Chapter 9

Postharvest Application of Biopolymer-Based Edible Coatings to Improve the Quality of Fresh Horticultural Produce

Bahareh Saberi and John B. Golding

Abstract Fresh fruit and vegetables are essential part of the human diet and with increasing growth in the world population and globalization of the supply chain, there is high consumer demand for fresh high quality fruit and vegetables with satisfactory shelf-life. Fruit and vegetables are living perishable commodities and maintaining their eating quality requires delaying and slowing the loss of quality and microbial spoilage in the supply chain. To actively manage produce quality, it is essential to understand the physiology and pathology associated with the storage and handling of fresh fruit and vegetables, for example changes in internal gas and volatiles composition within the produce affect the respiration and senescence rates of stored produce and hence final eating quality. Biopolymers including polysaccharides, proteins and lipids used alone or in combination, have been widely studied as edible coatings for fresh produce due to their widespread availability, ability to control gaseous exchange and to delay senescence, as well as their capability as a medium to carry various additives which can assist with the maintenance of produce quality. This chapter describes and discusses on selected biopolymer based edible coatings and their various applications on fresh fruit and vegetables to extend their shelf life and to improve final eating and nutritional quality through the supply chain.

Keywords Shelf life

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9.1 Introduction

Moisture loss from horticultural produce is mainly due to the gradient of water pressure (vapor pressure deficit) between the less saturated ambient atmosphere and the fruit and can be one of the major losses in quality and quantity of fresh fruit and vegetables. Moisture loss after harvest has detrimental impact on the quality of fruit and vegetables and results in commercial losses as the price of produce depends on its weight (Tesfay and Magwaza 2017). The preliminary signs of moisture loss from fresh fruit are shriveling of the peel/skin and can affect fruit shine (glossiness), firmness and apparent 'freshness' (Tesfay and Magwaza 2017). The extension of fruit shelf life and eating quality is optimized by reducing and managing water loss, ripening and senescence, and development of decay (Vanoli et al. 2015). Many postharvest techniques such as maintaining the optimum storage temperatures and atmosphere during storage and other postharvest treatments including some approved chemical treatments are commonly applied in many horticulture supply chains.

However due to increasing consumer demands for improved health and fruit quality, along with the industry desire to use ecologically friendly coatings for fresh horticultural products, a substantial increase in awareness has been grown among researchers and technologists to develop natural, edible, biodegradable and food safe coatings for fruit and vegetables. Edible coatings have been used for a long time as a method with pronounced capability to increase safety of fresh produces by reducing the effect of external environmental factors and increasing the shelf life (Carneiro-da-Cunha et al. 2009; Cerqueira et al. 2011; Álvarez et al. 2017). Application of a thin layer of edible coatings to the surface of the fresh produce creates a semi-permeable barrier to respiratory gases and water vapor between the surrounding atmosphere and the fruit and also develops a modified atmosphere around the product, decelerating respiration, senescence, and enzymatic processes (Vanoli et al. 2015). Edible coatings need to be water-resistant, stable, and semi-permeable to water vapor during storage. Moreover, they should not excessively reduce oxygen (O_2) or accumulate carbon dioxide (CO_2), and should not cause off-flavors or reduce glossiness, aroma, texture, taste and appearance in order to efficiently preserve food quality. Edible coatings also must have low viscosity, be transparent and cost-effective (Dhall 2013; Mahajan et al. 2014). It has been shown that the incorporation of functional components including antibrowning, antimicrobial agents, nutraceuticals, volatile precursors, and colors can also improve the characteristics of the coatings (Olivas and Barbosa-Cánovas 2005; Gutiérrez 2017a). Besides the microbial stability, appearance, and texture of coated products can be improved by addition of other constituents, such as preservatives, antioxidants, and firming agents (Bai and Plotto 2012; Cerqueira et al. 2009; Gutiérrez 2018). Nevertheless, it is crucial to select appropriate components in order to enhance the effectiveness and stability of edible coatings. An extensive range of different components involving polysaccharides, proteins, lipids or resins, alone or more commonly in combination have been used to produce edible coatings (Flores-López et al. 2016).

Natural biopolymers have excellent potential to improve the safety, quality and functionality of fresh and fresh-cut fruit and vegetables. While many researches have been conducted and reviewed on application of edible coatings for fresh and fresh-cut products, this chapter summarizes and highlights the application of biopolymer based edible coatings on fresh horticultural produce for the past 5 years.

9.2 Polysaccharide–Based Coatings

The application of polysaccharides edible coatings to fresh and fresh-cut fruit and vegetables has been of increasing interest over the last few years due to the wide availability, low cost, and nontoxicity of polysaccharides, where they can be applied as film-forming solution to improve and control the texture, flavor, and shelf-life of produce (Williams and Phillips 2000). Water-soluble polysaccharides are long-chain polymers that give a thickening or viscosity-building effect by dissolving or dispersing in water (Nussinovitch 1997). These compounds are commercially available for use in food and non-food industries such as adhesive, mouth feeling, stabilizing, thickening and gelling agents, crystallization inhibiting, and encapsulating agents (Whistler and Daniel 1990; Izydorczyk et al. 2005; Gutiérrez and Álvarez 2017). They can also act as emulsifier because their stabilizing function on emulsions originates from an increase in viscosity of the aqueous phase of the edible coating (Nussinovitch 1997), therefore the kinetic motion of the oil droplets is decreased, leading to a lower rate of flocculation and coalescence in the coating (Nisperos-Carriedo 1994). Polysaccharides consist of many monosaccharide residues that are linked one to the other by O-glycosidic linkages. The physical attributes of polysaccharides including solubility, flow behavior, gelling potential, and/or surface and interfacial characteristics are dictated by their great diversity of structural features deriving from variations in the monosaccharide composition, linkage types and patterns, chain shapes, and degree of polymerization (Izydorczyk et al. 2005).

Polysaccharide based coatings usually have less moisture barriers in comparison with those of commercial ones. They also have reasonably low oxygen permeability but have selective permeability to O_2 and CO_2 (Lacroix and Le Tien 2005). Consequently, polysaccharide based coatings have been applied to, either fresh or minimally processed fruit and vegetables to protect from dehydration, decrease their respiration rate by producing modified atmosphere conditions inside the product, provide a moderate barrier to moisture, improve mechanical handling characteristics, and to deliver additives along with contributing to the preservation and even the creation of volatile compounds (Olivas and Barbosa-Cánovas 2005). Polysaccharide coatings can act as a sacrificial moisture barrier to the atmosphere by reducing moisture loss of the coated produce (Kester and Fennema 1986). The major advantage of application of polysaccharides is, acting a gas barrier rather than postponing water loss due to their hydrophilic nature (Lin and Zhao 2007).

Polysaccharides based edible coatings made of starch and non-starch polysaccharides (hydrocolloids or gums), which can be made from a variety of sources including cellulose derivatives (carboxymethylcellulose (CMC), methylcellulose (MC), hydroxypropyl cellulose (HPC), hydroxypropyl methyl cellulose (HPMC), microcrystalline cellulose), seaweed extracts (agar, alginates, carrageenans), various plant and microbial gums (arabic, ghatti, tragacanth, guar, locust bean, xanthan, gellan, pullulan), connective tissue extracts of crustaceans (chitosan) (Gutiérrez 2017b), and some mucilage compounds (Lacroix and Le Tien 2005), which have been extensively investigated by means of prolonging the shelf life of fresh and minimally processed fruit and vegetables.

