Edible Films and Coatings for Fruits and Vegetables: Composition, Functions, and Regulatory Aspects

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Abstract

Edible coatings and film are sustainable and environment friendly solutions and possess the potential to replace the convention packaging material. In the past two decades, a lot of advancement has been made in edible food packaging material. Many researchers are working on improving the physicochemical properties of edible packaging material. Various biochemical reactions and uncertain environment conditions are the major cause of the postharvest losses of horticulture commodities. Edible film (EF) and edible coating (EC) can provide a tool for preventing postharvest losses of fruits and vegetables. Horticulture commodities greatly vary in their composition and requirements for their postharvest preservation; therefore, product-specific EF or EC is required for preservation and preventing losses. These can be incorporated with bio-actives and other ingredients, for example, antimicrobials, flavoring compounds, pigments, nutrients, etc. The resulting film/coating not only acts as an effective barrier but also enhances its functions. Edible packaging materials are effective in

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controlling growth of microbes, biochemical changes, preserving texture, and sensory attributes of the fruits and vegetables, which ultimately results in enhanced shelf-life and better acceptability by consumers. This review article discusses various types of edible films and coating for fruits & vegetables, their composition, functions, properties, and effects as well.

Keywords

Edible film · Edible coating · Fruit and vegetables · Packaging material · Shelf-life · Active ingredients

10.1 Introduction

India is one of the countries whose economy is dependent on agriculture. According to the report published by the National Horticulture Board (NHB 2017) of India, of the total horticulture produce, 90% is accounted for fruits and vegetables. In total world's fruits and vegetable production, India holds a second position and a leader in the production of several horticulture crops. The production of horticulture crops has been significantly increased from 1991–1992 to 2016–2017 and mainly fruits and vegetable production increased from 2874 to 6480 MT and 5593–10,290 MT, respectively. This enormous increase in the production also resulted in an increase in post-harvest losses of horticulture crops (NHB 2017). These are highly perishable commodities; all fruits and vegetables contain 65–95% water. The transpiration and respiration rate affect the quality of the commodity. The high rate of water loss and use up of stored food accelerates the decay process and the produce becomes inedible. The main cause of physiological deteriorations is respiration, transpiration, ripening, physical damage, diseases, and pests. Also, the external conditions such as temperature and relative humidity affect the freshness of fruits and vegetables (FAO 1985; Baldwin 1994; Oms-Oliu et al. 2008b). Due to these reasons, a lot of care is required after harvesting, transportation, and storage, otherwise produce becomes unfit for consumption. Methods are required for a reduction in wastage for economical purposes also. There are several methods available to minimize the loss in quality. To increase the safety and to minimize wastage of horticulture produce, various processing operations and techniques such as drying, canning, packaging, blanching, and other value addition methods are generally exercised. These processing methods more or less result in the loss of vitamin C and other heat-labile bioactives. The enrobing of polymeric material, for example, starch, proteins, oils/fats, and herbal extracts, on fruits and vegetables surface also enhances shelf-life by maintaining the organoleptic attributes. These films and coatings are treated as packaging material that can be consumed along and easily biodegradable if not consumed. It also provides preservation like an encapsulation of antioxidants, antimicrobials, flavoring compounds, etc. (Seydim and Sarikus 2006). If the edible films and coatings are applied in multilayer, this can constrain the metabolic reactions by providing a gas barrier, degradation of nutritional content such as vitamin A, C, etc. (Brasil et al. 2012). The edible packaging materials have many advantages, but it cannot be considered as an ideal packaging material due to some limitations such as fruits and vegetables coated with edible packaging material requires over coating of other packaging material for handling and hygienic purpose (Debeaufort et al. 1998). This paper is focused upon the need for edible packaging material, components, limitations, and regulatory issues related to edible films and coatings.

10.2 Edible Films and Coatings

Edible packaging material can be defined as “a film, sheet, thin layer or coating which is an integral part of a food and is eaten with it is termed as edible coating” (Debeaufort et al. 1998). In other words, the edible packaging material is that which is made of edible material formed into thin sheets, which is consumed, provides a barrier to transfer phenomena (Du et al. 2011; Bourtoom 2008). Edible films and coatings terms are often used synonymously but there exists a difference between them. Edible film is independent, performing thin structures which are then wrapped on the surface of fruits and vegetables may or may not be removable. On the other hand, edible coating is packaging material that is formed directly on the surface and consumed along (Debeaufort et al. 1998). Edible film is formed by spreading the film-forming solution which is followed by drying and removal of solvent by adopting the process of extrusion, co-extrusion, lamination which is only for multi-layer coatings whereas edible coating methods involve spray fluidization, falling, pan coating, spraying, dipping, brushing, etc. (Debeaufort et al. 1998; Kester and Fennema 1986; Cuq et al. 1995; Falguera et al. 2011). For the structural matrix of edible films and coatings, polymers like polysaccharides, proteins, lipids, and composites are preferred (Falguera et al. 2011; Bourtoom 2008; Cuq et al. 1995; Gennadios et al. 1993). Plasticizers are also added to improve the properties of film formation. Edible films and coatings can be obtained via two processes such as wet or dry methods (Guilbert et al. 1997). In a dry process, the polymeric material is being heated above their melting points which make material to start flow by the process of molten casting, extrusion, heat processing (Gennadios et al. 1993). It does not involve the use of solvent but requires the knowledge of thermoplastic properties of material for film formation. Wet film formation involves the dispersion of film-forming solution in solvent which is sprayed, spread, or dipped followed by drying for removal of solvent (Cuq et al. 1995; Kester and Fennema 1986). The solvent for film formation should be food grades like water, ethanol, biodegradables, etc. For homogenous film structure, various factors are responsible such as pH, temperature, relative humidity, drying conditions, solvent used, solubility of solvent concentration, matrix, thermo-plasticity of polymer such as phase transition temperature, glass transition, gelatinization temperature, hydrophilic properties such as surface tension, viscosity, solid surface energy (Cuq et al. 1995; Guilbert et al. 1997; Kester and Fennema 1986). The chemistry of film formation is not yet well explained. Film-forming solution gelatinizes to form a rigid structure as a result of solvent removal

Table 10.1 Functions of edible film and coatings

Selective properties	Active properties
• Barrier to gases (oxygen, carbon dioxide, and nitrogen) • Light (UV) • Organic vapors (aroma compounds and solvents) • Water vapor • Solutes (salts, lipids, additives, pigments)	• Encapsulation or carriage of flavorings, antimicrobials, antioxidants, pigments, and other additives • Enhancement of mechanical and optical properties • Individual protection of small pieces of food (Separation of food by individual portion, soluble package for pre-dosed food ingredients or additives)

Source: Debeaufort et al. (1998)

supported by interactions like covalent, electrostatic, and ionic form (Gennadios et al. 1993). There is a phase transition from the polymer in water or solvent to water in polymer (Kester and Fennema 1986). Edible films and coatings provide elective and active properties which are summarized in Table 10.1.

