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REVIEW ARTICLE / ÜBERSICHTSBEITRAG

Usage Possibilities of Edible Coating and Films for Storage of Fruits

Osman Nuri Ocalan[1] · Kenan Yildiz[1] · Onur Saracoglu[1]

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Abstract

There are considerable amounts of losses in quality and quantity of products in the period from farm to the fork. Factors such as water loss, browning, and rotting occurring during storage cause post-harvest loss in quality criteria such as nutritional content, taste, and appearance of fruits and vegetables. As a result, the consumer suffers from quality losses, and the producer suffers from reduced commercial value. Some effective techniques such as low temperature storage, controlled atmosphere, irradiation, and coating are used to extend the post-harvest life of fresh fruits and vegetables. In recent years, due to consumer concerns about the use of synthetic chemicals and legal restrictions, research has been focused on using natural compounds to maintain the quality of these fresh products during storage. Many studies have shown that edible coating materials can be used as an effective technique in reducing post-harvest quality losses of fresh fruits and vegetables. In addition, the fact that these materials are environmentally friendly and reliable in terms of health increases the interest of consumers.

Keywords Food safety · Lipid · Storage · Polysaccharide · Protein

Introduction

The methods used in the preservation of food continue to develop from ancient times to the present day. The preservation of food quality is important for our health to ensure the consumption of food with high nutritional values (Sabir et al. 2021). Today, there are many preservation methods, traditional or modern such as low temperature, modified atmosphere packaging, irradiation, and coating, used to preserve the quality of foods for a long time and to prevent their spoilage. Most fruits and vegetables will become senescence and inedible in a short time if they are not properly preserved (James 2003). The quality and quantity losses occurred from the farm to the fork decrease the level of economic benefit of fruit and vegetable greatly. After harvest, a change begins in the gas balance between oxygen consumption and carbon dioxide production of fruit. In this new case, the cells cannot be renewed and their gas transfer rate increases, causing a metabolic loss and leading the fruit to a gradual maturation and ultimate senescence. Gas transfer rate depends on internal and external factors. While internal factors include parameters such as species, variety, and growth status; external factors include stress factors such as atmospheric composition (O_2, CO_2 and ethylene ratios) and temperature (Dhall 2013; Kluge et al. 2002). Water loss, browning, rotting, and other reasons that occur in the post-harvest period cause deterioration in quality criteria such as nutritional content, flavor, and appearance of fruit. As a result of this, as the commercial value of the product decreases, the income of the producer decreases accordingly. In recent years, due to consumer concerns about the use of chemicals and legal restrictions, researches are focused on natural compounds to maintain the quality of fruit during storage (Silva-Weiss et al. 2013; Eça et al. 2014; García-Pastor et al. 2020). Among these preventions, edible coating materials are one of the promising methods that can prevent the loss of aroma and moisture. These materials prevent both senescence and the development of microorganisms by limiting the oxygen input to the plant tissue, and at the same time, are suitable for food safety (Jianglian and Shaoying 2013). Edible coatings or edible films have been used in the food industry for centuries to preserve food products. So, this is a well-known conservation technique from time immemorial. For example, waxing on fruits and vegetables and the cellulose coatings in the preservation of meats have long been used. Although edible coatings have

✉ Onur Saracoglu
onur.saracoglu@gop.edu.tr

[1] Faculty of Agriculture, Department of Horticulture, Tokat Gaziosmanpaşa University, 60240 Tokat, Turkey

been used in China since the 12th century; it was first evaluated commercially in 1922 (Raghav et al. 2012). Edible coatings, consisting of proteins, polysaccharides, lipids or mixtures thereof, form a barrier against physical, chemical or biological changes in the food they are applied to and are most preferred because they are biodegradable (Galus and Kadzińska 2015). Combining lipids, polysaccharides and proteins used in the coating materials improve their barrier properties (Raghav et al. 2012). In this review, the results of some studies on the effects of edible coatings applied pre- or post-harvest on the quality criteria of fruits are summarized.

