Chapter 19
Development of Edible Coatings in the Preservation of Fruits and Vegetables

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Abstract Edible coatings are thin layers obtained from biopolymers (proteins, polysaccharides, lipids or combinations of these components) and are applied to food products. Some of its functions are to protect the product from physical, chemical and biological deterioration during storage and distribution. Due to the problem related to losses of horticultural products caused by different factors, including postharvest spoilage due to high moisture content, edible coatings have been recently studied in order to enhance the quality of food products. The application of edible coatings on fresh fruits and vegetables has shown promising results in extending its shelf life and improving safety. This chapter aims to analyze the recent advances in the development of edible coatings in the postharvest.

Keywords Biopolymers · Edible coatings · Postharvest

19.1 Introduction

The use of edible coatings as protective layers on the food surface is not a recent approach, as they have been used for centuries in food production (Ansorena et al. 2018). The first documented applications were documented in the twelfth century in China. In the twentieth century, different coatings to prevent the moisture loss from fruits and vegetables, as well as to add the bright effect were used (Hassan et al. 2018). An edible coating is a thin layer formed directly on a food product, while the edible film is first formed as a self-supporting layer and can then be placed on a food product or between food components. Both structures are prepared from a liquid film-forming solution of edible materials which play a role as a structural matrix (polysaccharide, protein, lipid or different mixture of those components) (Saberi and Golding 2018). The main difference between them is the application technique:

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the edible coating is applied by an immersing or spraying method, while the edible film is dried or molded and then applied as a separate layer or a wrap on the food product (Falguera et al. 2011).

Fruits and vegetables are horticultural products which are characterized as highly perishable products with a short shelf life, which constitutes a continuous challenge for the food industry, particularly in the regions where refrigerated storage is limited. Despite of different postharvest technologies which have been investigated and applied, many harvested fruits and vegetables are still wasted, thus adequate and advanced postharvest processing approaches are required. Therefore, the use of edible coatings as protective layers is the most desired approach in order to avoid or limit a waste problem by improving its quality acceptance. It can be observed that recent scientific studies are focused on the development of different edible coatings and their application to extend the shelf life of fresh of fresh fruits and vegetables, both whole and fresh-cut.

19.2 Film-Forming Materials

Edible films and coatings are produced from edible polymers which are usually classified into three categories: hydrocolloids, lipids and their composites (Gutiérrez 2018a). Table 19.1 summarizes the main materials used in the preparation of edible films and coatings. Hydrocolloids (polysaccharides and proteins) are the most widely used structural materials for edible materials (Valencia and do Amaral Sobral 2018). They are more neutral, transparent and tasteless than those obtained from lipids, which are rather opaque. Edible films and coatings obtained from polysaccharides or proteins are usually good oxygen barriers and provide good mechanical strength (Garrido et al. 2018). However, these materials are hydrophilic in nature, thus they are characterized as poor water vapor barriers. On the other hand, lipids (fats and oils) are excellent hydrophobic materials and a low water vapor permeability. Nevertheless, the hydrophilic character of polysaccharide and protein-based

Table 19.1 Main materials used in the preparation of edible films and coatings

Source	Polysaccharides	Proteins	Lipids
Vegetable	Cellulose and cellulose derivatives, starch, pectin, tara gum	Soy proteins, corn zein, wheat gluten	Vegetable oils, seed oils, nut oils, candelilla wax, carnauba wax, rice bran wax
Animal	Chitosan	Gelatin, milk proteins, collagen, egg proteins, myofibrillar proteins	Beeswax, shellac, fish oil
Seaweed extracts	Alginate, agar, carrageenan	–	–
Microbial	Pullulan, gellan gum, xanthan gum	–	–

Note: – not found

materials can be improved efficiently by incorporation of lipids (Galus and Kadzińska 2015). In recent studies on edible film-forming materials, the combination of different polysaccharides, proteins and/or lipids can be observed (Merino et al. 2019). The aim of these researches is to take advantages of properties of each component in order to obtain new coating materials with improved functional properties which depend on their miscibility and compatibility. Nonetheless, the new materials must be developed, characterized and analyzed. One of the examples can be fruit or/and vegetable purees, wastes or byproduct-based films and coatings usually prepared with the addition of hydrocolloid agents. Wang et al. (2011) observed that only one kind of hydrocolloid did not solve the problem of the poor mechanical strength of carrot films. The authors combined carboxylmethyl cellulose, corn starch and gelatin in order to improve functional properties of carrot puree films which can be suitable as wrappers or edible packaging for food products.