10.3 Development of Edible Film and Coatings

The terminology of edible films and coatings may be new but the concept is not new. These have been used for so long without having the knowledge of its chemistry. Even edible films were used to write instructions that if they get caught, can be easily destroyed by eating. In Japan, the first-ever commercial edible film named “Yuba” made with the skin of boiled soy milk was used since the fifteenth century (Gennadios et al. 1993). Edible films and coatings were used for fruits and vegetables since ages to protect them from the moisture loss. The first use of fruits and vegetables was seen in China in the twelfth century for citrus fruits (Guilbert et al. 1997). Citrus fruits were kept inside the boxes and wax was poured on that (Hardenburg 1967; Embuscado and Huber 2009). Later on, wax coatings were used to add shine and prevent moisture loss from the surface (Baldwin 1994). Even since the 1930s, wax emulsion and oil in water were also coated on the surfaces of fruits and vegetables to improve appearance and preservation (Debeaufort et al. 1998). In Europe, larding was used to preserve fruits and vegetables (Embuscado and Huber 2009).

Edible films and coatings were used for various foods other than fruits and vegetables since ages but an edible coating finds more of an application than edible films. To prevent the shrinkages in meat and cheese larding (animal fat), coatings were used (Kester and Fennema 1986; Debeaufort et al. 1998). Candies coated with zein (corn protein), nuts coated with sugar were most common (Krochta and Mulder-Johnston 1997). Cellulose coatings are used in the bakery, confectionary, and meat industry. Meat was coated with the edible film made with gelatin (Embuscado and Huber 2009). Other than the food industry, edible films and coatings find application in the pharmaceutical industry also such as sugar and gelatin coatings on pills and soft capsules, respectively (Gennadios et al. 1993; Krochta and Mulder-Johnston

1997). Sausage casings are made of collagen. Edible films and coatings are gaining importance day by day and find its excellent potential in food processing.

10.4 Need for Edible Packaging Material for Fruits and Vegetables

There are enormous numbers of reasons which trigger the use of edible packaging material. The primary reason is that packaging material that is being used to date are petroleum-, metal-, or paper-based manufactured using nonrenewable sources. These take thousands of years to decompose resulting in an increase of non-biodegradable waste. According to a report prepared on plastic industry by FICCI (2014), out of the total plastic generation, 43% is used /consumed for manufacturing of packaging material for food materials which makes a significant part of the total. In the food processing industry, the consumption of plastic as packaging material is in different forms. For instance, 33% is used in polyethylene form, 29% as polypropylene (FICCI 2014). This industry is expected to grow at higher rates due to increased income of consumers, change in their eating habits, and inclination toward the consumption of the packaged product. An alternative to this plastic waste generation is recycling, but it is also a high cost and energy demanding process which includes cost of transportation and disposal. According to a report by USEPA (2015), the use of edible packaging material can result in the following:

- Reduce cost of waste disposal.
- Save money of recycling.
- Reduce environmental impacts.
- Reduce health-related issues.

For fruits and vegetables, there are various reasons as they undergo several changes post-harvest. The primary reason is the physiological changes. After the harvesting of fruits and vegetables, physiological processes continue to occur but in a different manner. Once produce is harvested, fruits and vegetables have no source to obtain nutrients so draw nutrients from reserves. These results in the aging process and slowly fruits and vegetables decay, that is, become unacceptable for consumption (FAO 1985). The two major physiological processes are respiration and transpiration (water loss) (Baldwin 1994). These changes also cause a decrease in nutrition content of these commodities such as dry matter content as reserves are used continuously and vitamin C content also decreases with time.

During respiration, the plant takes up the oxygen and releases carbon dioxide. It is one of the necessary reactions in plants, in which oxygen breaks down the carbohydrates into carbon dioxide, water, and energy, that is, heat which is in a continuous process in the plant, but after harvesting continues on the account of the reserves. Once this reserve ends, fruits and vegetables die (Baldwin 1994; FAO 1985). Air movement while storing the product is necessary to remove heat from respiration. When the produce is kept in poor ventilation, carbon dioxide accumulation leads to quick deterioration in the quality (FAO 1985).

Before harvesting, the plant continues to replace water that is lost through transpiration to take water from the soil, but once produce is harvested, there is continuous loss of water. Fruits and vegetables shrink, and loss of weight occurs. The crucial factor that affects the rate of water loss is the ratio of surface area to the volume of produce. The type of produce is another important factor that affects the rate at which water is lost, for example, the presence of waxy skin with large number of pores in green leafy vegetables is the main cause of rapid loss of water. In contrast, the rate of water loss is gradual in potatoes because of thick corky skin with less pores (FAO 1985; Baldwin 1994).

Fruits and vegetables are basically of two kinds. One is climacteric which ripens after being detached from the parent plant and other are non-climacteric which ripens only when attached to the parent plant. Fruits and vegetables continue to ripen after harvest which is followed by senescence which degrades the quality. During ripening, ethylene gas is produced which is triggered by consumption of sugars. In climacteric fruits, the produce is harvested before ripening (green stage) and then transported to remote locations. But once fruits and vegetables become fully mature, ethylene production continues which deteriorates quality. Any injury during transportation, handling, or because of attack by parasites increases the production rate of ethylene (Baldwin 1994; Oms-Oliu et al. 2008a, b; FAO 1985). In earlier times, people used to grow fruits and vegetables for their own needs and can be consumed fresh. But in the last few decades, fruits and vegetables are being transported and stored. To cover this whole food supply chain, it takes a considerable amount of time to reach the final consumer. During this time period, commodities can lose their color, appearance which reduces its aesthetic value (Embuscado and Huber 2009). Edible packaging can be one of the solutions to the entire above-mentioned problem.

10.5 Components and Composition of Edible Film and Coating

Like other packaging materials, polymers are also the basic material for formation of edible films and coatings. The major polymeric contributing materials are polysaccharides, protein, lipids, and resins shown in Table 10.2 (Falguera et al. 2011; Bourtoom 2008; Cuq et al. 1995; Gennadios et al. 1993). It is not necessary that the edible film will be based upon polymer only. Waxes and resins with or without addition of polymers are used to develop bilayer or composite films and coatings (Baldwin 1994).

Plasticizers are added to film-forming solution as a component. Plasticizers can be defined as the agents that are low in molecular weight which when added to the film-forming solutions decrease its glass transition temperature (Gennadios et al. 1993). They are basically of two types one which interrupts the polymer-polymer bonding to keep them farther and itself interacts with polymer by forming hydrogen bonds. It interacts with water molecules and results in bigger hydrodynamic radius and high moisture content (Sothornvit and Krochta, 2001). There are various factors

