswax emulsions. *Journal of Food Science* 71(6): E290–E296.

Helander, I.M., Nurmiaho-Lassila, E.L., Ahvenainen, R., Rhoades, J., and Roller, S. 2001. Chitosan disrupts the barrier properties of the outer membrane of Gram-negative bacteria. *International Journal of Food Microbiology* 71(2–3): 235–244.

Hernandez-Izquierdo, V.M. and Krochta, J.M. 2008. Thermoplastic processing of proteins for film formation—A review. *Journal of Food Science* 73: 30–39.

Hernández-Muñoz, P., Almenar, E., Ocio, M.J., and Gavara, R. 2006. Effect of calcium dips and chitosan coatings on postharvest life of strawberries (*Fragaria ananassa*). *Postharvest Biology and Technology* 39: 247–253.

Hernández-Muñoz, P., Kanavouras, A., Ng, P.K.W., and Gavara, R. 2003. Development and characterization of biodegradable films made from wheat gluten protein fractions. *Journal of Agricultural and Food Chemistry* 51(26): 7647–7654.

Janjarasskul, T. and Krochta, J.M. 2010. Edible packaging materials. *Annual Review of Food Science and Technology* 1: 415–448.

Jiang, Y., Li, J., and Jiang, W. 2005. Effects of chitosan coating on shelf life of cold-stored litchi fruit at ambient temperature. *LWT-Food Science and Technology* 38: 757–761.

Kester, J.J. and Fennema, O.R. 1986. Edible films and coatings: A review. *Food Technology* 40: 47–59.

Kokini, J.L., Cocero, A.M., Madeka, H., and de Graaf, E. 1994. The development of state diagrams for cereal proteins. *Trends in Food Science and Technology* 5: 281–288.

Kramer, M.E. 2009. Structure and function of starch-based edible films and coatings. In *Edible Films and Coatings for Food Applications*, eds. M.E. Embuscado and K.C. Huber, pp. 113–134. New York: Springer.

Krochta, J.M. 2002. Protein as raw materials for films and coatings: Definitions, current status, and opportunities. In *Protein-Based Films and Coatings*, ed. A. Gennadios, pp. 1–41. Boca Raton, FL: CRC Press.

Krochta, J.M., Pavlath, A.E., and Goodman, N. 1990. Edible films from casein-lipid emulsions for lightly-processed fruits and vegetables. In *Engineering and Food*, Vol. 2, eds. W.E.L. Spiess, and H. Schubert, pp. 329–340. New York: Elsevier.

Le Tien, C., Vachon, C., Mateescu, M.A., and Lacroix, M. 2001. Milk protein coatings prevent oxidative browning of apples and potatoes. *Journal of Food Science* 66(4): 512–516.

Lin, B., Du, Y., Liang, X., Wang, X., Wang, X., and Yang, J. 2011. Effect of chitosan coating on respiratory behavior and quality of stored litchi under ambient temperature. *Journal of Food Engineering* 102: 94–99.

Maftoonazad, N. and Ramaswamy, H.S. 2005. Postharvest shelf-life extension of avocados using methyl cellulose-based coating. *LWT—Food Science and Technology* 38: 617–624.

Mali, S., Grossmann, M.V.E., García, M.A., Martino, M.M., and Zaritzky, N.E. 2004. Barrier, mechanical and optical properties of plasticized yam starch films. *Carbohydrate Polymers* 56: 129–135.

Mangiacapra, P., Gorrasi, G., Sorrentino, A., and Vittoria, V. 2006. Biodegradable nanocomposites obtained by ball milling of pectin and montmorillonites. *Carbohydrate Polymers* 64: 516–523.

Maqbool, M., Ali, A., Ramachandran, S., Smith, D.R., and Alderson, P.G. 2010. Control of postharvest anthracnose of banana using a new edible composite coating. *Crop Protection* 29: 1136–1141.

