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Development of Edible Coatings for Fresh Fruits and Vegetables: Possibilities and Limitations

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ABSTRACT

The development of edible coatings to extend the shelf-life of fresh fruits and vegetables has been one of the most important goals of the post harvest industry. Thus, in the last decade, research efforts have resulted in edible coatings based on biodegradable biopolymers (proteins and polysaccharides) that at the same time allow the reutilization of some by-products of the food industry. Generally, these hydrocolloids are used as a support matrix since they show excellent film-forming ability, good mechanical properties and selective permeability to gases. However, due to their poor water vapour barrier properties, they have to be combined with lipid compounds in order to obtain composite edible coatings with the desired functional characteristics. Moreover, edible coatings for fruits and vegetables can be especially designed to incorporate and/or controlled release antioxidants, vitamins, nutraceuticals, prebiotics and antimicrobial agents. This work reviews the composition and main properties of formulations and commercial applications available at present, as well as their main effects on the quality and shelf-life of fruit and vegetables during storage.

Keywords: commercial application, food, shelf-life, quality, review

Abbreviations: CMC, Carboximethyl cellulose; **HPC**, Hydroxypropyl cellulose; **HPMC**, Hydroxypropyl methylcellulose; **MC**, Methylcellulose; **PEG**, Polyethylene glycol; **SSD**, surface solid density; **WPC**, whey protein concentrate; **WPI**, whey protein isolate; **WVR**, water vapour resistance

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INTRODUCTION

The use of coatings for fresh fruits and vegetables is not a new concept. Fruits and vegetables are coated in nature by a natural waxy coating called cuticle, consisting of a layer of fatty acid-related substances, such as waxes and resins, with low permeability to water (Baldwin 1994). Wax was the first coating used in fruits, specifically, in citrus fruits. It is believed that they were applied to oranges and lemons at the beginning of the 12th or 13th centuries in China. Later on, in the 1930s, hot-melt paraffin waxes became commercially available as edible coatings for fresh fruits (Park 1999). Since the 1950s, carnauba wax and colloidal suspensions or emulsions based on oils or waxes dispersed in water, have been used to coat fresh fruits and vegetables. During these years, the most successful coatings have been lipid films made of acetylated monoglycerides, waxes (beeswax, carnauba and candelilla wax, paraffin and rice bran) as well as surfactants. These coatings are used to control the moisture transport and permeability of O_2 and CO_2 and to reduce surface abrasion during fruit handling.

The purpose of edible coatings for fruits and vegetables is basically to mimic or enhance their natural barrier, if already present, or to replace it in the cases where washing and handling have partially removed or altered it (Baldwin 1994). Coatings could also improve the mechanical handling properties (helping to maintain the structural integrity of coated commodities), retain volatile flavour compounds and can carry food additives such as antimicrobial agents and antioxidants. Moreover, one of the most important advantages of this technology is the fact that they can be eaten together with the fruit, thus reducing packaging wastes.

According to Guilbert *et al*. (1995), edible coatings may be defined as a thin layer of material that covers the surface of the food and can be eaten as part of the whole product. The composition of edible coatings must therefore conform to the regulations that apply to the food product concerned. Thus, the European Directive (Directiva 95/2/CE; Directiva 98/2/CE) and the US Code of Federal Regulations (FDA 21CFR172 2006) define edible coatings as those coatings that are formulated with food-grade additives.

As stated by Kester and Fennema (1986), edible coatings have to follow some functional requirements, which also depend on the kind of coated product and its metabolic pathways, such as:

- Sensory properties: Edible coatings must be transparent, tasteless and odourless.
- Barrier properties: Coatings must have an adequate water vapour and solute permeability and selective permeability to gasses and volatile compounds.

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Review

Table 1 Composition of edible films and coatings.

Compound	Source	WVR /O_2 and CO_2 permeability	Others	E-Number	Reference
Polysaccharides					
Methylcellulose	Cellulose	Low/high	GRAS[1]/flexible	461	Hernández 1994
Hydroxypropyl- cellulose	Cellulose	Low/high	GRAS/ flexible	463	Hernández 1994
Hydroxypropyl methylcellulose	Cellulose	Low/high	GRAS/ flexible	464	Hernández 1994
Carboximethylcellulose	Cellulose	Low/high	GRAS/ flexible	466	Hernández 1994
Dextrin	Starch	High/moderate	Dries slowly		Greener and Fennema 1994
Alginate	Algae extracts	Low/moderate	Fragile	401-405	Glicksman 1983
Chitosan; N,O-carboxymethyl chitosan	Crustacean shells	Moderate/high	GRAS antimicrobial		Tharanathan and Kittur 2003
Pectin	Fruit Peels	Low/high	GRAS	440	Liu *et al*. 2006
Carrageenan	Algae extracts	Low/moderate	Fragile	407	Greener and Fennema 1994
Gum Arabic	Acacia tree	Low/moderate	Good adhesion	414	Greener and Fennema 1994
Guar gum	Seed extracts	Low/moderate	Firming agent	412	Greener and Fennema 1994
Xanthan gum	*Xanthomonas campestris*	Low/moderate	Good adhesion	415	Greener and Fennema 1994
Proteins					
Zein	Corn	Low/high	GRAS		Koelsch 1994
Gluten	Wheat	Solvent and pH dependent/ high	Fragile		Guilbert 2000
Soy	Soybean	Low/low	Flexible		Cho and Rhee 2004
Whey protein	Milk	Moderate/high	Flexible		Maté *et al*. 1996
Casein	Milk	Moderate/low	Brittle		Dangaran *et al*. 2006
Lipids					
Shellac	Insects	High/high	GRAS	904	Hagenmaier 2000
Beeswax	Beeswax	High/low	GRAS	901	Hagenmaier and Baker 1997
Carnauba wax	Plant exudates	High/low	GRAS	903	Martin-Polo *et al*.1992a, 1992b
Candelilla wax	Plant exudates	High/low	GRAS	902	Hagenmaier and Baker 1997
Fatty acids	Plant or animal material	According to type/low	GRAS	471	Martin-Polo *et al*. 1992a, 1992b