Table 10.2 Components of edible film and coatings

Components	Material
Basic material	**Polysaccharides:** Starch (maize, cassava), modified starch, modified cellulose (CMC, MC, HPC, HPMC, ethyl cellulose), alginates (sodium alginate), pectin, carrageenan, pullulan, chitosan, galactomonnas, gums such as gellan, xanthan, guar, locust, etc. **Proteins:** Soy proteins, pea proteins, rice proteins, pea proteins, gluten, casein, whey proteins, collagen, etc. **Lipids (waxes and resins):** Rice bran wax, candelilla wax, shellac, paraffin wax, terpene, acetoglycerides, etc.
Plasticizers	Glycerin, propylene glycol, sorbitol, sucrose, polyethylene glycol, corn syrup, water
Active ingredient	Antioxidants, antimicrobials, nutrients, anti-browning agents, flavorings, pigments, bacteriocins (nicin or pediocin or netamycin)
Other additives	Emulsifying agents such as lecithin, Tweens, and Spans; lipid emulsions such as edible waxes and fatty acids; crosslinkers such as calcium chloride

that affect the plasticizer's action such as size, shape, number of oxygen atoms, and efficiency of plasticizer (Sothornvit and Krochta 2001). Plasticizers work by breaking the polymer-polymer interaction increases the distance between the polymers and rather forms bonds with the polymer. Thus, resulting in increase in the mobility of polymer, decrease in crystalline region to amorphous especially in the case of polysaccharide, protein films, decrease in gelatinization temperature, increase in mechanical properties and resistance to vapor or gases. Water also works as a plasticizer, but it dehydrates at low humidity, add plasticizer with hydrophilic properties. In charged molecules, repulsive forces whereas between the same charged molecules, polar and non-polar molecules also provide plasticization effect by increasing the distance (Gennadios et al. 1993).

Selection and use of polymers in producing edible packaging material is often decided by studying tensile properties. These properties are accomplished by drying the produced film or coating on flat surfaces or glass. In case of fruits and vegetables, water barrier efficiency and oxygen barrier are required. Prior is necessary to prevent the surface dehydration and latter to prevent the ripening of fresh fruits and vegetables. There are some safety and health issues associated with the selection of polymer material. These are generally regarded as safe (GRAS), shelf-life, light processing, respiration, transpiration, controlled atmospheric pressure (CAP) and modified atmospheric pressure (MAP), allergenicity (Attila et al. 2009). Materials which have been selected for the formation of edible films and coatings should have a GRAS status as material will be in direct contact with the food material. The selection of polymers should solely be not on the basis of GRAS as there are also other factors to consider. The polymers selected for formation of edible packaging material should have shelf-life compatible with fruits and vegetables. According to Attila, the edible material should have at least shelf-life of 2 weeks during which fruits and vegetables can go through the whole supply chain and still should be in the condition that can be consumed by the consumer. Edible material also should have some durability to light processing (Attila et al. 2009). Light processing includes a variety of processes that are used for fruits and vegetables to convert them in edible form without much change in their original quality (Shewfelt 1987). During the light processing, certain changes occur such as the tissues get disrupted which creates many membrane-related problems and eventually become perishable in nature. The polymer can be subjected to light processing without undergoing any change in itself and also in fruits and vegetables. As mentioned earlier, fruits and vegetables undergo various reactions after harvesting. These reactions result in loss of texture which is undesirable by the consumers. Thus, decreases the value in the market so polymer should be such that it can prevent these kinds of reactions after harvesting. Temperature is one of the major factors which affect the quality during transportation as fruits and vegetables are exposed to temperature abuse so, as a result, they are packaged in modified atmosphere packaging (MAP) or controlled atmospheric storage (CAS). But during the temperature fluctuations, the water condensates on the surface and causes spoilage. An edible film or coating should not impart any taste to fruits and vegetables should not be detectable upon consumption, that is, good sensory characteristic. It should provide good barrier properties like gases and water vapor, confers mechanical stability which may be able to withstand pressure and prevent mechanical injury during transporting and handling. Polymeric material should have enough biochemical, physicochemical, and microbial stability. It should not degrade with passage of time and produce substances that are harmful upon consumption for humans. Ideal edible films and coatings are that which fulfill all the functions performed by packaging material but cost is also an important criterion. The raw material and process required for producing such types of packaging material should be less. Moreover, it should require simple technology for production (Debeaufort et al. 1998).

10.5.1 Polysaccharides

Different types of polysaccharides such as starch, non-starch carbohydrates such as cellulose, pectin derivatives, chitosan, etc., gums, and fibers (Han 2014; Bourtoom 2008; Xiao et al. 2011) which are used for edible films and coatings. Major polysaccharides are neutral in nature while some of the gums are positively charged with the exception of negative charge (Han 2014). Neutral carbohydrates have hydroxyl or hydrophilic moieties on the surface in large numbers which is useful in film formation. The presence of hydrophilic moieties on polysaccharides structures confers poor water vapor barrier properties (Kester and Fennema 1986; Brasil et al. 2012; Vásconez et al. 2009). Alginate- and gellan-based coating when coated upon papaya showed poor water vapor barrier (Tapia et al. 2007). Even the addition of sunflower oil did not show significant difference in water vapor pressure. But due to this hydrophilic nature, polysaccharide-based coatings can be used to prevent the moisture loss from the surface of fruits and vegetables (Kester and Fennema 1986). This prevents the texture loss which is also desirable. In one of the studies used the polysaccharides such as alginate-, pectin-, and gellan-based edible film was formed to coat the fresh-cut melon (Oms-Oliu et al. 2008a, b). The film was investigated for the gas exchange, antioxidant properties, color, firmness, sensory quality, and microbial quality for 15 days at 4 °C. The film showed the increased water vapor resistance which prevents the dehydration of cut melon pieces. Polysaccharides such as alginate- and gellan-based edible coatings were formed to coat the fresh-cut pieces of fuji apples and effect on shelf-life was studied (Rojas-Graü et al. 2008). Then, alginate- and gellan-based film wrapped on cut fuji apples were evaluated for changes in headspace gas composition, color changes, firmness, and microbiological quality which was stored for 23 days at 4 °C. It was found that edible coating was able to effectively prolong the shelf-life of cut fuji apples by 2 weeks. In the same study, the significant reduction in the mesophilic and psychrophilic microorganisms was also observed.

Closed tightly packed and hydrogen bonding in polysaccharides confers good gas barrier properties to edible films (Yang and Paulson 2000). These are able to modify gas atmosphere in fruits that delay the ripening (Baldwin 1994). Gas, especially the oxygen barrier property is highly dependent on the relative humidity. More the relative humidity, the more the mobility, the more the mass transfer across the film due to plasticizing effect (Bonilla et al. 2012). As if the humidity is high, it causes the swelling in polysaccharide matrix which in result increases the permeability and diffusivity across the film (Kumins 1965). Polysaccharide-based edible films also provide other additional functions such as it minimizes the browning when incorporated with anti-browning agents and also the textural changes (Rojas-Graü et al. 2008). The different polysaccharide materials used for fruits and vegetables are summarized and shown in Table 10.3.