9.2.1 Starch–Based Coatings

Starch is widely found in nature and has been extensively used as an alternative for producing edible coatings as it is abundant, inexpensive, biodegradable and edible (Gutiérrez et al. 2015; Cazón et al. 2017). Starch granules constitute two main polysaccharides: amylose and amylopectin. Amylose is a linear chain polymer of α-1,4 anhydroglucose units with a molecular size varying from 20 to 800 kg/mol and constitutes about 20–25% of the granular starches (Cazón et al. 2017). Amylopectin is a branched polymer of short α-1,4 chains connected by α-1,6 glycosidic branching points which occurs every 25–30 glucose units and normally has a very high molecular weight (5000–30,000 kg/mol) (Peressini et al. 2003; Jiménez et al. 2012). The changes of structure and molecular weight between amylose and amylopectin result in various molecular properties, which can be utilized to develop coatings (Cazón et al. 2017). The starch based coatings characterized by forming hydrogen bonds between hydroxyl groups during drying of a gelatinized dispersion (Jiménez et al. 2012). Starch-based coatings are often very fragile and have poor mechanical characteristics due to amorphous regions shaped by amylose causing extensive intermolecular forces which consequently impart brittleness of starch coatings (Peressini et al. 2003). It is therefore essential to add a plasticizer or combine starch with other compounds or chemically modify the starch to manage this problem (Bertuzzi et al. 2007; Xiong et al. 2008).

A key benefit with the use of these coatings on fresh fruit and vegetables is to lessen the fruit's natural high respiration and senescence rate, however it is critical that the coating allows some gas exchange for the fruit to continue to respire. Starch coatings have good oxygen barrier properties due to the high-ordered hydrogen-bonded configuration in which the amylose and amylopectin establish crystalline and non-crystalline districts in irregular layers (Lin and Zhao 2007). Starch based coatings can reduce the fruit deterioration rate by reduction of respiratory metabolism and retardation of some enzymatic reactions related to ripening, and accordingly preserve the appearance, texture and nutritional composition of coated fruit (Franco et al. 2017; Álvarez et al. 2018).

Nawab et al. (2017) showed that coatings made of mango kernel starch were effective at maintaining overall postharvest quality of tomato during storage at 25 °C and 60% RH for 20 days. The strawberry fruit coated with oxidized and acetylated cassava starch had lower weight loss, better texture, lighter and brighter appearance, lower soluble solids and higher total acidity compared with native cassava starch coated fruit, indicating that the modifications in the starch coating possibly improved its function in retarding some enzymatic reactions related to ripening (Franco et al. 2017).

Starch based coatings have also been used as a medium for carrying additives for preservation fresh and minimally processed (fresh-cut) fruit and vegetables. Ojeda et al. (2014) found that cassava starch coatings with ascorbic acid reduced browning, changes in hue and the activity of the polyphenol oxidase, phenylalanine ammonia lyase and polyphenol oxidase in minimally processed sweet potato. Whilst Pająk et al. (2017) showed that potato starch with white and green tea extracts prevented weight loss, darkening, and reduction in antioxidant activity and total phenolic content in apple slices during storage at 5 °C and 84% RH for 6 days.

9.2.2 *Non–Starch Polysaccharide–Based Coatings*

The application of non-starch polysaccharides edible coatings on fresh and fresh-cut fruit and vegetables, has been significant interest in recent years due to their low cost and nontoxicity (Williams and Phillips 2000).

Water-soluble non-starch polysaccharides are heterogeneous groups of long chain polymers categorized by their capability of developing viscous dispersions and/or gels when dispersed in water (Saha and Bhattacharya 2010). These compounds are commercially used in the food industry as agents for improving mouth feel, stability, thickening and gelling inhibiting crystalization, and encapsulating agents (Stephen et al. 2006; Izydorczyk et al. 2005). Non-starch polysaccharides can also act as emulsifiers due to their stabilizing functions, which increase the viscosity of the aqueous phase of the edible coating (Nussinovitch 1997). This reduces the kinetic motion of the oil droplets, leading to a low rate of flocculation and coalescence in the coating (Nisperos-Carriedo 1994).

Typically, non-starch polysaccharide coatings have poor moisture barriers, but low oxygen permeability with selective permeability to O_2 and CO_2 (Lacroix and Le Tien 2005). Consequently, non-starch polysaccharide based coatings have been examined on fresh and minimally processed fresh fruit and vegetables, to reduce water loss, decrease the respiration rates by modifying the atmospheric conditions inside the product, improve mechanical handling characteristics, deliver additives, and to maintain and improve volatile profiles (Olivas and Barbosa-Cánovas 2005). Table 9.1 summarizes several studies on application of various non-starch polysaccharides edible coatings and gums in extending shelf life of fruit and vegetables.

Table 9.1 Several recent studies on application of non-starch polysaccharide-based coatings on fresh and fresh-cut fruit and vegetables

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Cellulose		Honeydew winter melon	Coating reduced internal O_2 levels, leading to a considerable increase in ethane, acetaldehyde, ethanol, and ethyl acetate amounts. The cellulose coating caused anaerobic respiration in fruit	Vanoli et al. (2015)
CMC	Garlic essential oil	Strawberry	Coatings had a positive effect on the WL, DR, TSS, TA, and AAC, and on maintaining higher concentrations of TPC and anthocyanins of strawberries	Dong and Wang (2017)
	Moringa leaf extract	Avocado	The combination of CMC (1%) and 2% moringa reduced WL, electrical conductivity, and RR and had higher values for F and phytochemical characteristics	Tesfay and Magwaza (2017)
	Nano-ZnO	Fresh cut pomegranate aril	Coatings reduced total yeast + mold during 12 days of storage while total mesophilic bacteria were decreased during 6 days of storage. Coatings decreased WL, suppressed TSS and TPC changes and also the greatest juice percent was in coated arils. Total anthocyanin, AAC, and antioxidant capacity were higher in coated arils	Saba and Amini (2017)
	Extract of *Impatiens balsamina L.* stems	Tangerine and navel orange	Coatings had an inhibitory influence on mold growth, decreased DR and WL, maintained commercial quality and enhanced the activities of antioxidant and defense-related enzymes	Zeng et al. (2013) and Chen et al. (2017)

(continued)

Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
CMC	Calcium chloride and ascorbic acid	Fresh-cut apple	Coatings suppressed browning, retained F, AAC and antioxidant capacity and decreased PPO and POX activity, TSS, TA and pH changes of the slices	Saba and Sogvar (2016)
HPMC	Oregano and bergamot essential oils	Plum	Coatings decreased RR, EP, WL, TMC, C change, and fruit softening	Choi et al. (2016)
MC		Strawberry	Coating did not affect TA, anthocyanin and antioxidant activity of coated strawberry compared to the control one	Nadim et al. (2015)
Pectin	Ascorbic acid, citric acid and sodium chlorite	Fresh-cut apple	Coatings reduced microbial spoilage while did not significantly influence sensory and nutritional qualities. The anti-browning agents further enhanced this ability	Guerreiro et al. (2017)
	Orange peel essential oil	Fresh-cut orange	Coatings reduced the quality loss and improved the sensory scores during storage. The nanoemulsion pectin-based coatings containing 1% essential oil were the most effective in bacterial and fungal inactivation	Radi et al. (2017)
		Blueberry	Coating increased the F and the blue hue color and decreased the growth kinetics of yeasts and mesophilic aerobic bacteria	Mannozzi et al. (2017)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Pectin	Citral and eugenol	Raspberry	Coatings were not cytotoxic and did not considerably change the general physicochemical and nutritional characteristics of raspberries. Their impact was mainly on decreasing food spoilage microorganisms and accordingly extending shelf-life	Guerreiro et al. (2016)
	Oregano essential oil (OEO)	Tomato	Coatings with OEO exhibited antifungal influence on inoculated tomatoes, and increased TPC and antioxidant activity. The sensorial acceptability of the coated tomatoes was well accepted by panelists	Rodriguez-Garcia et al. (2016)
Alginate	Lemon essential oil or orange essential oil	Red raspberry	The less red color verified in coated samples was coincident with the lower concentration of anthocyanins as well as the lower capacity for scavenging ABTS free radicals or quenching singlet oxygen. The coatings with the essential oil of orange were very efficient for controlling yeast and mold growth after 15 days of storage	Gomes et al. (2017)
	Olive oil	Ber fruit	Coatings decreased DR, WL, TSS and total sugars and increased the level of antioxidants. The delayed activity of PG, PL and PME was noticed in coated fruit representing the reduced softening and ripening process	Rao et al. (2016)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Alginate	Tea polyphenols	Chinese winter jujube	Coatings decreased red indices, TCC, RR, electrolyte leakage and malonaldehyde content and maintained the AAC, TPC and the activities of antioxidant enzymes while had no significant effect on F	Zhang et al. (2016)
	Ficus hirta fruit extract	Nanfeng mandarin	The DR, WL, RR and MDA content were much lower in the coated samples. The coating treatment enhanced the activities of antioxidant and defense-related enzymes such as SOD, CAT, POD, CHI, GLU and PAL and the accumulation of phenolic compounds	Chen et al. (2016)
	Bacteriocin	Minimally processed papaya	The alginate coating performed as a barrier to WVT and gas exchange, which delayed changes in TSS values, F, WL and ripening in coated samples. Coating preserved minimally processed papaya for 3 weeks without reducing physico-chemical qualities or microbial safety	Narsaiah et al. (2015)
	Grapefruit seed extract (GSE) or grapefruit essential oil (GEO)	Table grape	Coatings reduced WL, maintained F during storage, preserved the antioxidant activity of treated grapes and decreased DR in inoculated fruit	Aloui et al. (2014)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Xanthan	β-Carotene nanocapsules	Fresh-cut melon	The minor changes observed in the whiteness index and F. Incorporating of β-carotene nanocapsules into xanthan gum increased fruit shelf life	Zambrano-Zaragoza et al. (2017)
	α-Tocopherol nanocapsules	Fresh-cut apple	Firmness changes were reduced and the quality of fresh-cut apples was maintained by coating	Zambrano-Zaragoza et al. (2014a)
	Candeuba® wax nanoparticles	Guava	Coated fruit showed the lowest range of WL. High contents of nanoparticles caused physiological damage and also delayed the fruit maturation	Zambrano-Zaragoza et al. (2013)
	Cinnamic acid	Fresh-cut pear	Coating caused significant retardation of the oxidative browning, decline of AAC, degradation of TPC and reduction in antioxidant capacity	Sharma and Rao (2015)
Pullulan	Caraway essential oil	Fresh baby carrot	Coatings were active against all tested microorganisms and maintained better visual acceptability in comparison with control	Gniewosz et al. (2013)
	Sweet basil extract	Apple	Coating showed low antibacterial activity against mesophilic bacteria and good antifungal protection against *Rhizopus arrhizus* on apple surfaces They also contributed to a reduction in WL and lower changes in the C and TSS of apples. Coated fruit presented better overall preference parameters	Synowiec et al. (2014)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Pullulan	Sodium benzoate and potassium sorbate	Strawberry	Coating decreased WL, fruit softening and microbial growth and delayed changes of C and TSS content. In contrast, pH and TA were not affected. Sensory quality (color, flavor, texture, and acceptance) improved and DR decreased in coated strawberries	Treviño-Garza et al. (2015)
	n-Octenyl succinic anhydride	Sapota (*Manilkara zapota*)	Coating reduced flesh F loss and WL and delayed the ripening and senescence	Shah et al. (2016a)
		Jujube	Coating treatment inhibited fruit softening, increase in redness index scores, WL rates, and reduced the loss of AA and freshness. Defensive enzymes and antioxidant activity and antioxidant compounds increased in coating-treated fruit	Kou et al. (2017)
Gum Arabic	Oregano and rosemary essential oils	Plum	Coatings delayed the occurrence of soft rot and decreased the rotted plums at the end of storage. Coated fruit exhibited greater F, decreased WL and lower decrease of sugars and phenolics at the end of storage	Andrade et al. (2017)
	Ginger oil and ginger extract	Papaya	Coating delayed the ripening and showed antifungal activity. Quality of papaya fruit in terms of F, C, TSS and TA was maintained	Ali et al. (2016)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Gum Arabic	Calcium chloride	Mango	Coating reduced chilling injury, MDA content and electrolyte leakage. This treatment increased antioxidant activity and effectively inhibited the loss of TPC and AA. The treated fruit maintained cell membrane integrity	Khaliq et al. (2016)
		Tomato	Coatings delayed the ripening process by slowing down RR and EP and also maintained total antioxidant capacity, lycopene content, TPC and total carotenoids during storage	Ali et al. (2013)
Chitosan	*Cymbopogon citratus* (Dc. Ex Nees) (lemongrass) essential oil	Tomato	Coating decreased the severity of *Rhizopus* soft rot and more strongly delayed the infection when the fruit were artificially contaminated after coating application. The application of the coating preserved the general quality of tomato fruit	Athayde et al. (2016)
