Chapter 10
Delivery of Flavor and Active Ingredients Using Edible Films and Coatings

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10.1 Introduction

Edible films and coatings are promising systems for improvement of food quality, shelf life, safety, and functionality. They can be used as individual packaging materials, food coating materials, and active ingredient carriers. They can also be used to separate the compartments of heterogeneous ingredients within foods. In fact, edible films and coatings can incorporate food additives, such as anti-browning agents, antimicrobials, flavors, colorants, and other functional substances. Enhanced sensory properties of a food can be achieved by adding flavoring agents to an edible film or coating, leading to development of new flavor delivery systems that improve food quality and utility. Currently, there are numerous applications of edible films and coatings whose main purpose is to impart desirable mouthfeel to the coated product; this is especially true for snacks (e.g., popcorn, corn chips, and potato chips), nuts, meat, fish, and poultry. Further, incorporation of active ingredients can enhance functionality of edible films and coatings, thereby providing health benefits to consumers. For example, addition of probiotic organisms to films and coatings could open up opportunities to develop new, health-enhancing products. Edible films and coatings are promising delivery systems for flavor and active ingredients that improve food quality and functionality.

This chapter will focus on use of edible films and coatings as carriers of flavor and active ingredients in foods. It will also discuss incorporation of some flavoring and active substances into edible films and coatings, which can improve quality and functionality of foods. It will also provide insights about recent advances in this area.

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10.2 Historical Background

Application of edible films and coatings to foods to extend their shelf life is not a new practice. Edible films and coatings have been used for centuries to prevent moisture migration, improve food appearance, and increase product shelf life. Wax coatings on whole fruits and vegetables have been used since the 1800s. In fact, coating of fresh citrus fruits (oranges and lemons) with wax to retard desiccation was practiced in China in the twelfth and thirteenth centuries (Hardenburg 1967). Currently, edible coatings are widely used on whole fruits, such as apples, pears, oranges, lemons, and grapefruits, to reduce water loss, improve appearance by imparting sheen to the food surface, provide a carrier for fungicides or growth regulators, and create a barrier to gas exchange between the commodity and external atmosphere. In fact, application of a coating to tropical fruits is essential because they are susceptible to weight loss and, in some cases, to physiological breakdown. Coatings for tropical fruits such as mangos, avocados, papayas, melons, and pineapples usually consist of emulsions composed of carnauba wax (Grant and Burns 1994).

Edible films and coatings have also been used to preserve meats, nuts, snacks, and candies. A good example of this is M&M chocolate candies. The practice of applying edible coatings to candy was originally introduced in 1941 to overcome lack of chocolate sales during warm summer months. The coating application kept chocolate from melting during storage and handling.

Nevertheless, edible films and coatings have since been recognized for even more innovative uses and applications beyond their historical usage. They have a great potential to deliver functional compounds as carriers of special ingredients. For example, incorporation of probiotic and nutraceutical compounds represents a new advancement in the concept of edible films and coatings. The term “nutraceutical” has become synonymous with dietary supplements. It was originally defined in 1995 as any substance that may be considered a food or part of a food that provides medical or health benefits, including prevention and treatment of disease (Gulati and Ottaway 2006). The term, nutraceutical, is used to describe substances that are not traditionally recognized as foods (e.g., vitamins and minerals), but have positive physiological effects on the human body (Gulati and Ottaway 2006). In addition, probiotics have been defined as “live microbial feed supplements that have beneficial effects on the host by improving their intestinal microbial balance” (Adhikari et al. 2000). Potential health benefits and biological functions of bifidobacteria in humans include intestinal production of lactic and acetic acids, inhibition of pathogens, reduction of colon cancer risks, reduction of serum cholesterol, improved calcium absorption, and activation of the immune system, among others (Mitsuoka 1990; Gibson and Roberfroid 1995; Kim et al. 2002). A viable bifidobacteria population of 5 cfu/g in the final product has been identified as the therapeutic minimum to attain aforementioned health benefits (Naidu et al. 1999). In order to confer health benefits to humans, the viable count of bifidobacteria at the time of consumption should be 10^6 cfu/g (Samona and Robinson 1991). Ingestion of 10^6 cells per gram has been recommended for classic probiotic foods, such as yogurt (Kurman and Rasic 1991). It is also important for manufacturers and retailers to be able to confirm viable counts of these organisms in bifidus-containing products.

10.3 Edible Films and Coatings as Carriers of Flavors, Colorants and Spices

As previously outlined, edible films and coatings can deliver and maintain desirable concentrations of color, flavor, spiciness, sweetness, saltiness, etc. Several commercial films, especially Japanese pullulan-based films, are available in a variety of colors, with spices and seasonings included (Guilbert and Gontard 2005). Owing to its excellent oxygen barrier properties, pullulan films can be used to entrap flavors and colors and to stabilize other active ingredients within the film.