Among polysaccharides, proteins and lipids, additional compounds are usually needed in order to provide continuous and flexible structure of films and coatings (Álvarez et al. 2017). Plasticizers are used to limit negative characteristic such as fragility, brittleness or cracking. Polyols, oligosaccharides and lipids are different types of plasticizers used in edible materials prepared from hydrocolloids (Medina Jaramillo et al. 2016). In addition, water plays a role as a plasticizer and effect many physical properties of films. Other components can also be added to enhance its functionality, including crosslinking agents, emulsifiers or reinforcers (Collazo-Bigliardi et al. 2018). However, new research and recent publications on the production of edible films and coatings are focused on different substances or compounds (antioxidants, antimicrobials, color or flavor agents, nutraceuticals) incorporated into film matrix to improve physical properties as well as to give a new function such as active and intelligent (A&I) packaging films (Bracone et al. 2016; Gutiérrez 2018b).

The use of bioactive substances and biopolymers derived from agricultural byproducts or waste promotes the development of these environmentally friendly materials which can replace or at least limit the use of conventional plastics (Salgado et al. 2015). There is also a great research effort focused in developing and investigating the new film-forming materials, as well as the new processing systems, in order to optimize the composition, costs and functional properties of films and coatings.

19.3 Factors that Affect the Practical Approaches of Edible Coatings Applications for Fruits and Vegetables

Edible coatings have been applied to fruits and vegetables in order to provide a semi-permeable barrier to water vapor and other gases, which reduces weight loss and extends the shelf life of them. Fruits and vegetables are obtained from different parts of the plant and are characterized as highly heterogeneous products in terms of tissue structure, stage of development or metabolic rate. Therefore, the application of edible coatings can be designed for fresh, minimally processed horticultural products or other processed horticultural products. In general, many factors must be considered when designing coatings for fruits and vegetables, such as shape, size, maturity stage, tissue structure, porosity, juiciness, turgidity, surface texture, firmness, metabolic activity, processing, packaging and storage conditions.

These aforementioned factors affect the selection of the adequate edible material and the application technique (Montero-Calderón et al. 2016). The applications of edible coatings for the development of horticultural products with improved quality and prolonged shelf life can be designed for different approaches, including the modification of the internal atmosphere, the control of the mass transfer properties, the inhibition of spoilage microorganisms, the reduction of oxidative reactions and the improvement of the texture properties or gloss and shine on its surface (Gutiérrez and Álvarez 2017; Tapia-Blácido et al. 2018).

In recent times, the extensive review articles have focused on edible films and coatings for fruit and vegetable applications (Vargas et al. 2008; Dhall 2013; Ghidelli and Pérez-Gago 2018; Yousuf et al. 2018). In this chapter, the most recent trends are summarized, with emphasis on the new formulations and applications of edible coatings, which are listed in Table 19.2.

19.4 Advances in Edible Coatings for Fruits and Vegetable

For a long time, biopolymers were applied more in one-component coating formulation, whose tendency is still observed. However, two-component and multicomponent edible coatings provide improved functional properties. In this context, edible coatings based on sodium alginate and pectin were used by Silva et al. (2018) to preserve the quality of the minimally processed mangoes. Chitosan (Cs) is one of the promising materials that has been applied, either as a one-component coating or as a main polymer in the component structures, for many horticultural products due to the excellent film-forming ability and characteristics antimicrobial (Gutiérrez 2017a; Paul et al. 2018). Ortiz-Duarte et al. (2019) observed that the respiration rate and the ethylene production of the fresh-cut melon were reduced after the Ag-Cs nanocomposite coating treatments. The coated samples also had better sensory quality with lower translucency and texture degradation after 13 days of storage at 5 °C. Kharchoufi et al. (2018) incorporated the by-product pomegranate peel extract and the biocontrol agent into Cs and locus bean gum coating in order to control the growth of *Penicillium digitatum* and reduce the postharvest decay of oranges. The results of antifungal effectiveness showed the potential synergistic effect between the biocontrol agents and the natural bioactive compounds. Yan et al. (2018) observed that a layer-by-layer edible coating based on Cs and carboxymethyl cellulose was significantly effective in inhibiting the loss of fruit firmness and aroma volatiles of strawberry. The authors found, after an untargeted metabolomics analysis, that the layer-by-layer application reduced the primary metabolite contents involved in the metabolism of carbohydrates, fatty acids and amino acids.

