Stewart Postharvest Review
An international journal for reviews in postharvest biology and technology

Novel sources of edible films and coatings

Olivia López[1], María A García[1] and Noemí E Zaritzky[1,2]*
[1]Centro de Investigación y Desarrollo en Criotecnología de Alimentos (CIDCA), CCT-La Plata, CONICET, Facultad de Ciencias Exactas UNLP, Argentina
[2]Dpto. de Ingeniería Química, Facultad de Ingeniería, Universidad Nacional de La Plata, La Plata, Buenos Aires, Argentina

Abstract
Purpose of the review: This work reviews novel sources of edible films, coatings and formulations, including combined materials and a lipid phase, and highlights the main results of the most recent investigations carried out on the topic. New tendencies based on the incorporation of diverse active compounds (antimicrobials, antioxidants, nutraceuticals), that are applied on fruits and vegetables, are also mentioned.
Findings: The diverse biological materials used in edible packaging formulations are generally classified as polysaccharides, proteins, lipids or resins. A plasticiser is often added to increase flexibility. Edible composite packaging materials have been developed by blending biocomponents for specific applications, taking advantage of complementary functional properties. They can be considered as new materials for formulating films and edible coatings. When composite films combine lipid compounds with a hydrocolloid-based structural matrix, the lipid components in the formulation reduce water transmission, whereas the hydrocolloid components serve as selective gas barriers and provide strength and structural integrity. Other additives can be added to modify and enhance film physical properties or functionality.
Directions for future research: The potential of edible coatings has been recognised as an alternative or synergistic addition to conventional packaging to enhance food quality and protection. One important advantage of using edible films and coatings is that several active ingredients can be incorporated into the matrix and consumed with the food, improving safety or nutritional and sensory attributes. The new tendencies are to use edible coatings as carriers of functional ingredients by incorporating antimicrobial, antibrowning, and nutraceutical agents to improve the quality of fruits and vegetables. The development of new technologies to improve the delivery properties of edible films and coatings is one of the issues requiring future research. Most of the studies on food applications have been conducted at a laboratory scale. Further research on cost reduction and production in larger scales, and on stability and safety are necessary for promoting the feasibility of commercialised edible coated fruits and vegetables.

Keywords: novel materials; edible coatings; minimally-processed fruits and vegetables; functional additives; novel composite coatings; quality improvement and storage life extension

***Correspondence to:** Noemí E Zaritzky, Centro de Investigación y Desarrollo en Criotecnología de Alimentos (CIDCA), CCT-La Plata, CONICET, Facultad de Ciencias Exactas UNLP, [2]Dpto. de Ingeniería Química, Facultad de Ingeniería, Universidad Nacional de La Plata, 47 y 116, La Plata (1900), Buenos Aires, Argentina. Fax; +54 221 4254853; email: zaritzky@ing.unlp.edu.ar

Stewart Postharvest Review 2010, 3:2
Published online 01 September 2010
doi: 10.2212/spr.2010.3.2

Online ISSN:1945-9656
www.stewartpostharvest.com

Introduction
The development of new edible coatings with improved functionality and performance for fresh and minimally processed fruits and vegetables is one of the challenges of the postharvest industry. Research efforts have focused on the design of new eco-friendly coatings based on biodegradable polymers, which not only reduce the packaging requirements but also lead to the conversion of food industry by-products into value-added film-forming components [1]. Increased consumer demands for higher quality food in combination with the environmental need to reduce dispos-

Abbreviations

EO	Essential Oil
FFA	Free Fatty Acid
MC	Methylcellulose
WP	Whey Protein
WPC	Whey Protein Concentrate
WPI	Whey Protein Isolate

able packaging waste have led to increased interest in research into edible films and coatings.

Edible films and coatings are defined as thin layers of edible material formed on a food surface as a coating, or placed (pre-formed) between food components. Their purpose is to extend the food product shelf-life and provide a barrier against hazards. Traditionally, edible coatings have been used as a barrier to minimise water loss, delaying the natural senescence of coated fruits and vegetables through selective permeability to gases [2]. They extend the shelf life of minimally-processed fruits and vegetables by reducing moisture and solute migration, gas exchange, respiration and oxidative reaction rates, suppress physiological disorders, delay changes in textural properties, and improve mechanical integrity or food handling characteristics. Diverse coatings have a high selective gas permeability ratio CO_2/O_2 compared with conventional synthetic films [3]; in this case, the modified atmosphere created by the coating generates a physical capture of CO_2 inside the fruits or vegetables and a partial sealing of the pores, reducing the gaseous exchange and reducing the gas transfer rates.

Film and coatings forming materials

Diverse biological materials used in edible packaging formulations generally fall into the categories of polysaccharides, proteins, lipids and resins; combined materials can also be used. Often, a plasticiser is added to increase flexibility. Other additives can be combined to modify and enhance film physical properties or functionality. Excellent reviews and books on edible coatings and packaging materials have been published in the last few years [4, 5**, 6**, 7**, 8**].