[1] Generally Recognize as Safe

Moreover, edible coating formulations have to contain safe and food-grade substances and the cost of the technology and raw materials from which coatings are produced have to be relatively low.

It is important to remark that the effectiveness of a specific coating depends on the fruit and vegetable as well as the thickness of the coverage (Baldwin 1994). What is more, the impact of coating application can also differ among cultivars of the same fruit or vegetable.

This mini-review gathers some of the most recent information on the application of edible coatings to fresh fruits and vegetables.

COMPOSITION OF EDIBLE COATINGS FOR FRESH FRUITS

The main components used in the formulation of edible coatings for fruits and vegetables are hydrocolloids (polysaccharides and proteins) and lipids. The characteristics of these compounds that are relevant in terms of edible coating technology are summarized in **Table 1**.

Polysaccharides are the most common component of edible coatings for fruits (Kester and Fennema 1986; Krochta and De-Mulder Johnston 1997), as they are present in the major part of the commercially available formulations. In spite of being highly hydrophilic and show high water vapour permeability, they have effective gas barrier properties. There is a wide variety of proteins that can be incorporated into the formulations of fruits such as soya and wheat proteins, corn zein, caseins and whey proteins.

Casein and whey protein based edible coatings are attractive for food applications due to their high nutritional quality, excellent sensory properties, and good potential to adequately protect food products from their surrounding environment. Whey proteins have been intensively investigated in the past decade. When a plasticizer is added, heat-denatured whey proteins produce transparent and flexible water-based edible coatings with excellent oxygen, aroma, and oil barrier properties at low relative humidity. However, the hydrophilic nature of whey protein coatings causes them to be less effective moisture barriers.

Proteins that are not water soluble such as corn zein and wheat gluten produce coatings that are not soluble, whereas soluble proteins produce coatings of varying solubility, depending on the protein and the conditions of coating formation (Krochta 2002). For example, whey protein isolate produces totally water-soluble coatings but heat-denatured solutions of whey protein isolate produce coatings in which the protein is insoluble (Pérez-Gago *et al.* 1999). Moreover, protein solubility is considered to be dependent on pH so, this parameter should be taken into account during the formulation and application of coatings. Only if soluble proteins have been denatured, is solubility not considered as an important factor.

Edible lipids used to develop edible coatings include beeswax, candelilla wax, carnauba wax, triglycerides, acetylated monoglycerides, fatty acids, fatty alcohols, and sucrose fatty acid esters.

Lipid-based edible coatings have a low affinity for water, which explains why they have low water vapour permeability. The latter is extremely important, as a great number of studies deal with the use of coatings on fresh fruits and vegetables to control their desiccation (Morillon *et al.* 2002).

Due to the fact that each hydrophobic substance has its own physicochemical properties, each lipid-based edible coating exhibits a variable behaviour against moisture transfer. The polarity of lipid constituents has to be considered, that is, the distribution of electrostatic potentials on the molecules that depends on the chemical group, aliphatic chain length, and on the presence of unsaturation. As the carbon number increases (from 14 to 18), so does the moisture barrier efficiency of fatty alcohols and fatty acids because the non-polar part of the molecule increases and does not favour water solubility in the film and thus, moisture transfer (Morillon *et al.* 2002).

The main disadvantage of lipid based coatings is their poor mechanical properties and thus, at present, research efforts are focused on the design of composite coatings that are based on both, lipids and hydrocolloids in order to take advantage of the special functional characteristics of each group, diminishing their drawbacks (Greener and Fennema 1994). Generally, lipids contribute to the improvement of the water vapour resistance, whereas hydrocolloids confer

