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Edible Coatings for Fresh-Cut Fruits

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The production of fresh-cut fruits is increasingly becoming an important task as consumers are more aware of the importance of healthy eating habits, and have less time for food preparation. A fresh-cut fruit is a fruit that has been physically altered from its original state (trimmed, peeled, washed and/or cut), but remains in a fresh state. Unfortunately since fruits have living tissue, they undergo enzymatic browning, texture decay, microbial contamination, and undesirable volatile production, highly reducing their shelf life if they are in any way wounded. Edible coatings can be used to help in the preservation of minimally processed fruits, providing a partial barrier to moisture, oxygen and carbon dioxide, improving mechanical handling properties, carrying additives, avoiding volatiles loss, and even contributing to the production of aroma volatiles.

Keywords minimally processed fruit (MPF), edible coating, shelf life, fruit ready to eat, lipids, hydrocolloids, fresh-cut fruit

INTRODUCTION

As consumers are more aware of the importance of healthy eating habits and have less time for food preparation, the production of fresh-cut fruits is increasingly more relevant from the food processor's perspective. This review briefly discusses the relevance of the production and consumption of fresh-cut fruits, describing the potential use of edible coatings as a way to extend their shelf life. Specific details related to the study, selection, composition, and use of edible coatings on minimally processed fruits are included as well. State of the art and challenges on the use of edible coatings to extend the shelf life of minimally processed fruits are described, and a suitable approach to develop edible coatings for fresh-cut fruits is presented.

Minimally Processed Fruits

The term "minimally processed fruit" refers to any type of fruit that has been physically altered from its original state (trimmed, peeled, washed, and/or cut), but remains in a fresh, "unprocessed" state. Within this context, "fresh-cut fruits" are fruits that are presented to the consumer in a state that allows for direct and immediate consumption without need for previous preparation or transformation. The production of minimally processed ready-to-eat fruits represents a big challenge, as cut fruits deteriorate faster than their intact counterpart, mainly due to the damage caused to cells and tissues by cutting and trimming and to the removal of their natural protective skin (Watada and Qi, 1999). When fruits are cut, peeled or in any other way wounded, their tissue responds with a steep rise in respiration rate, causing accelerated consumption of sugars, lipids, and organic acids, and increasing ethylene production, which induces ripening and causes senescence (Kays, 1991). The shelf life and quality of cut fruits is further reduced by a series of decay processes also triggered by physical damage, including enzymatic browning, loss of texture, water loss, increased susceptibility to microbial spoilage, and production of undesirable odors and flavors.

Browning of cut fruits occurs when phenolic compounds naturally present in vegetal tissues are exposed by mechanical damage to oxygen, coenzymes (e.g., copper), and oxidizing enzymes (polyphenol oxidases), leading to the formation of dark compounds (Ahvenainen, 1996). The physical and chemical methods available to reduce enzymatic browning include modified atmospheres, temperature control, use of additives such as enzyme inhibitors, oxygen and phenolic scavengers, acidulants, competitive substrates, and compounds that react with intermediate reaction products before these can produce dark pigments (Garcia and Barret, 2002). Compounds such as carboxylic acids, sulfur-containing aminoacids, ascorbic acid, 4-hexylresorcinol, and even honey have been used with different degrees of success to reduce or prevent browning (Iyengar and McEvily, 1992; Luo and Barbosa-Cánovas, 1996; Sapers and Miller, 1998; Buta et al., 1999; Son et al., 2001; Lee et al., 2003). As previously mentioned, the increase in ripening rate and water loss promoted by cutting and trimming notably accelerate texture decline of fruits. Structures such as the cell wall, middle lamella, and cellular membrane are subjected to biochemical alterations during

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ripening that lead to loss of cohesion among cells resulting in softer and weaker structures. At the individual cell level, water loss promotes the loss of turgor of cells, conducing to mushy textures due to the presence of "deflated" cells within the structure, also reflecting negatively on the overall texture of fruits (Garcia and Barret, 2002). Occurrence of these undesirable events may be arrested or at least delayed by reducing water migration, and by strengthening of the tissue through the addition of compounds such as calcium chloride, which cross links pectins in the cell wall and middle lamella reinforcing cohesion among cells (Ponting et al., 1971, 1972; Poovalaiah et al., 1988; Rocha et al., 1998; Sams, 1999). Cutting and peeling fruits also increase their susceptibility to microbial spoilage. The removal of the natural protective epidermal barrier and the increase in moisture and dissolved sugars on the surface provide ideal conditions for the colonization and multiplication of microorganisms (Nguyen-The and Carlin, 1994). Antimicrobials like benzoic acid, sodium benzoate, potassium sorbate, and propionic acid may be used to avoid microbial spoilage of fresh-cut fruits (Baldwin et al., 1995); however, diffusion of the preservative into the fruit may decrease their effectiveness over time (Vojdani and Torres, 1990). The increase in respiration rate caused by cutting and peeling may also modify the characteristic flavor and aroma of fruits (Kays, 1991; Beaulieu and Baldwin, 2002). Alteration of the respiration rate by storage of fresh-cut fruits under controlled-atmosphere conditions of low O_2 and high CO_2 content also affects the flavor and aroma of fruits by significantly reducing the synthesis of characteristic fruit aroma compounds such as acetate esters (Fellman et al., 1993; Ke et al., 1994; Mattheis and Fellman, 2000).

Different fruits may have different responses to minimal processing, contributing to a good or poor quality fresh-cut product. The extent to which the mentioned deteriorative processes may occur on a given minimally processed product depends on several factors such as fruit variety, harvest date, post-harvest and post-process handling, and even on the quality of the implements employed during minimal processing. Hence, it is very important to identify the optimum conditions for minimal processing (Elgar et al., 1997; Sams, 1999; Gunes et al., 2001; Johnston et al., 2001; Fellman et al., 2003).

FRESH-CUT FRUIT CONSUMPTION TRENDS

Consumption of fresh whole fruit in the U.S. increased from 282.1 to 284.6 lb/year per capita during the last decade of the twentieth century (USDA, 2003) (1992–1999), probably as a consequence of an increased public awareness regarding the importance of healthy eating habits. Nevertheless, this trend was apparently interrupted in subsequent years (USDA, 2003) (1999–2001), when an increase on the consumption of frozen fruit instead of fresh fruit was witnessed, probably as an indication of the consumer's inclination to eat ready-to-eat cut fruits, pointing to the growing consumer preference towards minimally processed fruits. A recent study conducted by the International Fresh-cut Product Association revealed that 76% of surveyed households buy fresh-cut produce at least once a month, and 70% buy fresh-cut fruit every few months (IFPA, 2003). Around 30% of consumers prefer fresh-cut fruits and vegetables to their unprocessed counterparts. Women are more likely to buy fresh-cut fruits than men, and as the income level increases, the probability of consuming fresh-cut fruits also increases (Sonti et al., 2003). Sales of fresh-cut produce have increased since 1994 from 5 to around 10–12 billion, being at the present about 10% of the total U.S. produce sales (IFPA, 2003). Table 1 shows some minimally processed fruits already available on the market in the U.S.