Table 19.2 Latest potential applications of edible coatings for fruits and vegetables and their main advantages

Fruit or vegetable	State	Coating material	Functional compound	Advantage	Reference
Apple	Fresh-cut	Carboxymethyl cellulose	*Aloe vera*, ascorbic acid, calcium chloride, cysteine	Inhibited browning, retained color, decreased CO_2 production and O_2 consumption	Kumar et al. (2018)
Melon	Fresh-cut	Chitosan (Cs) or carboxymethyl cellulose	Citral	Superior antimicrobial protection; improved appearance; extended storability	Arnon-Rips et al. (2019)
Strawberry	Whole	Cs	Shrimp carotenoproteins	Reduced fungal decay and weight loss, and inhibited phytopathogenic growth	Hajji et al. (2018)
Melon	Fresh-cut	Cs	Ag nanoparticles	Reduced respiration rate and ethylene production, and improved sensory quality	Ortiz-Duarte et al. (2019)
Banana	Whole	Rice starch, carrageenan	–	Reduced weight loss, maintained firmness, improved the visual appearance and delayed fruit ripening	Thakur et al. (2019)
Garambullo fruits	Whole	Gelatin	Tomato oily extract	Delayed changes in weight loss, brix degrees, titriatable acidity and pH; retained concentration of bioactive compounds	López-Palestina et al. (2018)
Plum	Whole	Rice starch, carrageenan	Sucrose fatty acid ester	Reduced weight loss and respiration rate; inhibited ethylene production	Thakur et al. (2018)
Tomato Chili pepper Eggplant	Whole	Cs	Cs nanoparticles	Decreased weight loss and improved antifungal activity	Divya et al. (2018)
Eggplant	Fresh-cut	Soy protein isolate	Cysteine	Improved quality and prolonged shelf-life	Ghidelli et al. (2018)
Apricot	Whole	Soy protein isolate, Cs	–	Decreased weight loss, retained firmness and textural properties, and inhibited pectin degradation	Zhang et al. (2018)
Orange	Whole	Cs, locus bean gum	Pomegranate peel extract, biocontrol yeast	Reduced disease incidence and inhibited of green mold	Kharchoufi et al. (2018)
Tomato	Whole	Cassava starch, Cs	Rosemary pepper essential oil, pomegranate peel extract	Delayed ripening; reduced total soluble solids content and weight loss; maintained firmness	Araújo et al. (2018)

(continued)

Table 19.2 (continued)

Fruit or vegetable	State	Coating material	Functional compound	Advantage	Reference
Strawberry	Whole	Cs	Cinnamon essential oil, extract of Roselle calyces	Reduced weight loss, remained fruit firmness and increased antioxidant capacity	Ventura-Aguilar et al. (2018)
Dates	Whole	Poly vinyl alcohol, Cs	Tannic acid	Prolonged shelf life	El-Dein et al. (2018)
Figs	Whole	–	Mucilage extract from *O puncia ficus-indica* cladodes	Maintained weight loss and fruit firmness	Allegra et al. (2018)
Strawberry	Whole	Protein isolate and gum from *Cajanus cajan* seeds	–	Reduced weight loss, total soluble content and the consumption of citric acid	Robles-Flores et al. (2018)
Capsicum	Whole	Cs, sodium alginate	Pomegranate peel extract	Inhibited microbial growth, reduced weight loss and fruit firmness, maintained color and sensory scores	Sneha Nair et al. (2018)
Carrot	Fresh-cut	Sodium alginate, sunflower oil	Probiotic culture *L. acidophilus*	Reduced carrot metabolism, maintained weight loss and color changes	Shigematsu et al. (2018)
Cherry tomatoes	Whole	Cs	Grapeftuit seed extract	Delayed microorganism growth and reduced weight loss	Won et al. (2018)
Apple	Fresh-cut	Gelatin	Aloe vera, green tea extracts	Inhibited microbial growth and reduced softening trend	Amiri et al. (2018)
Guava	Whole	Arabic gum, sodium caseinate	Cinnamon and lemon grass essential oils	Improved overall quality and maintained bioactive compounds	Murmu and Mishra (2018)
Avocado	Whole	Carboxyl methylcellulose	Moringa plant extracts	Reduced weight loss, ethylene production and respiration rate, prolonged shelf life and maintained overall quality	Tesfay et al. (2017)
Kiwi	Fresh-cut	Sodium alginate	Poly-ε-lysine	Reduced CO_2 production; maintained green color, total chlorophylls content, ascorbic acid, antioxidant capacity and morphological properties	Li et al. (2017)
Mandarins	Whole	Carboxymethyl cellulose, arabic gum, persian gum	Beeswax, carnauba wax	Reduced weight loss	Khorram et al. (2017)