10.5.2 Proteins

Proteins are generally used for formation of edible films and coatings. Different types of proteins which are used for formation can either be plant proteins or animal proteins. Animal proteins include casein protein, whey protein, meat proteins such as gelatin, feather keratin whereas plant protein includes wheat, soy, corn proteins, mung beans proteins, and peanut proteins (Gennadios et al. 1993; Bourtoom 2008). A protein generally in their native state exists as fibrous and globular proteins. Out of both the types of fibrous proteins are insoluble in water whereas globular proteins are soluble in water (Scope 1994). During edible film formation, fibrous proteins due to their fully extended structure these proteins can associate them in parallel. This association is through bonds such as hydrogen, ionic, hydrophobic, and covalent bonding. On the other hand, globular proteins form spherical structures held by bonds such as hydrogen, ionic, hydrophobic, and covalent, that is, disulfide bonds which are undesirable for edible film formation (Scope 1994). Proteins have unique characteristics such as their conformational denaturation, electrostatic charges, and amphiphilic nature (Han 2014). So, proteins primary, secondary, and tertiary structure can be treated with acids, alkalis, metal ions, salts, chemical hydrolysis, enzymatic treatment, heat denaturation, pressure, irradiation, mechanical treatment, and chemical crosslinking to bring about the desirable changes which are required

Table 10.3 Polysaccharide-based films for fruits and vegetables

Polysaccharide	Fruit/vegetable	Properties/functions	Reference
Cashew gum (20 g/ 100 mL water)	Mango	• Decreases weight loss, Prevent the change in TSS and pH	Souza et al. (2010)
Chitosan coating (0.2 g/ mL)	Fresh-cut papayas	• Reduce deteriorative process, maintains quality • Enhances shelf-life	Gonzalez-Aguilar et al. (2009)
Calcium-alginate coating (sodium alginate 4%, $CaCl_2$ 5%)	Fresh-cut carrot	• Prevent microbial growth, preserve sensory qualities • Enhance shelf-life	Costa et al. (2012)
Pectin (1%, 1 g/33.33 mL water, 15 g/500 mLwater)	Mellon, peach, mango	Improves fruit sensory acceptance • Promote the reduction of product respiration rate • Maintenance color characteristics • Pectin edible film formulated with cinnamon leaf oil decreases bacterial growth, increases antioxidants status • Reduces rate of texture softening, increases shelf-life	Ferrari et al. (2013), Ayala-Zavala et al. (2013)
Carrageenan (0.2–0.8%, w/v)	Papaya	• Delays ripening, extends shelf-life	Hamzah et al. (2013)
Alginate (1–5%)	Button mushroom, mango, cherry, persimmon fresh-cut apples, fresh-cut melon, fresh-cut mango	• Good gas barrier property, poor water barrier property • Effective in maintaining firmness of mushroom • Effective in delaying browning, preserve color, and sensory qualities, control microbial growth, higher elasticity	Jiang et al. (2013), Robles-Sánchez et al. (2013), Díaz-Mula et al. (2012), Neves et al. (2012), Chiabrando and Giacalone (2014), Raybaudi-Massilia et al. (2008), Salinas-Roca et al. (2016)
Basil-seed gum (5%) Coatings	Fresh-cut apricots	• Enhances shelf-life, control microbial growth	Hashemi et al. (2017)
Sucrose-based polymer (0.1–1%)	Mandarin	• Increase concentration of soluble solids, Vit. C content, sugar content, and carotenoids	Tao et al. (2012)

(continued)

Table 10.3 (continued)

Polysaccharide	Fruit/vegetable	Properties/functions	Reference
		• Surges catalase, peroxidase, and superoxidase dismutase activities • Reduces decay rate, TA and polyphenol oxidase activity	
Gelatin (5%)	Persimmon	• Good gas barrier, good for preserving flavor, affects the appearance	Neves et al. (2012)
Aloe vera gel (5%, 15%, 50%, 100%)	Fresh-cut apple, kiwifruit, pomegranate arils	• Reduces deterioration and respiration rate • Reduces microbial load, good sensory attributes • Delays browning	Song et al. (2013), Benitez et al. (2013), Martinez-Romero et al. (2013)
Maize starch (20 g/L)	Brussels sprouts	• No change in the contents of ascorbic acid and total flavonoids • Increases the radical-scavenging activity • No reduction in nutritional quality	Vina et al. (2007)

for edible films and coatings formation (Han 2014). Globular protein structure can be subjected to any of the above-mentioned treatments to get more of the extended structures that are required for edible film formation. More the number of extended structures is more the number of interactions. As a result of interactions, the edible films and coatings forms are stronger. But at the same time, these are less flexible, less permeable to gases, water vapors, and liquids (Kester and Fennema 1986).

On the surface of some proteins, there are some groups that are bonded to polymers via hydrogen bonding or ionic bonds, the edible films or coating forms are susceptible to moisture but barrier to oxygen. So, the edible films or coatings based on proteins provide a barrier to oxygen at low humidity (Bourtoom 2008). Edible films and coatings based on protein show high water vapor permeability due to their hydrophilic nature which is not desirable in fruits and vegetables. Film formed with high concentration of gelatin showed high water vapor permeability (Fakhoury et al. 2012; Jongjareonrak et al. 2006). Similarly, edible film formed with cornstarch and gelatin plasticized with glycerol, with increase in gelatin amount had increased water vapor permeability but less opacity (Fakhouri et al. 2015). The different protein materials used for coating of fruits and vegetables are summarized and shown in Table 10.4.

Table 10.4 Protein-based edible films and coatings for fruits and vegetables

Protein	Composition	Method of application	Fruits/ vegetables	Properties/functions	References
Rice bran protein	Rice bran protein (4 g), gelatin (4 g), fructose (2 g), grape seed extract (1%), and water (100 mL)	Wrapping in film	Strawberry	• Increases shelf-life by 2 days • No significant change in color and sensory properties	Shin et al. (2012)
SPI (soy protein isolate)	SPI to Glycerol in 2:1 ratio, cysteine (0.5%)	Dipping in coating	Apple	• Retain firmness • Controlled enzymatic browning • Extend shelf-life	Ghidelli et al. (2010)
Caseinate	NaCas: Glycerol (1:0.3 ratio), NaCas to lipid ratio 1:0.5, and lipid fraction composed of oleic acid to beeswax in 70:30 mass ratio	By dipping	Dried pineapple	• Extend shelf-life	Talens et al. (2012)
Whey protein isolate nano Fibrils	WPNF (5%, w/v), glycerol (4%, w/v), and Trehalose (3%, w/v)	Dipping	Apples	• Retard change total phenolic content • Prevents browning, and product weight loss	Feng et al. (2018)
Whey protein	5% protein (calcium caseinate or whey protein powder), 2.5% glycerol, 0.25% CMC, and 0.125% $CaCl2$	Dipping	Apple and potato slices	• Delays browning • Whey protein shows better antioxidant property than calcium caseinate	Tien et al. (2001)
Protein isolate of white mouth croaker (CPI)	CPI (35 g), MMT (5 g), and glycerol (10.5 g)	Immersion	Fresh-cut papaya	• Reduces weight loss • Preserve firmness • Effective in controlling color and microbial growth	Cortez-Vega et al. (2014)
Soy protein	SPI (5% w/v), SPI:Glycerol ratio 2:1	Immersion	Fresh-cut eggplant	• Controls enzymatic browning • Extend shelf-life	Ghidelli et al. (2014)