Table 1 Minimally processed fruits on the market

Apple	Slices and chunks
Cantaloupe	Chunks and balls
Mango	Slices
Orange	Segments
Grapefruit	Segments
Honeydew	Chunks and balls
Watermelon	Chunks
Strawberries	Destemmed and sliced
Pineapple	Slices, chunks and cored cylinders
Tomato	Slices

Fresh-cut fruits are a very convenient way to supply consumers with nutritive, healthy, and tasty food products. Washed, bite-size cut, and packaged fresh fruit ready-to-eat allows consumers to eat healthy, on the run, and to save time on food preparation. Availability of fresh-cut fruits in vending machines in schools and at work (for example) would constitute an excellent strategy to improve the nutritional quality of snacks and convenience foods in a time when obesity and nutrition-related illnesses affect large percentages of the population. However, short shelf life, and quality loss faced by fresh-cut fruits during storage severely shorten the reach of such approach; hence, it is of paramount importance to determine the best way to preserve minimally processed fruits, considering all the previously mentioned factors promoting quality loss. The use of edible coatings as a strategy to extend the shelf life of fresh-cut fruits is discussed in the following sections as a potential method to improve the quality of minimally processed fruits.

Definition and History of Edible Coatings on Minimally Processed Fruits

Use of edible coatings on minimally processed fruits consists on the application of a layer of any edible material on the surface of a cut-fruit with the purpose of providing it with a modified atmosphere, retarding gas transfer, reducing moisture and aroma loss, delaying color changes, and improving the general appearance of the product through storage. The practice of coating whole fruits has been conducted for centuries with the purpose of increasing storage time. Wax coating of oranges and lemons in China dates back to the 12th century (Hardenburg, 1967). Edible films have been widely used since then on whole fruits like orange, grapefruit, lemon, apple, and pear, mainly with the purpose of reducing water loss, with waxes being the most commonly employed materials. Use of edible coatings on fruits in the U.S. dates back to the 1910s; A.F. Hoffman, in 1916 patented a method to preserve fruits where whole fruits are chilled in cold water, sterilized by ultraviolet rays, and then coated with molten wax (Hoffman, 1916). D. S. Bryan, in 1972 patented a method to coat grapefruit halves with low methoxy pectin and locust bean gum dispersed in grapefruit juice, constituting one of the first documented examples of the use of edible coatings on minimally processed fruits (Bryan, 1972).

Table 2 Controlled and modified atmosphere storage recommendations for selected fresh-cut fruits (Gorny, 1997)

Product	Temperature	O_2 (%)	CO_2 (%)
Apple, Sliced	0–5	<1	—
Cantaloupe, Cubed	0–5	3–5	6–15
Honeydew, Cubed	0–5	2	10
Kiwifruit, Sliced	0–5	2–4	5–10
Orange, Sliced	0–5	14–21	7–10
Peach, Sliced	0	1–2	5–12
Pear, Sliced	0–5	0.5	<10
Persimmon, Sliced	0–5	2	12
Pomegranate, arils (seed coating)	0–5	—	15–20
Strawberry, Sliced	0–5	1–2	5–10

Use of Edible Coatings on Minimally Processed Fruits

Edible coatings may be applied on minimally processed fruits to serve several different purposes, all of them focused on meeting the challenges posed by fresh-cut fruits. Some of the potential uses of edible coatings on minimally processed fruits are shown in Box 1.

Edible coatings are capable of producing a modified atmosphere on coated fruits by isolating the coated product from the environment. Table 2 shows the recommended modified atmosphere conditions for storage of fresh-cut fruits. Coatings with selective permeability to gases are capable of decreasing the interchange of O_2 and CO_2 between coated fruits and the environment, slowing down the metabolism by decreasing internal O_2 concentration and increasing CO_2 concentration. High CO_2 concentration within fruit tissues also delays ripening by decreasing the synthesis of ethylene, a hormone essential for ripening (Saltveit, 2003). It has been demonstrated that the respiration rate of apple slices decreases 20% when coated with a film based on whey protein (Lee et al., 2003), and that the evolution rate of ethylene decreases 90% when apple slices are coated with a polysaccharide/lipid bilayer coating (Wong et al., 1994).

Another reason for applying edible coatings to fresh-cut fruits is to regulate the transfer of moisture, aroma, and flavor compounds from the fruit to the environment. Coating apple slices with a carbohydrate/lipid bilayer film reduces water loss during storage between 12 to14 times when compared to the water loss suffered by uncoated apple slices in similar storage conditions (Wong et al., 1994). However, although reduction of gas transfer from the fruit to the environment is desirable, extremely impermeable coatings may induce anaerobic conditions that can lead to a decrease on the production of characteristic aroma volatile compounds in fruits (Mattheis and Fellman, 2000; Fellman et al., 1993; Ke et al., 1994). Such problem, nevertheless, may be overcome by taking advantage of yet another potential ability of edible coatings: the use of coatings as additive carriers. Coating formulations may be enhanced with the addition of volatile precursors such as fatty acids, which can be incorporated by fruits into their metabolism promoting the synthesis of aroma compounds (Olivas et al., 2003). For instance, it is known that apples can produce acetate esters as butyl and hexyl acetate by β-oxidation using externally supplied fatty acids as substrates (Paillard, 1979). It has also been demonstrated that pear wedges coated with films composed of methylcellulose and stearic acid show higher production of hexyl acetate and butyl acetate during refrigerated storage than uncoated controls (Olivas et al., 2003). Edible coatings can be used to carry many other types of additives as well. Coatings carrying antimicrobials can effectively protect fresh-cut fruit against bacterial contamination by retaining preservatives on the surface of the cut fruit where they are needed, avoiding diffusion into the tissue (Vojdani and Torres,1990; Baldwin et al., 1995). Carboxymethyl cellulose coatings carrying potassium sorbate and sodium benzoate have been successfully used to reduce microbial growth on apple cores (Baldwin et al., 1996). Enzymatic browning of fresh-cut fruits can be retarded as well by adding antioxidants to coating formulations. Baldwin et al. (1996) found that ascorbic acid delayed apple browning more effectively when applied as part of an edible coating than by direct immersion of apple slices into an aqueous solution of ascorbic acid, and also found that use of carboxymethyl cellulose coatings without additives does not delay browning (Olivas et al., 2003). Calcium caseinate and maltodextrin coatings carrying ascorbic acid have been successfully employed to preserve the color of apple slices as well (Brancoli et al., 2000; Tien et al., 2001). Coating apple slices with films based on carrageenan and whey protein carrying anti-browning agents and calcium chloride successfully preserved color and texture of apple slices (Lee et al., 2003). Texture enhancers such as calcium chloride may be added to edible coatings to enhance

Box 1. Potential uses of edible coatings on cut fruit

- Produce a modified atmosphere in the fruit
- Reduce decay
- Delay ripening of climacteric fruits
- Reduce water loss
- Delay color changes
- Improve appearance
- Reduce aroma loss
- Reduce exchange of humidity between fruit pieces
- Carriers of antioxidants and texture enhancers
- Carriers of volatile precursors
- Impart color and flavor
- Carriers of nutraceuticals

Box 2. Requirements for edible coatings to be used on cut fruit

- Stability under high relative humidity
- GRAS (generally recognized as safe) components
- Good water vapor barrier
- Efficient oxygen and carbon dioxide barrier
- Good mechanical properties
- Adhesion to the fruit
- Colorless and tasteless[1]
- Pleasant to taste
- Physico-chemical and microbial stability
- Reasonable cost

[1] Unless the objective of the film is to impart a specific color and flavor to the fruit.

fruit quality during storage by inhibiting the loss of firmness of minimally processed fruits. It is obvious that the number of uses of edible coatings as additive carriers for minimally processed fruits is very vast, and only limited by the ability of processors. Several more applications not described here, such as modifying the appearance of fresh-cut fruits or adding attractive colors and flavors to cut fruits attracting children and teenagers with pleasant combinations, are waiting to be explored by food processors.