Currently, the US Department of Agriculture's (USDA's) Agricultural Research Service (Albany, California), in cooperation with Origami Foods (Pleasanton, California), has developed vegetable and fruit edible films as alternatives to the seaweed sheets (nori) traditionally used for sushi and other Asian cuisine. These wraps, produced as soft and pliable sheets using infrared drying, can be made from broccoli, tomato, carrot, mango, apple, peach, pear, as well as a variety of other fruit and vegetable products. They can also be used to contain spices, seasonings, colorants, flavors, vitamins, and other beneficial plant-derived compounds. These food films are made commercially available by California-based Origami Foods and the USDA for use in a growing number of food applications, such as a bright orange, carrot-based wrap to encircle a cucumber, garlic, and rice filling; a deep red, tomato and basil-based wrap to hold a spicy tuna and rice filling; a blueberry or strawberry-based wrap to cover creamy cheesecake in mini-desserts; a pineapple–apricot–ginger–based wrap to enclose rice and diced roast pork in elaboration of a sushi; and a broccoli-based wrap to encircle sushi of carrots, onions, and asparagus. Other uses might include snack crackers wrapped with fruit and vegetable films, apple wedges wrapped in peach film and tempura strawberry wrapped bananas.

In a recent study, Laohakunjit and Kerdchoechuen (2007) coated nonaromatic milled rice with 30% sorbitol–plasticized rice starch, containing 25% natural pandan leaf extract (*Pandanus amaryllifolius* Roxb.). This extract is primarily responsible for the jasmine aroma of aromatic rice. The rice starch coating containing natural pandan extract produced nonaromatic rice with aroma compounds similar to that of aromatic rice. Additionally, coating treatment also reduced *n*-hexanal content of storage grains. This coating technique represents a promising approach for improving rice aroma and, at the same time, for reducing potential for oxidative rancidity during grain storage.

10.4 Edible Films and Coatings Carrying Nutraceuticals

Edible films and coatings also have capacity to hold many active ingredients that could be used to enhance nutritional value of food products. However, few studies have actually reported integration of nutritional or nutraceutical ingredients into edible films or coatings of foods, though there is a recent growing interest in this area. For such applications, the concentration of nutraceuticals added to the films or coatings must be carefully studied in relation to basic properties (e.g., barrier and mechanical) of carrier films.

Mei and Zhao (2003) evaluated feasibility of milk protein-based edible films to carry high concentrations of calcium and vitamin E. They used calcium caseinate (CC) and whey protein isolate (WPI) films containing 5 or 10% Gluconal Cal (GC), a mixture of calcium lactate and gluconate, or 0.1 or 0.2% of α-tocopheryl acetate (VE), respectively. Both CC and WPI films were capable of carrying high concentrations of calcium or vitamin E, though film functionality can be compromised in the process. For example, vitamin E incorporation at tested levels increased elongation at break and reduced tensile strength of films. In contrast, incorporation of calcium into CC films reduced tensile strength for both levels of GC addition, and decreased both elongation at break and water vapor permeability values at 10% GC addition level.

In subsequent studies, Park and Zhao (2004) evaluated functionality of chitosan-based films containing a high concentration of calcium (Gluconal Cal- GC), 5–20% zinc lactate (ZL), vitamin E (5–20% α-tocopheryl acetate) and acetylated monoglyceride (AM). Addition of GC significantly increased the pH and decreased the viscosity of film-forming solutions; however, addition of ZL or VE resulted in no such effects. Water barrier properties of the films were improved as either the concentration of mineral or vitamin E component within the film matrix increased. Nevertheless, tensile strength of films was affected by the incorporation of high concentrations of GC or VE, although other mechanical properties such as film elongation, puncture strength, and puncture deformation were not affected. They concluded that both milk protein and chitosan films may be used as carriers of nutraceuticals.

Some studies have reported that edible coatings might serve as excellent carriers of low levels of nutrients for fruits and vegetables, thereby improving nutritional value. Mei et al. (2002) developed xanthan gum coatings, containing high concentrations of calcium and vitamin E (5% Gluconal Cal and 0.2% α-tocopheryl acetate, respectively), for the purpose of enhancing nutritional and sensory qualities of fresh baby carrots. Calcium and vitamin E contents of the coated carrot samples increased from 2.6 to 6.6% and from 0 to 67% of the Dietary Reference Intakes (DRI) values per serving (85 g), respectively. Furthermore, these nutrient levels were achieved without affecting fresh aroma, flavor, sweetness, crispness, or β-carotene levels of the carrots. Because peeled baby carrots are poor sources of calcium and vitamin E, incorporating both nutrients into edible coating is an excellent approach for enhancing nutritional qualities of this type of product.