10.5.3 Lipids and Resins

Lipids and resins used for producing edible packaging materials are waxes and paraffin, acetoglycerides, and shellac resins (Bourtoom 2008). Edible film made with waxes to coat fruits and vegetables has been used since long. Polysaccharides and proteins are polymers, but lipids and resins are not polymers. But lipids and resins are edible, biodegradable, and cohesive biomaterials which make lipid a suitable material for film formation (Han 2014). Lipids and resins have the property to be semisolid at room temperature which is undesirable for formation of edible films and coatings formation. Along with this property, lipids and resins also have the property of characteristic phase transition temperature. Due to this property of phase transition, lipids and resins can be modified into any shape (Han 2014). The transition in lipids and resins can be brought about by subjecting them to heat treatment which causes the change in transition between solid, semisolid, and liquid state. Lipids are hydrophobic in nature hence, the film or coatings made are high in water resistance and low in surface energy (Han 2014). Film or coating blocks the transport of water due to low polarity. Due to this moisture barrier property, these films are also able to reduce weight loss of fruits and vegetables due to desiccation (Krochta and Mulder-Johnston 1997). The migration of water across the film depends on various factors such as length of chain, degree of unsaturation, and number of acyl groups. Length of hydrocarbon chain is in direct relation with water migration whereas rest other factors are in inverse relation (Krochta and Mulder-Johnston 1997; Coma et al. 2001). One of the disadvantages associated with the edible films and coatings made with lipids and resins is that they are brittle and thick (Bourtoom 2008).

This disadvantage can be overcome by making them in association with other polymers such as association of lipid film with polysaccharides results in formation of film with increased mechanical strength (Bourtoom 2008). Similarly, this can be associated with other polymers which can result in desirable properties required for film formation. Other issues related to fatty acid-based edible films its vulnerability to oxidation and sensory issues (Brody et al. 2001). Lipid-based edible films are able to provide selective barriers to gases. More is the length of hydrocarbon more the oxygen permeability across the membrane. Unsaturation and permeability of oxygen show inverse relation (Krochta and Mulder-Johnston 1997). Lipids being the water-insoluble, the water-soluble pigments of fruits and vegetables will not migrate to the membrane and will retain with fruits and vegetables. The different lipids and resins used for coating of edible films and coatings are summarized and shown in Table 10.5.

10.5.4 Composites

Sometimes above discussed polymers, lipids, and resins are not effective in preserving the quality of fruits and vegetables by themselves. So, these are made effective by using them in combination. These combinations can be protein-carbohydrate,

Table 10.5 Lipid- and resin-based edible films and coatings for fruits and vegetables

Lipids/ resin film	Composition	Method of application	Fruits/ vegetables	Properties/ functions	References
Beeswax emulsion	–	By emitting	Sweet pepper, mango, avocado	• Improved peal resistance to penetration. • Improved sensory firmness. • Reduced rate of decay.	Bustan and Lahav et al. (Bustan and Lahav 2012)
Wax and various oils	Mustard oil (100%) or coconut oil (100%) or castor oil (100%) or sesamum oil (100%) or liquid paraffin wax (100%)	Dipping	Lime	• Coconut oil was most effective in preserving quality. • Acceptable sensory and optical properties. • No incidence of molds & their growth up to 18 days of storage.	Bisen et al. (2012)
Carnauba and mineral oil coatings	Commercial carnauba Stafresh 2505™ (SF 2505) and mineral oil Stafresh 151™ (SF 151)	Manually applied using ArtexMR brushes	Tomato	• Preserves freshness without any adverse effect on nutrients.	Dávila-Aviña et al. (Dávila-Aviña et al. 2014)

protein-lipid, or carbohydrate-lipid (Bourtoom 2008). As far as the structure of composite film is concerned, it can be bilayer or conglomerate. In bilayer, there is one layer above another. On the other hand, conglomerate is a mixture of several layers in one layer. Conglomerate can be further classified into components distinct and components intermixing. In component distinct conglomerate composites, all the components are distinctly visible whereas in components intermixing conglomerate composites not all the components are distinctly visible shown in Fig. 10.1.

Combination of different films for formation of edible films and coatings results in enhanced properties such as mechanical and permeability property of edible film. For instance, polysaccharide-based edible film alone cannot provide good water vapor properties (WVP) due to its hydrophilic nature but addition of lipid can produce a film with water vapor barrier properties and also high gas permeability specifically at high RH (Coma et al. 2001). An edible film based upon hydroxypropyl methylcellulose (HPMC), a polysaccharide was formulated with

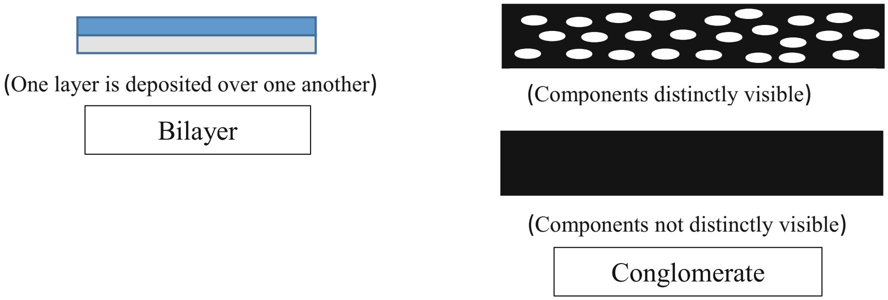

Fig. 10.1 Types of composite edible film and coatings

the incorporation of stearic acid known as fatty acid showed high water vapor barrier properties (Coma et al. 2001). One more α-nanoparticles ionic gelation was formulated (Medina et al. 2019). The prepared film was applied to blueberries and tomatoes as an internal coating to PET. Quinoa does not possess good film property whereas chitosan films do not have good mechanical property and have antibacterial property. Film formed with both results in the hydrophilic interaction as H- bonding also reported by Abugoch et al. (2011) as FTIR peak between quinoa and chitosan. Moreover, film showed high antibacterial against *Botrytis cinerea.* The interaction between these two gives synergistic effects. The anionic sulfide group of chitosan interacts ionically with protonated amino group of the chitosan which results in the production of film with completely new mechanical, barrier, elongation, and adhesive properties even without the addition of plasticizer (Abugoch et al. 2011). Composite edible film produced with rapeseed protein hydrolysate and chitosan results in the increase of α helix structure between 15.4% and 25% as addition of chitosan causes conformational changes in protein. This change affects the properties of film in a positive manner, that is, the tensile strength of film increased from 16.04 to 23.46 MPa. Moreover, the hydrolysis of protein results in the production of smaller proteins which increases the interaction of the protein with chitosan (Zhang et al. 2019). It is not necessary the edible film can only be produced with above-mentioned combinations. Piccirilli et al. (2019) formulated a film with the combination of whey protein concentrate (WPC) and liquid smoke (LS). WPC film showed high UV barrier properties in the range of 200–400 nm, but the addition of LS increases the range up to 400 nm which is highly desirable in the case of fruits and vegetables with light sensitive components. The increased range for UV light barrier is attributed to the presence of phenolic and carbonyl groups in LS (Piccirilli et al. 2019). Transparency is also one of the important characteristics of the edible film for consumer acceptance. The solvent used for preparation has an effect on the film formation (Tsai and Weng 2019). Whey protein and zein edible film when prepared with deionized water showed more transparency as compared to when prepared with ethanol. But sometimes this combination works less. For instance, carboxymethylcellulose film in combination with soy protein showed even poorer water barrier properties due to their hydrophilic nature (Baldwin et al. 1996). Hence, composite edible films and coatings can be better for fruits and vegetables because these can serve multipurpose. Dhumal et al. (2019) developed triphasic film, that is, composite film of chitosan, guar gum, and whey protein isolate with the addition of different antimicrobial essential oils such as eugenol, carvacrol, and citral. The addition of essential oils resulted in the reduction of the tensile strength due to their lipophilic nature which is not required for fruits and vegetables packaging. On the other hand, WPI composite film developed with the addition of rapeseed oil resulted in more oxygen and carbon dioxide permeability which is a desirable characteristic for fruits and vegetables as they respire after harvesting (Galus and Kadzińska 2019). The different composite materials used for coating of fruits and vegetables are summarized and shown in Table 10.6.