In order for edible coatings to accomplish the previously described tasks of improving the quality and shelf life of cut fruits, some requirements must be fulfilled (Box 2). Not all edible coatings are adequate for any given type of fruit, and even within the same type of fruit, some edible coatings may sometimes work well in one variety and not in another. Hence, careful studies need to be conducted in order to determine what components are required to formulate edible films for specific products.

Before fine-tuning the formulation of an edible coating, there are some basic factors that need to be taken into account when formulating edible coatings for fresh-cut fruits. Two of these factors are the mechanical structure of the film and the affinity between the coating material and the fruit. Coating of fruits may be achieved by immersion, spraying, or brushing followed by drying and cooling. When coating materials are placed on the surface of fruits, two forces develop: cohesion of the molecules within the coating, and adhesion between the coating and the fruit. The degree of cohesion of the coating governs barrier and mechanical properties of the coating. The higher the cohesion, the higher the barrier properties and the lower the flexibility of the film (Guilbert and Biquet, 1996). On the other hand, the degree of adhesion depends on the chemical and electrostatic affinity of the coating material with the surface of the fruit. Higher adhesion ensures longer durability of the film on the surface of the fruit. The water solubility of a coating is another basic factor that needs to be considered as well. If the cut-fruit to be coated has very high water activity (as it is usually the case) a coating with low water solubility must be selected. Doing otherwise would cause the coating to be soggy, which, besides presenting an undesirable appearance, would have poor barrier and mechanical properties.

Examples of strategies to formulate edible coatings for minimally processed fruits can be found in some U.S. patents. As mentioned before, a patent granted to D.S. Bryan in 1972 deals with the use of edible coatings to extend the shelf life of citrus fruit halves (Bryan, 1972). Low methoxy pectin and locust bean gum mixed in citrus juice are used to form the coating with the objectives of keeping natural juices in the cut fruit from evaporating and preventing spoilage. It is claimed that grapefruit coated following this approach retains its natural taste, color, and juice in the fruit after shipping. In 1991 J.M. Krochta patented a method to preserve high moisture fruits like apple slices by the use of coatings containing a mix of protein and a hydrophobic materials (Krochta, 1991). Under this patent, it is suggested that sodium caseinate and acetylated monoglyceride can be used to coat apple slices. The coating procedure may consist of either: presoaking apple slices in calcium ascorbate solution at pH 4.6 (isoelectric point of the casein) prior to coating, soaking slices in ascorbate solution after application of the coating, or just coating with the casein/monoglyceride emulsion without soaking. However, it is claimed in this patent that the soaking step ensures a 25% reduction in moisture loss of coated apple slices, hence should be selected as the preferred application method. Nisperos-Carriedo and Baldwin got a patent in 1993 for the preservation of fruits and vegetables by the use of edible coatings. The purpose of this patented process is to preserve the quality of commodities by avoiding loss of freshness, loss of flavor volatiles, spoilage, abnormal ripening, oxidation, growth of microorganisms, discoloration, and desiccation (Nisperos-Carriedo and Baldwin, 1993). Nisperos-Carriedo and Baldwin in 1994 patented another method to increase the stability of fruits and vegetables by the use of edible coatings as well. This rather comprehensive patent describes the use of coatings containing: at least one polysaccharide polymer, a preservative, and an acidulant. Depending on the type of product, the coating may also include: resins, plasticizers, protein emulsifiers, firming agents, antioxidants, plant growth regulators, and/or chill-injury protectants. It is claimed that this method can be used to preserve whole, peeled or cut fruits (Nisperos-Carriedo and Baldwin, 1994). A patent by Krochta et al. (1996) suggests the use of edible coatings on fresh or minimally processed fruits and vegetables to avoid white blush, which is a quality defect caused by dehydration (Krochta, 1996). Chen et al., 1999 patented a formulation based on calcium salts by the trade name of Nature Seal™, to protect apple slices from color, taste, and texture changes (Chen et al., 1999). It has been proven that a combination of Nature Seal™ and soy protein coatings carrying antibrowning agents and preservatives prolongs the storage life of cut apple by about 1 week when stored in overwrapped trays at 4°C (Baldwin et al., 1996). Although the use of edible coatings on whole fruit is a very common commercial practice, the use of edible coatings on minimally processed fruits is still rare. Currently there are a growing number of commercially available edible coatings for food products in the market. Table 3 shows some commercially available coatings used on fruits, but not necessarily on fresh-cut fruits.

Table 3 Commercially available edible coatings for fruit (USFDA, 2001)

Coating	Major ingredients	Applications
TAL Pro-Long (Courtaulds Group)	Blend of sucrose esters of fatty acids and sodium carboxymethylcellulose.	Pears
Nutri-Save (Nova Chem)	N, O-carboxymethychitosan edible film.	Pears, apples
Semperfresh, (Surface System Intl. Ltd.)	Sucrose ester based with sodium carboxymethyl cellulose.	Most fruits and vegetables, nectarines
PacRite products (American Machinery Corp.)	Water-based carnauba-shellac emulsions, shellac and resin water emulsions, water-based mineral oil fatty acid emulsions.	Apples, citrus, peaches, plums, nectarines
Fresh-Cote product line (Agri-Tech Inc.)	Variety of products including; shellac-based, carnauba-based and oil emulsion edible films.	Apples, pears, stone fruits
Vector 7, Apl-Brite 300C, Citrus-Brite 300C (Solutec Corp.)	Shellac with morpholine; the Apl-Brite and Citrus-Brite are carnauba-based films.	Apples and citrus fruits
Primafresh Wax (S.C. Johnson)	Carnauba-wax emulsion.	Apples, citrus and other firm-surfaced fruit
Shield-Brite products (Pace Intl. Shield-Brite)	Shellac, carnauba, natural wax and vegetable oil/wax and xanthan gum products.	Citrus, pears, stone fruit
Sta-Fresh Products (Food Machinery Corp.)	Natural, synthetic, and modified natural resin products and combinations thereof.	Citrus, apples, stone fruits, pomegranates, pineapple, and cantaloupes
Fresh Wax products (Fresh Mark Corp.)	Shellac and wood resin, oxidized polyethylene wax, white oil/paraffin wax products.	Citrus, cantaloupes, pineapples, and apples
Brogdex Co. products	Carnauba wax emulsions with or without fungicides, high shine wax, carnauba-based emulsion, vegetable oil, resin-based and concentrated polyethylene emulsion.	Apples, melons, bananas, avocado, papaya, mango, pineapple, and citrus.
FreshSeal^{TM} (CPG Technologies of Agway, Inc. to produce)	Cellulose derivatives and emulsifiers.	Avocado, cantaloupe, mangoes and papaya
Nature Seal^{TM}, AgriCoat (Mantrose Bradshaw Zinsser Group)	Composite polysaccharide	Sliced apples, pears, avocados, and bananas

Composition of Edible Coatings for Fresh-Cut Fruits

Hydrocolloids and lipids usually constitute the basic composition of edible coatings for fresh-cut fruits. Hydrocolloids (proteins or carbohydrates) tend to form hydrophilic networks, usually being good barriers to oxygen and carbon dioxide, but poor barriers to water permeability, while lipids in general yield hydrophobic coatings with good water barrier properties. Combination of these complementary abilities is key for the successful development of edible coatings for fresh-cut fruits. Application of two layers, one formed by hydrocolloids and a second formed by lipids instead of applying only one layer of the mixture of the two components may be a successful strategy, and should be considered as well. Table 4 shows some edible coatings that have been developed to be used on minimally processed fruits.