Application of edible coatings carrying nutraceutical compounds has also been studied with fruits. In fact, Han et al. (2004) added calcium and vitamin E to chitosan-based coatings to improve shelf life and nutritional properties of fresh and frozen strawberries and red raspberries. The addition of high concentrations of Gluconal Cal or α-tocopheryl acetate into chitosan-based coatings does not alter native antifungal and moisture barrier functions associated with chitosan. Coatings significantly reduced incidence of decay and weight loss and delayed changes in color, pH and titratable acidity of strawberries and red raspberries during cold storage. In addition, chitosan-based coatings demonstrated great capacity to hold high concentrations of calcium or vitamin E, thereby increasing significantly the content of these nutrients in both the fresh and frozen fruits. For one serving (100 g), coated fruits contained 34–59 mg of calcium and 1.7–7.7 mg of vitamin E, depending on the type of fruit and time of storage, whereas uncoated fruits contained only 19–21 mg and 0.25–1.15 mg of calcium and vitamin E, respectively. Similarly, Hernández-Muñoz et al. (2006) observed that the amount of calcium (3,079 g/kg dry matter) retained by coated fruit was greater than that obtained with calcium dips alone (2,340 g/kg). On the other hand, addition of 1% calcium gluconate to the chitosan coating formulation (1.5% in 0.5% acetic acid) did not extend shelf life of coated strawberries.

10.5 Edible Films and Coatings to Carry Probiotic Organisms

Incorporation of probiotics into functional edible films and coatings has been scarcely studied. Recently, Tapia et al. (2007) developed probiotic edible films for coating fresh-cut fruits. In this work, feasibility of alginate (2% w/v) and gellan (0.5%) based edible coatings as carriers of organisms, such as bifidobacteria, was investigated in an attempt to obtain functional probiotic-coated fruits. Fresh-cut apples and papayas were successfully coated with alginate or gellan film-forming solutions containing viable bifidobacteria. In fact, values higher than 10^6 cfu/g *Bifidobacterium lactis Bb*-12 were maintained on both papaya and apple pieces for up to 10 days of refrigerated storage (Fig. 10.1). This observation demonstrated that alginate- and gellan-based edible coatings could feasibly carry and support viable probiotics on fresh-cut fruits. Furthermore, water vapor permeability for alginate (6.31 and 5.52 $\times 10^{-9}$ g m/Pa s m^2) and gellan (3.65 and 4.89 $\times 10^{-9}$ g m/Pa s m^2) probiotic coatings of papayas and apples, respectively, was higher than in the corresponding cast

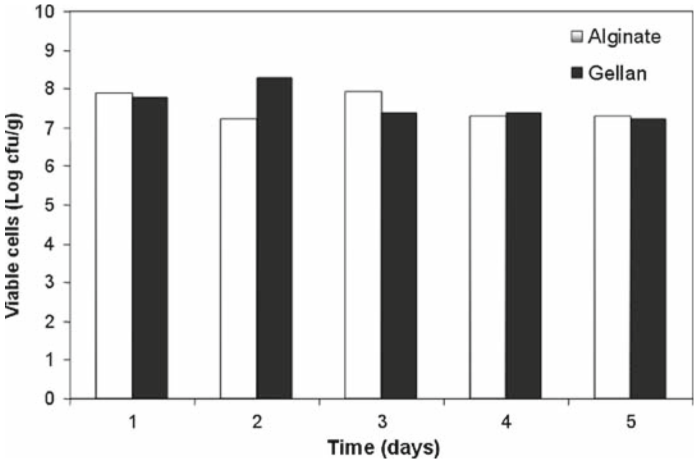

Fig. 10.1 Viable cells (log ufc/g) of *Bifidobacterium lactis* Bb-12 in alginate and gellan coatings, containing sunflower oil, glycerol, and *N*-acetylcysteine applied on fresh-cut apples, followed by refrigerated (2°C) storage (adapted from Tapia et al. 2007)

films. This work represents a recent advancement in the use of edible films and coatings as carriers of diverse food additives, and opens new possibilities for development of probiotic film and coating products.

10.6 Edible Films and Coatings to Carry Antimicrobial Agents

Active compounds, such as antimicrobials, can be incorporated into edible films and coatings. These antimicrobial edible films and coatings inhibit spoilage and pathogenic bacteria by maintaining effective concentrations of active compounds on food surfaces (Gennadios and Kurth 1997). There are several categories of antimicrobials that can be potentially incorporated into edible films and coatings: organic acids (acetic, benzoic, lactic, propionic, sorbic); fatty acid esters (glyceryl monolaurate); polypeptides (lysozyme, peroxidase, lactoferrin, nisin); plant essential oils (cinnamon, oregano, lemongrass); and nitrites and sulfites (Franssen and Krochta 2003). Within these categories, plant essential oils are outstanding alternatives to chemical preservatives, and their use in foods meets consumer demands for minimally processed natural products (Burt 2004). Essential oils are designated as "Generally Recognized as Safe" (GRAS) (Burt 2004), and are used as flavoring agents in various foods (Fenaroli 1995). These compounds can also be added to edible films and coatings to modify food flavor, aroma, and odor (Cagri et al. 2004). In two recent studies, Rojas-Graü et al. (2006a, 2007c) compared effects of oregano, cinnamon, and lemongrass oils, incorporated into apple puree and alginate–apple puree edible films, for effectiveness against *Escherichia coli* O157:H7. Both works showed that edible films, as carriers of antimicrobial compounds, constitute a feasible approach for incorporating plant essential oils onto fresh food surfaces.

