Chapter 21
Active Edible Coatings for Fresh Fruits and Vegetables

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Abstract Fruits and vegetables are perishable products due to their high metabolic activities, water loss and susceptibility to pathogens. Thus, each year huge losses occur in horticultural products during handling and transportation. Various pre and postharvest treatments are available to attenuate these losses. Amongst these, use of edible coatings is a key means to enhance the storability of the product. The edible coatings are environment-friendly greener approach to mitigate the postharvest losses. Edible materials having suitable moisture and gas barrier properties are applied as a thin layer on the surface of the product to minimize the changes that occur due to biochemical processes. There is a paradigm shift in the development of coatings that are added with features such as improved functionality through incorporation of certain antimicrobials, texture enhancers and nutraceuticals. The use of active edible coatings is a novel approach to extend the shelf-life of the product by incorporating active ingredients into the polymer matrix, which can be consumed with the food, thus enhancing safety, and nutritional and sensory attributes. On the other hand, the smart edible packaging makes use of immobilized antimicrobial nanoparticles applied on the food surface to control the release of active ingredients that enhance the storage life of the product for desired duration. The materials used for the edible coating must be generally recognized as safe (GRAS) and must be approved by the FDA. The success of edible coatings for fresh products depends completely on the control of internal gas composition and ethanol fermentation, changes in color, firmness loss etc. This chapter will cover the recent advances in the development of coatings from different polymers incorporated with functional ingredients to improve quality and ease of use on fresh fruits and vegetables.

Keywords Active Edible Coating Additives · Antimicrobial · Antioxidant · Probiotic

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T. J. Gutiérrez (ed.), *Polymers for Agri-Food Applications*,
https://doi.org/10.1007/978-3-030-19416-1_21

21.1 Introduction

Fruits and vegetables are a basket of nutrients required to keep ones's body healthy. However, they are very perishable and are victim of many physical, physiological, biochemical and pathological deteriorations. These factors affect the commercialization of the products resulting in huge economic losses (Gutiérrez et al. 2016). Since the purchase of any product depends on its aesthetic appeal, it must be attractive in terms of colour, firmness and the overall appearance. However, perishable horticultural products are prone to shrinkage, softening, colour change etc. during handling and storage. Of the several techniques to extend the shelf-life of fruits and vegetables, edible coatings have gained importance due to ease of use and fabrication according to the functional attribute desired. The application of these coatings on the product surface can be achieved by dipping, spraying or brushing. The coatings adhere to the food surface and create a modified atmosphere that provides a barrier to oxygen, moisture and the movement of solutes (Gutiérrez and Álvarez 2017; Tapia-Blácido et al. 2018). The eco-friendly polymer based edible coatings not only reduce the requirements of synthetic plastic packaging, but also uses the by-products of the food industry. The traditional use of edible coating was mainly focussed on minimizing water loss and delaying senescence through selective permeability to gases. However, the new generation of edible coatings is being specially designed to allow the incorporation and controlled release of nutraceuticals, antioxidants and natural antimicrobial agents through diverse fabrication techniques (Gutiérrez 2017, 2018a). These coatings are thin layers of edible material applied to the product surface and are used as an alternative to natural protective waxy coatings (Ansorena et al. 2018).

21.2 Historical Background of Edible Coatings

Edible coatings have been used for centuries to prevent the moisture migration, improve the food appearance and increase product shelf life. The use of wax coating on fruits by dipping is one of the oldest methods that was in vogue at the beginning of the twelfth century (Krochta and Mulder-Johnston 1997). The coating of citrus fruits with wax to retard desiccation was practiced in China in the twelfth and thirteenth centuries (Hardenburg 1967). In the 1930's, hot-melt paraffin waxes were commercially used as edible coatings for apples and pears (Park 1999). Since 1980's sucrose fatty acid esters (SFAEs), Semperfresh™, Tal Pro-long™, zein proteins are commercially used to coat fruits and vegetables, thus, the firmness, colour and weight during storage are retained (Dhall 2008). During fifteenth century, a protein-based edible film called Yuba was traditionally used in Asia to improve the appearance and preservation of some foods (Gennadios et al. 1993). In the nineteenth century, to prevent oxidation and rancidity of dried nuts during storage, sucrose was applied as an edible protective coating. The more important application of edible coatings so far concerns the use of an emulsion made of oil and waxes in water that is spread on fruits and vegetables to retard the moisture loss, improve their appearance, in terms of colour and sheen, and slow down the softening and start of mealiness (Debeaufort et al. 1998).