	Natamycin, nisin, pomegranate and grape seed extract	Strawberry	Coating reduced the O_2consumption of the fruit and showed better effects on delaying changes of pH, TSS, water activity and TMC. The incorporation of different antimicrobial agents into chitosan matrix did not reveal any significant effect on C of strawberry	Duran et al. (2016)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Chitosan		Red kiwifruit berries	Coating did not affect the changes in weight during the first 12 days of storage. No significant differences in terms of F were determined at the end of storage. Coated berries showed higher amounts of biologically active substances and TSS	Kaya et al. (2016)
	Lemongrass oil	Grape berry	Coating with nano-droplet of oil showed higher initial inhibition of *Salmonella typhimurium*; greater growth inhibition of microorganisms and higher retention of C, TSS, antioxidant activity and better SE during storage	Oh et al. (2017)
	Salvia fruticosa Mill. extract	Table grapes	The efficacy of the coating against grey mold was statistically equal to the synthetic fungicide thiabendazole. Coating decreased the rate of fruit WL during cold storage, while preserved TSS and TA. Coatings did not affect quality attributes and the bioactive compounds in table grapes	Kanetis et al. (2017)
	Thyme essential oil nanoparticles	Avocado	The coating reduced the incidence of *C. gloeosporioides* on avocado. Coating did not affect the quality of avocado; moreover, fruit F was better maintained than untreated fruit	Correa-Pacheco et al. (2017)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Chitosan		Mango	Chitosan delayed the climacteric peak, WL and F. Further, few changes in TSS, TA, pH of the pulp as well as in sugar content and decreased starch degradation were observed	Silva et al. (2017)
		Pomegranate	Coating effectively reduced rot incidence of *Botrytis sp*	Munhuweyi et al. (2017)
Carrageenan	Bacteriocin	Apple cubes	Reduced viable *Listeria* counts compared to the untreated apple cubes	Aguayo et al. (2016)
		Papaya	Increased firmness and delayed ripening and C changes	Hamzah et al. (2013)
Tragacanth gum	*Satureja khuzistanica essential oil*	Button mushroom (*Agaricus bisporus*)	Increased F, reduced TMC and browning index. Higher levels of TPC and AAC were observed in coated samples. SE demonstrated the capability of coating for preserving the quality of mushroom during the storage	Nasiri et al. (2017)
Locust bean gum	Biocontrol agent	Mandarin	Coating provided excellent control of postharvest decays caused by *P. digitatum* and *P. italicum* on mandarins	Parafati et al. (2016)
Tara gum	Ascorbic acid, citric acid and $CaCl_2$	Minimally processed peach	Reduced WL, C alteration and growth of molds and yeasts and maintained F	Pizato et al. (2013)
Guar gum	Silver nanoparticle	Kinnow	Coating preserved the fruit aroma and sensory quality	Shah et al. (2016b)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Gellan	Sunflower oil, ascorbic acid, citric acid and $CaCl_2$	Fresh-cut pineapple	Coating reduced RR and WL and maintained the F and C. Coating did not change pH, TA and TSS and did not show any antimicrobial effect	Azarakhsh et al. (2014)
	Calcium gluconolactate	Ready-to-eat mango	Coating improved mango bars sensory characteristics (appearance and F) and stability in terms of syneresis, C and volatiles content during storage	Danalache et al. (2016)
	Potassium sorbate, calcium chloride, 1-methylcyclopropene (1-MCP)	Pre-cut jackfruit	Coating decreased the ripening rate; WL, and RR and preserved F, C, TSS, TA as well as pH until 12 d of storage. Microbial growth was hindered until the12th d of storage in coated fruit	Vargas-Torres et al. (2017)
Lignin		Lime	Maintained WL and C change. This coating formula also exhibited higher antifungal activities	Jonglertjunya et al. (2014)
Basil-seed gum	*Origanum vulgare subsp. viride* essential oil	Fresh cut apricot	Coatings reduced the TMC and significantly enhanced TPC and antioxidant activity of coated samples at the end of cold storage	Hashemi et al. (2017)
Flaxseed gum	Lemongrass essential oil	Ready-to-eat pomegranate arils	Coatings were effective in reducing TMC and reduced WL, ripening index, and changes in TSS, pH, TA and C	Yousuf and Srivastava (2017)
Almond gum		Sweet cherry	Fruit coated with almond gum showed a significant decrease in RR as well as EP. Moreover, coatings were able to delay changes in weight, F, TA, TSS and C development	Mahfoudhi and Hamdi (2015)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Persian gum		Mandarin	Coatings reduced the weight loss. Persian gum caused glossiness in coated fruit; however, they were less effective than the commercial wax coating	Khorram et al. (2017a)
		Orange	Coating increased fruit gloss and was effective at improving postharvest quality of fruit during storage. Coating was not stable and showed visible cracks during storage	Khorram et al. (2017b)
Nopal mucilage	Nanoemulsion of α-tocopherol	Fresh-cut apple	PME activity in the coated apples was lower helping maintain the F of the coated fruit. At 21 days of storage, PPO activity decreased by 65% in the coated apples with nanoemulsion, as reflected in the lower browning indexes	Zambrano-Zaragoza et al. (2014b)
Opuntia cladodes mucilage		Fig	Coating improved the quality of fig during storage by maintaining fruit fresh weight, visual score values, F and total carotenoid content. Coated fruit showed a significantly lower development of *Enterobacteriaceae* than control ones	Allegra et al. (2017)
	TWEEN® 20	Kiwifruit slices	Coated samples showed a significant higher F and a lower WL until 5 d of shelf life. The treatment with Tween 20 did not affect the flavor of the kiwifruit slices, while increased microbial growth at the end of the monitoring period	Allegra et al. (2016)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Aloe vera		Strawberry	Coating reduced rot incidence, RR, WL, and DR and preserved F, AAC, and other quality parameters. Furthermore, aloe vera gel delayed the changes in external C and retained all other postharvest quality	Nasrin et al. (2017)
		Tomato	Coating reduced fruit EP, ripening index (TSS/TA) and maintained the overall quality of the tomato fruit. Lycopene and β-carotene content were reduced while AAC, TPC and antioxidative status were increased. Fruit F, TA, WL, RR and fruit C did not differ among treatments	Chrysargyris et al. (2016)
		Kiwifruit slice	Aloe vera coating maintained the F of the fruit, prevented the AA losses and yellowing due to ripening and reduced microbial proliferation. The sensory panel preferred the kiwifruit slices treated with Aloe vera compared to the other coatings	Benítez et al. (2015)
	Calcium chloride, ascorbic acid, and vanillin	Fresh-cut papaya	Coating preserved TPC and AA and reduced microbial load and relatively low PPO and POX activity during storage	Kuwar et al. (2015)
		Raspberry	Coated samples maintained higher levels of antioxidant capacity, TPC, total anthocyanin and antioxidant enzymes during storage periods	Hassanpour (2015)