Hydrocolloids

Generally speaking, protein and polysaccharide films are very good gas barriers. However, these barrier properties decline as relative humidity increases due to the ability of proteins and polysaccharides to adsorb moisture (Gennadios et al., 1994), hence, the capacity of hydrocolloid-based films to function as water vapor barriers increases as their solubility in water decreases (Greener and Fennema, 1989; Kester and Fennema, 1986). Protein-based coatings are more effective in terms of permeability to oxygen and water vapor when the pH of their formulation is raised above their isoelectric point, producing insoluble coatings (Baldwin et al., 1996). A common strategy used to reduce the water vapor permeability of hydrocolloid films is to combine hydrocolloids and lipids in the formulation of the film. An important aspect of employing protein-based coatings on fresh-cut fruits is that they may increase the nutritional value of coated products. However, this type of coating may also make fresh-cut fruit products less appealing to vegetarian consumers (if proteins of animal origin are employed), also introducing the potential for allergic reactions and intolerance (Baldwin and Baker, 2002). Another interesting characteristic of hydrocolloids that can be exploited to the advantage of edible coatings on fresh-cut fruits is that some of them possess antioxidant properties, helpful to maintain the color of fruits. Le Tien et al. (2001) found that edible coatings based on calcium caseinate, whey protein and carboxymethylcellulose show important antioxidant capacity. According to the authors, coating apple slices with these films delays browning thanks to their inherent oxygen barrier properties and to their ability to act as scavengers of reactive oxidative species as well (Le Tien et al., 2001). The antioxidant ability of alginate and carboxymethyl chitosan films has also been reported in literature (Xue et al., 1998).

Examples of some polysaccharides that have been successfully used to coat minimally processed fruits are: carrageenan, maltodextrin, methylcellulose, carboxymethyl cellulose, pectin, alginate and microcrystalline cellulose (Bryan, 1972; Rousse and Moore, 1990; Krochta, 1991; Pavlath, 1993; Wong, 1994; Baldwin et al., 1996; Brancoli and Barbosa-Cánovas, 2000, 2003; Le Tien et al., 2001; Olivas et al., 2003). Whey protein concentrate, whey protein isolate, casein, and soy protein

Table 4 Edible coatings on minimally processed fruits

Coating	Additives and plasticizers	Fruit	Results	Reference
Carrageenan	AA, OA, CA, glycerol, PEG	Apple slices	Extension of shelf life by 2 weeks in packed trays at 3C	Lee et al., 2003; Park, 1999)
WPC + CMC	AA, OA, $CaCl_2$, glycerol	Apple slices	Good sensory properties, 20% decrease in initial respiration rate, better firmness	Lee et al., 2003 (Park, 1999)
MC MC + stearic acid	AA, $CaCl_2$, PS, PEG	Pear slices	Delaying of browning on both coatings. The coating containing stearic acid presented resistance to water loss and higher production of hexyl acetate.	Olivas et al., 2003
WPC WPI	Glycerol	Apple cubes	Delaying of browning and texture loss on both coatings. WPC coating was most effective retaining weight loss.	Sonti et al., 2003
WPI + beeswax	Glycerol	Cut apples	Inhibition of browning. Moisture loss was not prevented by the coatings.	Perez-Gago et al., 2003
Calcium caseinate + CMC WPC + CMC	$CaCl_2$, glycerol	Apple slices	Delaying of browning, being whey protein films the best.	Le Tien et al., 2001
Apple puree + beeswax or vegetable oil (wraps and coatings)	AA, CA, glycerol	Cut apple	Wraps were more effective than coatings on avoiding moisture loss	McHugh and Senesi, 2000; McHugh and Senesi Apple wraps, 2000
Maltodextrin + MC	AA. PS, $CaCl_2$, glycerol	Apple slices	Decrease in ethylene production and surface discoloration	Brancoli and Barbosa-Cánovas, 2000
Nature Seal ^{TM}, CMC, and soy protein concentrate	AA, PS, soy oil, $CaCl_2$	Apple slices	Extension of shelf life by 1 week in overwrapped trays at 4C.	Baldwin et al., 1996
CMC	Lecithin, PEG, BA, CA	Sliced mango	Retention of color	Nisperos-Carriedo et al., 1994; Nisperos-Carriedo and Baldwin, 1994
Double coating: Carrageenan/AMG Pectin/AMG Alginate/AMG MCC/AMG	AA, CA, $CaCl_2$ and NaCl	Apple cylinders	Decline in the rate of carbon dioxide and ethylene evolution of 50–70% and 90% respectively. Alginate films presented more resistance to water vapor than the rest of the coatings.	Wong et al., 1994
Casein, alginate and AMG	—	Cut apple	Protection against moisture loss	Pavlath et al., 1993; Pavlath et al., 1993
Casein + AMG	—	Sliced apple	Reduction in moisture loss by 50–70%	Krochta, 1990
Carrageenan and locust bean gum	—	Cut citrus fruits	—	Rouse and Moore, 1972
Low methoxy pectin, locust bean gum, and grapefruit juice	Ca cyclamate	Fruit citrus halves	Retention of color, taste, and juice.	Bryan, 1972

WPC = whey protein concentrate, CMC = carboxymethyl cellulose, MC = methylcellulose, WPI = whey protein isolate, MCC = microcrystalline cellulose, AMG = acetylated monoglyceride, AA = ascorbic acid, OA = oxalic acid, CA = citric acid, $CaCl_2$ = Calcium chloride, NaCl = sodium chloride, PS = Potassium sorbate, BA = benzoic acid, PEG = polyethylene glycol.

concentrate are some examples of proteins also used to coat minimally processed fruits (Krochta, 1990; Pavlath et al., 1993; Baldwin et al., 1996; Le tien et al., 2001; Sonti et al., 2002; Lee et al., 2003; Pérez-Gago et al., 2003).

Lipids

As mentioned before, lipids can be included in the formulation of edible coatings in the form of a single layer of a lipid-based film, as lipids dispersed in a network formed by hydrocolloids, or as a secondary layer (a lipid layer over a hydrocolloid layer). Lipid coatings are in general good water vapor barriers, however, lipids that are solid at storage temperatures form coatings with better water vapor barrier properties than those lipids that are liquid under the same conditions, mainly because the solubility of water vapor in lipids is lower in films with a more ordered molecular organization (Kester and Fennema, 1986). The degree of saturation and the chain length of fatty acids also influence the water vapor permeability of edible coatings. Saturated large-chain fatty acids form coatings with the best water vapor barrier properties among fatty acids because they produce a more densely packed structure and have less mobility than unsaturated short-chain fatty acids (Kamper and Fennema, 1984). Unfortunately, coatings comprised exclusively by lipids can lack structural integrity (fatty acids and alcohols) so they may require the use of hydrocolloids as matrix for the film (Baldwin et al., 1997). In addition lipid films are generally opaque, rigid, and waxy tasting and may not adhere to hydrophilic cut surfaces (Baldwin et al., 1995; Pérez-Gago and Krochta, 2001), which limit the utility of lipid edible coatings on fresh-cut fruits. Formulations including a lipid dispersed on a hydrocolloid matrix are then the best strategy to produce edible coatings for fresh-cut fruits. Beeswax, acetylated monoglycerides, fatty alcohols, and fatty acids, are some of the lipids that have been successfully employed to coat cut-fruits, always applied in combination with a polysaccharide or protein.