Table 2 Application of edible coatings to fresh fruits and vegetables

Type of coating	Composition	Application	Main results	References
Polysaccharide	Chitosan and Tween 80	Fruits (strawberry, raspberry, sweet cherry, tomato, table grape, litchi, citrus, peach, Japanese pear; kiwi fruit, longan); vegetables (carrot, lettuce)	Reduction of fungal infection, retention of fruit firmness, extension of shelf-life	El Gaouth *et al.* 1991; Du *et al.* 1997; Zhang and Quantick 1997, 1998; Li and Yu 2000; Jiang and Li 2001; Romanazzi *et al.* 2002, 2003; Devlieguere *et al.* 2004; Han *et al.* 2004; Park and Zhao 2004; Caro and Joas 2005; Joas *et al.* 2005; Kang *et al.* 2005; Park *et al.* 2005; Chien *et al.* 2007
Polysaccharide	Alginate Alginate and glycerol	Fruits (apple); vegetable (mushroom, onion)	Extension of shelf-life, reduction of moisture loss and better appearance	Nussinovitch and Kampf 1993; Hershko and Nussinovitch 1998a, 1998b; Falcão-Rodrigues *et al.* 2007
Polysaccharide	Cactus mucilage extract and glycerol	Fruits (strawberry)	Extension of shelf-life maintaining sensory properties	Del-Valle *et al.* 2005
Polysaccharide	*Aloe Vera* L. gel	Fruits (sweet cherry, table grape)	Extension of storability	Valverde *et al.* 2005; Martínez-Romero *et al.* 2006
Protein	Soy protein, glycerol, malic acid, lactic acid	Fruits (apple)	No significant effect on sensory quality	Eswaranandam *et al.* 2006
Protein-polysaccharide	CMC[1], WPI[2], caseinates and glycerol	Fruits (strawberry)	Reduction of mold infection	Vachon *et al.* 2003
Polysaccharide	MC[3] and glycerol	Fruits (strawberry, avocados)	Delay in senescence	Maftoonazad and Ramaswamy 2005; Park *et al.* 2005
Polysaccharide	Medium or high amylase content starch and glycerol	Fruits (strawberry)	Delay in senescence and improvement of overall organoleptic conditions	García *et al.* 1998a, 1998b
Polysaccharide	MC, lauric acid, stearic acid, palmitic acid and PEG[4]	Fruits (strawberry); vegetables (bean)	Reduction of weight loss	Ayranci and Tunç 1997
Polysaccharide	Chitosan, MC, Tween 80	Fruits (strawberry)	Delay in senescence	Vargas *et al.* 2006b
Polysaccharide-lipid	Pullulan, non-ionic sucrose fatty acid ster and sorbitol	Fruits (strawberry, kiwi)	Reduction in internal O_2, firmness and colour retention; increase in internal ethylenene in kiwi fruits	Diab *et al.* 2001
Polysaccharide-lipid	Maltodextrin, CMC, propylenglicol, fatty acid sters Sodium benzoate	Fruits (mango)	Extension of postharvest storage	Díaz-Sobac *et al.* 1996
Polysaccharide-lipid	HPMC[5], shellac, stearic acid and glycerol	Fruits (plum)	Effects were only noticeable at long term storage	Pérez-Gago *et al.* 2003
Polysaccharide-lipid	MC, PEG, stearic acid, citric acid, ascorbic acid	Fruits (apricot); vegetables (green pepper)	Decrease in moisture loss	Ayranci and Tunc 2004
Polysaccharide-lipid	Chitosan, oleic acid, Tween 80	Fruits (strawberry)	Delay in senescence and fungal infection	Vargas *et al.* 2006a
Polysaccharide-lipid	CMC, paraffin wax, beeswax, soybean oil, oleic acid and sodium oleate	Fruits (mandarin, peach, pear)	Delay in ascorbic acid loss of mandarins and extension of shelf-life	Togrul and Arslan 2004a, 2004b
Protein-lipid	WPI, sodium caseinate, beeswax and glycerol	Vegetables (green Bell pepper)	No significant effect on moisture loss, respiration rate or colour	Lerdthanangkul and Krochta 1996
Protein-lipid	Wheat gluten, glycerol, estearic acid, palmitic acid and beeswax	Fruits (strawberry)	Lipids reduced weight loss and preserved mechanical properties	Tanada-Palmu and Grosso 2005

[1]Carboxymethyl cellulose; [2]Whey Protein Isolate; [3]Methylcellulose; [4]Polyethylene glycol; [5] Hydroxypropyl methylcellulose

selective permeability to O_2 and CO_2, durability and structural cohesion and integrity (Krochta 1997).

Composite coatings can be created by the subsequent deposition of different layers or can be made by the deposition of a single layer of material. Bilayer coatings are formed in two stages: in the first stage, the layer of polysaccharide or protein is cast and dried and in the second one, the lipid layer is applied (Krochta 1997). As an example, Debeaufort *et al.* (2000) developed bilayers by adding a mixture of lipids (paraffin oil, paraffin wax or a mixture of hydrogenated palm oil and triolein) into a methylcellulose layer. Wong *et al.* (1994) coated apple cubes with double layers of polysaccharides (cellulose, carrageenan, pectin or alginate) and acetylated monoglyceride. Nevertheless, in monolayer composite edible coatings, the lipid is dispersed in the hydrophilic phase of an emulsion (Shellhammer and Krochta 1997). In this sense, Bertan *et al.* (2005) used stearic and palmitic acid to allow the incorporation of a hydrophobic exudate into a gelatine-based coating. This mixture was emulsified using triacetin as plasticizer. Bosquez-Molina *et al.* (2003) obtained emulsified coatings by mixing mesquite gum (structural matrix) and a combination of some lipids (candelilla wax, mineral oil, oleic acid or beeswax).