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Table 9.1 (continued)

Coatings	Additional compounds	Fruit/ vegetable	Results	References
Aloe vera	Rosehip oil	Peach, plum, nectarine and sweet cherry	Coating reduced RR in all fruit, and EP in the climacteric ones (peaches, plums and nectarine). In addition, all the parameters related with fruit ripening and quality, such as WL, softening, C change and ripening index, were also delayed in treated compared with control fruit	Paladines et al. (2014)

AAC ascorbic acid content, *C* color, *CAT* catalase, *CHI* chitinase, *DR* decay rate, *EP* ethylene production, *F* firmness, *GLU* β-1,3-glucanase, *MDA* maleicdialdehyde. *PAL* phenylalanine ammonia lyase, *PG* polygalacturonase, *PL* pectate lyase, *PME* pectin methyl esterase, *POX* peroxidase, *PPO* polyphenol oxidase, *RR* respiration rate, *SE* sensory evaluation, *SOD* superoxide dismutase, *TCC* total chlorophylls content, *TFC* total flavonoid content, *TMC* total microbial count, *TPC* total phenolic content, *WL* weight loss, *WVT* water vapor transmission

9.3 Protein–Based Coatings

Coatings may also be developed from both animal and plant protein sources (Cerqueira et al. 2016). Proteins are macromolecules with amino acid sequences and molecular conformation structures. The unique conformational structure, electrostatic charges, and amphiphilic nature are the most exclusive characteristics of proteins compared with other coating-forming materials (Hun and Cennadios 2005). The presence of different charged, polar and non-polar amino acids in the protein provides multiple sites for chemical interaction to improve and tailor the protein functional properties. Proteins are not entirely hydrophobic and encompass a range of hydrophilic amino acid residues restricting their moisture-barrier characteristics (Shit and Shah 2014). However protein coatings have a good oxygen barrier and be used to create an efficient semi-permeable barrier to respiratory gases resulting in development of a modified atmosphere (MA) within the fresh produce, in which O_2 is not freely replaced, nor can the CO_2 produced freely escape (Baldwin and Baker 2002). The MA within the produce reduces respiration and ethylene production rate, delays ripening and senescence, and ultimately extends the produce shelf life. Proteins which have been used in coatings include zein, soy protein, wheat gluten, whey protein, casein, gelatin, and collagen (Hun and Cennadios 2005). Protein based coating films serving as a vehicle to incorporate various active agents have been investigated on different fresh produce.

Soy protein isolate (SPI)-coatings incorporated with the essential component citral and limonene at 10% reduced weight loss of Persian lime (*Citrus latifolia Tanaka*) after 9 days storage at 13 °C and 95% RH, demonstrating their effectiveness in producing a physical barrier to moisture loss and hence postponing dehydration and fruit shriveling (González-Estrada et al. 2017). It was deduced that storage of coated fruits at 25 °C and 75% RH caused a darkening of the rind and/or desiccation of the fruit due to creation of a modified atmosphere around the coated product, which influenced the respiration rate, during this process that comprises the production of CO_2, water and heat through oxidation carbohydrates, negative changes in color of the fruit occurred (Galus and Kadzińska 2015). At the end of storage, coatings started to remove easily from surface of the limes demonstrating that the biodegradation of the coatings such as hydrolysis of polymer chain due to the acidity of fruit or respiration and gas exchanges was dependent on the storage conditions (González-Estrada et al. 2017).

The cereal protein gluten has been also examined as a fruit coating where gluten-based coatings incorporating pomegranate peel and curry leaf extracts did not cause any undesirable color changes in cherry tomatoes and mangoes, but they considerably enhanced the glossiness of the fruit (Kumari et al. 2017). However the use of gluten protein as a coating ingredient maybe limited with widespread gluten intolerance in the community.

Baraiya et al. (2015) evaluated the efficiency of zein-based coatings including cysteine (0.2%), ascorbic acid (0.2%), and jamun leaves extract (JLE) (0.2%) on shelf life and quality of fresh jamun fruit at 10 °C for 2 weeks storage. The results demonstrated that coated fruit had lower weight loss and decay incidence, low accumulation of sugars, and reduced softening and ripening compared to that of uncoated fruit. The levels of antioxidants were found to higher in zein coated fruit which also had higher antioxidant activity. Furthermore the coated fruit had higher firmness and textural qualities with lower activities of polygalacturonase (PG) and pectate lyase (PL). Yun et al. (2015) also showed that zein-based coatings with the addition of cinnamon essential oils decreased the population of *Salmonella enterica serovar Typhimurium* in cherry tomato during 7 days of storage at 10 °C. These coatings decreased the loss of firmness and weight and preserved or improved the quality of fruit (Yun et al. 2015).

Butt et al. (2015) reported that coating with a mixture of 2% sodium caseinate fortified with 40 ppm ZnO was the most effective coating in maintaining the quality characteristics of fresh apricots at 4–6 °C and 85% RH for 6 weeks.

Gelatin coatings with low content of lactic acid (below 0.2%) have been shown to delay ripening in plums after 12 days of storage at 20 °C (Peter et al. 2017). Yang et al. (2017) also studied the potential of application of gelatin extracted from dried Alaska pollock with addition of pine needle extract on quality maintenance of grape berries. They showed that this coating reduced the populations of total aerobic bacteria and yeast and molds and retarded weight loss and changes in anthocyanin content of the grape berries after 20 days of storage.

9.4 Lipid–Based Coatings

Edible lipids including neutral lipids (esters of glycerol and fatty acids), fatty acids, waxes (esters of long-chain monohydric alcohols and fatty acids), and resins (a group of acidic substances that are usually secreted by special plant cells into long resin ducts or canals in response to injury or infection in many trees and shrubs) are traditional coating materials for fresh produce, which provide a good moisture barrier and improve surface appearance (Hagenmaier and Baker 1994, 1995; Morillon et al. 2002). Lipids can be added as formulations of edible coatings as a single layer of lipid dispersed in a hydrocolloid network or in a secondary layer (a lipid layer over a hydrocolloid layer) (Olivas and Barbosa-Cánovas 2009). Emulsion-based coatings in which the lipid is dispersed in the biopolymer matrix are prepared during only one film-forming casting and one drying process (Galus and Kadzińska 2015). Their characteristics are dependent on preparation methods, type and number of components (hydrocolloid and lipid) and their compatibility, as well as the microstructural heterogeneity (Fabra et al. 2011). These emulsion-based coatings are more water permeable than bilayer coatings due to the lack of the homogeneous distribution of lipids in coating matrix, but they have desirable mechanical strength and are relatively easy to manufacture and apply, while multilayer coatings require a complex set of procedures depending on the number of coatings (Galus and Kadzińska 2015). However, it should be noted that the small size of lipid particles and their homogeneous distribution reduce emulsion instability and water vapor permeability (Pérez-Gago and Krochta 2001).

The compatibility of using lipid-based coatings with other coating-forming agents with high gas-barrier and water vapor properties is a major advantage as compared to the use of polysaccharides- and protein-based coatings (Greener and Fennema 1989), since lipids exhibit a very low tendency for water absorption, coatings comprising of lipids generally have good moisture barrier characteristics. However, the differential properties of the lipid component such as its physical state, degree of saturation and chain length of fatty acids all affect the physical and mechanical properties of lipid-based coatings (Olivas and Barbosa-Cánovas 2009). Saturated long-chain fatty acids have a more densely packed structure and less mobility than unsaturated short-chain fatty acids, and therefore have been shown to have the best water vapor barrier properties (Morillon et al. 2002). Lipids which are in the liquid at the desired storage temperature, will have lower water vapor barrier properties than lipids which are solid under same conditions, since the solubility of water vapor in lipids is principally higher in coatings having less ordered molecular organization (Galus and Kadzińska 2015). The gas barrier characteristics of lipids are also strongly determined by their chemical composition. Hydrophobic compounds are generally more permeable to gases owing to their greater chemical affinity and solubility (Miller and Krochta 1997), causing an increase in oxygen permeability of the coating (Navarro-Tarazaga et al. 2011; Jiménez et al. 2013). The shorter the hydrocarbon chain length of the fatty acids, the weaker the attraction forces between molecules, which consequently increases the CO_2 transmission rate of these coatings (Ayranci and Tunc 2001).

The candelilla wax-based edible coating with fermented extract of tarbush (as natural antioxidants source) and carnauba-shellac wax containing lemon essential oil, significantly improved the quality and shelf life of apples stored at room temperature and cold storage (De León-Zapata et al. 2015; Jo et al. 2014). Ochoa-Reyes et al. (2013) also described that an edible coating of candelilla wax with extract of tarbush inhibited weight and firmness loss, and preserved the appearance of green bell peppers.