Polysaccharide-Containing Coatings

Polysaccharides impart brittleness, hardness, compactness, thickness, stickiness, and viscosity to a variety of edible coatings. Polysaccharides consist of polymer chains with excellent gas barrier properties and are soluble in water. They provide the desired modified atmosphere with low oxygen permeability without creating anaerobic conditions. Thus, they can extend the shelf life of fruits and vegetables by reducing respiratory rate (Raghav et al. 2012; Cazón et al. 2017). Polysaccharide films consist of substances such as starch (obtained from potato, corn, wheat, rice, and other derivatives), cellulose (obtained from cotton, wood, and other derivatives), gums (obtained from guar, locust bean, alginates, carrageenan, pectins, and other derivatives) or chitin/chitosan (Dursun and Erkan 2009).

Starches are tasteless and odorless carbohydrates mostly derived from potatoes and grains. They are used for the preservation of post-harvest fruits and vegetables. It has been stated that the coating materials containing corn starch preserved the physicochemical and organoleptic properties of brussels sprouts (Viña et al. 2007) and guava (Oliveira et al. 2018), controlled phytochemicals especially in brussels sprouts. It has been determined that rice starch and carrageenan (red seaweed extract) films allowed proper preservation of plum fruit by maintaining its quality properties (Thakur et al. 2018), and that cassava starch minimized weight loss of fresh-cut apples (Chiumarelli and Hubinger 2012) and guava (Oliveira et al. 2018).

Cellulose found in the cell structure of plants is included in coating materials in the forms of carboxymethyl cellulose, hydroxypropyl cellulose, and methylcellulose. By using of cellulose-reinforced coating materials, fruit quality characteristics such as loss of firmness and weight in apricot, green peppers (Ayranci and Tunc 2004), grape (Yinzhe and Shaoying 2013) and pear (Dave et al. 2017) were preserved and microbial rotting in orange (Potjewijd et al. 1995), baked apples (Tavera-Quiroz et al. 2015), grape (Marín et al. 2016), and avocado (Tesfay et al. 2017) were controlled.

Gums are a preferred type of polysaccharide for the preparation of edible coatings because of their strong texture and water solubility. The gum arabic improved the quality properties of strawberry fruit such as phytochemical contents and firmness (Tahir et al. 2018), also guar gum coating material controlled microbial activity in strawberries (Oregel-Zamudio et al. 2017), reduced the respiration rate and the weight loss of the mango fruits (Ebrahimi and Rastegar 2020), and preserved fruit quality by increasing tissue tightness in mushrooms (Huang et al. 2019). It has been stated that coating materials containing locust bean gum delayed microbial decay in orange (Aloui et al. 2015) and mandarins (Parafati et al. 2016).

Alginate is a polysaccharide obtained from brown seaweed and contains alginic acid salts. Available in white, yellow color and fibrous powder form, alginate is commonly used in the form of sodium alginate. It is preferred in the production of coating materials due to its colloidal properties such as intensification, suspending, gel-forming, and stabilizing emulsion and strong moisture barrier properties. Alginates can maintain the quality of the foods they are applied to (Raghav et al. 2012; Cazón et al. 2017). Alginate containing films has been determined that play an effective role in protecting the quality criteria of fruits such as weight loss and color change and struggle microbial activity by slowing down their metabolic activities and inhibiting oxidative enzymes in apricot (Morsy and Rayan 2019), freshly cut apple, papaya (Tapia et al. 2007), strawberry (Fan et al. 2009; Moayednia et al. 2009), freshly cut melon (Raybaudi-Massilia et al. 2008), orange (Aloui et al. 2015), and carrot (Shigematsu et al. 2018).

Pectin is a polysaccharide found naturally in the plant. It has been used in the preparation of coating materials in post-harvest storage. Pectin-based films have good gas permeability properties, but poor water barrier properties although these films have been used to retard moisture loss and migration of lipids (Cazón et al. 2017). It has been stated that avocado (Maftoonazad et al. 2007), peach (Ayala-Zavala et al. 2013), and jujube (Padmaja and Bosco 2014) fruits coated with pectin-containing materials have increased their resistance to microbial-induced physical and physiological changes after harvest, and especially peach preserved its unique odor.