Although emulsified coatings are less efficient than bilayers due to the non-homogeneous distribution of lipids, they have received more attention because they need only one drying step instead of the two needed for bilayer films, and they can be applied on food at room temperature. Moreover, both their hydrophilic and lipophilic nature allow their adhesion onto any support whatever its polarity and exhibit good mechanical resistance (Quezada Gallo *et al.* 2000).

Minor components that can be found in coating formulations include plasticizers such as glycerol and polyethylene glycol, and acids or basis to control the pH (lactic acid, acetic acid, etc.) of the film-forming solution. In addition, as shown in **Table 2**, coatings can incorporate in the formulations chemical preservatives and antimicrobial agents such as sodium benzoate, acetic, lactic, malic or sorbic acid, lysozyme, nisin, some essentials oils and spice extracts or chitosan (Diaz-Sobac *et al.* 1996; Brul and Coote 1999;

Outtara *et al.* 2000; Park *et al.* 2004; Pranoto *et al.* 2005; Zivanovic *et al.* 2005; Rojas-Grau *et al.* 2006; Seydim and Sarikus 2006; Vargas *et al.* 2009), as well as nutraceutical compounds (Park and Zhao 2004).

POSTHARVEST LIFE OF COATED FRUITS AND VEGETABLES

Harvested fruits and vegetables are considered to be living organisms because their metabolical function continues during postharvest storage (Kays 1991). The impact of production practices (harvesting techniques, packaging, handling, etc.) on the quality of fruits and vegetables can be explained by changes in their metabolism, which coincide with the degree of stress suffered. Thus, the extension of the shelf-life of fresh fruits and vegetables is mainly based on the knowledge of fruit and vegetable physiology. In general, the higher the product's respiration rate, the shorter its storage life. Thus, one possibility to extend the shelf life of these products is to minimise their respiration rate by, for example, adding a barrier around the product to modify the composition of the storage gaseous atmosphere to which postharvest products are exposed. In most products, when there is a restricted air flow, the equilibrium is shifted towards a decrease in internal oxygen (O_2) and an increase in carbon dioxide (CO_2). As the internal oxygen concentration decreases, so does the respiration until a critical O_2 concentration (extinction point) is reached. At very low oxygen concentrations, the respiration rate begins to increase, aerobic respiration is blocked and anaerobic fermentation begins. However, the products are usually stored under low O_2 atmospheres (e.g. 1 to 3 %) to diminish the respiration rate and to increase the shelf-life of most cold-stored fruits and vegetables. On the other hand, an increase in the external carbon dioxide concentration limits the forward movement of the respiratory pathway, resulting in a decrease in the respiration rate. This is the basis of the technology of storage under controlled atmospheres.

Edible coatings could also be applied to obtain similar effects to the storage under controlled or modified atmospheres. So, surface coatings can delay the ripening of fruits by modifying their internal atmospheres (decreasing O_2 and/or increasing CO_2, as well as inhibiting ethylene biosynthesis and action) acting on skin permeance to gases. This effect is mainly achieved by blocking a greater or lesser proportion of the pores on the fruit surface (Hagenmaier and Baker 1995; Banks *et al.* 1997) and it might be expected that commodities with different skin characteristics might have very distinct types of interactions with a surface coating.

APPLICATION OF EDIBLE COATINGS TO FRESH FRUITS AND VEGETABLES

Research and development efforts are leading to an improvement in the functional characteristics of the coatings, which depend on the properties of the fruit to be preserved or enhanced. These can be achieved by an optimum and precise control of gas permeability, texture and colour changes by means of quantitative or qualitative changes in coating formulation.

For the optimization of surface coatings, it is important not to overlook the variable nature (variability among cultivars of the same commodity and among fruit of the same cultivar) and the barrier properties of the commodity´s skin (Amarante and Banks 2001). Moreover, it is also essential to know the total solid content in the coating formulation (related to the thickness of the film) so that coated commodities may not have an excessive restriction of gas exchange through the skin, resulting in anaerobiosis and further development of off-flavors. Knowing the wettability of the coatings is also of particular importance, since it is a parameter that defines the ability of the coating to be uniformly distributed on the surface to cover.

The level of modification of the internal atmosphere results mainly from the interaction among the skin, coating and respiration rate of the commodity. Thus, direct measurement of the commodity's permeance to gas exchange under controlled environmental conditions should be preferred for the selection and optimization of surface coatings (Amarante and Banks 2001). As regards the control of moisture transfer, water vapour resistance (WVR) is a parameter that allows us to determine whether the coating has the expected water barrier properties when applied to the product's surface.