An increase in the quality and shelf life was also observed for strawberry coated with candelilla wax-biocontrol bacteria (*B. subtilis*) (Oregel-Zamudio et al. 2017), pomegranate coated with carnauba wax-putrescine (Barman et al. 2014) and plum with carnauba wax-lemongrass oil coatings (Kim et al. 2013). Rice bran wax coating has been reported as an efficient alternative for preservation cherry tomato at 0 °C for 20 days (Zhang et al. 2017).

The activity of the antioxidant enzymes has also been shown to increase in the flesh of Ponkan (*Citrus reticulate* Blanco) fruit coated with wax incorporated with cinnamaldehyde (Duan et al. 2017). Lipid-based coatings are thought to protect the cell membrane structure and the fruit tissue by hindering the buildup of reactive oxygen species, leading to less oxidative stress and destruction to fruit (Duan et al. 2017).

9.5 Biocomposite Coatings

Coatings based on polysaccharides commonly exhibit efficient O_2 and CO_2 barriers, but have poor mechanical strength and high moisture sensitivity (Al-Hassan and Norziah 2012). To overcome these problems, their physical and functional properties can be modified by combining with other biopolymers, hydrophobic constituents, and antimicrobial/antioxidant compounds (Saberi et al. 2017; Álvarez et al. 2018). The blending of biopolymers has been demonstrated to improve the mechanical characteristics of the resultant coating (Veiga-Santos et al. 2005) depending on the compatibility/incompatibility of binary polymeric blends, their molecular weight, chemical structures, conformations, and hydration behaviors (Phan The et al. 2009; Gutiérrez and Alvarez 2017).

Forato et al. (2015) applied a composite edible coating made of cashew gum (CG) and carboxymethylcellulose (CMC) on fresh and fresh-cut red guavas. The results showed that the uncoated samples had the fastest degradation rate (around 2.5% of their mass daily), while the coating formulations performed appropriately as a conservative agent, decreasing the mass loss to approximately 2% a day for both intact and sliced fruit. Textural softening in coated guavas in both intact and in sliced forms was delayed as a consequence of reduction of the level of ethylene and enzymatic activity, as well as respiratory activity. Magnetic Resonance Imaging (MRI) confirmed that the addition of CMC presented a relevant role in forming coatings which decreased the free water content in coated fruit resulting from the hydrolysis of starch into sugar plus water and preserved the appearance by reducing color change as the maturation proceeded.

Lai et al. (2013) concluded that tapioca starch/decolorized hsian-tsao leaf gum (dHG) composite coating was suitable for prolonging the shelf life of fresh-cut carrots. The application of tapioca starch/dHG coating containing ascorbic acid and calcium chloride was also suggested for fresh-cut apples, as it could protect qualities in terms of color and firmness, and extended the shelf life up to 5–7 days by conferring preferable microbial quality (Pan et al. 2013). The application of biocomposite edible coating based on sodium alginate and pectin reduced the loss of firmness and microbial growth on blueberries (Mannozzi et al. 2017).

Proteins have the capability to develop extensive intermolecular hydrogen bonds with other biopolymers owing to the existence of a large number of polar (-OH and -NH) groups in their structure; electrostatic and hydrophobic bonds due to their random coil nature. Moreover, the moisture barrier, mechanical strength, O_2 and CO_2 barrier properties of protein based coatings can be improved by incorporating polysaccharide materials in their matrix (Siew et al. 1999).

Murmu and Mishra (2017) noted that an edible coating containing Arabic gum and sodium caseinate had a significant influence on changing the O_2, CO_2, and water vapor transmission rate of the coated guava in comparison with the uncoated control. Coating formulation with low concentration of Arabic gum (5 g/100 mL) was too thin to decelerate rate of respiration, ripening, senescence, and mold growth, while those with high concentration (12 g/100 mL) produced too thick coating leading to high rate of O_2 consumption, CO_2 evolution, mass loss, lower softening and overall acceptability of guava following 7 days of storage at 28 °C. It is thus crucial to optimize the solid content in the coating formulation so that coating may not have an unnecessary constraint of gas exchange through the skin, causing anaerobic and further development of off-flavors (Vargas et al. 2008).

Improved appearance and lower weight loss in Red Crimson grapes treated with starch-gelatin coating was observed after 21 days storage under refrigerated conditions. Sensory evaluation also presented that the coatings did not influence acceptability scores (Fakhouri et al. 2015). A composite chitosan–gelatin coating was applied to peppers and its effectiveness on fruit quality and storability was analyzed (Poverenov et al. 2014b). It was concluded that the composite coating decreased microbial decay, noticeably improved fruit texture and extended the possible cold storage period up to 21 days and fruit shelf-life up to 14 days, without changing the respiration or nutritional content of the fruit.

Fresh cut apples, potatoes and carrots were coated by a composite whey protein-pectin coating by addition of transglutaminase (Marquez et al. 2017). Coating not only prohibited microbial growth in all samples analyzed, but also preserved the phenolic content and carotenoid in carrots. Finally, an obvious reduction of hardness and chewiness loss was noticed after 10 days of storage in all the coated samples.

Lipid materials are also commonly examined in combination with polysaccharide- or protein-based coating materials to make composite coatings. Because lipid-based coatings alone can produce a greasy surface with adverse organoleptic characteristics such as a waxy taste and lipid rancidity of the coated produce (Olivas and Barbosa-Cánovas 2009). In addition, some waxes can result in a lower gas exchange of O_2 and CO_2 between atmosphere which causes the internal O_2 level reaching too low to provide aerobic respiration (Alleyne and Hagenmaier 2000). The subsequent anaerobic respiration results in the formation of ethanol, acetaldehyde which are responsive for many of the off-flavors in fruit (Dhall 2013; Porat et al. 2005). Furthermore, some lipid materials such as shellac, are unstable when exposed to variations of temperature, where a white waxy layer usually forms when transferring fruit from cold storage to the market (Lin and Zhao 2007). This is known as 'chalking' and is not acceptable in many markets.

Moreover, high water activity ($a_w > 0.94$) and high biochemical activity because of mechanical damages during peeling or slicing are two main features of minimally processed fruit and vegetables (Galus and Kadzińska 2015). The high solubility of hydrocolloid coatings at high water activity restricts their application due to disintegration and loss of their properties. Lipid based coatings can be a good substitute owing to their stability. Nonetheless, they can adversely affect the sensory characteristics of produce, for example, resulting in a waxy sensation. That confirms the need for more studies which aim to produce composite edible coatings preserving fruit and vegetables effectively and at the same time having no undesirable effect on product properties.

The application of lipid based coatings (carnauba wax emulsion coating formulated with poly ethylene glycol and sodium alginate) have been shown to reduce the loss of firmness, moisture, weight, lightness, TPC and antioxidants activity in eggplants packaged in 35 μ polypropylene pouches during ambient storage (Singh et al. 2016).