Edible films and coatings, as carriers of antimicrobial compounds, provide a novel means by which to improve safety and shelf life of food systems. Several studies have demonstrated that antimicrobial edible films can reduce bacterial levels on meat products. For instance, antimicrobial chitosan films, containing acetic or propionic acid, reportedly inhibited growth of *Enterobacteriaceae* and *Serratia liquefaciens* on bologna, cooked ham, and pastrami (Ouattara et al. 2000). Cagri et al. (2002) also incorporated *p*-aminobenzoic (PABA) and sorbic acids into whey protein isolate films to inhibit *Listeria monocytogenes*, *Escherichia coli* O157:H7 and *Salmonella enterica* on bologna and summer sausage. Oussalah et al. (2004) applied milk protein-based edible films containing oregano, pimento, or oregano–pimento essential oil mix onto beef muscle slices to control growth of *E. coli* and *Pseudomonas* spp., thereby increasing product shelf life during refrigerated storage. The same authors also applied alginate-based edible films, containing Spanish oregano or Chinese cinnamon essential oils, onto beef muscle slices for control of *E. coli* O157:H7 and *Salmonella typhimurium*. Incorporation of essential oils into films helped to reduce growth of both bacterial species on beef muscle during 5 days of storage (Oussalah et al. 2006).

10.7 Edible Films and Coatings to Carry Antioxidant Agents

Antioxidants are used to protect against oxidative rancidity, degradation, and enzymatic browning in fruits and vegetables. Ascorbic acid (Soliva-Fortuny et al. 2001; Son et al. 2001), 4-hexylresorcinol (Dong et al. 2000; Luo and Barbosa-Canovas 1997; Monsalve-Gonzalez et al. 1993), and some sulfur-containing amino acids, such as cysteine and glutathione (Gorny et al. 2002; Molnar-Perl and Friedman 1990; Nicoli et al. 1994; Son et al. 2001) have been widely studied, individually and in combination, for their ability to prevent enzymatic browning, to serve as sulfite substitutes, and to improve shelf life of minimally processed fruits (Pizzocaro et al. 1993; Rojas-Graü et al. 2006a, b). Several authors have studied incorporation of many of these antibrowning agents into edible films used to coat minimally-processed fruits (Wong et al. 1994; Baldwin et al. 1996; Lee et al. 2003; Perez-Gago et al. 2006). Rojas-Graü et al. (2007a) and Tapia et al. (2005) applied alginate- and gellan-based coatings to fresh-cut apples and papayas, demontrating that coatings were good carriers for antioxidant agents, including cysteine, glutathione, and ascorbic and citric acids. Most of these antibrowning agents, however, are hydrophilic compounds, and may increase water vapor transmission rate and induce water loss when incorporated into films and coatings (Ayranci and Tunc 2004).

10.8 Technical Development

Edible films and coatings can be applied by different methods such as brushing, wrapping, spraying, dipping, casting, panning, or rolling. Dipping is advantageous when a product requires several applications of a coating to obtain uniformity on an irregular surface. After dipping the product and draining away the excess coating, the film is allowed to set or solidify on the product (Donhowe and Fennema 1994).

Casting is another technique used to apply edible coatings to food. For casting, film-forming solutions are poured onto a level surface and allowed to dry, usually within a confined space. Casting produces freestanding films that exhibit a specified thickness, smoothness, and flatness (Donhowe and Fennema 1994). Depending on firmness and flexibility, cast films can then be used to wrap surfaces. This wrapping technique allows films to be cut to any size, and serves as an innovative and easy method for carrying and delivering a wide variety of ingredients such as flavorings, spices and seasonings that can later be used to cover foods. This method is especially useful when applied to highly spicy materials that need to be separated from the food product.

Another technique, spraying, provides a more uniform coating. Spraying is desirable when a coating application is needed only on one side of the food product or when a dual application must be used to achieve the desired function (e.g., cross-linking of alginate or pectin coatings by subsequent coating with $CaCl_2$) (Donhowe and Fennema 1994). Sometimes it is advisable to heat product after spraying to hasten the drying process and to improve uniformity of film solution on the food surface (Grant and Burns 1994).

The type of food product dictates the most appropriate method for coating application. For example, the most effective method for coating nuts is panning; cheese, on the other hand, is often dipped in or brushed with wax. Spraying is the conventional method for applying most coatings to fruits and vegetables. Meat products, however, are coated using any of several techniques such as foaming, dipping, spraying, casting, brushing, individual wrapping, or rolling (Donhowe and Fennema 1994).

Coatings are more prevalently used than films. For example, collagen films are used for sausage casings; some hydroxymethyl cellulose films, such as soluble pouches, are used for dried food ingredients. Shellac and wax coatings are most commonly used on fruits and vegetables, zein coatings on candies, and sugar coatings on nuts (Krochta and De Mulder-Johnston 1997). Another typical example of using coatings is a type of Japanese polysaccharide film that is used for meat products, such as ham and poultry packaging, before they are smoked and/or steamed. The film dissolves during the process, and coated meat exhibits improved yield, structure, and texture, as well as reduced moisture loss (Labell 1991; Stollman et al. 1994). Use of carboxymethylcellulose and methylcellulose as matrix in elaboration of coatings is predominant with fruits, vegetables, meats, fish, nuts, confectionery products, baked goods, grains and other agricultural products (Nussinovitch 2003).