Composite and Bilayer Films

Edible coatings employing both, hydrocolloids and lipids, may be applied in the form of a composite film where all the components are mixed into one homogenous coating layer, or applied in the form of two layers, formulating one of them with hydrocolloids and the other with lipids (bilayer films). Combination of hydrocolloids and lipids has been successfully employed as a means to improve the barrier characteristics of edible coatings covering fresh fruit. Such strategy takes advantage of the good water barrier properties of lipids and the good gas barrier properties of hydrocolloids. Composite films are less effective as barriers to gases and water vapor than bilayer films since the surface of fruits coated with composite films is only covered by one component at a time, as coatings are formed by a matrix where lipids and hydrocolloids alternate. Nevertheless, composite films are more convenient to apply since they only require one application and one drying step, and also because they adhere better to a larger number of surfaces thanks to possessing both polar and non-polar characteristics (Pérez-Gago and Krochta, 2001). The physicochemical attributes of lipid-hydrocolloid emulsions employed on the preparation of composite edible coatings, as well as the type and concentration of their constituents define the physical, mechanical, and barrier properties of composite films. Increasing the lipid content or the size of lipid droplets emulsified on hydrocolloid aqueous solutions turn coatings more opaque, while reducing the droplet size or improving lipid distribution (i.e. by homogenization) improves the overall properties of coatings reducing their water vapor permeability (Quezada-Gallo et al., 2000; Pérez-Gago and Krochta, 2001). Although in general, increasing the lipid content of composite films decreases their water vapor permeability, it has been found that under some circumstances, increasing the content of lipids over certain values leads to the increase on the water vapor permeability of films (Sapru and Labuza, 1994). Such adverse effect has been attributed to the inadequate dispersion of lipids on aqueous emulsions containing high concentrations of lipids (Avena-Bustillos and Krochta, 1993). Orientation of lipid molecules within the coating is also an important issue. It has been demonstrated that the water vapor permeability of composite coatings separating regions with different relative humidity is lower when the lipid fraction in the films is oriented towards the side with the higher relative humidity (Avena-Bustillos and Krochta, 1993). However, in the case of fresh-cut fruits coated with hydrocolloid-lipid emulsions, the lipid fraction of the coating tends to orient towards the outside (i.e. the environment, hence the low humidity side), as hydrocolloids have in general more affinity for fruit surfaces than lipids. An example of the use of composite films in the preservation of fresh-cut fruits can be found in Pavlath et al. (1993) where fresh-cut apple was coated with a composite film made from an aqueous emulsion of casein, alginic acid and acetylated monoglyceride, protecting apple wedges from moisture loss and discoloration. Examples of the use of bilayer films for the preservation of fresh-cut fruits can be also found in literature. Wong et al. (1994) coated apple cylinders with a film composed of a mix of polysaccharides (pectin, carrageenan, alginate, and microcrystalline cellulose), followed by the application of a second layer containing acetylated monoglyceride, reducing water loss between 12 to 14 times when compared to uncoated apples (Wong et al., 1994). It was also reported that a 50–75% reduction in the internal oxygen concentration of coated apples was achieved by the use of this bilayer film (Wong et al., 1994).

Additives

The properties of the film (functional, nutritional, organoleptic, and mechanical) can be improved by the use of additives such as antibrowning agents, preservatives, firming agents, plasticizers, nutraceuticals, volatile precursors, flavors, and colors, widening the usefulness of coatings for minimally processed fruits. Additives can also be helped by the coatings to accomplish their work. It has been demonstrated that some additives work more effectively on food when applied as part of an edible coating than when applied as aqueous solutions by spraying or dipping, since the coating can maintain additives on the surface of the food for longer time (Vojdani and Torres,1990; Baldwin et al., 1996). Some additives have been used on coated cut-fruits such calcium chloride to inhibit loss of firmness, ascorbic acid to decrease browning rate, and potassium sorbate and benzoic acid to inhibit microbial growth (see Table 4).

Another additive frequently used in edible films and coatings is a plasticizer, which is included in the formulation with the purpose of modifying the mechanical properties of the base components (hydrocolloids and/or lipids), producing more flexible coatings. The compounds most often used as plasticizers in the formulation of edible coatings for cut-fruits are: glycerol and polyethylene glycol (see Table 4). Such substances have the ability of modifying the mechanical properties of the coatings by combining with the main components of films and interspersing between polymer chains, moving the chains apart and reducing the rigidity of the structures (Guilbert and Biquet, 1996). Water may play the role of plasticizer in hydrophilic coatings (Cisneros-Zeballos and Krochta, 2002).

Evaluation and Selection of Edible Coatings

Every minimally processed fruit possesses specific characteristics that makes it different from the other fruits, therefore,

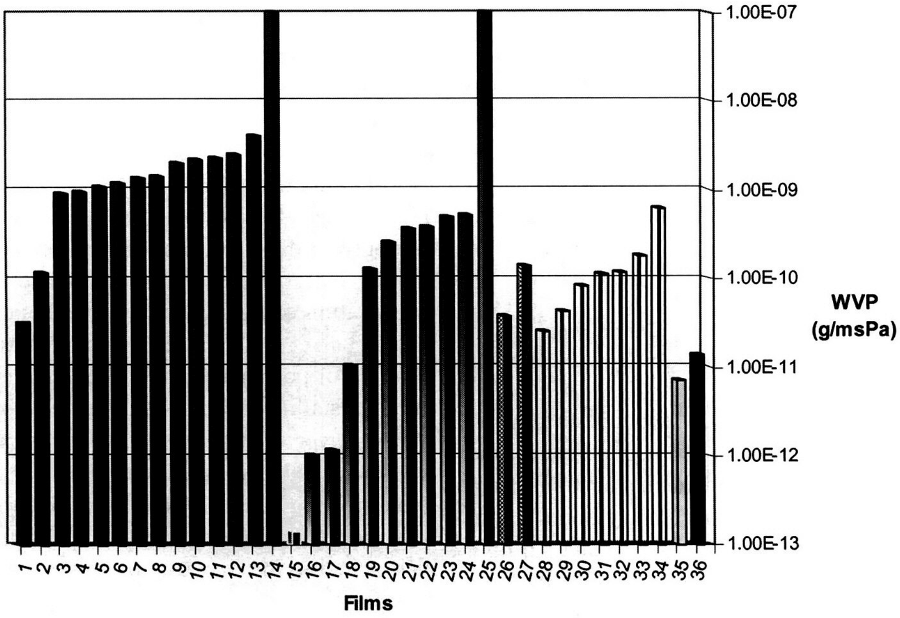

Figure 1 Water vapor permeability of edible films under different RH conditions: ■ ~50–100%RH, ■~0–100% RH, ▨ ~20–80%RH, ◫ ~0–85%RH, ⊟ ~0–50%RH and ■ ~0–20%RH (temperature ranges between 21 and 30C). Each column represents the water vapor permeability of selected edible films with formulation encountered in literature (see Table 5 for identification of numeric codes).

development and analysis of edible films have to be conducted in order to select the optimum coating for a specific minimally processed fruit (Park, 1999). Since some coating properties such as gas permeability and mechanical properties are impossible or very difficult to measure on coatings after placement on fruits, the examination of edible films alone can provide a notion about how the coatings will behave once on the fruit. For such procedures to be effective, analyses of edible films have to be conducted under conditions similar to the ones the coating will face when placed on the fruit, like very high relative humidity and low temperature, since minimally processed fruits are generally products with very high water activity which are stored under refrigeration temperatures. There are many interesting works characterizing edible films in technical and scientific literature. Figure 1 and Table 5 show water vapor permeability, oxygen permeability, and mechanical properties of some edible films reported in literature.