Pérez-Gallardo et al. (2015) investigated the effect of a starch-beeswax dispersion comprising 2% (w/v) modified tapioca starch added with either 0.5 or 1.0% (w/v) beeswax for spray coating on freshly harvested blackberries (*Rubus spp.*) during 16 days storage at 4 °C and 88% RH. The micrographs of fruit presented a smooth and continuous surface without cracks or pores and more surface area was protected by a thicker coating as the beeswax concentration enhanced. Both coatings caused a considerable increase in volatiles such as 1-octanol, and ethanol and aldehydes after 9 days, which have been associated with fermentative metabolism. The authors explained that this behavior was related to an enhanced ripening process generated by coatings, resulting in higher production of ethylene and CO_2 and accumulation of some volatiles in the intracellular tissue (Amarante and Banks 2010). Coating application reduced the anthocyanins and total phenols in blackberries due to the stress prompted by coatings and increased ethylene production, as well as accumulation of CO_2 destructing internal tissues and inducing oxidation of phenolic compounds by enzymatic reactions, including polyphenoloxidase and peroxidase (Duan et al. 2011).

It has been reported that incorporation of oleic acid and palm oil into MC-based coating improved shelf life of green chili (*Pusa jwala*) and Sapota (*Manilkara zapota* L. var. *Kalipatti*), respectively (Chaple et al. 2017; Vishwasrao and

Ananthanarayan 2017). The efficiency of edible composite coatings based on HPMC, beeswax, and various food preservatives with antifungal activities on preservation of cherry tomatoes during cold storage was also observed (Fagundes et al. 2013, 2014, 2015).

The use of quinoa protein-chitosan-sunflower oil coating presented a substantial lower amount of mold and yeast growth in coated strawberries and blueberries during storage (Abugoch et al. 2016; Valenzuela et al. 2015). Kowalczyk et al. (2017) demonstrated that the coating composed of CMC, candelilla wax (CnW) and potassium sorbate (KS) caused anaerobic respiration and the signs of superficial scald in pears after 9 days storage at 22 ± 1 °C, 50 ± 5% RH. It was explained that superficial scald was probably due to accumulation of CO_2 (up to a critical level) in the internal atmosphere of coated fruit (Lurie and Watkins 2012). High CO_2 level may trigger the creation of reactive oxygen species (Larrigaudière et al. 2004), which are greatly active and may extensively induce lipid peroxidation, leading to the more development of free radicals. However, the coating treatment retained green color of pears owing to decreasing chlorophyllase activity and creation of the modified atmosphere within the fruit tissues. (Guevara et al. 2001). It was also observed that uncoated fruit had common symptoms of contamination including softening, browning, or necrosis on the 2nd or the 3rd/4rd day of storage.

9.6 Layer–By–Layer Coatings

The layer-by-layer (LBL) electrostatic deposition technique as an approach to improve the functional and mechanical properties of coatings has extensive range of applications (Arnon et al. 2015). Breaks in the fruit skin and wax layers increase the movement of water from the fruit, initiating mass flow and quality reduction (Liu et al. 2017). Therefore, the LBL technique is a useful and simple approach to develop thin coating that prevents these surface breaks (Wang et al. 2011). LBL technique is based on the different deposition of oppositely charged polyelectrolytes (Arnon et al. 2015), which can be originated by many weak interactions, such as electrostatic interactions, hydrogen-bonds, coordination bonds, charge transfer interactions, and guest-host interactions (Jia and Li 2015). A LBL approach based on a combination of two polysaccharides, CMC as an internal layer and chitosan as an external layer, was applied on ‘Rishon’ and ‘Michal’ mandarins as shown in Fig. 9.1 (Arnon et al. 2015). It was found that the mandarins coated by LBL formulation were firmer than the fruits coated by commercial wax. Regarding weight loss, bi-layered coating was more effective than was the single coating and less efficient than the commercial wax. The bi-layered coating slowed down the ripening progress, as was detected by restriction of mandarin color change. There was not significant differences in CO_2 concentration in the internal atmosphere of mandarins coated by LBL coating and the ones coated by commercial wax. Whereas, the

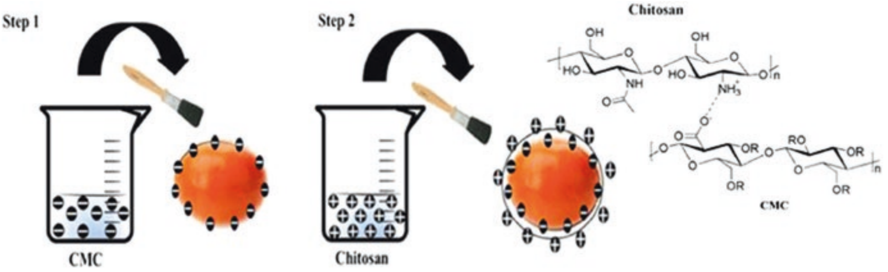

Fig. 9.1 Schematic presentation of the electrostatic deposition method used to form LBL edible coatings of mandarin fruit. (Reprinted from Arnon et al. (2015), Food Chem 166, 465–472. With permission)

ethanol concentration in the juice of LBL-coated fruit was considerably higher than the ethanol concentration in the juice of commercial wax-coated fruit. A similar observation of higher levels of ethanol causing increased perception of off-flavors upon application of the LBL method (pea starch-guar gum as an internal layer and shellac as an external layer) was determined in ‘Valencia’ oranges (Saberi et al. 2018).

Reyes-Avalos et al. (2016) treated figs (*Ficus carica*) with an alginate-chitosan bilayer edible coating and stored fruit at 6 °C. They showed that the application of the bilayer coating resulted in lower CO_2 production and weight loss and increased firmness and ethylene emission in figs. Moreover, coated figs had better retention of color as well as lower visual fungal infection than uncoated fruit during storage. A bilayer CMC-chitosan coating was also shown to inhibit weight loss, softening and slow surface browning of fresh-cut apples (Liu et al. 2017). A multilayer coating with the following elements: calcium chloride, chitosan with encapsulated trans-cinnamaldehyde, pectin, and calcium chloride, maintained the physicochemical and sensory quality of fresh-cut cantaloupe for 3–5 additional days than the uncoated control slices during storage at 4 °C (Martiñon et al. 2014).

The LBL formulations based on gelatin-chitosan for fresh cut melon, CMC-chitosan, alginate-chitosan for fresh cut mango, and cactus mucilage/pullulan/linseed/aloe mucilage-chitosan on fresh cut pineapple demonstrated improved quality during storage (Poverenov et al. 2014a; Arnon et al. 2014; Souza et al. 2015; Treviño-Garza et al. 2017). Sipahi et al. (2013) showed that the color, odor, and flavor attributes of fresh-cut watermelon coated with a multilayered antimicrobial coating containing sodium alginate, beta-cyclodextrin and microencapsulated transcinnamaldehyde (natural antimicrobial agent), pectin, and calcium lactate was acceptable to consumers after 13 days storage, whereas the control sample showed signs of decay. Three layer beeswax-chitosan-beeswax coating considerably reduced the senescence rate and weight loss of strawberries and resulted in better overall quality of the strawberries (Velickova et al. 2013), however the sensory evaluation showed that the three-layer coating had lower visual appearance and taste scores, and was less preferable by the consumer panel.