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

McHugh, T.H., Huxsoll, C.C., and Krochta, J.M. 1996. Permeability properties of fruit puree edible films. *Journal of Food Science* 61(1): 88–91.

McHugh, T.H. and Senesi, E. 2000. Apple wraps: A novel method to improve the quality and extend the shelf life of fresh-cut apples. *Journal of Food Science* 65: 480–485.

Mittal, K.L. 1997. The role of the interface in adhesion phenomena. *Polymer Engineering and Science* 17: 467–473.

Morillon, V., Debeaufort, F., Blond, G., Capelle, M., and Voilley, A. 2002. Factors affecting the moisture permeability of lipid-based edible films: A review. *Critical Reviews in Food Science and Nutrition* 42(1): 67–89.

Nussinovitch, A. 2009. Biopolymer films and composite coatings. In *Modern Biopolymer Science*, eds. S. Kasapis, I.T. Norton, and J.B. Ubbink, pp. 295–326. London, U.K.: Academic Press.

Olabarrieta, I., Gallstedt, M., Ispizua, I., Sarasua, J.R., and Hedenqvist, M.S. 2006. Properties of aged montmorillonite-wheat gluten composite films. *Journal of Agricultural and Food Chemistry* 54: 1283–1288.

Olivas, G.I. and Barbosa-Cánovas, G. 2009. Edible films and coatings for fruits and vegetables. In *Edible Films and Coatings for Food Applications*, eds. M.E. Embuscado and K.C. Huber, pp. 211–244. New York: Springer.

Olivas, G.I., Mattinson, D.S., and Barbosa-Cánovas, G. 2007. Alginate coatings for preservation of minimally processed 'Gala' apples. *Postharvest Biology and Technology* 45: 89–96.

Oms-Oliu, G., Rojas-Graü, M.A., González, L.A., Varela, P., Soliva-Fortuny, R., Hernando, M.I.H., Munuera, I.P., Fiszman, S., and Martín-Belloso, O. 2010. Recent approaches using chemical treatments to preserve quality of fresh-cut fruit: A review. *Postharvest Biology and Technology* 57: 139–148.

Oms-Oliu, G., Soliva-Fortuny, R., and Martín-Belloso, O. 2008. Edible coatings with anti-browning agents to maintain sensory quality and antioxidant properties of fresh-cut pears. *Postharvest Biology and Technology* 50: 87–94.

Park, H.J. and Chinnan, M.S. 1995. Gas and water vapor barrier properties of edible films from protein and cellulosic materials. *Journal of Food Engineering* 25: 497–507.

Peressini, D., Bravin, B., Lapasin, R., Rizzotti, C., and Sensidoni, A. 2003. Starch–methylcellulose based edible films: Rheological properties of film-forming dispersions. *Journal of Food Engineering* 59(1): 25–32.

Pérez-Gago, M.B. and Krochta, J.M. 2005. Emulsion and bi-layer edible films. In *Innovations in Food Packaging*, ed. J.H. Han, pp. 384–402. London, U.K.: Academic Press.

Pérez-Gago, M.B., Serra, M., Alonso, M., Mateos, M., and del Rio, M.A. 2003. Effect of solid content and lipid content of whey protein isolate-beeswax edible coatings on color change of fresh cut apples. *Journal of Food Science* 68(7): 2186–2191.

Pérez-Gago, M.B., Serra, M., and del Rio, M.A. 2006. Color change of fresh-cut apples coated with whey protein concentrate-based edible coatings. *Postharvest Biology and Technology* 39: 84–92.

Petersson, L. and Oksman, K. 2006. Biopolymer based nanocomposites: Comparing layered silicates and microcrystalline cellulose as nanoreinforcement. *Composites Science and Technology* 66: 2187–2196.

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

Reinoso, E., Mittal, G.S., and Lim, L.T. 2008. Influence of whey protein composite coatings on plum (*Prunus domestica* L.) fruit quality. *Food Bioprocessing and Technology* 1: 314–325.