Water Vapor Permeability

The most common method to determine WVP is a variation of the ASTM Standard method E 96 (Martin-Polo and Voilley, 1992; Gennadios et al., 1994; McHugh and Krochta, 1994; ASTM, 2000). The capacity of films to work as barriers to water vapor depends on the relative humidity and temperature of the environment. Figure 1 shows how as relative humidity of the environment in which the film is placed increases, water vapor permeability (WVP) also increases. It is important to include hydrophobic compounds as part of the formulation of an edible film if it is expected to have good water vapor barrier properties. Figure 1 shows that those films containing lipids like fats, waxes, and fatty acids achieve the lowest WVP. The capacity of lipids to reduce water loss in fresh-cut produce is affected by the type of employed lipid, the amount of lipid included in the formulation, and the chain size of the employed lipid molecule. Some of the lipids most efficiently used to control or limit WVP are: beeswax, carnauba, candelilla, milk fat, and large chain saturated fatty acids. Water vapor permeability decreases as the hydrophobicity of the lipid in the film increases (Ayranci and Tunc, 2003).

It is important to stress that no edible film having lower WVP than artificial-polymer plastic films has been developed so far (to our knowledge), and poor control of water migration is still a weakness related to the use of edible films on fresh-cut produce. Minimally processed fruits intended for retail need then to be packaged in a plastic box or bag to handle them and achieve low water vapor permeabilities, while the simultaneous use of an edible coating would ensure low gas permeability, mechanical protection, and homogeneous and constant delivery of additives. Such an approach would constitute a double layer strategy with two controlled atmospheres, one controlled by the edible coating and the second one controlled by the plastic film.

Gas Permeability

There are various methods to determine oxygen permeability of edible films (McHugh and Krochta, 1994); the most commonly used being a commercial permeation testing equipment produced by MOCON Corporation (Minneapolis, MN). For cases where this kind of equipment is not available, Ayranci and Tunc (2003) developed a method involving the flow of oxygen and nitrogen gasses on both sides of the edible film coupled with a chemical analysis. Methods to

Table 5 Mechanical properties and oxygen permeability of some edible films (numbers in first column identify the bars in Figure 1)

	Mechanical Properties					Oxygen Permeability (O_2P)			
Film	T (°C)	%RH	Thickness (μm)	% Elongation	Tensile Strength (MPa)	T (°C)	%RH	Thickness (μm)	O_2P^b
1 Bilayer zein /sorghum wax: TG 1:7.4 (Weller et al., 1998)	25	50	91	153	1.2	—	—	—	—
2 Chitosan:PEG 1:0.5 (Caner et al., 1998)	—	—	—	—	—	—	—	—	—
3 WPI: sorbitol 2:1 (Shaw et al., 2002)	23	50	97.9	~10	~9	—	—	—	—
4 WPI: xylitol 2:1 (Shaw et al., 2002)	23	50	97.9	~18	~8	—	—	—	—
5 Pullulan: gly: sorbitol 2:0.3:0.3 (Kim et al., 2002)	25	50	50.1	25.4	7.8	—	—	—	—
6 HCMS: gly 1:0.3 (Kim et al., 2002)	25	50	70.8	7.7	9.7	—	—	—	—
7 WPI: gly 2:1 (Shaw et al., 2002)	23	50	97.7	~37	~3	—	—	—	—
8 HCMS: sorbitol 1:0.3 (Kim et al., 2002)	25	50	84.5	2.8	10.2	—	—	—	—
9 Soyprotein isolate: PG alginate 1:0.1	25	50	64	~130	~5	—	—	—	—
10 WPI:sorbitol 1:0.83 (Anker et al., 2001)	23	50	160	~28	~2.2	—	—	—	—
11 HCMS: sorbitol: gly 2:0.3:0.3 (Kim et al., 2002)	25	50	69.8	5.1	16	—	—	—	—
12 Zein (Weller et al., 1998)	25	50	133	130	1.05	—	—		
13 WPI:glycerol 1:0.48 (Anker et al., 2001)	23	50	~135	~33	~2.4	—	—	—	—
14 Rice bran:gly 1:.02 (Gnanasambandam et al., 1997)	23	55	—	—	7	35	55	190	.41
15 Candelilla wax (Shellhammer and Krochta, 1997)	—	—	—	—	—	—	—	—	—
16 Beeswax (Shellhammer and Krochta, 1997)	—	—	—	—	—	—	—	—	—
17 Carnauba (Shellhammer and Krochta, 1997)	—	—	—	—	—	—	—	—	—
18 Milk fat fraction 15:1:10.6 (Shellhammer and Krochta, 1997)	—	—	—	—	—	—	—	—	—
19 WPI: gly: beeswax 15:1:10.6 (Shellhammer and Krochta, 1997)	—	—	—	—	—	—	—	—	—
20 WPI: gly: milkfat15:1:10.6 (Shellhammer and Krochta, 1997)	23	52	—	~2.6	~19	—	—	—	—
21 WPI:gly: candelilla 5:1:10.6 (Shellhammer and Krochta, 1997)	23	52	—	~1	~17	—	—	—	—
22 WPI:gly: carnauba 15:1:10.6 (Shellhammer and Krochta, 1997)	23	52	—	~1.5	~23	—	—	—	—
23 Alginate: gly 1:0.4 (Olivas and Barbosa-Cánovas, 2004)	25	59	43	2.4	58.5	—	—	—	—
23 Alginate: gly 1:0.4 (Olivas and Barbosa-Cánovas, 2004)	25	98	47	8	19.3				
24 WPI: gly 15:1 (Shellhammer and Krochta, 1997)	—	—	—	—	—	—	—	—	—
25 Muscle protein: gly 1:0.4 (Paschoalick et al., 2003)	—	—	—	—	—	—	—	—	—
26 MC: PEG: and paraffin wax 1:0.3:0.4 (Quezada-Gallo et al., 2000)	25	4	—	~15	33.1	—	—	—	—
27 MC: PEG: HPO and triolein 1:0.3:0.4 (Quezada-Gallo et al., 2000)	25	4	—	~24	32.8	—	—	—	—
28 Locust bean gum: PEG .7:1 (Aydinli and Tutas 2000)	—	—	—	—	—	—	—	—	—
29 Calcium caseinate/beeswax (Cisneros-Zeballos and Krochta, 2002)	—	—	—	—	—	—	—	—	—
30 HPC: PEG:AM 1:0.3:1 (Park and Chinnan 1995)	—	—	—	—	—	30	0	150	297.2
31 HPC: PEG 1:0.1 (Park and Chinnan 1995)	—	—	—	—	—	30	0	50	308.4
32 Corn-zein: gly 1:0.2 (Park and Chinnan 1995)	—	—	—	—	—	30	0	120–310	31.1
33 Sodium caseinate: AM (Cisneros-Zeballos and Krochta, 2002)	—	—	—	—	—	—	—	—	—
34 Wheat gluten: gly 1:0.3 (Park and Chinnan 1995)	—	—	—	—	—	30	0	230–420	17.28
35 MC:PEG 3:1.8 (Ayranci et al., 1997)	—	—	—	—	—	—	—	—	—
36 Konjac glucomannan (Cheng et al., 2002)	30	20–85	—	10–12.2	5–4	—	—	—	—