9.7 Combination of Biopolymer–Based Coatings with Other Physical Storage Technologies

Physical-based storage technologies (such as temperature, humidity, pressure and gas composition) are the primary techniques to maintain quality and shelf life of horticultural products (Krasaekoopt and Bhandari 2011). Cold storage, modified atmosphere packaging (MAP), and gamma irradiation are some physical-based methods to maintain quality and shelf-life of intact and fresh-cut fruit and vegetables (Ma et al. 2017). Various studies presented in Table 9.2 have shown that biopolymer-based coatings can act in synergy with physical-based preservation techniques to improve the physicochemical, nutritional and microbiological quality of fruit and vegetables during storage.

9.8 Conclusion

The proper combination of product and coating is essential for the establishment of correct storage conditions to optimize fruit and vegetable quality after storage. The results presented in this chapter focused on the potential applications of biopolymer-based edible coating and packaging for fresh and minimally processed fruit and vegetables and showed the different effects of biopolymer-based edible coatings on the physiological and quality of fruit and vegetables. Biopolymers have been shown to maintain fruit and vegetable quality in the laboratory but commercial development of application edible coatings on various fruit and vegetables is limited. Numerous factors including inadequate understanding and accessibility of suitable coating substances, poor moisture-barrier characteristics, weak surface adhesion of some coating components, possible allergenicity to coating materials, unpleasant sensory quality of some coating materials, and viability of scale-up to an industrial setting have been restricting the application of edible films and coatings for fruit and vegetables. New application in biopolymer research should highlight the production of tailor-made coatings, comprising the most compatible coating formulation ingredients and active compounds for intact and minimally processed fruit and vegetables, in relation to particular industrial requirements. It is critical to work with industry to ensure that its application is practical and cost-effective. To support this, there is also a need to investigate contribution of coatings on biochemical and secondary metabolites to manage the association of the internal atmosphere induced by the coating with the rate of physiological ripening processes.

Table 9.2 Several examples of combination biopolymer-based coatings with physical-based preservation techniques on fresh and fresh-cut fruit and vegetables

Fruit	Physical-based preservation	Coatings	Additives	Storage condition	Results	References
Broccoli	γ-Irradiation	Alginate	Lemongrass essential oil, sodium diacetate, natamycin	4 °C for 14 d	Active coating acted in synergy with γ-irradiation on broccoli floret to demolish pathogens by increasing the lag phase to 12 days and prolonging the shelf-life.	Ben-Fadhel et al. (2017)
Fresh-cut cantaloupe	Pulsed light	Pectin, alginate, chitosan, and gellan		4 °C for 28 d	Alginate and RPL treatment was the most efficient treatment condition to prolong the shelf-life of fresh-cut cantaloupes by preserving physicochemical, nutritional and microbiological quality up to 28 d with reducing fluid loss and enhancing firmness compared to samples treated with RPL alone.	Koh et al. (2017)
Plum	Gamma irradiation	CMC		25 °C for 20 d and 3 °C for 35 d	CMC at 1.0% w/v and 1.5 kGy irradiation was superior in retaining the chlorophyll and retarding the decay rate, resulting in retention of storage quality.	Hussain et al. (2015)
Wolfberry	Hot water dip	Chitosan		2 °C for 28 d	The synergistically treated fruit had higher ascorbic acid and total phenolic contents, antioxidant capacity and lower decay along with higher acceptability achieved by sensory analysis.	Ban et al. (2015)
Cauliflower florets	γ-radiation or negative air ionization (NAI) with ozone	MC + maltodextrin	Lactic acid, citrus extract, lemongrass essential oil	4 °C for 7 d	The bioactive coating performed in synergy with γ-radiation, leading to no bacterial growth of *L. innocua* and *E. coli*, in addition to the inhibition of the growth of mesophilic bacteria during 7 d.	Boumail et al. (2016)

(continued)

Table 9.2 (continued)

Fruit	Physical-based preservation	Coatings	Additives	Storage condition	Results	References
Fresh-cut mango	Pulsed light	Alginate	Malic acid	4 °C for 14 d	The combination contributed to preservation of the color and firmness of fruit and reduction of microbial population for 14 d.	Salinas-Roca et al. (2016)
Fresh-cut carrots	MAP	Cassava starch	Montmorillonite (MMT) nanoparticles	4 °C for 4 w	The combined application of coating and MAP led to the protection of the total antioxidant activity, the volatile and organic acids of fresh-cut carrots.	Guimarães et al. (2016)
Fresh-cut apple	Pulsed light	Pectin	Apple fiber	4 °C for 14 d	Coated and PL-treated fruit significantly presented higher antioxidant activity values than fresh and PL control samples. At the end of storage, the combination of both treatments caused microbial count reduction.	Moreira et al. (2017)
Fresh-cut eggplant	MAP	Soy protein isolate	Cysteine	5 °C for 8 d	MAP packaging conditions (low O_2 and high CO_2) were not suitable for storage of fresh-cut eggplants, because it caused damage of the tissue. The coating under air atmospheric conditions was the best and cheapest method for preserving fresh-cut eggplant	Ghidelli et al. (2014)
Green bean	High hydrostatic pressure (HHP) or pulsed light	Chitosan	Nanoemulsion of mandarin essential oil	4 °C for 14 d	The combination induced a significant reduction of *L. innocua* and firmness retention during storage, due to an antimicrobial synergism effect. However, the combination of the coating application with PL had a slight antagonistic impact, and had a slight unfavorable effect on color attributes	Donsì et al. (2015)

Fruit	Physical-based preservation	Coatings	Additives	Storage condition	Results	References
Fresh-cut persimmon	MAP	Pectin	Nisin, citric acid, and calcium chloride	5 °C for 9 d	The combined methods decreased the growth of mesophilic aerobic bacteria, browning index, and the CO_2 emission and O_2 consumption in the package	Sanchís et al. (2017)
Fresh-cut artichoke	MAP	Soy protein isolate (SPI) + beeswax	L-cysteine	5 °C for 7 d	The combination of the coating with MAP did not prolong the shelf-life of artichoke slices, but maintained the antioxidant capacity as compared with the control packaging conditions	Ghidelli et al. (2015)
Peach	γ -radiation	CMC		25 °C for 15 d and 3 °C for 35 d	Combination of CMC at 1.0% (w/v) and 1.2 kGy irradiation prohibited disease incidence of peach up to 7 days during ambient storage at 25 ± 2 °C, RH 70% following 30 d of refrigeration	Hussain et al. (2016b)
Cherry	γ -radiation	CMC		25 °C for 9 d and 3 °C for 28 d	Combinatory treatments demonstrated positive influence in preserving the storage quality as well as retarding the decay rate of cherry fruit	Hussain et al. (2016a)
Fresh-cut apple	Pulsed light	Gellan gum	Apple fiber	4 °C for 14 d	The combined application of coating and PL treatment delayed the microbiological contamination of fresh-cut apples and maintained the sensory attributes during storage	Moreira et al. (2015)
Green chili	MAP	Shellac		8 °C for 48 d	Coated and MA packed chilies showed 48 d shelf life compared with uncoated and MA packed (28 d), control (15 d) ones, and shellac coated chilies (30 d)	Chitravathi et al. (2016)

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