10.6 Regulatory Aspect of Edible Films and Coatings

Regarding the regulatory aspect of edible films and coatings, there is not much information available. As these are consumed along with the food product, the requirement should be that are being followed for the food products. Even the component in Table 1 used for forming film solution should be safe to consume and does not cause any health hazard to consumers. These should hold GRAS which is generally regarded as safe and have status as this will be in direct contact with the food material. Polymer used should be approved by FDA and if the polymer has not been approved by FDA, then the manufacturer of edible film and coating can file the petition for approval of material. Attila et al. (2009) stated that, "there are three types of GRAS designations. (1) Self – affirmed, where the manufacturer has carried out necessary work and is ready to defend GRAS status if challenged, (2) FDA pending, where results of research have been submitted to FDA for approval, (3) No comment – which is the response of FDA if after review, it has no challenges."

According to Debeaufort et al. (1998), edible films and coatings can be classified as foods or food ingredients. If this is applied on any food product, then there should be proper labelling containing the information about the ingredients used for functional ingredients also and any allergic compounds (Gennadios et al. 1997; Falguera et al. 2011). Since, there is some migration of chemicals from the packaging material to the food product. There is a need to set the overall migration limits (OMLs) and specific migration limits (SMLs) (Falguera et al. 2011). However, Food Safety and Standards Authority of India (FSSAI 2019) has recommended maximum permissible limit of food additives for coating the surface of fresh fruits and vegetables. There are various food additives (beeswax, candelilla wax, carnauba wax, glycerol ester of wood rosin, iron oxide, microcrystalline wax, ortho-phenylphenol, sodium ortho-phenylphenol, polyethylene glycol, polyvinylpyrrolidone, sulfites, shellac, bleached, sucroglycerides, beeswax, lauric arginate ethyl ester, phosphates, shellac) enlisted by FSSAI under Food Safety and Standard Regulation 2011 (Food Products Standards and Food Additives) (FSSAI 2019). The permissible limit of all food additives is well mentioned in Table 10.7.

Table 10.6 Composite edible films and coatings for fruits and vegetables

Composition of coating/films	Method of application	Fruits/vegetables	Properties/functions	References
Ca-Caseinate (2.5% w/v), whey protein (2.5% w/v), and glycerol (2.5% w/v)	By spraying	Strawberry	• Enhance shelf-life.	Vu et al. (2012), Robledo et al. (2018a , 2018b)
Gum tragacanth and aloe vera in 50:50 ratio	By immersion	Mushroom	• Extend shelf-life. • Preserve texture. • Retard ripening process.	Mohebbi et al. (2012)
Palm Oil and Beeswax in 1:1 ratio	By Hand-wipe technique	Guava	• Reduces the rate of weight loss and yellowness and. • Slow down the decline of glossiness, lightness, and greenness of guava.	Ruzaina et al. (2013)
80 g kg − 1 SC of Hydroxypropyl methylcellulose and beeswax: shellac in ratio of 1:3	Dip coated by immersion	Mandarin	• Effective in controlling weight loss. • Extend shelf-life. • Can result in off flavor development.	Contreras-Oliva et al. (2012)
Corn starch (waxy, modified, and native) and GEL in 1:4 ratio; GEL contains plasticizer (sorbitol or glycerol) (100 g/kg of the GEL)	By Immersion	Red crimson grapes	• Gelatin significantly increased mechanical strength, solubility in water, permeability to water vapor, and thickness of the biofilms, while also decreasing the opacity. • Sorbitol had significantly lower permeability to water vapor and higher tensile strength than the films plasticized with glycerol.	Fakhouri et al. (2015)
Whey protein concentrate and Glycerol in 3:1 ratio and bee wax (20% dry basis)	By immersion	Fresh-cut apple	• Facilitates incorporation of antioxidants in coating. • Antioxidant incorporated edible coating was better in reducing browning in comparison to that of antioxidants used alone. • Coating does not affect the weight loss.	Perez-Gago et al. (2006)

(continued)

Table 10.6 (continued)

Composition of coating/films	Method of application	Fruits/vegetables	Properties/functions	References
Methylcellulose (3 g) Polyethylene glycol (1 ml), Stearic acid (0.6 g)	By immersion	Mushroom and cauliflower; apricots and green peppers	• Lowers the water loss rate. • Coating incorporated with antioxidants was effective in slowing browning reactions and lowers Vitamin C loss.	Ayranci and Tunc (2003); Ayranci and Tunc (2004)
Cassava starch (3% w/w), Glycerol (1.5% w/w), Carnauba wax (0.2% w/w) and Stearic acid (0.8% w/w)	By immersion	Apples	• Better mechanical properties. • Effective barrier to moisture and gas exchange.	Chiumarelli and Hubinger (2014)
Alginate or pectin (2 g/100 ml water) and Gellan (0.5 g/100 ml water)	By immersion	Melon (Piel de Sapo)	• Increase the water vapor resistance. • Prevent desiccation and • Maintain fruit firmness throughout storage	Oms-Oliu et al. (2008b)
Alginate (1 g/100 g), trans-cinnamaldehyde (2 g/100 g), and Pectin (2 g/100 g)	Layer by layer technique	Water melon	• Extend shelf-life, • Prevent weight loss and preserve texture during storage. • Effective carrier of natural antimicrobial compounds.	Sipahi et al. (2013)
Sodium Alginate (1.6 g), Acerola puree (100 g), and water (50 g)	Film	Acerola fruits	• Better moisture barrier property. • Higher strength and modulus of film compared to other fruit puree films.	Azeredo et al. (2012)
Chitosan (2 g/100 g) and pectin (1 g/100 g)	Layer by layer deposition by immersion method	Fresh-cut papaya	• Reduces losses of Vitamin C and total carotenoids content. • Improves microbiological & physicochemical quality.	Brasil et al. (2012)
Alginate (1.5%), Chitosan (1.5%), and CaCl2 (5%)	Layer by layer	Fresh-cut melon	• Shown good adhesion with antimicrobial property, retains firmness.	Poverenov et al. (2014)
Agar agar based (1%), chitosan (0.2%), and acetic acid (0.2%)	By immersion	Garlic	• Reduces respiration and moisture loss.	Geraldine et al. (2008)