Another polysaccharide used to maintain the post-harvest quality of fruits and vegetables is pullulan. Pullulan-added coating materials have been shown to control microbial rotting of blueberry fruits, to preserve fruit quality (Kraśniewska et al. 2017) and to extend the storage life of kiwi fruits three times compared to control (Xu et al. 2001).

Although polysaccharides are generally used for coating material for post-harvest treatments, chitosan is a preferred

Table 1 Positive effects of polysaccharide-containing coating studies applied to some fruit and vegetable varieties

Substance/agent	Application time	Maintaining quality	Species	Resources
Chitosan	Pre-harvest	Microbial rot Weight loss Overall quality	Table grape	Nia et al. (2021)
Nanostructured chitosan	Post-harvest	Microbial rot Phytochemical	Bell peppers	Hernández-López et al. (2020)
Nano-chitosan	Post-harvest	Microbial rot Overall quality	Strawberry	Nguyen et al. (2020)
Nano-chitosan/chitosan	Post-harvest	Microbial rot Overall quality	Strawberry	Nguyen and Nguyen (2020)
Chitosan	Pre-harvest	Microbial rot Phytochemical Overall quality	Table grape	Ahmed et al. (2020)
Chitosan	Post-harvest	Microbial rot Overall quality	Mango	De Oliveira et al. (2019)
Submicron chitosan dispersions	Pre-harvest	Microbial rot	Jujube	Guo et al. (2017)
Chitosan	Pre-harvest	Microbial rot Overall quality Phytochemical	Table grape	Shen and Yang (2017)
Chitosan	Pre-harvest	Microbial rot Overall quality	Strawberry	Landi et al. (2017)
Chitosan	Pre-harvest	Microbial rot Firmness Overall quality	Peach	Gayed et al. (2017)
Chitosan	Post-harvest	Microbial rot Phytochemical	Cherry	Koçak and Erdinç (2017)
Chitosan	Pre-harvest	Microbial rot Phytochemical	Strawberry	Saavedra et al. (2016)
Chitosan	Post-harvest	Microbial rot Overall quality	Strawberry	Vargas et al. (2006)
Chitosan	Post-harvest	Microbial rot	Tomato	Sharma et al. (2006)
Sodium alginate	Post-harvest	Color change Weight loss	Carrot	Shigematsu et al. (2018)
Sodium alginate	Post-harvest	Microbial rot Overall quality	Strawberry	Moayednia et al. (2009)
Sodium alginate	Post-harvest	Color change Weight loss	Strawberry	Fan et al. (2009)
Alginate	Post-harvest	Overall quality	Apricot	Morsy and Rayan (2019)
Alginate	Post-harvest	Microbial rot Overall quality Phytochemical	Fresh cut melon	Raybaudi-Massilia et al. (2008)
Alginate	Post-harvest	Microbial rot Color change Weight loss	Fresh cut apple and papaya	Tapia et al. (2007)
Carboxylmethyl cellulose	Post-harvest	Microbial rot Overall quality	Avocado	Tesfay et al. (2017)
Carboxymethyl cellulose	Post-harvest	Overall quality	Grape	Yinzhe and Shaoying (2013)
Carboxymethyl cellulose, hydroxypropyl cellulose, methyl cellulose	Post-harvest	Microbial rot	Orange	Potjewijd et al. (1995)
Hydroxypropylmethyl cellulose	Post-harvest	Microbial rot	Grape	Marín et al. (2016)
Methyl cellulose	Post-harvest	Microbial rot	Baked green apple	Tavera-Quiroz et al. (2015)
Methyl cellulose	Post-harvest	Weight loss	Apricot, green pepper	Ayranci and Tunc (2004)

Table 1 (Continued)