The first edible films made from fruit purees were developed by McHugh et al. (1996), who also characterized their water vapor and oxygen permeability properties. Soon afterwards, a patent application was filed on products and processes for wrapping foods with fruit- and/or vegetable-based edible films (McHugh and Senesi 1999). After that, they developed a novel method (apple wraps) to extend shelf life and improve quality of fresh-cut apples. These wraps were made from an apple puree that contained various concentrations of fatty acids, fatty alcohols, beeswax and vegetable oil. Fruit and vegetable wraps can be used to extend the shelf life of fresh-cut fruits and vegetables, as well as to enhance nutritional value and increase consumer appeal. Additionally, fruit and vegetable wraps can be used as barriers for other food systems such as nuts, baked goods and confectionery products (McHugh and Senesi 2000).

10.9 Properties and Functions

Potential properties and applications of edible films and coatings have been extensively reviewed (Bravin et al. 2006; Jagannath et al. 2006; Min et al. 2005; Serrano et al. 2006). Edible films and coatings are known to improve product shelf life and food quality, as they are selective barriers to moisture transfer, oxygen uptake, and loss of volatile aromas and flavors (Kester and Fennema 1986). When used to coat fresh-cut fruits and vegetables, edible films may reduce deleterious effects concomitant with minimal processing. Moisture barrier properties of edible films and coatings have been extensively studied by measuring their water vapor properties, because of water's key role in deteriorative reactions.

Edible films coatings made from naturally occurring polymers, such as polysaccharides and proteins are regarded as good oxygen barriers because of their hydrogen-bonded network structures, which are very tightly packed and ordered (McHugh and Krochta 1994). Major drawbacks of such films and coatings are their relatively low water resistance and poor vapor barrier properties (Yang and Paulson 2000). Incorporation of lipids, either in an emulsion or as a layer coating of film formulations, greatly improves their water vapor barrier properties (García et al. 2000; Yang and Paulson 2000). In addition to the increased barrier properties, edible films and coatings control adhesion, cohesion and durability, and they improve appearance of coated foods (Krochta and De Mulder-Johnston 1997).

Besides physical and chemical quality enhancements, edible films and coatings contribute to better visual quality, surface smoothness, color and, in addition, serve as carriers of various active agents such as emulsifiers, antioxidants, antimicrobials, nutraceuticals, flavors and colorants. These active compounds, which serve to enhance food quality and safety, may be added up to the levels in which they could interfere with physical and mechanical properties of films (Kester and Fennema 1986; Gennadios and Weller 1990; Guilbert and Gontard 1995; Krochta and De Mulder-Johnston 1997; Miller et al. 1998).

For instance, edible coatings can improve effectiveness of the popping process for popcorn (Wu and Schwartzberg 1992), acting as adhesion agents between heterogeneous food ingredients (Anonymous 1997). Furthermore, edible coatings are applied to surfaces of snack foods and crackers, as the base or adhesive for seasonings. For example, fat and oil have traditionally been used for adhering seasonings and flavorings to surfaces of cereal-based snack foods. However, as a result of recent market demands for reduced-fat and fat-free snack foods, many companies have introduced other edible coatings that are especially useful in low-fat applications as a replacement for oil-based adhesives. For example, oil-roasted and dry-roasted peanuts, which require an adhesive to act as a coating or bonding agent for salt and/or seasonings, now utilize a coating solution made from modified food starch, corn syrup, water and glycerol. This solution is applied to peanuts during tumbling, after which seasoning or salt may be added.

In addition, edible films and coatings allow the incorporation of preservation agents as well as nutrients and nutraceuticals. This practice improves product quality, as is the case with colored/flavored confectionery goods, glazed bakery goods, flavored nuts and vitamin-enriched rice. Active compounds can be added to food coatings to extend shelf life, preserve color, and improve nutritional value of foods. Multifunctional edible films and coatings can be utilized for value-added confections, medicinal and therapeutic foods, pharmaceutical products, and other nutraceuticals, as well as conventional perishable foods (Han 2002).

In addition to improving health and nutritional value, incorporated flavors and colorants can improve taste and visual appeal of coated products. For example, edible coatings can be sprayed or dipped onto surfaces of snack foods and crackers to serve as adhesives for flavorings (Druchta and De Mulder Johnston 1997). They can also be used as carriers of flavors in precooked meats. The practice of coating is gaining popularity in development of a variety of ready-to-heat products for quick meals. Candies are often coated with edible films to improve their texture by reducing stickiness (McHugh and Senesi 2000). Because of the various chemical characteristics of these active additives, the film composition should be modified to maintain a homogeneous film structure as these additives are incorporated into the film structure (Debeaufort et al. 1998).