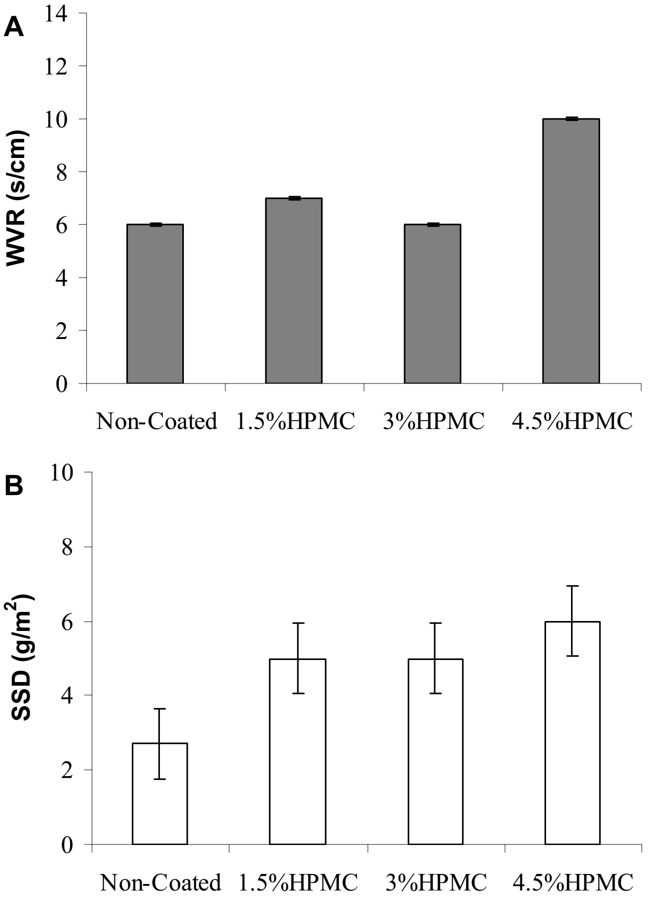

Fig. 1 (**A**) Water vapour resistance (WVR) at 75% RH and 5°C and (**B**) Sur¥face solid density (SSD) of strawberries (*Fragaria x ananassa* cv. 'Ventana') coated with Sugin- Hydroxypropyl methylcellulose (HPMC) edible coatings as affected by HPMC concentration. Mean values and standard deviation. *n* = 10. Methodology in **Appendix**.

Fig. 1 shows water vapour resistance (WVR) and surface solid density (SSD) of strawberries coated with an emulsified coating based on Sugin and different concentrations of HPMC, where the effect of the increase in SSD on the increase in the WVR of coated samples is pointed out.

Edible coatings can have several different effects on the quality of coated fruits, since there are many mechanisms involved. These mechanisms include the controlled moisture transfer between the fruit and the surrounding environment, the controlled release of chemical agents like antimicrobial substances, flavour compounds and antioxidants; the reduction of the internal oxygen partial pressure with a decrease in fruit metabolism, as well as some kind of structural reinforcement (Shaidi *et al.* 1999). As shown in **Table 2**, some of the effects that have been observed in coated fruits during storage are a decrease in weight loss (Baldwin *et al.* 1999), a delay in the occurrence of enzymatic browning (McHugh and Senesi 2000; Le Tien *et al.* 2001), a reduction in the respiration rate (El Gaouth *et al.* 1991; Wong *et al.* 1994; Vargas *et al.* 2006a) and, in general, a significant extension of fruit shelf-life.

Figs. 2A and **2B** show the respiratory pattern of strawberry samples coated with Sugin and different contents of