21.3 Functionality of Edible Coatings

As previously mentioned, edible coatings are thin layer of edible material that is applied to the product surface in addition to or as a replacement for natural protective waxy coatings, which provide a barrier against the movement of gas, moisture and solutes, and can be eaten along with the commodity (Dhall 2008). It is thus important that the composition of edible coatings must comply with food regulations (Guilbert et al. 1995). A good quality of edible coatings should meet some important criteria such as moisture barrier, solute or gas barrier, water/lipid solubility, good mechanical characteristics, nontoxicity, etc. The effective use of coatings depends greatly on temperature, thickness, alkalinity, type of coating and condition of fruits or vegetables (Park et al. 1994).

In addition to improving shelf life of fruits and vegetables, edible coatings also impart functionality to the product. The improvement in sensory properties of food can also be achieved by using an edible coating containing either colourants, flavours, anti-browning agents, antimicrobials and other functional substances, thereby making the products more attractive. Novel edible materials have been derived from many natural sources that are safe to use. Among all these applications, the use of edible coatings as active packaging stands out as a promising application for food packaging (Bracone et al. 2016). These are promising new approaches to extend the quality and shelf life of fruits and vegetables. Active packaging refers to the incorporation of additives into the package in order to maintain or extend the product quality and shelf life (Gutiérrez and Alvarez 2017a, b).

21.4 Properties of Edible Coating

The properties of edible coating depend mainly on molecular structure rather than chemical constitution and molecular size. Material of any kind cannot be used for coating purposes. Arvanitoyannis and Gorris (1999) detail certain specific requirements, such as:

1. It should not interfere with the quality of fruits and vegetables and should not impart an undesirable odour.
2. The coating material should be water resistant.
3. It should not reduce oxygen or build up excessive carbon dioxide to avoid anaerobic respiration.

4. It should have reduced water vapour permeability.
5. It should improve mechanical handling properties and appearance, maintain structural integrity, carry active agents such as antioxidants, vitamins, etc. and retain volatile flavour compounds.
6. It should be easily emulsifiable.
7. Materials must be dissolved in all types of solvent such as water, alcohol or a mixture of other solvents.
8. It must be economical.

21.5 Composition of Edible Coatings

It is known that edible coatings improve the food quality, since they are selective barriers to oxygen uptake, moisture transfer and loss of volatile aromas and flavours. The moisture barrier properties of edible coatings have been extensively studied by measuring their water vapour properties, because water plays a key role in spoilage reactions in foods. However, the barrier properties of edible coatings mainly depend on the material from which they are derived. Most of the edible coatings are derived from natural polymers having film-forming ability, such as polysaccharides, proteins and lipid (Álvarez et al. 2017). Edible coatings are produced from materials with film-forming ability. It includes polysaccharides such as cellulose, starch, chitin, chitosan (Cs), alginates, pectins etc., and proteins namely casein, whey protein, keratin, collagen, gelatin, soy protein, wheat gluten, corn-zein, peanut protein, cottonseed protein etc., lipids such as wax and oil-based coatings, monoglycerides, fatty acid resins and emulsions etc. (Gennadios et al. 1994; Gutiérrez and Alvarez 2017c; Gutiérrez 2018b; Merino et al. 2019). Their presence and abundance determine the barrier properties of material regarding oxygen, water vapour and carbon dioxide transfer in food systems.