In general, due to their hydrophilic nature, polysaccharide and protein films, generally exhibit poor water vapour barrier ability. Lipids or other hydrophobic compounds are often used to make moisture barrier coatings or enhance the moisture-barrier properties of hydrocolloid-based films, because of their low water affinity, low polarity and dense-structured molecular matrices [5**].

An important research trend is the exploration of food industry by-products and waste as potential new edible packaging materials: whey protein from cheese production, chitosan from crustacean shells, corn zein from ethanol production, potato starch from potato chip waste, mung bean protein from mung bean starch [9], and fruit pomace from beverage production [10]. These prevent competition for food resources and reduce environmental impacts and waste disposal costs. New sources of materials and blends have been used in the last few years to formulate edible films and coatings, including fruits and vegetable purees [11–13].

Characterisation of edible films and coatings

Generally filmogenic solutions or suspensions are used to obtain either coatings or films, depending on the obtention procedure and the intended purpose or function. Rheological behaviour of the filmogenic solution should be regulated to be adequate to the application coating mode; spraying requires a low viscosity, while a higher viscosity is required for immersion. Coating integrity is a critical factor that depends on surface tension, adhesion to food substrate and flexibility of the coating itself, and the plasticiser addition.

The main attributes involved in characterising biodegradable films are: optical properties, water-solubility, water sorption/desorption, thickness, microstructure, crystallinity, biopolymer compatibility, thermal behavior, barrier properties (vapour and gaseous permeabilities) and mechanical behaviour. Barrier properties determine the ability of films and coatings to improve food products storage or shelf-life. Film or coating permeability to CO_2 and O_2 measurement is essential to understanding quality and physiological aspects of coated fruit products during storage.

Novel polysaccharide sources

Starch is the most commonly used agricultural raw material for biodegradable and edible film formulation; it is an appropriate matrix-forming material with a low cost relative to other alternatives, widely available and relatively easy to handle. Amylose is responsible for the film-forming capacity of starch. To overcome the brittleness inherent to starch films, the incorporation of a plasticiser is required. Plasticisers reduce intermolecular forces and increase the mobility of polymer chains, decreasing the glass transition temperature of these materials and improving their flexibility. They must be compatible with the film-forming polymers; hydrophilic compounds, such as polyols (glycerol and sorbitol) are commonly used in starch films [14, 15].

Starch films are excellent oxygen barriers, due to their tightly packed, ordered hydrogen-bonded network structure and low solubility. O_2 permeabilities were much lower than those of CO_2, indicating a selective action of these films on gas permeabilities. Amylomaize films with higher amylose content showed higher crystallinity and therefore lower permeabilities than corn starch films. Edible coatings with selective gas permeabilities are examples of active packaging controlling respiratory exchange and improving the conservation of fresh fruits and vegetables [16].

Non traditional starches have also been used for the formulation of edible films. Yam starch (*Discorea alata*) was used to form films with a homogeneous matrix and stable structure at ambient conditions that can be used in the postharvest conservation of fruits and vegetables [17, 18]. Mali and Grossmann [18] proposed the use of yam starch films as packaging for strawberries contained within plastic trays, and compared the performance of these films with those of PVC. Native starches isolated from non-conventional sources include: okenia (*Okenia hypogaea*), banana (*Musa paradisiaca*) and mango (*Manguifera indica*) were used to produce edible films and their mechanical, physicochemical and microstructural characteristics were analysed [19]. Besides, native starches can be chemically modified to improve its functionality and to expand its use. Modified starches are also new sources for edible coatings. Acetylated corn starch showed adequate film forming capacity, and glycerol concentration regulates the mechanical properties of these films [20].

Novel non starch polysaccharides have been used as new sources of edible films and coatings applied to fruits and vegetables [21]. Prickly pear cactus mucilage (*Opuntia ficus indica*) was used to extend strawberry shelf-life. Cactus mucilage is a hetero-polysaccharide mix, obtained from plant stems containing residues of D-galactose, D-xylose, L-arabinose, L-rhamnose and D-galacturonic acid. Edible mucilage films were tested to determine their effects on colour, texture and sensory quality of the fruit; the use of mucilage coatings increased strawberry shelf-life.

Aloe vera is a tropical and subtropical plant that has been used for centuries for its medicinal and therapeutic properties [22]. The two major *A. vera* liquid sources are yellow latex (exudate) and clear gel (mucilage), which proceeds from the large leaf parenchymatic cells, being the gel juice used for the well known medical purposes [22]. Besides, antifungal activity of *A. vera* gel against several pathogenic fungi including *B. cinerea* has also been reported. Processing techniques used to obtain *A. vera* gel are very important to ensure product quality and to maintain almost all the bioactive components. A novel edible coating based on *A. vera* gel has been used to maintain sweet cherry quality as well play a role in controlling microbial spoilage [22]. During cold storage, sweet cherry treated with *A. vera* gel significantly delayed respiration rate, weight loss, colour changes, softening and ripening, and storability could be extended. The sensory analyses revealed beneficial effects in terms of delaying stem browning and dehydration, maintenance of fruit visual aspect without any detrimental effect on taste, aroma or flavours. Similarly, *A. vera* gel was also applied to maintain the quality and safety of cv. *Crimson Seedless* table grapes during cold storage [23].