Substance/agent	Application time	Maintaining quality	Species	Resources
Pullulan	Post-harvest	Overall quality Microbial rot	Blueberry	Kraśniewska et al. (2017)
Corn starch, cassava starch	Post-harvest	Weight loss Physicochemical Organoleptic properties	Guava	Oliveira et al. (2018)
Rice starch/carrageenan	Post-harvest	Overall quality	Plum	Thakur et al. (2018)
Corn starch	Post-harvest	Overall quality Phytochemical	Brussels sprouts	Viña et al. (2007)
Pectin	Post-harvest	Microbial rot Antioksidan Odor acceptability	Fresh cut peach	Ayala-Zavala et al. (2013)
Guar gum	Post-harvest	Respiration rate Weight loss Ascorbic acid	Mango	Ebrahimi and Rastegar (2020)
Guar gum	Post-harvest	Firmness Overall quality	Mushroom	Huang et al. (2019)
Gum arabic	Post-harvest	Phytochemical firmness	Strawberry	Tahir et al. (2018)
Locust bean gum	Post-harvest	Microbial rot	Mandarin	Parafati et al. (2016)
Locust bean gum	Post-harvest	Microbial rot	Orange	Aloui et al. (2015)
Aloe vera gel	Post-harvest	Phytochemical Weight loss Browning	Lychee fruit	Ali et al. (2019)
Aloe vera gel	Post-harvest	Fruit ripening Color change Firmness Microbial rot	Strawberry	Nasrin et al. (2017)
Aloe vera gel	Post-harvest	Overall quality	Jujube	Padmaja and Bosco (2014)
Aloe vera gel	Post-harvest	Overall quality Fruit ripening	Tomato	Athmaselvi et al. (2013)
Aloe vera gel	Post-harvest	Microbial rot Overall quality	Apple	Ergun and Satici (2012)

polysaccharide for both post-harvest and pre-harvest applications. Chitosan is found in the shells of arthropods (crab, shrimp, lobster, etc.) and the cell walls of some bacteria and fungi. It is a polymer formed by deacetylation of chitin in an alkaline solution and the most common polymer in nature after cellulose (Dursun and Erkan 2009). Chitosan is nontoxic, biodegradable, biofunctional, and biocompatible. It has strong antimicrobial and antifungal activities that can effectively control of fruit rotting (Jianglian and Shaoying 2013). In studies on effects of chitosan-containing coating materials on change in fruit quality after harvest, it has been emphasized that microbial rotting was reduced and delayed in strawberries (Bal and Ürün 2021; Vargas et al. 2006), cherry (Koçak and Erdinç 2017), mango (de Oliveira et al. 2019), tomato (Sharma et al. 2006), and bell peppers (Hernández-López et al. 2020). Besides, it has been stated that use of the nano-chitosan with $CaCl_2$ (Nguyen et al. 2020), and nano-chitosan with chitosan (Nguyen and Nguyen 2020) controlled the microbial activity and maintained the quality of strawberries during the storage period. Similarly, microbial rotting was delayed in strawberry (Saavedra et al. 2016; Landi et al. 2017), peach (Gayed et al. 2017), table grape (Shen and Yang 2017; Ahmed et al. 2020; Nia et al. 2021), and jujube (Guo et al. 2017) and the quality criteria of fruits maintained when they were sprayed with chitosan.

Aloe vera gel obtained from the leaf extract of the semi-tropical *Aloe vera* plant is used in edible coatings on a large scale to increase the shelf life of fruits and vegetables (Raghav et al. 2016). *Aloe vera* gel applied after harvesting delayed fruit ripening, color change, fruit softening and decreased microbial rot in strawberry (Nasrin et al. 2017), delayed weight loss and tissue browning, and maintained phytochemical content in lychee fruit (Ali et al. 2019), delayed microbial decay and maintained fruit quality characteristics in apple (Ergun and Satici 2012), minimized quality losses in jujube (Padmaja and Bosco 2014) and tomato (Athmaselvi et al. 2013) and retarded fruit ripening in tomato. The

positive effects of polysaccharide-containing coating studies applied to some fruit and vegetables are compiled in Table 1.