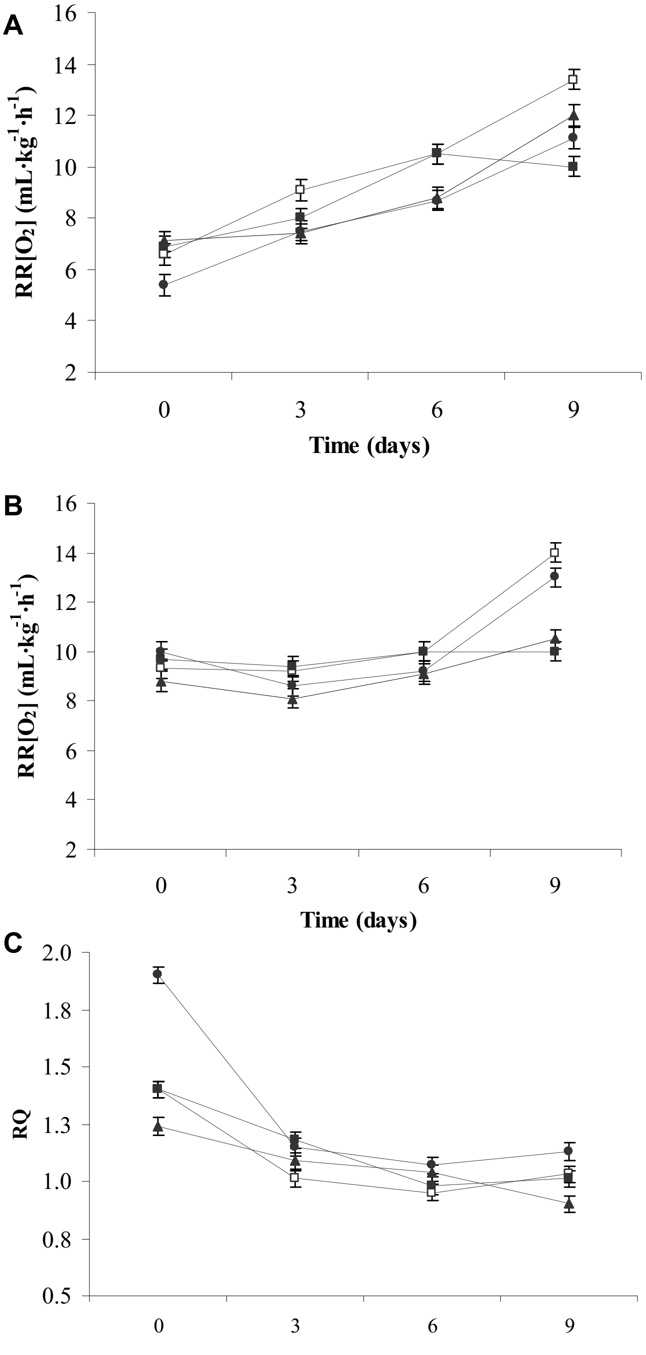

Fig. 2 Respiration rate (RR) of strawberries (*Fragaria x ananassa*) cv. 'Ventana') non-coated strawberries (☐) and coated with an emulsified coating based on Sugin (3 wt %) and different concentrations (%) of HPMC (■ 1.5%, ▲ 3%, ● 4.5%) in terms of (**A**) CO_2 generation (**B**) O_2 consumption and (**C**) Respiratory quotient. Mean values and standard deviation. *n* = 3. Methodology in **Appendix**.

HPMC. As can be observed, coating application led to a significant decrease in the respiration rate of strawberries, especially at the end of cold storage. Respiration quotient was near to one in all cases, thus indicating that the fermentation process has not been promoted by coating application.

The fact that coatings delay tissue senescence, that has been pointed out by several authors (see **Table 2**), can be evaluated from the changes in the mechanical response of coated and non-coated samples during storage. **Fig. 3** shows the compression profiles of a fresh strawberry together with the profiles of coated and non-coated samples after 9 days of cold storage. After this period of cold storage, coated strawberries presented a mechanical response which was more similar to the fresh ones, while the non-coated ones led to a flatter curve, typical of softer tissues.

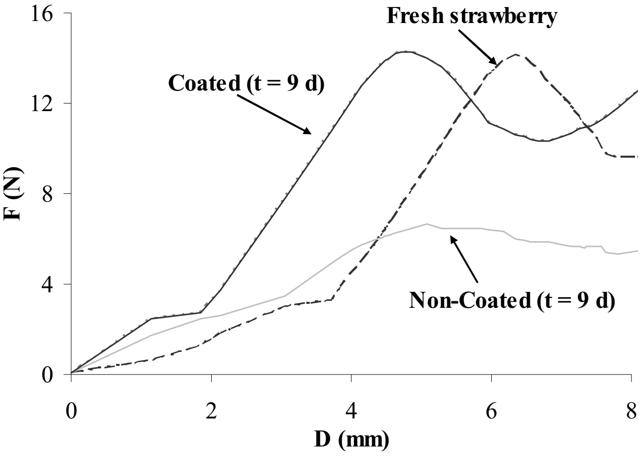

Fig. 3 Compression profiles (Force *versus* distance at the rupture point) of fresh strawberries (*Fragaria x ananassa*) cv. 'Ventana') at the beginning of the storage (t = 0 d) and compression profiles of non-coated and coated samples after 9 days of cold storage (5°C). Methodology in **Appendix**.

Finally, the sensory properties of the coatings should also be evaluated, through the external appearance (colour, brightness, opacity, etc.) and flavour of the products, once coated. Coated fruits and vegetables usually become less aromatic, as has been observed in the case of strawberries (Vargas *et al.* 2006a, 2006b). The major limitation comes when coatings modify the optical or colour attributes of the product, leading to a poor appearance. Nevertheless, some coatings are not visually perceived and can impart proper properties to the product, such as brightness.

FUTURE OF THE EDIBLE COATINGS TECHNOLOGY

In the future, the application of edible coatings will be one of the most effective methods to extend the commercial shelf-life of fresh fruits and vegetables. Nowadays, although applying coating technology to fruit and vegetable products is still scarce, in the next years it is expected to spread through all kind of products, fresh or treated (e.g. dried, rehydrated, candied), thus substituting the traditional packaging materials and making the packaging process more environmentally friendly (as less waste materials are generated). **Table 3** shows some of the commercial formulations of edible coatings currently available on the market for fresh fruits and vegetables. These coatings consist of different mixtures of polysaccharides and lipid compounds and they have been applied to a wide variety of fruits and vegetables.

The trend will focus on the development of effective delivery coatings with bioactive components as they would be technologically developed to extend the shelf-life of products and to better control the safety and quality of food. These coatings would act by releasing the novel bioactive components like vitamins, nutraceuticals, enzymes, pre- or probiotics into the food matrix throughout time. Initially these components will mainly act on the surface of the product, later diffusing inside the matrix to a different extent, depending on the mass transport properties of each compound. Taking into account the current trends in consumer preferences (towards fresh and additive-free food), these bioactive ingredients will be preferably natural components.