Other sources for edible coatings are novel galactomannans, which are present in the endosperm of numerous plants, particularly the *Leguminosae* family. Galactomannans are polysaccharides built up of a β-(1–4)-D-mannan backbone with single D-galactose branches linked α-(1–6). Their mannose/galactose (M/G) ratios differ according to the species. They are excellent stiffeners and stabilisers of emulsions, and the absence of toxicity allows their use pharmaceutical, biomedical, cosmetics and food industries [24]. Coatings of galactomannans from different plant species were evaluated [24]. *Adenanthera pavonina*, a plant native from tropical Asia, is used in reforestation and as an ornamental plant. *Caesalpinia pulcherrima* is a plant found throughout India and other regions where it is used as an ornamental plant. Galactomannan from *A. pavonina* presents a M/G ratio of 1.35, while the galactomannan obtained from *C. pulcherrima* seeds presents a M/G ratio of 2.88. Cerqueira *et al.* [24] analysed the suitability of these galactomannans to be used as edible coatings for different tropical fruits: acerola (*Malpighia glabra*), cajá (*Spondias lutea*), mango (*Mangifera indica*), pitanga (*Eugenia uniflora*) and *seriguela* (Spondias purpurea) and to determine the most adequate formulation to coat these fruits, based on the fruit surface properties and by optimising the composition of the coating in terms of its wettability and permeability properties. Mechanical properties of the selected coatings were measured; however the authors have not analysed the effect of coatings on the shelf-life of the fruits.

Lima and coworkers [25] developed films produced from blends of collagen and the galactomannans aforementioned plasticised with glycerol. They selected the formulations presenting the best coating ability (based on the wettability) in terms of their physical–chemical properties and evaluated their use on fruits (apple and mango) featuring different respiration patterns. These blends decreased the fruit's gas transfer rates.

Edible coatings based on policaju gum and a surfactant, were tested on apple fruit. Policaju gum is a bark exudate from *Anacardium occidentale L.*, a tree that grows in tropical and subtropical countries. This gum is a complex polysaccharide, and has a highly branched galactan framework consisting of chains of (1-3)-linked β-D-galactopyranosyl units with interspersed β(1-6) linkages. The relationship between film properties and coating performance was studied [26].

Another important application of edible coatings the reduction the oil uptake in deep fried products. Excess of fat in the diet has been linked to coronary heart disease, thus coatings applied to food before frying can help in reducing health problems associated with fat overconsumption. Cellulose derivatives, including methylcellulose (MC) and hydroxypropyl-methylcellulose, which exhibit thermal gelation, can be used to reduce oil absorption through film formation at temperatures above their incipient gelation point. García *et al.* [27, 28] reported that the use of 1% MC edible coatings containing sorbitol reduced the oil uptake of fried potatoes by 40.6% without causing detrimental effects on quality attributes (surface colour and texture). Likewise, the mechanisms of frying and the effect of the coating were analysed and mathematically modelled [29].

Proteins as sources of edible films and coatings

In general, wheat gluten, corn zein, soy protein isolate, collagen, gelatin and milk proteins (caseins and whey proteins) have been used for edible films and coatings [5**, 30]. Many methods based on physical, chemical and enzymatic treatments have been investigated to improve edible protein film properties. Protein chemical properties and structure are affected by: the film forming solution pH, the presence of broken intramolecular disulfide bonds that form intermolecular cross-linking, heat denaturation, the modification of protein side chains (by adding salts or changing the solvent) and the use of an enzymatic treatment (such as transglutaminase to catalyse cross-links between the glutamine and lysyl groups) [5**, 30]. Protein physical modifications include lamination, formation of composites or emulsions, addition of nanoparticles, aging, orientation, and annealing/heat curing [31–33]. Irradiation has been used to covalently cross-link aromatic amino acids. Enhancing intermolecular interactions and improving molecular order with mechanical energy by ultrasound and microfluidisation techniques have been attempted.