TG = Triglyceride, gly = Glycerol, PG = Propyleneglycol, WPI = Whey protein isolate, HCMS = Highly carboxymethylated starch, PEG = Polyethylene glycol, HPC = Hydroxypropylcellulose, AM = Acetylated monoglyceride, MC = Methyl cellulose, HPO = Hydrogenated palm oil, P = Permeability. $^{b}\text{cm}^3\,\mu\text{m/m}$ (Kays, 1991) dkPa.

determine CO_2 permeability have been also developed based on modifications to the method employed to measure WVP (Ayranci et al., 1999). As it is the case with water vapor permeability, gas permeability of edible films is also influenced by atmospheric relative humidity and temperature (Cisneros-Zeballos and Krochta, 2002). Contrary to water vapor permeability, lower oxygen permeabilities can be achieved by the use of edible coatings than when using conventional plastic films. Oxygen permeability of some edible films is shown in Table 5.

Mechanical Properties

Tensile strength, elongation, and elastic modulus are the most common mechanical properties evaluated on edible films. Tensile strength (TS) indicates the maximum stress developed in a film in a tensile test. Elongation (E) indicates the capacity of the film to stretch (Gennadios et al., 1994). Table 5 shows the TS and %E of some edible films. The magnitude of TS and %E depends closely on the relative humidity. As relative humidity increases, tensile strength and elastic modulus decrease while elongation increases, due to the increase on the amount of water in the coating (Olivas and Barbosa-Cánovas, 2004). The amount of plastizicer present in the film affects in the same way the mechanical properties (Gennadios et al., 1994). Mechanical properties may vary with film thickness, speed of testing, and type of grips used so it is very important to be aware of this when working and comparing mechanical properties in edible films (ASTM, 1997).

Other Analysis

Besides barrier and mechanical properties there are some other important properties to evaluate in edible films such as thickness, solubility, wettability, sorption isotherms, flavor, color, and microbiological stability, all of them also important for the selection of an edible coating.

Analysis of the Coated Product

After a suitable film has been identified through testing of the film alone, an analysis of the behavior of the coating when applied on the minimally processed fruit is required. Among the analyses that have to be addressed on the fruit are: oxygen and carbon dioxide concentration, volatiles production (ethanol, ethylene, and acetate esters), changes in color and texture, microbial growth, water loss, changes in titratable acidity, soluble solids, and sensory properties.

Water Loss

Change in weight of the fruit coated has to be monitored during the storage period to determine how effective the coating is as a moisture barrier. It can be considered that weight loss corresponds almost exclusively to water loss since other components that can be lost such as aromas or flavors, and gases product of respiration are practically undetectable in terms of weight.

Texture

Texture is a very important indicator of fruit quality (Huxoll, 1989). Various tests can be used to determine the texture changes in the coated fruits such as texture profile analysis (TPA), compression, and puncture tests. In TPA test the fruit sample is compressed twice imitating the action of the jaw and the parameters obtained from this test correlate well with sensory ratings (Bourne, 1982). Olivas et al. (2003) used the TPA test to determine changes in texture quality of coated pear wedges (Olivas et al., 2003). Lee et al. (2003) and Brancoli and Barbosa-Cánovas (2000) used a compression test to observe changes in firmness of apple slices and cubes, determining the force needed to compress 50% and 75% the sample, respectively.

Microbial Analysis

As mentioned before, minimally processed fruits are a suitable environment for microorganisms to grow due to the high amount of moisture and sugar present on their surface. Presence of microorganisms on fresh-cut fruits can result from defective washing, or from peeling, slicing, or cutting under unsanitary conditions with contamination coming from the equipment and material used or from the coating solutions. At refrigerated temperatures the ability of the microorganisms to multiply is reduced, however refrigeration temperatures alone cannot completely prevent growth of pathogenic microorganisms. Under refrigerated storage conditions, pathogen populations can reach levels capable of causing disease before spoilage of the product by the native microflora occurs (USFDA, 2001). The microflora commonly found in fruits and vegetables are *Pseudomonas* spp., *Erwinia herbicola*, *Flavobacterium*, *Xanthomonas*, *Enterobacter agglomerans*, lactic acid bacteria such as *Leuconostoc mesenteroides* and *Lactobacillus* spp., and molds and yeasts (Zagory, 1999).

It is also important to consider that coating the product will create a modified atmosphere, which may change the growth rate of spoilage and pathogenic bacteria. Modified atmospheres may inhibit the growth of organisms usually responsible for spoilage, while encouraging the growth of pathogens. For example, growth and toxin production by *C. botulinum*, which usually would not be a cause of concern on fresh fruit, could however occur when fruits with high pH (>4.8) like tropical fruits are covered with a coating with strong oxygen barrier properties. It is important also to be aware that the extension of shelf life caused by coating of minimally processed fruits gives more time for pathogens to grow, even under refrigeration conditions, where psychotropic foodborne pathogens such as *L. Monocytogenes*, *Yersinia enterocolitica and Aeromonas hydrophila* may represent a potential problem (USFDA, 2001). Study of the development of populations of mesophilic bacteria, psychotropic bacteria, molds, and yeast during storage of fresh cut minimally processed fruits is then required to ensure the microbiological safety of such products.

Color

The effect of the studied coatings on the color of the fruit is an important parameter since color relates directly to the perception of quality by the consumer. The surface color of the fruit has to be analyzed during storage, measuring color in several locations of the sample. The most commonly used systems for measurement of color are Hunter Lab, CIE L*a*b*, CIE L*C*h, CIE XYZ, and CIE Yxy, which are based on the fact that the human eye has three types of color sensors which are sensitive to the colors red, green, and blue and that all colors are seen as a mixture of these three colors (Abbott, 1999).

Measurements may be conducted by using a colorimeter; in the case of the CIE L*a*b*scale, L* indicates lightness and a* and b* are the chromaticity coordinates (rectangular coordinates), +a* is the red direction, −a* is the green direction, +b* is the yellow direction, and −b* is the blue direction. The center of these coordinates is achromatic and as a* and b* values increase, the saturation of the color increases. The L* C* h color system uses the same principle as the L* a* b*system but employs cylindrical coordinates. Considering the way in which these chromatic systems work, it is imperative to always report three values (L* a* b*or L* C* h) when describing a color, since only the combination of these three values on a three-dimensional space define a color, and independent comparison of each value is often meaningless (McGuire, 1992).