21.6 Current Status and Recent Advances

Edible coatings are currently used in many food applications to improve handling, extend shelf life and modify appearance and flavour. It can be considered as a novel technique for carrying antimicrobials to the food surfaces of high moisture content, maintaining the flavour profile of foods with high aroma and retarding oxidation in intermediate and low moisture foods. Edible coatings also have the potential to maintain the quality of foods even after opening the package. There are multiple applications of edible coatings in the food industry. These include extending the shelf life of oxygen-sensitive foods, reducing packaging of whole and pre-cut fresh fruits and vegetables, extending product shelf life of frozen foods by reducing moisture loss, respiration and colour change, avoiding oxidation, as well as preventing moisture, aroma or colour migration (Marín et al. 2016). It is expected that the active packaging systems market has a promising future due to its integration in packaging materials or systems.

21.7 Applications of Active Edible Coatings on Fruits and Vegetables

The uses of edible coatings made from polysaccharides, proteins, lipids and composites containing several food additives, probiotics, antioxidants and oxidizing agents are discussed in this section. For some time, the main polysaccharides of interest for the coating fruits and vegetables have been cellulose, gums, starch, pectin and Cs (Saberi and Golding 2018). Polysaccharide coatings have a poor moisture barrier but have a good gas barrier and mechanical properties. Proteins from soy, milk, corn and wheat gluten are also used to prepare edible coatings (Garrido et al. 2018). Amongst them, zein is the only commercially produced protein used for such applications. Lipids such as bee wax, rice bran oil, paraffin wax and acetylated monoglycerides are also used in coating formulations. Lipids are hydrophobic and therefore, act as good moisture barriers. However, its mechanical properties are inferior to protein and polysaccharide-based films.

21.7.1 Edible Coatings as Carriers of Flavour, Colourant and Texturizer

As previously outlined, edible coatings can maintain and deliver desirable concentrations of functional ingredients to improve the product quality. Edible coatings can be incorporated with flavours, seasonings, vitamins, colourants and other beneficial plant-derived compounds. Table 21.1 briefly describes the use of edible coatings as carriers of flavours, colourants and texturizers.

21.7.2 Active Edible Coatings Carrying Nutraceuticals

Edible coatings also have the capacity to contain many active ingredients that could be used to enhance the nutritional and functional quality of food products (Gutiérrez and Álvarez 2016; Gutiérrez 2017). However, the integration of nutritional or nutraceutical ingredients into coatings of foods (Table 21.2) has been reported only by few workers, though there is growing interest in this area.

Table 21.1 Application of active edible coatings for imparting desirable flavour, colour and textural attributes

Matrix used	Applied on	Concentration	Effect	References
Alginate	Melon	Calcium lactate 2% w/v	Maintenance of firmness	Raybaudi-Massilia et al. (2008)
Alginate	Pineapple	Calcium chloride 2% w/v	Retention of internal liquids	Montero-Calderon et al. (2008)
Alginate and gellan	Fuji apple	1% *N*-acetyl cysteine and glutathione mixed with 2% w/v alginate and 0.5% w/v gellan	Maintenance of a∗ value	Rojas-Graü et al. (2007)
Cs	Raspberries	Calcium gluconate 5% w/v	Retention of textural quality	Han et al. (2004)
Whey protein concentrate	Apples	Calcium chloride 1% (w/v)	Retains firmness	Lee et al. (2003)

Table 21.2 Edible coatings as carriers of nutraceuticals

Produce	Coating used	Ingredient	Quantity of application	Effect	References
Papaya	Alginate	Ascorbic acid	Ascorbic acid @ 1.0 (w/v)	Retention of ascorbic acid in the fruit	Tapia et al. (2008)
Apple, papaya	Alginate and gellan	*Bifidobacterium lactis*	*Bifidobacterium lactis* @ 2.0 (w/v)	Maintenance of fruit quality up to 10 days during storage	Tapia et al. (2007)
Strawberries and raspberries	Cs-based coatings	Vitamin E	Cs containing 0.2% dl-α-tocopheryl acetate	Delayed change in colour, titratable acidity and pH of the fruits during cold storage	Han et al. (2004)

21.7.3 Edible Coatings as Carrier for Probiotic Organisms

Probiotics are live microorganisms, which at a given concentration can confer health benefits to the host (Sanders 2008). Probiotics help to support the growth of beneficial microorganisms, reduce potentially harmful bacteria and reinforce the body's natural defence mechanisms. Table 21.3 describes the beneficial use of edible coatings as carriers of probiotics in various fruits and vegetables. Such active packaging systems help to deliver novel health-enhanced products for the consumers.