10.10 Sensory Evaluation of Edible Films and Coatings with Active Ingredients

For the majority of cases, edible coatings with little or no taste are desired to prevent their detection during consumption (Contreras-Medellin and Labuza 1981). To accomplish this purpose, films must have neutral organoleptic properties (e.g., clarity, transparency, lack of discernible odor and taste, etc.). Since edible films and coatings are intended to be consumed with their respective products, the incorporation of compounds such as nutraceuticals, antioxidants and antimicrobial agents should not adversely affect consumer acceptance.

Several studies have investigated sensory characteristics of coated food products when nutraceutical ingredients are incorporated. The taste contributed by these ingredients has been considered a particularly important aspect, since many nutraceutical compounds have natural bitter, astringent, or other undesirable off-flavors (Drewnowski and Gomez-Carneros 2000) that can lead to unacceptable attributes in these products (LeClair 2000). Han et al. (2005) evaluated sensory attributes of fresh strawberries treated with chitosan-based edible coating material, with and without addition of vitamin E incorporated into the coating. Coated strawberries were evaluated by consumers for acceptance attributes and by trained panelists for descriptive analysis of their appearance, texture and flavor. Results from consumer testing 1 week after coating application indicated that all chitosan coatings evaluated increased the appearance scores of strawberries. On the other hand, the incorporation of vitamin E reduced the glossiness of coated strawberries, which could affect consumer acceptance.

Other studies have illustrated effects of incorporating other compounds, such as antibrowning agents, on sensory qualities of coated products. The type and concentration of different antioxidant compounds incorporated into coatings of whey protein concentrate (WPC)/beeswax (BW) and their effect on the color and sensory quality of fresh-cut apples have been studied (Perez-Gago et al. 2006). Results showed that incorporation of ascorbic acid (AA-0.5% and 1%), cysteine (Cyst-0.1%, 0.3% and 0.5%) or 4-hexylresorcinol (0.005% and 0.02%) as antioxidant agents into coating formulations reduced apple browning. The most effective WPC/BW coatings were those containing 1% AA or 0.5% Cyst. A sensory panel was able to discriminate between samples coated with WPC/Cyst solution and those just dipped in Cyst aqueous solution. Notably, panelists were also able to detect a smell of sulfur in Cyst-coated samples, which supports the conclusion that use high concentrations of sulfur-containing compounds, such as *N*-acetylcysteine and glutathione, as dipping agents may produce an unpleasant odor in fruits and vegetables (Iyidogan and Bayindirli 2004; Richard et al. 1992; Rojas-Graü et al. 2007a, 2006b). Interestingly, no differences were noted between coated and uncoated samples containing AA (Perez-Gago et al. 2006), which make the WPC/AA coating a good alternative to application of AA alone.

Lee et al. (2003) studied the effect of two edible coatings (carrageenan and whey protein concentrate) in combination with antibrowning agents on fresh-cut apple slices, and observed that the incorporation of ascorbic acid, citric acid and oxalic acid did not negatively affect their sensory characteristics. Hence, addition of antibrowning agents to these coating solutions was advantageous in maintaining color over a 2-week time span. Also, in quality testing, apples coated with any of the assayed formulations had higher sensory scores than uncoated apples. Whey protein concentrate coating solutions (5 g/100 mL), containing ascorbic acid (1 g/100 mL) and $CaCl_2$ (1 g/100 mL), were most effective in preserving sensory quality of apples.

However, incorporation of some antimicrobial agents into edible coatings might be anticipated to alter original flavors of foods as a result of the strong flavors associated with them, especially when plant essential oils are used. Indeed, essential oils have been extensively evaluated for their ability to protect foods against pathogenic bacteria, in addition to being used as flavoring agents in baked goods, sweets, ice cream, beverages and chewing gum (Fenaroli 1995). Currently, little is known about sensory characteristics of edible films and coatings that include essential oils in their formulations. Recently, Rojas-Graü et al. (2007b) evaluated sensory quality of coated fresh-cut apples containing plant essential oils, such as lemongrass, oregano oil, and vanillin. Essential oils were incorporated into apple puree–alginate edible coatings used to surface-coat fresh-cut "Fuji" apples. Taste evaluations indicated that coated fresh-cut apples containing incorporated vanillin (0.3% w/w) were the most acceptable in terms of sensory quality after 2 weeks of storage. In contrast, the lowest overall preference was observed for coated apple samples containing oregano oil (Fig. 10.2). Despite the low concentration of