Extensive work has been done on the film formation using whey proteins (WP). WP remain soluble after casein is precipitated at pH 4.6 during the cheese-making process, it is commercially available as whey protein concentrates (WPC; 25–80% protein) and whey protein isolates (WPI; >90% protein). WP are globular and heat labile in nature; β-lactoglobulin, the predominant protein in whey, contains one free thiol group and two disulfide groups per monomer; 4 hydrophobic groups are located inside the globular structure. Research on WP film formation has mainly involved heat-induced molecular thiol-disulfide interchange reactions. Both native and heat-denatured WPI films are transparent, flavourless, and have similar water vapour and oxygen permeabilities; however, they have different solubilities and mechanical properties. The unfolded structure and the disulfide bonding of heat-denatured WP film contribute to water-insolubility and stronger, stiffer, tougher and more stretchable films. The low energy bonding and the globular structure of native WP films account for complete solubility in water and lower strength, stiffness and stretchability [34]. Other sources of proteins for film formation were reported. Bamdad *et al.* [35] prepared edible films from lentil seed (*Lens culinaris*) extracted proteins and determined their mechanical, optical and barrier properties and Adebiyi and co-workers [36] developed films from rice bran protein. In both cases, the films had functional properties comparable to other edible protein ones.

Lipids in edible films and coatings

Many edible lipid materials have been used as protective coatings against moisture transfer and to add sheen. Unlike other macromolecules, lipid and resin compounds are not biopolymers; they do not have a large number of repeating units connected by covalent bonds to form a large molecular structure. Thus, they are fragile and do not generally form cohesive, self supporting film structures. Owing to their relatively low polarity, lipids and resins have been incorporated into edible film-forming materials to provide a moisture barrier within composite films. Nevertheless, there are disadvantages of employing lipids in edible packaging materials, such as their waxy taste and texture, greasy surface, and potential rancidity [5**].

Neutral esters of glycerol and fatty acids, including mono-, di-, and triacylglycerides have been used alone or in combination with other edible ingredients to coat food products. Solubility and water vapour resistance of fatty acids and their derivatives, are dependent on their physical state, chain length, and saturation degree. Generally, increasing unsaturation degree or acyl chain branching or reduction in carbon chain length increased water vapour permeability [5**, 37].

Waxes are esters of a long-chain fatty acid with a long-chain alcohol. They are more resistant to diffusion of water than most lipid or nonlipid edible films, owing to the very low level of polar groups. Natural waxes, such as carnauba wax, candelilla wax, rice bran wax and beeswax have been used as protective coatings, alone or in combination with other ingredients [38].

Emulsifiers are surface active compounds, that can modify interfacial energy at the interface of immiscible systems. Emulsifiers are essential for the formation and stabilisation of well-dispersed lipid particles in composite emulsion-films or to achieve sufficient surface wettability to ensure proper surface coverage and adhesion to the coated surface [33]. Some common emulsifiers are acetylated monoglyceride, lecithin, glycerol monopalmitate, glycerol monostearate, polysorbate 60, polysorbate 65, polysorbate 80, sodium lauryl sulphate, sodium stearoyl lactylate, sorbitan monooleate, and sorbitan monostearate. Many proteins have emulsifying properties due to their amphiphilic nature [5**, 33].

Beaulieua *et al.* [39] produced biodegradable lipid films from various soapstocks (cottonseed and safflower), an underused byproduct from the vegetable oil industry. In processing oil-bearing materials, free fatty acids (FFAs) are extracted with the main components of edible oil, triacylglycerols. In general soapstock is mostly made of FFAs with minor components including glycerol, acylglycerides, sterols, phospholipids, phenolics and their degenerated compounds. The oilseed-derived soapstocks were used to produce lipid films with different hydration ratios, and paraffin wax for application on ‘Camelot’ bell peppers. Besides, bilayer films from oilseed lipids can be produced. It is important to note that to avoid potential allergenicity concerns in cottonseed soapstock, additional cleanup steps and tests with commonly used edible coating additives would be required before attaining food grade status.

Composite materials

Blending has acquired importance in improving the performance of polymeric materials. It has become an economical and versatile way to obtain materials with a wide range of desirable properties. Edible composite packaging materials have been developed by blending biocomponents for specific applications, taking advantage of complementary functional properties. They can be considered as new materials for formulating films and edible coatings. When composite films combine lipid compounds with a hydrocolloid-based structural matrix, the lipid components in the formulation reduce water transmission, whereas the hydrocolloid components serve as selective gas barriers and provide strength and structural integrity [5**].

Composite films obtained from the blending of chitosan and corn starch were developed and the physicochemical, water vapour barrier and mechanical properties were determined [40]. Chitosan addition decreased both film solubility and water vapour permeability, while the addition of glycerol enhanced film flexibility. Methylcellulose and chitosan were used to obtain composite films by casting. Film microstructure was characterised by SEM, X-ray diffraction and FTIR spectroscopy to analyse the compatibility of both polysaccharides [41, 42]. Again, chitosan addition allowed tailoring of film solubility. Composite films were also developed using banana flour, (obtained from banana cv. *Kluai Namwa*) glycerol and pectin. The effect of banana flour content on film oxygen permeability and mechanical properties of films were studied, showing good sealability, which can make these films suitable as sachets or pouches for dry foods [43].