Protein-Containing Coatings

Protein-containing films used in the preservation of fruits and vegetables are generally superior to polysaccharide-containing films in terms of their mechanical and barrier properties. Also, these films greatly increase the nutritional value of the food that they are coated on. They are divided into two groups as animal origin proteins (casein, whey protein, collagen, gelatin, etc.) and plant origin proteins (corn zein, wheat gluten, soy protein, etc.) (Dursun and Erkan 2009). In general, the use of protein-containing films may be limited due to ethical or religious beliefs as well as allergic risks, besides, protein-based edible coatings are reported to be fragile and susceptible to cracking (Lin and Zhao 2007; Riva et al. 2020).

Among the proteins of animal origin, casein and whey are milk-derived proteins. They contain hydrophilic and hydrophobic ends, which gives them amphipathic properties (Raghav et al. 2012). They play an active role in the preservation of fruits and vegetables by participating in edible films. Casein reinforced films were tested on apple, celery sticks (Avena-Bustillos et al. 1997), grapes (Marín et al. 2016), pumpkin (Avena-Bustillos et al. 1994b), and carrots (Avena-Bustillos et al. 1994a; Jagannath et al. 2006), and positive results have been obtained in terms of maintaining quality. It was observed that the quality of fruits could be maintained during the storage period of kiwi (Hassani et al. 2012) and apple (Bai et al. 2003), and browning in freshly cut apples was decreased when the fruit was coated with whey protein-added films (Perez-Gago et al. 2006).

Gelatin is obtained from collagen, a product of the skin and connective tissues of animals (Dursun and Erkan 2009). Gelatin helps to maintain the market quality values of fruits. Gelatin-containing solutions have been reported to control the sensory properties, weight loss, and physicochemical properties of guava fruit (Oliveira et al. 2018), and to minimize firmness loss, weight loss, phytochemical loss, and rotting in palm fruit (El-Gioushy and Baiea 2020). Protein-containing coating studies applied to some fruit and vegetables are given in Table 2.

Table 2 Positive effects of protein-containing coating studies applied to some fruit and vegetable varieties

Substance/agent	Application time	Maintaining quality	Species	Resources
Soy protein isolate	Post-harvest	Firmness Weight loss Shelf life	Pear	Dave et al. (2017)
Soy protein isolate	Post-harvest	Overall quality	Kiwi	Xu et al. (2001)
Pea protein	Post-harvest	Polyphenol Firmness Brightness	Brussels sprouts	Kowalczyk (2011)
Pea protein	Post-harvest	Overall quality Firmness Color change	Broccoli	Kowalczyk et al. (2010)
Whey protein concentrate/Rice bran oil	Post-harvest	Overall quality Color change	Kiwi	Hassani et al. (2012)
Putrescine	Post-harvest	Overall quality Phytochemical	Plum	Dursun (2019)
Putrescine	Pre-harvest	Overall quality	Cherry	Koyuncu et al. (2018)
Putrescine	Pre-harvest	Overall quality	Pear	Hosseini et al. (2017)
Polyamines Putrescine (Put), spermidine (Spd)	Pre-harvest	Microbial rot Phytochemical Firmness	Table grape	Mirdehghan and Rahimi (2016)
Gelatin	Post-harvest	Microbial rot Weight loss Phytochemical	Palm	El-Gioushy and Baiea (2020)
Casein	Post-harvest	Microbial rot Overall quality	Carrot	Jagannath et al. (2006)
Calcium or sodium caseinate	Post-harvest	Overall quality	Apple, celery sticks	Avena-Bustillos et al. (1997)
Calcium caseinate	Post-harvest	Weight loss	Pumpkin	Avena-Bustillos et al. (1994b)

Soy protein films delayed softening and weight loss in the pears and increased the shelf life of the fruit (Dave et al. 2017). Likewise, films with pea protein, have contributed positively to the quality of grape (Kowalczyk and Pikula 2010), broccoli (Kowalczyk et al. 2010), and brussels sprout (Kowalczyk 2011) and during their storage period. Putrescine, which is formed because of the breakdown of proteins, is used in storage studies. Putrescine applied to pear (Hosseini et al. 2017) and cherry fruits (Koyuncu et al. 2018) before harvest have contributed positively to the cold storage and maintenance of quality criteria of fruits after harvest. By post-harvest putrescine application to plum (Dursun 2019) and table grapes (Mirdehghan and Rahimi 2016), the biochemical contents of the fruits were ensured to be properly preserved, and the anti-microbial effect of putrescine has been observed in table grapes.