Table 21.3 Application of probiotic-containing edible coatings on fruits and vegetables

Fruit/ Vegetable	Matrix used	Probiotic incorporated	Additives used	Effect	References
Carrot slices	Sodium alginate	*Lactobacillus acidophilus*	Calcium chloride	Control growth of *Bacillus cereus* and *Staphylococci.*	Shigematsu et al. (2018)
Grape	Hydroxypropylmethylcellulose, corn starch, sodium caseinate & pea protein	*Candida sake*	Oleic acid, span 80, tween 85, glycerol	Inhibit *Botrytis cinerea* (gray mould)	Marín et al. (2016)
Mandarin	Locust bean gum	*W. anomalua*, *M. pulcherrima*, *A. pullulans*	No additives used	Control mould caused by *P.digitatum* & *P. italicum*	Parafati et al. (2016)
Apple snacks	Methyl cellulose	*L. plantarum*	Fructooligosaccharides, ascorbic acid.	Organoleptically good up to 90 days during storage	Tavera-Quiroz et al. (2015)
			Citric acid & sorbitol		
Orange	Sodium alginate & locust bean gum	*W. Anomalua*	Glycerol	Control green mould (*P. digitatum)*	Aloui et al. (2015)
Grape	Carboxymethylcellulose (CMC) & alginate	Brewer yeast	No additives were used	Showed good sensory quality up to 13 days	Yinzhe and Shaoying (2013)
Strawberry	Alginate	*C. laurentii*	Glycerol, palmitic acid, glycerol monostearate β-cyclodextrin.	Inhibit the growth of mould and maintain the quality up to 20 days	Fan et al. (2009)
Fresh-cut apples and Papayas	Alginate/Gellan	*B. lactis* Bb-12	Glycerol	Prevents decay up to 10 days	Tapia et al. (2007)
Tomato	Cs	*C. utilis*	Tween-80	Prevent the growth of *A. alternata* and *G. candidum*	Sharma et al. (2006)

21.7.4 Edible Coatings as Carrier of Antimicrobial Agents

Active compounds such as antimicrobials are incorporated into edible coatings to inhibit spoilage/pathogenic bacteria by maintaining effective concentrations of active compounds on food surfaces. There are several categories of antimicrobials that can potentially be incorporated into edible coatings: (1) organic acids, namely lactic, acetic, propionic, benzoic, sorbic, (2) fatty acid esters such as glyceryl monolaurate, (3) polypeptides such as peroxidase, lysozyme, lactoferrin, nisin, and (4) plant essential oils such as cinnamon, oregano, lemongrass and nitrites and sulphites, as listed in Table 21.4 (Álvarez et al. 2018). The incorporation of these antimicrobials can help in delivering safe food.

21.7.5 Active Edible Coatings Carrying Antioxidants

Antioxidants are free radical acceptors that delay, inhibit or interrupt the stage of propagation of autooxidation. These are used to protect against oxidative rancidity and enzymatic browning in fruits and vegetables. The incorporation of natural antioxidants into edible coatings can improve their functionality and applicability in foods. A wide range of natural antioxidants such as essential oils and plant extracts, as well as pure compounds, such as α-tocopherol and ascorbic acid have been incorporated into edible coatings to improve their bioactive properties. Table 21.5 shows the beneficial effect of antioxidant-containing edible coatings. In addition, antioxidants prevent the loss of vitamin C and the browning reactions, especially in the fresh-cut fruits and vegetables, thereby maintaining colour and improving the shelf-life and acceptability of the commodity.

21.7.6 Commercially Available Active Edible Coatings

Since the research on active edible coatings began, many products have been launched in the commercial market, which may or may not be specific to each product. Table 21.6 gives some of these formulations of active edible coatings that are available in the market.