Cassava starch (10 g/L) and glycerol (10 g/L)	By immersion	Fresh-cut mango	• Promotes a higher weight loss of cut mangoes. • Affects fruit texture characteristics. • Increasing carotenogenesis, and. • Favor growth of microbes during storage,	Chiumarelli et al. (Chiumarelli et al. 2010, 2011), Chiumarelli and Hubinger (2014)
150 mL honey/L of water +50 g SPI/L of water	Dip coating	Fresh-cut kajari melon	• Better sensory results. • Effective in maintaining color and ascorbic acid. • Limits the microbial growth.	Yousuf and Srivastava (2017)

Table 10.7 Recommend limits of food additives for surface treatment of fresh fruit (As per FSSAI, 2019)

Food category name	Food additive	INS No	Max. recommended level
Surface-treated fresh fruit[a]	Beeswax	901	Good manufacturing practice
	Candelilla wax	902	Good manufacturing practice
	Carnauba wax	903	Good manufacturing practice
	Glycerol ester of wood rosin	445(iii)	110 mg/kg
	Iron oxide		1000 mg/kg
	Microcrystalline wax	905c(i)	50 mg/kg
	ortho-Phenylphenol	231	12 mg/kg
	Sodium ortho-phenylphenol	232	12 mg/kg
	Polyethylene glycol	1521	Good manufacturing practice
	Polyvinylpyrrolidone	1201	Good manufacturing practice
	Sulfites		30 mg/kg
	Shellac, bleached	904	Good manufacturing practice
	Sucroglycerides	474	Good manufacturing practice
Surface-treated fresh vegetables (including mushrooms and fungi, roots and tubers, fresh pulses and legumes, and aloe vera) sea weeds, nuts and seeds	Beeswax	901	Good manufacturing practice
	Candelilla wax	902	Good manufacturing practice
	Carnauba wax	903	Good manufacturing practice
	Glycerol ester of wood rosin	445(iii)	110 mg/kg
	Lauric arginate ethyl ester	243	200 mg/kg
	Microcrystalline wax	905c(i)	50 mg/kg
	Phosphates		1760 mg/kg
	Shellac, bleached	904	Good manufacturing practice

[a] As per FSSAI (2019), **surface-treated fresh fruit defined as** "the surfaces of certain fresh fruit are coated with glazes or waxes or are treated with other food additives that act as protective coatings and/or help to preserve the freshness and quality of the fruit. Examples include apples, oranges, dates, and longans, etc."

10.7 Concluding Remarks

Edible films and coatings can serve as a potential packaging material for the whole fruits and vegetables as well as for the cut. These can perform almost all the functions that a packaging material can perform. Along with the basic functions of packaging material, it can perform other functions too. These can be formulated with the incorporation of various active ingredients for example antimicrobials, antioxidants, etc. Furthermore, research is required in this field as these are solely not able to protect fruits and vegetables due to their mechanical stability issues. Moreover, edible packaging material based on proteins has potential to cause allergic reactions to the person's vulnerable to allergens. This should be studied before or must be labeled properly for consumer's sake. Edible packaging materials can only be considered as a primary packaging material. Edible films give poor heat sealability which requires more research in this concern. Another limitation associated with the use is their adhesion to surface. This can be overcome by either multilayer electrodeposition which involves layer by layer coating. Some issues are there in commercialization because of the requirement of whole new machinery, new processes which will add cost on the manufacturer's part. Consumer acceptance is also necessary as they are somewhat reluctant in accepting the new product. However, edible films and coatings have enormous potential to substitute the existing packaging material.

References

Abugoch LE, Tapia C, Villamán MC, Yazdani-Pedram M, Díaz-Dosque M (2011) Characterization of quinoa protein–chitosan blends edible films. Food Hydrocoll 25(5):879–886

Attila E, Orts W, Embuscado ME, Huber KC (2009) Edible films and coatings: why, what, and how? Edible films and coatings for food applications. Springer, NY, pp 1–23

Ayala-Zavala JF, Silva-Espinoza BA, Cruz-Valenzuela MR, Leyva JM, Ortega-Ramírez LA, Carrazco-Lugo DK, Pérez-Carlón JJ, Melgarejo-Flores BG, González-Aguilar GA, Miranda MRA (2013) Pectin-cinnamon leaf oil coatings add antioxidant and antibacterial properties to fresh-cut peach. Flavour Frag J 28(1):39–45

Ayranci E, Tunc S (2003) A method for the measurement of the oxygen permeability and the development of edible films to reduce the rate of oxidative reactions in fresh foods. Food Chem 80(3):423–431

Ayranci E, Tunc S (2004) The effect of edible coatings on water and vitamin C loss of apricots (*Armeniaca vulgaris* Lam.) and green peppers (*Capsicum annuum* L.). Food Chem 87(3):339–342

Azeredo HM, Miranda KW, Rosa MF, Nascimento DM, de Moura MR (2012) Edible films from alginate-acerola puree reinforced with cellulose whiskers. LWT-Food Sci Technol 46(1):294–297

Baldwin EA (1994) Edible coatings for fresh fruits and vegetables: past, present, and future. In: Edible coatings and films to improve food quality. CRC Press, pp 25–63

Baldwin EA, Nisperos MO, Chen XIUHUA, Hagenmaier RD (1996) Improving storage life of cut apple and potato with edible coating. Postharvest Biol Technol 9(2):151–163

Benítez S, Achaerandio I, Sepulcre F, Pujolà M (2013) Aloe vera based edible coatings improve the quality of minimally processed 'Hayward'kiwifruit. Postharvest Biol Technol 81:29–36

Bisen A, Pandey SK, Patel N (2012) Effect of skin coatings on prolonging shelf life of kagzi lime fruits (*Citrus aurantifolia* Swingle). J Food Sci Technol 49(6):753–759

Bonilla J, Atarés L, Vargas M, Chiralt A (2012) Edible films and coatings to prevent the detrimental effect of oxygen on food quality: possibilities and limitations. J Food Eng 110(2):208–213

Bourtoom T (2008) Edible films and coatings: characteristics and properties. Int Food Res J 15(3):237–248

Brasil IM, Gomes C, Puerta-Gomez A, Castell-Perez ME, Moreira RG (2012) Polysaccharide-based multilayered antimicrobial edible coating enhances quality of fresh-cut papaya. LWT-Food Sci and Technol 47(1):39–45

Brody AL, Strupinsky ER, Kline LR (2001) Active packaging for food applications. Technomic Publishing Co., Inc., Lancaster, p 218

Bustan A, Lahav J (2012) Influence of organic beeswax-based coating emulsion on the post storage quality of sweet pepper, mango, and avocado fruit. Acta Hortic 934:807–814

Chiabrando V, Giacalone G (2014) Effect of essential oils incorporated into an alginate-based edible coating on fresh-cut apple quality during storage. Qual Assur Safety Crops Foods 7(3):251–259

Chiumarelli M, Hubinger MD (2014) Evaluation of edible films and coatings formulated with cassava starch, glycerol, carnauba wax and stearic acid. Food Hydrocoll 38:20–27