Recent studies point to the application of micro and nanotechnologies to develop coatings which incorporate micro or nanoencapsulated compounds that are released by pH, temperature or osmotic changes in the medium. Encapsulation will protect bioactive ingredients in a form that will be biologically active when the food is eventually consumed. Thus, the biological activity will be maintained when they are introduced into a complex food system (Weiss *et al.* 2008). Nanocomposite films incorporating nanosized clay

Table 3 Commercial coating formulations.

Coating (Trademark)	Composition	Application	References
Apl-Brite, Citrus-Brite	Carnauba-based films	Fruits (apple, citrus)	Farber *et al.* 2003 US FDA 2001
Ban-seel, Brilloshine, Nu-Coat Fo, Snow-White, White Wash products	Sucrose ester based fruit coatings with sodium carboxymethyl cellulose products manufactured exclusively from food ingredients available in dip or spray	Most fruits and vegetables (processed and whole potatoes)	Farber *et al.* 2003 US FDA 2001
Brogdex Products	Carnauba wax emulsions with or without fungicides, emulsion wax, high shine wax, water-based emulsion wax, carnauba-based emulsion, vegetable oil, resin-based and concentrated polyethylene emulsion, wax products	Fruits (apple, avocado, banana, breadfruit, carambola, citrus, coconut, guava, grapefruit, mango, melon, papaya, pineapple, tomato); vegetables (cucumber pumpkin, eggplant, pepper, potato)	US FDA 2001
Food Coat	Fatty acids and polysaccharides	Fruits (sweet cherry)	Alonso and Alique 2004
Fresh Wax Products	Shellac and wood resin, oxidized polyethylene wax, white oil/paraffin wax products	Fruits (apple, citrus, pineapple, cantaloupe, pomegranate, stone fruits, tomato); vegetables (sweet potato)	US FDA 2001
Fresh-Cote product line	Shellac-based, carnauba-based and oil emulsion edible films	Fruits (apple, pear, stone fruits, tomato); vegetables (cucumber, eggplant)	US FDA 2001
FreshSeal^{TM}		Fruits (avocado, bananas, cantaloupe, lime, mango, papaya, pineapple)	US FDA 2001
AgriCoat, NatureSeal	Composite polysaccharide-based coating using cellulose derivatives as film formers	Fruits (apple, avocado, banana, carambola, grapefruit, mango, orange, pear); vegetables (carrot, green bell pepper, lettuce, onion, potato)	Hallman *et al.* 1994a, 1994b, 1995; Potjewijd *et al.* 1995; Baldwin *et al.* 1996; Hallman and Foos 1996; Baldwin *et al.* 1999
Nutri-Save	N, O-carboxymethyl chitosan	Fruits (apple, breadfruit, cherry)	Lau and Yastremski 1991; Meheriuk *et al.* 1991; Lau and Meheriuk 1994; Worrell *et al.* 2002
PacRite Products	Water-based carnauba-shellac emulsions, shellac and resin water emulsions, water-based mineral oil fatty acid emulsions	Fruits (apple, citrus, nectarine, peach, plum, tomato); vegetables (cucumber, green pepper, squash)	US FDA 2001
Primafresh Wax	Carnauba-based wax	Fruits (apple, carambola, citrus, grapefruit, mango)	Castrillo and Bermudez 1992; Hallman *et al.* 1994; US FDA 2001
Pro-Long	Sucrose polysters of fatty acids and sodium salts of CMC	Fruits (apple, mango)	Banks 1985; Dhalla and Hanson 1988
Semperfresh^{TM}	Short chain sucrose esters of fatty acids, sodium carboxymethyl, mono and diglycerides of fatty acids	Fruits (apple, breadfruit, cherry, mango, quince, pomegranate, tomato); vegetables (green slender pepper, lettuce, sweet cucumber, zucchini)	Tasdelen and Bayindirli 1998; Soria *et al.* 1999; Carrillo-López *et al.* 2000; Nanda *et al.* 2001; Yaman and Bayoindirli 2001, 2002; Ozden and Bayindirli 2002; Schreiner *et al.* 2003; Avena-Bustillos *et al.* 1997; Yudurgül 2005
Shield-Brite Products	Shellac, carnauba, natural wax and vegetable oil/wax and xanthan gum products	Fruits (citrus, pears, stone fruits)	US FDA 2001
Sta-Fresh	Natural, synthetic and modified natural resin products and combination thereof	Fruits (avocado, breadfruit, grapefruit, guava, orange)	Hallman and Foos 1996; Ladaniya 2001; Worrell *et al.* 2002; Jeong *et al.* 2003; Pal *et al.* 2004
TAL Pro-Long	Blend of sucrose esters of fatty acids and sodium carboxymethyl cellulose	Fruits (apple, banana, pear)	Courtois 1983; Banks 1984a, 1984b; Bancroft 1995
Tropical Fruit Coating 213	5% Carnauba wax and fatty acid soaps	Fruits (mango)	Baldwin *et al.* 1999
Vector 7	Shellac-based film with morpholine	Fruits (apple, citrus)	Farber *et al.* 2003

materials as a film forming material and electrodeposition techniques to build multilayer coatings (Vargas *et al.* 2007, 2008) will also be further studied and developed to improve and better control the coating properties.