21.8 Limitations for Use

Edible coatings are being developed with incorporation of active compounds such as antioxidants, antimicrobials, flavourings and nutraceuticals. Research is being done to maintain the mechanical properties, since they can be affected dramatically

Table 21.4 Examples of antimicrobials added into edible coatings applied on fruits and vegetables

Used on	Coating used	Antimicrobial compound added	Application	Effect	References
Capsicum	Cs and alginate	Pomegranate peel extract (PPE)	Cs (1% w/v) and alginate (2% w/v) combined with 1% w/v PPE	Control of *Colletotrichum gloeosporioides* during 20 days of low temperature storage	Nair et al. (2018a)
Strawberry	Cs	Caroteno proteins (CP)	Cs (1–3%) mixed with CP (0–3%)	Delayed yeast and mould growth during storage at 4 °C for 11 days	Hajji et al. (2018)
Blueberries	Sodium alginate (AL) and Cs	Apple fiber, orange fiber, inulin and oligofructose	Fiber used at concentrations of 7 g kg^{-1} with 20 g kg^{-1} Cs and 20 g kg^{-1} AL	Reduced decay rate by more than 50%, enhanced antioxidant properties, retention of fruit firmness during storage at 5 °C for 18 days	Alvarez et al. (2018)
Bell pepper	Cs	Lemongrass essential oil	Lemon grass oil @ 0.5% and 1.0% was incorporated into 0.5% and 1.0% of Cs Cs solution	Control of anthracnose both under *in vitro* and *in vivo* condition	Ali et al. (2015)
Satsuma mandarin	Cs	Clove oil	1% Cs combined with 0.5 mL/L clove oil	Inhibition of *Penicillium digitatum* both under *in vitro and in vivo* conditions	Shao et al. (2015)
Dates	Cs and locust bean gum	Citrus essential oils	Cs–2% (v/v) mixed with 2% citrus essential oil	Inhibition of *Aspergillus flavus* during storage of 12 days.	Aloui et al. (2014)
Broccoli	Cs	Essential oils and bioactive compounds	Cs solutions (2 g/100 mL) mixed with 1 mL essential oils and bioactive compounds	Control of *E. coli* and *L. monocytogenes*	Alvarez et al. (2013)
Pineapple	Sodium alginate and pectin	β-Cyclodextrin and trans-cinnamaldehyde)	Sodium alginate and carriers are added @ 2 g/100 g	Extension of shelf-life to 15 days at 4 °C by inhibiting microbial growth	Mantilla et al. (2013)
Papaya (fresh cut)	Cs and pectin	β-Cyclodextrin and trans-cinnamaldehyde	Microencapsulated β-cyclodextrin and trans-cinnamaldehyde complex (2 g/100 g)	Extending shelf life of fresh-cut papaya up to 15 days at 4 °C, higher retention of vitamin C and total carotenoids	Brasil et al. (2012)