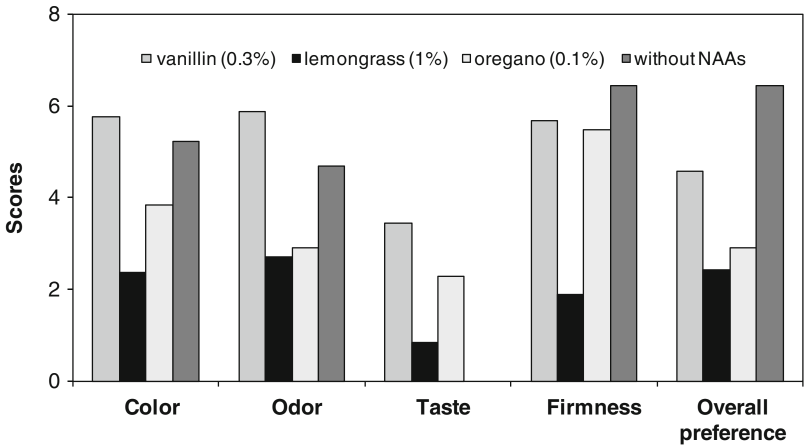

Fig. 10.2 Sensory attribute scores for coated fresh-cut apple, with or without antimicrobials agents, after 2 weeks of storage (adapted from Rojas et al. 2007)

oregano oil used (0.1% w/w), some consumers detected a residual aromatic herbal taste that diminished overall preference for these cut apples.

In contrast with sensory changes observed when plant essential oils are incorporated into coatings, several studies report good results when other antimicrobial compounds are used. The effects of a casein coating on properties of Kashar cheese, and its effectiveness in carrying natamycin to prevent mold growth, were studied by Yildirim et al. (2006). Five cheese groups were evaluated: uncoated, vacuum-wrapped, coated with casein, coated with casein containing natamycin, and dipped in natamycin solution. Sensory evaluation showed no significant differences among cheese samples, which support the thought that casein coating with natamycin can suppress mold growth for about 1 month without any adverse effects to cheese sensory quality.

Eswaranandam et al. (2006) incorporated malic and lactic acids into soy protein coatings, with the purpose of evaluating their effect on the sensory characteristics of whole apples and fresh-cut cantaloupe. Organic acids incorporated into films did not adversely impact sensory properties of either whole apples or cantaloupe cubes, as evaluated by trained sensory panelists.

Chen et al. (1999) developed edible coatings composed of methylcellulose, glycerol and fatty acid (stearic acid or palmitic acid) as carriers of preservatives to inhibit microbial growth on Taiwanese-style fruit preserves. In this study, two types of fruit (Ten-shing mei and Ching-shuan mei) prepared from plums were covered with edible coatings containing benzoic acid. Two osmophilic yeasts (*Zygosaccharomyces rouxii* and *Z. mellis*) were used as test microorganisms. Results indicated that yeast growth was inhibited in both coated fruit preserves containing 50–100 μg of benzoic acid per gram of coating solution. Furthermore, coated fruits were not significantly different from uncoated fruits in terms of sensory quality, suggesting that the edible coating could serve as a food additive carrier without modifying sensory properties.

It is important to highlight that many compounds used in development of edible films and coatings – including edible matrices, plasticizers and other active ingredients – can affect sensory attributes of coated products. These compounds have their own characteristic flavors and colors, and ingredient interactions may generate further diverse changes. For instance, hydrocolloid-based films are generally more neutral than those formed from lipids or lipid derivatives and waxes, which are often opaque, slippery and waxy tasting. On the other hand, some authors indicate that use of chitosan-based films or coatings generates slight flavor modifications; in fact, the typical astringent/bitter taste of chitosan currently limits its use. Generally, chitosan used to prepare edible coatings shows astringent attributes when dissolved in an acidic medium. This occurs as a result of a rise in amine protonated groups, which augment the salivary protein binding affinity. These astringent properties have been detected in several sensory evaluations of fruits (Rodriguez et al. 2003; Devlieghere et al. 2004).

Vargas et al. (2006) evaluated edible coatings based on high molecular weight chitosan, combined with oleic acid, to preserve quality of cold-stored strawberries. Addition of oleic acid not only enhanced chitosan's antimicrobial activity, but also improved the water vapor resistance of coated samples. Sensory analysis showed that coating application led to a significant decrease in strawberry aroma and flavor, especially when the ratio of oleic acid to chitosan was high in the film. Aroma and flavor of coated strawberries were considered less intense than those of uncoated samples. Panelists also detected an atypical oily aroma in samples coated with the formulation containing the highest level of oleic acid. Additionally, strawberries coated with 1% chitosan edible coatings were more astringent than the uncoated fruit, and were significantly more astringent than those coated with a mixture of chitosan and 4% oleic acid. Consequently, astringency detected in chitosan films appeared to be reduced by addition of oleic acid.

In contrast, Han et al. (2005) evaluated sensory quality of fresh strawberries coated with a 1% chitosan solution containing vitamin E, and observed that application of the coating resulted in no perception of astringency. Similarly, Chien et al. (2007) observed that low molecular weight chitosan (LMWC) did not adversely influence the natural taste of sliced red pitayas (dragon-fruit), a medium-large berry. The chitosan coating helped maintain the soluble solids content, titratable acidity, and ascorbic acid content and, in addition, inhibited microbial growth. Sensorial analysis revealed superior results for the LMWC-coated samples after 7 days of storage.