Emulsified films and coatings have generally been investigated to provide a better moisture barrier of the coated products. However, lipid-containing coatings, both coarse and nano emulsions, can be used for the delivery of valuable bioactive compounds, such as antimicrobial agents, antioxidants, dyes, flavors or nutraceutical agents (Galus and Kadzińska 2015). Arnon-Rips et al. (2019) analyzed the encapsulation of citral by utilizing coarse and nano emulsions using sunflower oil, which were integrated into Cs and carboxylmethyl cellulose coatings to be applied on melons. Both polysaccharides showed a good stabilizing effect in the formulation, however, the emulsions containing Cs were more stable. The nano emulsions were more stable, so the films obtained from these solutions were more organized and denser, with a greater water vapor barrier and mechanical resistance. The coatings based on nano emulsions applied to fresh-cut melons resulted in superior antimicrobial protection and improved appearance, as well as increased storage capacity. Nevertheless, the citrus aroma was significant in coated melons, which may limit their sensory acceptability, which indicates that the coating formulation analyzed would be more appropriate for citrus fruits. Thakur et al. (2019) managed to prolong the shelf life of banana for 12 days by applying starch-ι-carrageenan edible coatings containing sucrose fatty acid esters.

In the last decades, the incorporation of different natural compounds on the surface of food products in solid state began, but a more exhaustive investigation in this area is still necessary to be applied such substances in the food industry. For example, the extensive studies on the biological activity of rosemary extracts as an antioxidant agent resulted in their approval as a food additive E 392 by the Directives 2010/67/EU and 2010/69/EU (European Commission 2010a, b).

19.5 Advances in the Combination of Methods to Extend the Shelf Life of Fruits and Vegetables

The extension of the shelf life of fruits and vegetables is necessary due to several aspects, such as market demand and the limitation of a global waste problem. Recently published studies have focused on new formulations of edible coatings, as well as on the use of the combination method in order to produce functional protective layers. In this context, copolymer coatings based on hydrolyzed poly (vinyl alcohol) and Cs with the addition of tannic acid were prepared by El-Dein et al. (2018) using a triple blend to maintain the quality of shelf life of the dates during commercialization. The film-forming solutions were further exposed to the γ-irradiation before casting or using them. The results obtained showed that the γ-irradiation and the addition of tannic acid increased the mechanical properties of the films and successfully prolonged the shelf life of the dates during the marketing period, from 1 week to 1 month with an acceptable freshness and quality. Muñoz-Labrador et al. (2018) applied citrus pectin gels prepared by power ultrasound as edible coatings for fresh strawberries, resulting in a better fruit quality than control samples in terms of weight loss and color parameters.

The application of edible coatings can be done by different methods, among them soaking, or immersion are the most popular. However, Soares et al. (2018) used vacuum impregnation as an alternative method to soak techniques in the application of edible coatings of Cs and Cs/lauric acid on minimally processed pumpkin. The results showed that the vacuum impregnation method caused a greater incorporation of components, and more uniform and thicker coatings, meanwhile some important changes in pH, acidity, color and firmness indicated that this method led to larger changes in the properties of the pumpkin than the popular coating method. Todisco et al. (2018) analyzed the effect of the edible coating composition and the drying temperatures on the drying kinetics and the quality of the dried red guava. The authors obtained pectin-based coatings containing disintegrated guava by-products and applied them to guava slices prior to hot-air drying. The coatings improved nutritional quality, by high carotenoid and total phenolic retentions, without having an important impact on the drying times.

Salinas-Roca et al. (2018) evaluated the combined effect of pulsed light treatment, alginate coating and malic acid dip on quality attributes of fresh-cut mango. These treatment combinations prevented fruit browning during storage and resulted in the highest radical scavenging activity, indicating that this novel processing system can preserve bioactive compounds of fresh-cut mango for 14 days. Vivek and Subbarao (2018) observed that Cs coatings could delay the decomposition, both microbial and non-microbial, in fresh-cut kiwi treated in combination with ultrasound and sodium hypochloride, thus extending its shelf life for 10 days at 5 °C.