Comparison of color differences can be achieved by calculation of the ΔE^*_{ab} when using CIE L*a*b* color space, or the ΔH^* when using the CIE L*C*h scale. Although ΔE^*_{ab} defines the absolute amount of color difference, it does not define in what way the colors are different. On the other hand, the hue difference (ΔH^*) not only represents an absolute color difference, but also shows if the change in color leads toward more light, pale, dark or deep colors (Minolta Co., Ltd., 1994). Other indexes designed to monitor specific changes in color have been developed. For instance, a Browning Index (BI) was developed by Buera et al. (1985) to calculate the purity of brown color when browning of foods takes place. This index has been successfully employed as an indicator of browning in fresh-cut coated fruits (Olivas et al., 2003; Baldwin et al., 1997).

Titratable Acidity and Soluble Solids Content

The acid content of fruits tends to decrease with fruit maturity as sugar (soluble solids) content increases (Sadler and Murphy, 1998). Acid content in fruits can be measured by direct titration of fruit juice with sodium hydroxide, while soluble solids can be determined by refractometry. Water content and water loss in fruits during storage must always be considered for the interpretation of tritrable acidity and soluble solids values. Water loss causes an apparent increase on the concentration of both mentioned parameters that may be incorrectly interpreted as a true change in the amount of acids or sugars present on minimally processed fruits.

Volatiles

The flavor and aroma of minimally processed fruits can be affected by the presence of coatings, so volatiles concentration is an important parameter that has to be evaluated after a coating has been applied. A way to measure the concentration of volatiles in fruit tissue is by gas chromatography using solid phase microextraction (SPME), where fruit juice is placed in a vial and a SPME fiber is exposed to the headspace for a considerable period of time before GC injection (Mattheis et al., 1991). The addition of inorganic salts can enhance the activity coefficients of volatile components in aqueous solutions, increasing their concentration in the headspace. Fruit should be analyzed for volatiles periodically during storage. If the samples to be analyzed have lost some weight, a compensation for weight loss has to be considered (Olivas et al., 2003).

Respiration Rate

The respiration rate of minimally processed coated fruits can be measured by placing the fruit in a small container or a bag, and taking a sample of the atmosphere immediately, and after a certain period of time, and analyzing it by gas chromatography, adjusting for time between sampling, headspace, and size of the fruit (Johnston et al., 2002). In order to measure the internal concentration of oxygen, carbon dioxide, and ethylene in the fruit pulp, the tissue may be compressed, and the released gases collected in a syringe and analyzed by gas chromatography (Beyer and Morgan, 1970).

Sensory Analysis

The analysis of the sensory properties of coated fruits is very important since it will give a close idea about how the consumer will respond to the new product. Lee et al. (2003) evaluated the sensory properties of apple slices with 10 experienced panelists who analyzed color, firmness, flavor, and overall preference with a 9-point hedonic scale going from 1 = dislike extremely to 9 = like extremely. Brancoli and Barbosa-Cánovas (2000) (Brancoli and Barbosa-Cánovas, 2000) evaluated changes in color using a trained panel (11–14 panelists) and a 15 cm unstructured line using "brown" and "white" as anchors at the ends of the scale, obtaining a 0.86 correlation with an objective color measurement.

CONSUMER PERCEPTION OF EDIBLE COATINGS ON FRUITS

Among all the quality aspects related to the use of edible coatings on minimally processed fruits, consumer preferences and attitudes towards coated produce are not less important than physical or chemical characteristics. As a matter of fact, poor consumer appeal signifies poor selling power, even in the event that an edible film with good coating properties that satisfy the previously mentioned requirements for a specific product is identified. Hence, it is very important to take into account consumer preferences when developing a coating formulation. The sensory contributions of an edible coating to a fruit will depend on the thickness of the coating, its chemical composition and how it disintegrates during consumption of the fruit (Brancoli et al., 1997). Edible coatings having the best barrier properties, unfortunately, not always have the best sensory attributes, constituting organoleptic challenges (Guilbert and Biquet, 1996). According to Park (1999) consumers tend to be wary of waxy coatings, which make researchers look for coatings that can have good barrier properties and less waxy flavor/appearance, however very few studies have been conducted in this important topic. Sonti et al. (2002) and Sonti et al. (2003) analyzed the consumer perception of fresh-cut fruits and vegetables with edible coatings and found that 76.5% of consumers would buy them if they were coated with an FDA-approved edible coating. Consumers would not buy coated fruits if the coating were of animal origin. They also found that consumers with children at home were more likely to buy coated fresh-cut fruits than adults with no children. Conducted studies have found that it is necessary to explain to the consumer the importance and advantages of using edible coatings in fresh-cut fruits so they can have a predilection to the product. Sonti et al. (2002) found a 7% increase in purchase intent after describing to the consumer the advantages of edible coatings.

CHALLENGES AND DISADVANTAGES OF EDIBLE COATINGS ON MINIMALLY PROCESSED FRUITS

Minimally processed fruits usually are commodities with very high water activity, and it is well known that the capacity of films to function as barriers to water vapor and gases decreases as relative humidity of the environment increases (Rico-Peña and Torres, 1991; Hagenmaier and Shaw, 1990, 1991; McHugh and Krochta, 1994; Gontard et al., 1996). The capacity of edible films to have low permeability to water and gases relies on external conditions like temperature and relative humidity and characteristics of the film such as chemical structure, polymer morphology, degree of crosslinking, solvents used in casting film, and type of plasticizer used. Hagenmeier and Shaw (1991) found that coatings casted from ethanol had lower WVP, O_2, and CO_2 permeability than those casted from water. Nevertheless, if ethanol is used as a solvent for a coating formulation in minimally processed fruits and it is not completely evaporated, it can impart a bad flavor or be used by the fruit as a substrate to produce volatile compounds that could be undesirable (Olivas et al., 2003; Mattheis et al., 1991). The application of an artificial barrier to diffusion of gases and water by coating of fresh-cut fruits causes a modification of the atmosphere inside the fruit that could lead to a decrease in the production of characteristic flavor compounds (Ke et al., 1994; Fellman et al., 2003). Adding some compounds to the coating formulation that can be used by the fruit to produce acetate esters could compensate such deficiency (Olivas et al., 2003). Limited oxygen diffusion caused by the presence of edible coatings on cut fruit may limit respiration processes to an extent that forces fruit to undergo anaerobic respiration, metabolizing glucose into ethanol. Control of oxygen permeability of coatings and monitoring of ethanol production by fruits is extremely important, since exposure of cut-fruit to ethanol conduces to the formation of off-flavors, even when exposure is limited to short periods of time and prolonged exposure of fruit to anaerobic conditions results in cellular death (Kays, 1991).

CONCLUSION

Edible coatings can improve the quality of minimally processed fruits and extend their shelf life by providing the fruit with a modified atmosphere working as a barrier to moisture, oxygen and carbon dioxide. Food additives can be added to the coating to improve its performance. Coating composition, preparation, and application of the coating, storage temperature, and atmospheric gas composition, as well as the specific characteristics of the coated fruit will affect the final characteristics of the coated product. Applied components and whole films need to be tested on each type of fruit and variety before commercial application is possible. Attention needs to be placed on the interactions between coatings and fruit as they may lead to the formation of desirable or undesirable compounds in the final product.

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