Rojas-Grau *et al.* [10] and Tapia *et al.* [44] applied alginate-gellan-based coatings to fresh-cut apples and papaya, proving that the coatings were good carriers for antioxidant agents such as cysteine, glutathione, and ascorbic and citric acids. Besides these composite coatings containing calcium helped to maintain desirable quality characteristics of fresh-cut Fuji apples. [45]. Blends of alginate, pectin and gellan-based edible coatings were applied on fresh-cut melon [46] to prevent dehydration, inhibit ethylene production and maintain firmness due to calcium incorporation. Besides, Tapia *et al.* [44] reported that these matrixes were used as carriers for viable bifidobacteria and fresh-cut apple and papaya cylinders were successfully coated. The gellan coatings and films exhibited better water vapour properties in comparison with the alginate coatings. Values > 10^6 CFU/g *B. lactis Bb*-12 were maintained for 10 days during refrigerated storage of fresh-cut fruits, demonstrating the feasibility of alginate- and gellan-based edible coatings to carry and support viable probiotics on fresh-cut fruit.

Chlebowska *et al.* [47] studied the influence of the pullulan and pullulan- protein edible coatings on apple mass loss reduction during storage of apples. Pullulan is an extracellular polysaccharide produced by *Aureobasidium pullulans;* it has received permission to be applied as a food additive. Edible coatings from pullulan and soy protein blends significantly limited apples mass losses, the higher reduction was observed in apple coated with mixtures where the pullulan to protein ratios were: 6:4 and 5:5. These coatings stuck better to apples surface and were less susceptible to crumbling and to peeling off.

Mariniello *et al.* [48] used whole soy flour and apple pectin as raw materials for producing composite hydrocolloid edible films. The best ratio between the two components was determined in order to obtain films that could be perfectly handled for their consistence. Films were also prepared in the presence of transglutaminase, showing a smooth surface and high homogeneity and strength, and low flexibility.

Composite hydrocolloid-lipid films

Composite hydrocolloid-lipid films can be developed as either a stable lipid emulsion in a hydrocolloid matrix, or a hydrocolloid-lipid bilayer. In the emulsified lipid composite films, lipid globules are uniformly dispersed and entrapped into the dried continuous support matrix of hydrocolloid components; when necessary emulsifiers can be added to the system. The bi-layer composite films have a separate layer made of a lipid component over the hydrocolloid-based film [49].

Bilayer films exhibit much better moisture barrier properties than films obtained from emulsions. However, bilayer films are obtained from lamination of the melted lipid onto a hydrocolloid-based film previously formed on a support. This technique requires at least three manufacturing steps instead of only two in the case of edible films prepared from emulsions. Therefore, emulsion-based edible barriers are of greater interest for the food industry [50, 51].

The moisture permeability of emulsion-based films depends mainly on the distribution of the lipid globules within the film. The smaller the lipid globule size is, and the more homogeneously distributed they are, the lower the water vapour permeability is. Then, the emulsion structure has to be controlled and stabilised during film preparation and formation. However, heat and solvent evaporation during the drying of the film-forming-emulsion induces changes in the emulsion characteristics, particularly destabilisation phenomena such as creaming, aggregation or coalescence. The use of emulsifiers such as monoglycerides or esterified monoglycerides is often recommended [50, 51]

Phan The *et al.* [50, 51] developed arabinoxylan-lipid-based edible films and coatings. Arabinoxylans from maize bran are polyosidic chains included in the hemicellulosic chemical group. These are insoluble fibres in their native form, and they are characterised by a high moisture retention capacity; to overcome this alkaline extraction is conducted. Arabinoxylans solubility, their ability to form a continuous and cohesive matrix, and their neutral taste and odour has led to their use as film formers. The influence of film structure on the functional properties of films obtained from emulsions based on arabinoxylans, hydrogenated palm kernel oil and sucroesters as emulsifiers was analysed [50, 51]. The sucroesters have a great effect on the stabilisation of the emulsified film structure, improving the moisture barrier properties. The structure and stability of the emulsion during drying strongly affects barrier and mechanical properties of films. Emulsion destabilisation is favoured by high drying temperature and tends to give films having a "bilayer-like" structure, which tends to improve the functional properties of arabinoxylan-based edible films.

Han *et al.* [52, 53] characterised the physical properties of WPI coating solution incorporating ascorbic palmitate and *α*-tocopherol, and the antioxidant activity of the dried coatings against lipid oxidation in roasted peanuts during storage at 25°C was demonstrated. Viña *et al.* [54] applied starch-based coating formulated using glycerol, sorbitol or glycerol and sunflower oil on refrigerated Brussels sprouts. Coated vegetables were placed on expanded polystyrene trays and packaged with PVC; samples were stored at 0°C for 42 days. Commercial acceptability, weight loss, surface colour (of heads and bases), texture, ascorbic acid, total flavonoid contents and radical scavenging activity were measured. Brussels sprouts coated with formulations containing glycerol and covered with PVC showed the best performance for long-term refrigerated storage.