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APPENDIX

MATERIALS AND METHODS (Figs. 1, 2, 3)

Materials

Strawberries (*Fragaria x ananassa*) cv. 'Ventana' (Palos de la Frontera, Huelva, Spain) were bought in a local market and coating experiments were carried out on the same day. Strawberries of uniform size, shape and colour and without any signs of mechanical damage or fungal decay, were selected and washed in 10 mg/L sodium hypochlorite solution prior to coating. Hydroxypropyl methylcellulose (Methocel E-15 FG, Dow Chemical Company, Midland, USA), Sugin 471/PHK-40 (Degussa Texturant Systems S.A., Barcelona, Spain), and distilled water were used to obtain the film-forming solutions.

Preparation of the film-forming solutions and coating application

Three film-forming solutions were obtained using Hydroxypropyl methylcellulose (HPMC) at 1.5, 3.0 and 4.5% (w/v) and Sugin at 3.0% (w/v). Sugin was melted and solved in distilled water at 65°C while HPMC was dispersed and dissolved in 150 mL deionised water at 90°C with constant stirring. After 10 min, melted Sugin was added to the HPMC solution and the mixture was stirred for 10 min. The mixture was then emulsified using a rotor-stator homogenizer (Ultraturrax DI 25 basic-Yellowline, Janke and Kunkel, Staufen, Germany) at 12500 rpm for 10 min. Afterwards, the mixture was allowed to cool to room temperature (25°C), maintaining slow stirring. Finally the total solid concentration in formulation was adjusted by adding the required amount of water.

Selected strawberries were dipped in the film-forming solutions for 1 minute. Control samples were immersed in distilled water. Samples were dried by natural convection for 1 hour at 20°C and were packed in 750 mL perforated PET boxes (10 strawberries per box), to avoid further atmosphere modifications. Boxes were kept at 4 ± 1°C in an incubator Hot-Cold M4000668 (P-Selecta, Barcelona, Spain).

Surface solid density and water vapour resistance

Mean value of coating thickness was calculated in ten samples of each formulation by means of the quantification of the surface solid density (SSD) (Eq. 1). Average sample area (A_s) was estimated considering strawberry geometry as a cone with a known height (measured in triplicate using a digital calliper) and volume (measured using a pycnometer). Samples were weighed before and after coating, to determine the mass of coating solution adhered to strawberry surface (M_{Fa}). Mass fraction of solids (X_s) of each film-forming solution was also considered to calculate SSD.

In order to determine water vapour resistance, coated and uncoated samples were kept in desiccators where a 75% RH was generated by using saturated NaCl solution. Desiccators were kept in an incubator Hot-Cold M4000668 (P-Selecta, Barcelona, Spain) at 5°C. Water vapour resistance (WVR) was calculated using a modified equation of the First Fick Law (Eq. 2), as described by Avena-Bustillos *et al*. (1994).

$$SSD = \frac{M_{Fa} \cdot X_s}{A_s} \qquad (1)$$

$$WVR = \frac{a_w - \frac{\%RH}{100} \cdot P_{wv}}{R \cdot T} \times \frac{A_s}{J} \qquad (2)$$

where J is the slope of the weight loss curve in stationary conditions, A_s sample area, P_{wv} saturated vapour pressure, T absolute temperature R, the universal constant of gasses, and a_w water activity of samples, which was measured by means of a dew point hygrometer (Aqua Lab CX3, Decagon Devices Inc., Pullman, USA) at 25°C.

Mechanical properties

Mechanical properties were measured in ten samples of each formulation by using a Texture Analyser TA-XT-plus (Stable Micro Systems, Surrey, UK), with a 500 N load cell, using a 10 mm diameter cylindrical probe. Strawberry samples were cut longitudinally and 95% compressed at a 0.2 mm/s deformation rate. Force and distance at the rupture point were used as mechanical parameters.

Respiration rate

In order to measure the respiration rate a closed system was used. At each time of storage, strawberry samples (about 150 g) were placed in 0.847 L hermetic glass jars with a septum in the lid for sampling gas in the headspace at different times. The jars were stored in an incubator (P Selecta, Hot-Cold M 4000668) at 5°C. Gas sampling was carried out every 30 minutes by means of a needle connected to a gas analyser (CheckMate 9900 PBI Dansensor, Ringsted, Denmark). Three replicates were performed for each formulation.

Experimental points were considered in the time range where a linear relationship was observed between gas concentration and time. This means that no changes in the respiration pathway of the samples occurred in this period and so changes in the headspace composition did not produce notable alterations in their metabolism. Respiration rate (R_i, $mL \cdot kg^{-1} h^{-1}$) of the samples in terms of CO_2 generation and O_2 consumption was determined from the slope of the fitted linear equation, where y^i_t is the gas concentration ($\%O_2$, $\%CO_2$) at time t, i being O_2 (Eq. 3) or CO_2 (Eq. 4), *M* is the mass of samples (kg) and *V* the headspace volume (mL).

$$R_{O_2} = \frac{y_{t_0}^{O_2} - y_{t_t}^{O_2} \times V}{100 \times M \times t} \qquad (3)$$

$$R_{CO_2} = \frac{y_t^{CO_2} - y_{t_0}^{CO_2} \times V}{100 \times M \times t} \qquad (4)$$