19.6 New Coating Materials Testing for Applications to Fruits and Vegetables

Among the known biopolymers, new coating materials are being tested. In this context, the different concentration of *Aloe vera* gel were used by Mubarak and Rao Engakanah (2017) as edible coating on to maintain the postharvest quality of wax applies. These authors observed that 100% *Aloe vera* is most effective in retaining the bioactive compounds of stored apples and also has a tendency to reduce weight loss and fruit firmness. Allegra et al. (2018) applied an edible coating extracted from cladodes of *Opuntia ficus-indica* on breba fig fruit which was effective in maintaining the fruit fresh weight and fruit firmness. In addition, metabolic study showed that fig fruits exhibited important changes in primary metabolism as a result of coating treatment, including increased amounts of carbohydrates and most of the amino acids. Robles-Flores et al. (2018) developed new edible coatings from protein isolate and gum obtained from *Cajanus cajan* seeds to be applied to strawberries. The authors observed that coatings resulted in a reduction of the weight loss, the total soluble solid and the citrus consumption, while no sensory changes were obtained.

Shigematsu et al. (2018) developed alginate-based coatings containing sunflower oil and the probiotic culture *Lactobacillus acidophilus* to coat the minimally processed carrot slices. The results showed that application of these coatings had some advantages, such as better preservation of moisture content and color. The incorporation of *L. acidophilus* to the film-forming emulsions reduced the metabolism of the minimally processed carrot slices. Alvarez et al. (2018) prepared sodium alginate and Cs coatings incorporating different dietary fibers (apple fiber, orange fiber, inulin and oligofructose) in order to improve quality attributes of fresh blueberries. The results showed that the fiber-enriched Cs coatings allow the maintenance of freshness and the improve of the quality of blueberries as an innovative product with prebiotic potential and prolonged shelf life.

19.7 Edible Coatings From Fruits and Vegetables

In recent years, different purees of fruits and vegetables, pulp, juice or extract have been used in the production of edible films and coatings. The components that are added to the biopolymers provide different bioactive compounds with nutritional value and can play an important role on factors such as color or taste, thus affecting the physical properties of the edible films or coatings (Gutiérrez 2017b). In addition, some operations applied during the processing of fruits or vegetables can generate high amounts of waste, which are not attractive and are underutilized due to low market values, and which can be used as raw material for the development of films and coatings edible. However, the reduction of losses sustained during post-harvest treatments is the subject of latest research, which are focused on the application of overproduced, by-products or residues as a new unconventional source in the preparation of edible packaging. In this context, Torres-León et al. (2018) used mango by-products (peel and seeds) for the formation of biodegradable coatings for fresh peaches. The mango films showed good properties of permeability, color, antioxidants and greater hydrophobicity. The incorporation of antioxidants from extract of mango seed into film formulation, positively affected the surface properties. Fresh peaches coated with the solution containing mango peel and mango seed extract showed reduced ethylene and carbon dioxide production, as well as lower oxygen consumption compared to uncoated fruits. This study demonstrated the great potential of mango by-products in the production of low-cost biopackaging material and the longer shelf life of peaches. Nogueira et al. (2019) developed flexible films made from arrowroot starch and blackberry pulp. The obtained films provide the typical color and flavor of blackberry, bioactive compound and antioxidant capacity which may be attractive for some food applications. Rangel-Marrón et al. (2019) used a papaya puree as a base for the production of edible coatings containing alginate, glycerol and citric acid. The authors suggested that formulation obtained could be an alternative packaging system for different applications, e.g. sushi wraps or minimally processed fruits and vegetables with compatible colors.

19.8 Conclusions

The research and development (R&D) of edible coatings for fruits and vegetables has been intensified in recent decades, but its low presence in the market shows that future studies should be carried out. The benefits of edible coatings for horticultural products are numerous, but the most important should be highlighted as follows: reduction of weight loss, respiration rate and ethylene production, as well as the inhibition of the growth of microorganisms and the maintaining the content of active compounds. Therefore, the application of edible coatings for fruits and vegetables can positively affect the prolongation of the shelf life and, consequently, impact the economy of the food processes.

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