Tanada-Palmu and Grosso [55] reported that edible bilayer coatings based on wheat gluten and lipids (beeswax, stearic and palmitic acids) applied on strawberries had a significant effect on the retention of firmness, reduced weight loss and showed better results from the physico-chemical analysis compared with control fruit. Sensory evaluation of the strawberries showed that the gluten and the composite coatings maintained the visual quality of the fruits during storage, and the taste of the strawberries with the gluten coating was acceptable to consumers. However, the appearance and taste of the bilayer-coated fruit were unacceptable. Reinoso *et al.* [56] evaluated the quality of plums (*Prunus domestica* L.) coated with WPI and WPI composite coatings containing flaxseed oil blended with beeswax. WPI and 10% lipid composite coatings were less susceptible to cracks, flake, and blister defects during the 15 days storage at 5°C compared with the 5% lipid formulation. Mass loss of plums during storage was substantially reduced, especially when coatings of higher lipid content were used. Overall, sensory evaluation showed that the coated plums were more acceptable than the uncoated controls.

García *et al.* [15, 57] reported that composite active starch-based coatings containing antimicrobial agents (potassium sorbate plus citric acid), plasticiser (sorbitol) and emulsified lipid (sunflower oil), having selective gaseous permeability, extended the storage life of refrigerated strawberries, decreasing microbial growth. Plasticiser and lipid addition improved coating performance by decreasing water vapour permeability. Weight losses have been reduced, colour changes were delayed, firmness of the tissue and fruit appearance improved and modifications of the physiological parameters of the fruits slowed down.

In the last few years, essential oils (EOs) derived from plants, which are rich sources of volatile terpenoids and phenolic compounds and have the potential to inactivate pathogenic bacteria, have been incorporated into edible films and coatings. Du *et al.* [11] stressed that EOs from cinnamon, allspice and clove bud plants, are compatible with the sensory characteristics of apple-based edible films. These films could extend product shelf life and reduce the risk of pathogen growth (against *Escherichia coli* O157:H7, *Salmonella enterica* and *Listeria monocytogenes*) on food surfaces by both direct contact with the bacteria and indirectly by vapours emanating from the films.

Finally, the potential of edible coatings has been recognised as an alternative or synergistic addition to conventional packaging to enhance food quality and protection. One important advantage of using edible films and coatings is that several active ingredients can be incorporated into the matrix and consumed with the food, improving safety or nutritional and sensory attributes; the tendencies are to use edible coatings as carriers of functional ingredients by incorporating antimicrobials, antibrownings, and nutraceuticals to improve the quality of fruits and vegetables. The development of new technologies to improve the delivery properties of edible films and coatings is one the issues that requires future research. At the moment, most studies on food applications have been conducted at a laboratory scale. Further research on cost reduction and production in larger scales, and on stability and safety are necessary to promote the feasibility of commercialised edible coated fruits and vegetables.

References

Papers of interest have been highlighted as:
*Marginal importance
**Essential reading

1 Vargas M, Pastor C, Chiralt A, McClements, J and González-Martínez C. Recent Advances in Edible Coatings for Fresh and Minimally Processed Fruits. Critical Reviews in Food Science and Nutrition 2008: 48 (6):496–511.

2 Park HJ. Development of advanced edible coatings for fruits. Trends in Food Science & Technology 1999: 10: 254–260.

3 Guilbert S, Gontard N and Gorris LGM. Prolongation of the Shelf-life of Perishable Food Products using Biodegradable Films and Coatings. A review. Lebensmittel-Wissenschaft und-Technologie 1996: 29 (1–2): 10–17.

4 Lin D and Zhao Y. Innovations in the Development and Application of Edible Coatings for Fresh and Minimally Processed Fruits and Vegetables. Comprehensive Reviews in Food Science and Food Safety 2007: 6 (3):60–75.

5 Janjarasskul T and Krochta JM. Edible Packaging Materials. Annual Reviews in Food Science and Technology 2010: 1:415–448.

** This review summarised the development and characterisation of edible films as well as the different technologies used to obtain it. The employment of nanocomposite materials and the release mechanisms of active films are also investigated.

6 Embuscado M and Huber KH. Edible films and coatings for food applications. Thattanchavady, Pondicherry, India. Springer Science; 2009.

** This book summarized the uses of edible films and coatings developed from different polymer sources on diverse food matrix as well as their physicochemical and functional properties.

7 Rojas Graü MA, Soliva-Fortuny R and Martín-Belloso O. Edible coatings to incorporate active ingredients to fresh cut fruits: a review.Trends in Food Science & Technology 2009: (20): 438–447.

** This review summarised the potential uses of edible coatings as carriers of functional ingredients by incorporating antimicrobials, antibrownings and nutraceuticals to improve the quality of fruits and vegetables.

8 Han JH. New technologies in food packaging: Overview. In: Innovations in food packaging . Edited by Han JH . London, UK. Elsevier Academic Press 2005 pp 3–11.