Table 21.5 Coatings incorporating antioxidants

Used on	Matrix used	Additives	Effect	References
Guava	Cs and alginate	Pomegranate peel extract	Improved quality and shelf-life	Nair et al. (2018b)
Fuji apple slices	Cassava starch	Cinnamon bark essential oil & fennel essential oil	Higher total phenols and antioxidant activity	Oriani et al. (2014)
Mango (fresh-cut)	Alginate	Ascorbic acid & citric acid	Increased stability till 12 days at 4 °C	Robles-Sánchez et al. (2013)
Tomato	Rice starch	Coconut oil & green tea extract	Control of ripening and enhancement of total phenols and ascorbic acid content	Das et al. (2013)
Peach (fresh-cut)	Pectin	Cinnamon leaf oil	Increase in total phenolic and flavonoid content as well as antioxidant capacity	Ayala et al. (2013)
Table grapes	Pectin	Cinnamon leaf oil	Significant increases in the antioxidant capacity	Melgarejo-Flores et al. (2013)
Rose apple	Konjac glucomann	Pineapple fruit extracts (PE) from peel, pulp and core	Reduced PPO and POD activities with high retention of total phenols	Supapvanich et al. (2012)
Table grapes	Hydroxypropylmethylcellulose (HPMC) or Cs	Bergamot essential oil	Improved product appearance	Sanchez-Gonzalez et al. (2011)
Fresh-cut mango	Cassava starch	Citric acid	Delayed quality deterioration, retarded fruit respiration rate and better maintenance of colour	Chiumarelli et al. (2011)
Table grapes	HPMC	Ethanolic extract of propolis	Prevention of weight loss and browning	Pastor et al. (2011)
Sweet pepper	Cs	Cinnamon oil	Good sensory acceptability	Xing et al. (2011)
Pears	Cs	Rosemary extract	Reduced membrane permeability, vitamin C loss and weight loss	Xiao et al. (2010)
Lettuce and butternut squash	Sodium caseinate Cs and carboxymethyl cellulose	Oleoresins of rosemary, capsicum, cranberry and garlic	Maintained sensory acceptability	Ponce et al. (2008)
Pears (fresh-cut)	Alginate, gellan or pectin	*N*-acetylcysteine glutathione	Reduced vitamin C loss	Oms-Oliu et al. (2008)

Table 21.6 Commercially available active edible coatings

Coating	Composition
Semperfresh™	Sucrose esters with high proportion of short chain unsaturated fatty acid esters, sodium salts of CMC and mixed mono and diglycerides
Prolong	Mixture of sucrose fatty acid esters, sodium CMC and mono and diglycerides
Tal prolong	Mixture of sucrose fatty acid esters, sodium CMC and mono and diglycerides
Nature-seal™	Cellulose-based edible coating
Nu-coatFlo, Ban-seel	Sucrose esters of fatty acids and sodium salt of CMC
FreshSeal™	Polyvinyl alcohol, starch and surfactant
Citrashine	Sucrose ester and wax

with the incorporation of food grade additives. Therefore, the development of coatings with improved mechanical, functional and barrier properties is an important task. One of the main obstacles is the cost, which restricts its application in high value products. In addition to the cost, other limiting factors for the commercial use of edible coatings are the lack of materials with the desired functionalities, the investment cost for the installation of coating equipment, the strictness of the regulations and the difficulty of the production process. Despite these limitations, the food industry is looking for edible coatings that can be used in a broad spectrum of foods to add value to their products, increase product shelf life and/or reduce packaging. There is also a trend to develop new generation edible coatings which release active compounds using nanotechnological solutions such as nanoencapsulation and multilayer systems.

21.9 Regulatory Status for the Use of Edible Coatings

Since edible coatings are an integral part of the edible portion of food products, they should follow all required regulations pertinent to food ingredients. To maintain product safety and quality, all components, as well as functional additives should be food-grade and non-toxic materials. In addition, all process facilities should be acceptable for food processing and should strictly comply with current Good Manufacturing Practice (GMP). Acceptable ingredients for use in edible coatings should be Generally Recognized As Safe (GRAS), and used within any limitations specified by the Food and Drug Administration (FDA). According to the European Directive (1998) the ingredients that can be incorporated into the formulation of edible coatings are arabic and karaya gum, pectins, shellac, beeswax, candelilla wax, carnauba wax, lecithin, polysorbates, fatty acids and fatty acid salts. On the other hand, the FDA mentions other additives used as components of protective coatings applied to fresh fruits and vegetables such as morpholine, polydextrose, sorbitan monostearate, SFAEs, cocoa butter and castor oil (Vargas et al. 2008).

21.10 Conclusion

The trend of packaging research worldwide should be directed to produce active edible coatings that are affordable and can maintain high quality, wholesome, fresh-like products. These coatings are promising in postharvest management and will receive more attention in the near future. Natural ingredients have great potential for use as additives in edible coatings without the adverse effects associated with chemical preservatives. Future research should encourage additional studies to overcome the above limitations.

Acknowledgements The authors would like to thank colleagues and students who gave inputs for compiling this chapter.

Conflict of Interest The authors declare no conflict of interest.

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