Rhim, J.W. and Shellhammer, T.H. 2005. Lipid-based edible films and coatings. In *Innovations in Food Packaging*, ed. J.H. Han, pp. 362–383. London, U.K.: Academic Press.

Ribeiro, C., Vicente, A.A., Teixeira, J.A., and Miranda, C. 2007. Optimization of edible coating composition to retard strawberry fruit senescence. *Postharvest Biology and Technology* 44(1): 63–70.

Richard, F.C., Goupy, P.M., and Nicolas, J.J. 1992. Cysteine as an inhibitor of enzymatic browning. 2. Kinetic studies. *Journal of Agricultural and Food Chemistry* 40: 2108–2114.

Rojas-Graü, M.A., Avena-Bustillos, R.J., Friedman, M., Henika, P.R., Martín-Belloso, O., and McHugh, T.H. 2006. Mechanical, barrier, and antimicrobial properties of apple puree edible films containing plant essential oils. *Journal of Agricultural and Food Chemistry* 54: 9262–9267.

Rojas-Graü, M.A., Avena-Bustillos, R.J., Olsen, C., Friedman, M., Henika, P.R., Martín-Belloso, O., Pan, Z., and McHugh, T.H. 2007a. Effects of plant essential oil compounds on mechanical, barrier and antimicrobial properties of alginate-apple puree edible films. *Journal of Food Engineering* 81: 634–641.

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

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

Senesi, E. and McHugh, T.H. 2002. Film e coperture eduli com matrici a base di fruta. *Industrie Alimentari* 41(420): 1289–1294.

Shellhammer, T.H. and Krochta, J.M. 1997. Whey protein emulsion film performance as affected by lipid type and amount. *Journal of Food Science* 62: 390–394.

Shon, J. and Haque, Z.U. 2007. Efficacy of sour whey as a shelf-life enhancer: Use in anti-oxidative edible coatings of cut vegetables and fruit. *Journal of Food Quality* 30(5): 581–593.

Sothornvit, R. and Krochta, J.M. 2005. Plasticizers in edible films and coatings. In *Innovations in Food Packaging*, ed. J.H. Han, pp. 403–433. London, U.K.: Academic Press.

Tanada-Palmu, P.S. and Grosso, C.R.F. 2005. Effect of edible wheat gluten-based films and coatings on refrigerated strawberry (*Fragaria ananassa*) quality. *Postharvest Biology and Technology* 36: 199–208.

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

Vargas, M., Albors, A., Chiralt, A., and González-Martínez, C. 2006. Quality of cold-stored strawberries as affected by chitosan-oleic acid edible coatings. *Postharvest Biology and Technology* 41: 164–171.

Vodjani, F. and Torres, J.A. 1990. Potassium sorbate permeability of methylcellulose and hydroxypropyl methylcellulose coatings: Effect of fatty acids. *Journal of Food Science* 55(3): 841–846.

Vu, K.D., Hollingsworth, R.G., Leroux, E., Salmieri, S., and Lacroix, M. 2011. Development of edible bioactive coating based on modified chitosan for increasing the shelf life of strawberries. *Food Research International*, 44(1): 198–203.

Zhou, R., Li, Y., Yan, L., and Xie, J. 2011. Effect of edible coatings on enzymes, cell-membrane integrity, and cell-wall constituents in relation to brittleness and firmness of Huanghua pears (*Pyrus pyrifolia* Nakai, cv. Huanghua) during storage. *Food Chemistry* 124: 569–575.

Zhou, R., Mo, Y., Li, Y., Zhao, Y., Zhang, G., and Hu, Y. 2008. Quality and internal characteristics of Huanghua pears (*Pyrus pyrifolia* Nakai, cv. Huanghua) treated with different kinds of coatings during storage. *Postharvest Biology and Technology* 49(1): 171–179.