** This review described edible films and coatings as active materials and summarised their properties and potential uses.

9 Bourtoom T. Factors affecting the properties of edible film prepared from mung bean proteins. International Food Research Journal 2008: 15 (2):167–180.

10 Park S and Zhao Y. Development and characterization of edible films from cranberry pomace extracts. Journal of Food Science 2006: 71 (2):95–101.

11 Du WX, Olsen CW, Avena-Bustillos RJ, McHugh TH, Levin CE and Friedman M. Antibacterial activity against *E. coli O157:H7*, physical properties, and storage stability of novel carvacrol-containing edible tomato films. Journal of Food Science 2008: 73(7):378–383

12 Sothornvit R and Rodsamran P. Effect of a mango film on quality of whole and minimally processed mangoes. Postharvest Biology and Technology 2008: 47(3):407–417.

13 Azeredo HMC, Mattoso LHC, Wood D, Williams TG, Avena-Bustillos RJ and McHugh TH. Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. Journal of Food Science 2009: 74 (5):N31–35

14 García MA, Martino M and Zaritzky N. Edible starch films and coatings characterization: SEM, water vapor and gas permeabilities. Scanning. (Special Food Structure and Functionality Issue) 1999: 21(5): 348–353.

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

16 García MA, Martino M and Zaritzky N. Plasticizer effect on starch-based coatings applied to strawberries (*Fragaria x ananassa*). Journal of Agriculture and Food Chemistry 1998: 46: 3758–3767.

17 Mali S, Grossmann MV, García MA, Martino M and Zaritzky N. Microstructural characterization of yam starch films. Carbohydrate Polymers 2002: 50(4):379–386.

18 Mali, S and Grossmann, MVE. Effects of yam starch films on storability and quality of fresh strawberries (*Fragaria x ananassa*). Journal Agriculture and Food Chemistry 2003: 51(24): 7005–7011.

19 Romero-Bastida CA, Bello-Pérez LA, García MA, Martino M, Solorza-Feria J and Zaritzky N. Mechanical and microstructural characterization of films prepared by thermal or cold gelatinization of non-conventional starches. Carbohydrate Polymers 2005: 60 (2): 235–244.

20 López O, García MA and Zaritzky N. Film forming capacity of chemically modified corn starches. Carbohydrate Polymers 2008: 73: 573–581.

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

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

23 Valverde JM, Valero D, Martínez-Romero D, Guillen FN, Castillo S and Serrano M. Novel Edible Coating Based on Aloe vera Gel To Maintain Table Grape Quality and Safety. Journal of Agricultural and Food Chemistry 2005: 53: 7800–7807.

24 Cerqueira M, Lima AM, Teixeira JA, Moreira RA and Vicente AA. Suitability of novel galactomannans as edible coatings for tropical fruits. Journal of Food Engineering 2009: 94 (3–4): 372–378.

25 Lima AM, Cerqueira MA, Souza B, Santos EC, Teixeira JA, Moreira RA and Vicente AA. New edible coatings composed of galactomannans and collagen blends to improve the postharvest quality of fruits – Influence on fruits gas transfer rate. Journal of Food Engineering 2010: 97: 101–109.

26 Carneiro-da-Cunha M, Cerqueira MA, Souza B, Souza MP, Teixeira JA and Vicente AA. Physical properties of edible coatings and films made with a polysaccharide from *Anacardium occidentale L*. Journal of Food Engineering 2009: 95:379–385.

27 García A, Ferrero C, Bertola N, Martino M and Zaritzky N. Edible coatings from cellulose derivatives to reduce oil uptake in fried products. Innovative Food Science and Emerging Technologies 2002: 3: 391–397 .

28 García A, Ferrero C, Campana A, Bertola N, Martino M and Zaritzky Methylcellulose coating applied to reduce oil uptake in fried products. Food Science and Technology International 2004: 10 (5): 339–346.

29 Bertolini Suarez R, Campañone LA, García, MA and Zaritzky NE. Comparison of the deep frying process in coated and uncoated dough systems. Journal Food Engineering 2008: 84: 383–393.

30 Krochta JM. Protein as raw materials for films and coatings: definitions, current status, and opportunities. In: Protein-Based Films and Coatings. Edited by Gennadios A. New York: CRC Press 2002 pp 1–40.

31 Kim KW, Ko CJ and Park HJ. Mechanical properties, water vapor permeabilities and solubilities of highly carboxymethylated starch-based edible films. Journal of Food Science 2002: 67(1):218–222.

32 Gennadios A, McHugh TH, Weller CL and Krochta JM. Edible coatings and films based on proteins. In Edible coatings and films to improve food quality. Edited by Krochta JM, Baldwin EA and Nisperos-Carriedo M. Lancaster. Eds.Technomic. Pub. Co 1994 pp. 210–278.