Lipid-Containing Coatings

Due to their hydrophobic nature, lipids have strong moisture barrier properties that are important in preventing physiological spoilage of food products. However, their mechanical properties and adhesion to food products with hydrophilic surfaces are poor (Lin and Zhao 2007; Arnon-Rips and Poverenov 2018). Lipids give brightness and showiness to the food they are applied to. The most common lipid-based coating materials are carnauba wax, beeswax, paraffin wax, and mineral or vegetable oils (Lin and Zhao 2007; Raghav et al. 2012).

It has been reported that carnauba wax delayed moisture loss in freshly cut apples (Chiumarelli and Hubinger 2012). Beeswax coating contributed to maintenance of fruit quality characteristics of strawberry (Velickova et al. 2013), avocado (Maftoonazad et al. 2007), mandarin (Navarro-Tarazaga et al. 2008a), plum (Navarro-Tarazaga et al. 2008b), cherry tomato (Fagundes et al. 2014), and carrot (Avena-Bustillos et al. 1994a) and showed anti-microbial effects in other species than plum and mandarin. Coating materials with Candelilla wax achieved shine to brussels sprouts (Kowalczyk 2011), grape (Kowalczyk and Pikula 2010), guava (Tomás et al. 2005), and sweet lemon (Bosquez-Molina et al. 2003) and preserved their quality. Lipid-containing coating studies applied to some fruit and vegetables are gathered in Table 3.

Table 3 Positive effects of lipid-containing coating studies applied to some fruit and vegetable varieties

Substance/agent	Application time	Maintaining quality	Species	Resources
Candelilla wax	Post-harvest	Microbial rot Overall quality	Strawberry	Oregel-Zamudio et al. (2017)
Beeswax	Post-harvest	Microbial rot Overall quality	Cherry tomato	Fagundes et al. (2014)
Beeswax	Post-harvest	Microbial rot Overall quality Color change	Strawberry	Velickova et al. (2013)
Beeswax	Post-harvest	Overall quality Firmness	Mandarin	Navarro-Tarazaga et al. (2008a)
Beeswax	Post-harvest	Overall quality Firmness	Plum	Navarro-Tarazaga et al. (2008b)
Beeswax	Post-harvest	Microbial rot Color change Firmness	Avocado	Maftoonazad et al. (2007)
Beeswax	Post-harvest	Browning	Fresh cut apple	Perez-Gago et al. (2006)
Beeswax	Post-harvest	Overall quality White blush	Carrot	Avena-Bustillos et al. (1994a)
Carnauba wax	Post-harvest	Weight loss	Fresh cut apple	Chiumarelli and Hubinger (2012)
Shellac	Post-harvest	Brightness	Apple	Bai et al. (2003)
Candelilla wax	Post-harvest	Overall quality Brightness	Grape	Kowalczyk and Pikula (2010)
Candelilla wax	Post-harvest	Overall quality Color change Firmness Brightness	Guava	Tomás et al. (2005)
Candelilla wax	Post-harvest	Color change Brightness Weight loss	Sweet lemon	Bosquez-Molina et al. (2003)

Conclusion

Post-harvest losses in fresh fruits and vegetables are a serious problem faced by many countries, especially those whose economies depend on agriculture. These losses become even more important in our world where access to healthy food is becoming increasingly difficult for many people. It is understood from the literature information summarized above that edible coating applications can be used as an effective method to reduce these losses. It is seen that such cover applications are effective in slowing down the post-harvest ripening process and reducing quality losses, as well as improving the phenolic content of fruits and vegetables and delaying microbial decay. In addition, being environmentally friendly and health-safe makes these coating materials more acceptable to consumers. In addition to studies to develop new coating materials on this subject, the results to be obtained from research to find the most suitable coating material for each product will make an important contribution to reducing post-harvest losses.

Declarations

Conflict of interest O.N. Ocalan, K. Yildiz, and O. Saracoglu declare that they have no competing interests.

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