Flavor and coloring agents may also be added to an edible film or coating matrix to improve the sensory attributes of wrapped or coated products. Unfortunately, few studies have been reported regarding this topic.

10.11 Current State and Recent Advances

There are multiple applications of edible films and coatings in the food industry. These include (1) oxygen-sensitive foods, such as nuts, to extend shelf life and reduce packaging; (2) nuts, to prevent oil migration into surrounding food components (e.g., nuts in chocolate); (3) fragile foods, such as breakfast cereals and freeze-dried foods, to improve integrity and reduce loss due to breakage; (4) fresh fruits and vegetables, whole and pre-cut, to extend product shelf life by reducing moisture loss, respiration and color change; (5) moisture-sensitive foods or inclusions, (e.g., nuts, cookies and/or candies in ice cream) to provide a moisture barrier to keep products and inclusions crisp; (6) low-fat and non-fat snack foods, (e.g., chips) to keep seasonings adhered to products; (7) frozen foods, to prevent oxidation, as well as to prevent moisture, aroma or color migration; film separation layers for heterogeneous foods; and film pouches for dry food ingredients. Within these applications, use of edible films and coatings as carriers of active substances stands out as a promising application of active food packaging (Cuq et al. 1995; Han 2000).

10.12 Regulatory Status

Edible films and coatings can be classified as food products, food ingredients, food additives, food contact substances, or food packaging materials (Debeaufort et al. 1998). Therefore, edible films and coatings should follow all required regulations pertinent to food ingredients, since they are an integral part of the edible portion of food products (Guilbert and Gontard 1995). To maintain product safety and eating quality, all film-forming components, as well as any functional additives in the film-forming materials, should be food-grade, nontoxic materials; further, all process facilities should be acceptable for food processing and should strictly observe current Good Manufacturing Practice (cGMP) (Guilbert et al. 1996; Guilbert and Gontard 1995; Han 2002; Nussinovitch 2003). Ingredients acceptable for use in edible films and coatings should be GRAS, and used within any limitations specified by the Food and Drug Administration (FDA).

Since edible films and coatings may have ingredients included for functional effect, inclusion of such ingredients on product labels would be required. In Europe, the intended use of various food additives must always be included on packaging according to the specific functional category (antioxidant, preservative, color, etc.), with either their name or E-number. In European Community Legislation, a food additive is defined as "any substance not normally consumed as a food in itself and not normally used as a characteristic ingredient of food whether or not it has nutritive value, the intentional addition of which to food for a technological purpose results in it or its by-products becoming directly or indirectly a component of such foods". Food additives are intentionally added to foods to perform certain technological functions, for example, color, sweeten, or to preserve. Additives that are most likely to be found on food labels are antioxidants, colorants, emulsifiers, stabilizers, gelling agents, thickeners, flavor enhancers, preservatives and sweeteners. Flavorings, or substances used to give taste and/or smell to food, also must be present in the ingredient list on packaging of food products.

In the case of nutraceutical incorporation, specific regulations regarding its use must be applied. Within European Union Law, the legal categorization of a nutraceutical is, in general, made on the basis of its accepted effects on the body. Thus, if the substance contributes only to maintenance of healthy tissues and organs, it may be considered a food ingredient.

In food regulations of most countries, chemical substances added as antimicrobials are regarded as food additives, if the primary purpose of the substances is preservation of food to prolong its shelf life. For example, and according to U.S. regulations, organic acids including acetic, lactic, citric, malic, propionic and tartaric, as well as their salts, are GRAS for miscellaneous and general purpose usage (Doores 1993). On the other hand, many plant essential oils are used widely in food, health and personal care industries, and are also classified as GRAS substances or permitted as food additives (Kabara 1991).

Besides ingredient regulations, there is another important topic within the regulatory statutes. Many edible films and coatings are made with ingredients that can cause allergic reactions in some consumers. Allergens inherent to milk, soybeans, fish, peanuts, nuts, and wheat are the most important (Anonymous 2001). Several edible films and coatings are formed from milk (whey, casein), wheat (gluten), soy and peanut proteins. Therefore, a coating containing a known allergen must also be clearly labeled (Franssen and Krochta 2003).

10.13 Future Trends

Development of new technologies to improve carrier properties of edible films and coatings is a major issue for future research. Currently, use of such edible films and coatings is limited. One of the main obstacles is cost, restricting their application to products of high value. Besides cost, other limiting factors for commercial use of edible films and coatings are lack of materials with desired functionalities, cost of investment for the installation of new film production or coating equipment, difficulty of the production process and strictness of regulations.

In spite of these limitations, the food industry is looking for edible films and coatings that can be used on a broad spectrum of foods, add value to their products, increase product shelf life, and/or reduce packaging. However, more studies are yet necessary to develop new edible films and coatings containing active ingredients to understand interactions among components used in their production. When flavorings and active compounds (e.g., antimicrobials, antioxidants, and nutraceuticals) are added to edible films and coatings, mechanical properties can be dramatically affected. Studies addressing this subject are still very limited, and more information is needed to understand this behavior.

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