33 Krochta JM. Protein as raw materials for films and coatings: definitions, current status, and opportunities. In Protein-Based Films and Coatings. Edited by Gennadios A. New York. CRC Press and 2002 pp 1–40.

34 Perez-Gago MB and Krochta JM. 2002. Formation and properties of whey protein films and coatings. In: Protein-Based Films and Coatings. Edited by Gennadios A. New York: CRC Press 2002 pp 159–180.

35 Bamdad F, Goli AH and Kadivar M. Preparation and characterization of proteinous film from lentil (*Lens culinaris*). Food Research International 2006: 39: 106–111.

36 Adebiyi AP, Adebiyi AO, Jin D-H, Ogawa T and Muramoto K. Rice bran protein-based edible films. International Journal of Food Science & Technology 2008: 43(3): 476–483.

37 Kamper S and Fennema O. Water Vapor permeability of an edible film, fatty acid, bilayer film. Journal of Food Science 1984: 49: 1478–1481, 1485.

38 Baldwin EA. Surface treatments and edible coatings in food preservation. In: Handbook of Food Preservation. Edited by Rahman MS. Boca Raton, FL: CRC Press 2007 pp 478–508.

39 Beaulieua JC, Park HS, Ballew Mims AG and Kuka MS. Extension of green bell pepper shelf life using oilseed-derived lipid films from soapstock. Industrial Crops and Products 2009: 30: 271–275.

40 García MA, Pinotti A and Zaritzky NE. Physicochemical, water vapor barrier and mechanical properties of corn starch and chitosan composite films Starch/Stärke 2006: 58(9): 453–463.

41 García MA, Pinotti A, Martino M and Zaritzky NE. Characterization of composite hydrocolloid films. Carbohydrate Polymers 2004: 56: 339–345.

42 Pinotti A, García MA, Martino M and Zaritzky NE. Study on microstructure and physical properties of composite films based on chitosan and methylcellulose. Food Hydrocolloids 2007: 21 (1): 66–72.

43 Sothornvit R and Pitak N. Oxygen permeability and mechanical properties of banana films. Food Research International 2007: 40: 365–370.

44 Tapia MS, Rojas-Graü MA, Rodríguez RJ, Ramírez J, Carmona A and Martín-Belloso O. Alginate- and Gellan-Based Edible Films for Probiotic Coatings on Fresh-Cut Fruits. Journal of Food Science 2007: 72 (4): 190–196.

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

46 Oms-Oliu G, Soliva-Fortuny R and Martín-Belloso O. Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. LWT - Food Science and Technology 2008: 41: 1862–1870.

47 Chlebowska-Smigiel A, Gniewosz M and Swinczak E. An attempt to apply a pullulan and pullulan-protein coatings to prolong apples shelf-life stability. ACTA Scientiarum Polonorum Technologia Alimentaria 2007: 6(1): 49–56.

48 Mariniello L, Di Pierro P, Esposito C, Sorrentino A, Masi P and Porta R. Preparation and mechanical properties of edible pectin-/soy flour films obtained in the absence or presence of transglutaminase. Journal of Biotechnology 2003: 102: 191–198.

49 Perez-Gago MB and Krochta JM. Emulsion and bi-layer edible films. In Innovations in Food Packaging. Edited byHan JH. New York: Elsevier Academic 2005 pp 384–402.

50 Phan The D, Péroval C, Debeaufort F, Despré D, Courthaudon JL and Voilley A. Arabinoxylan-Lipids-Based Edible Films and Coatings. 2. Influence of Sucroester Nature on the Emulsion Structure and Film Properties. Journal of Agricultural and Food Chemistry 2002: 50: 266–272.

51 Phan The D, Péroval C, Debeaufort F, Despré D, Courthaudon JL and Voilley A. Arabinoxylan-Lipids-Based Edible Films and Coatings. 3. Influence of Drying Temperature on Film Structure and Functional Properties Journal of Agricultural and Food Chemistry 2002: 50: 2423–2428.

52 Han JH and Krochta JM. Physical properties of whey protein coating solutions and films containing antioxidants. Journal of Food Science 2007: 72(5): 308–314.

53 Han JH, Hwang HM, Min S and Krochta JM. Coating of peanuts with edible whey protein film containing α-tocopherol and ascorbyl palmitate. Journal of Food Science 2008: 73(8): 349–355

54 Viña S, Mugridge A, García MA, Ferreyra R, Martino M, Chaves R and Zaritzky NE. Quality of refrigerated Brussels sprouts. Effect of plastic packaging film and edible starch coatings. Food Chemistry 2007: 103: 701–709.

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

56 Reinoso E, Mittal GS and Lim L-T. Influence of Whey Protein Composite Coatings on Plum (*Prunus Domestica* L.) Fruit Quality. Food and Bioprocess Technology 2008: 1(4): 314–325.

57 García MA, Martino M and Zaritzky NE. Composite starch-based coatings applied to strawberries (*Fragaria x ananassa*). Nahrung/Food 2001: 45(4): 267–272.