Chiumarelli M, Pereira LM, Ferrari CC, Sarantópoulos CI, Hubinger MD (2010) Cassava starch coating and citric acid to preserve quality parameters of fresh-cut "Tommy Atkins" mango. J Food Sci 75(5):E297–E304

Chiumarelli M, Ferrari CC, Sarantópoulos CI, Hubinger MD (2011) Fresh-cut 'Tommy Atkins' mango pre-treated with citric acid and coated with cassava (*Manihot esculenta* Crantz) starch or sodium alginate. Innov Food Sci Emerg Technol 12(3):381–387

Coma V, Sebti I, Pardon P, Deschamps A, Pichavant FH (2001) Antimicrobial edible packaging based on cellulosic ethers, fatty acids, and nisin incorporation to inhibit *Listeria innocua* and *Staphylococcus aureus*. J Food Prot 64(4):470–475

Contreras-Oliva A, Rojas-Argudo C, Pérez-Gago MB (2012) Effect of solid content and composition of hydroxypropyl methylcellulose-lipid edible coatings on physico-chemical and nutritional quality of 'Oronules' mandarins. J Sci Food Agric 92(4):794–802

Cortez-Vega WR, Pizato S, de Souza JTA, Prentice C (2014) Using edible coatings from Whitemouth croaker (*Micropogonias furnieri*) protein isolate and organo-clay nanocomposite for improve the conservation properties of fresh-cut 'Formosa' papaya. Innov Food Sci Emerg Technol 22:197–202

Costa C, Conte A, Buonocore GG, Lavorgna M, Del Nobile MA (2012) Calcium-alginate coating loaded with silver-montmorillonite nanoparticles to prolong the shelf-life of fresh-cut carrots. Food Res Int 48(1):164–169

Cuq B, Gontard N, Guilbert S (1995) Edible films and coatings as active layers. In: Active food packaging. Springer, Boston, MA, pp 111–142

Dávila-Aviña JE, Villa-Rodríguez JA, Villegas-Ochoa MA, Tortoledo-Ortiz O, Olivas GI, Ayala-Zavala JF, González-Aguilar GA (2014) Effect of edible coatings on bioactive compounds and antioxidant capacity of tomatoes at different maturity stages. J Food Sci Technol 51(10):2706–2712

Debeaufort F, Quezada-Gallo JA, Voilley A (1998) Edible films and coatings: tomorrow's packagings: a review. Crit Rev Food Sci 38(4):299–313

Dhumal CV, Pal K, Sarkar P (2019) Characterization of tri-phasic edible films from chitosan, guar gum, and whey protein isolate loaded with plant-based antimicrobial compounds. Polym-Plast Technol Mater 58(3):255–269

Díaz-Mula HM, Serrano M, Valero D (2012) Alginate coatings preserve fruit quality and bioactive compounds during storage of sweet cherry fruit. Food Bioprocess Technol 5(8):2990–2997

Du WX, Avena-Bustillos RJ, Hua SST, McHugh TH (2011) Antimicrobial volatile essential oils in edible films for food safety. Sci Against Microbial Pathogens: Commun Curr Res Technol Adv 2:1124–1134

Embuscado ME, Huber KC (2009) Edible films and coatings for food applications, vol 9. Springer, New York, NY

Fakhouri FM, Martelli SM, Caon T, Velasco JI, Mei LHI (2015) Edible films and coatings based on starch/gelatin: film properties and effect of coatings on quality of refrigerated Red Crimson grapes. Postharvest Biol Technol 109:57–64

Fakhoury FM, Martelli SM, Bertan LC, Yamashita F, Mei LHI, Queiroz FPC (2012) Edible films made from blends of manioc starch and gelatin–influence of different types of plasticizer and different levels of macromolecules on their properties. LWT-Food Sci Technol 49(1):149–154

Falguera V, Quintero JP, Jiménez A, Muñoz JA, Ibarz A (2011) Edible films and coatings: structures, active functions and trends in their use. Trends Food Sci Technol 22(6):292–303

FAO (1985) The prevention of post-harvest food losses in fruits, vegetables and root crops, Food and Agriculture Organization, Rome

Feng Z, Wu G, Liu C, Li D, Jiang B, Zhang X (2018) Edible coating based on whey protein isolate nanofibrils for antioxidation and inhibition of product browning. Food Hydrocoll 79:179–188

Ferrari CC, Sarantópoulos CI, Carmello-Guerreiro SM, Hubinger MD (2013) Effect of osmotic dehydration and pectin edible coatings on quality and shelf life of fresh-cut melon. Food Bioprocess Technol 6(1):80–91

FICCI (2014) potential of plastic industry in northern India with special focus on plasticulture and food processing. The Federation of Indian Chambers of Commerce and Industry, India

FSSAI (2019) The food safety and standards (Food Products Standards and Food Additives) Regulations- 2011, Compendium of Food Additives and Regulations, (Version-IX (29.03.2019)). https://archive.fssai.gov.in/dam/jcr:f3124f1e-bc84-4835-8463-7347fcc71bfe/Compendium_Food_Additives_Regulations_29_03_2019.pdf

Galus S, Kadzińska J (2019) Gas barrier and wetting properties of whey protein isolate-based emulsion films. Polym Eng Sci 59(S1):E375–E383

Gennadios A, Brandenburg AH, Weller CL, Testin RF (1993) Effect of pH on properties of wheat gluten and soy protein isolate films. J Agric Food Chem 41:1835–1839

Geraldine RM, Soares NDFF, Botrel DA, de Almeida GL (2008) Characterization and effect of edible coatings on minimally processed garlic quality. Carbohydr Polym 72(3):403–409

Ghidelli C, Sanchís E, Rojas-Argudo C, del Río MA, Pérez-Gago MB, Mateos M (2010) Effect of edible coating and modified atmosphere packaging on enzymatic browning of fresh-cut apple. In: XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium, vol 34, pp 515–522

Ghidelli C, Mateos M, Rojas-Argudo C, Pérez-Gago MB (2014) Extending the shelf life of fresh-cut eggplant with a soy protein–cysteine based edible coating and modified atmosphere packaging. Postharvest Biol Technol 95:81–87

González-Aguilar GA, Valenzuela-Soto E, Lizardi-Mendoza J, Goycoolea F, Martínez-Téllez MA, Villegas-Ochoa MA, Ayala-Zavala JF (2009) Effect of chitosan coating in preventing deterioration and preserving the quality of fresh-cut papaya 'Maradol'. J Sci Food Agric 89(1):15–23

Guilbert S, Cuq B, Gontard N (1997) Recent innovations in edible and/or biodegradable packaging materials. Food Addit Contam 14:741–751

Hamzah HM, Osman A, Tan CP, Ghazali FM (2013) Carrageenan as an alternative coating for papaya (*Carica papaya* L. cv. Eksotika). Postharvest Biol Technol 75:142–146

Han JH (2014) Edible films and coatings: a review. In: Innovations in food packaging, 2nd ed., pp. 213–255

Hardenburg RE (1967) Wax and related coatings for horticultural products; a bibliography

Hashemi SMB, Khaneghah AM, Ghahfarrokhi MG, Eş I (2017) Basil-seed gum containing origanumvulgare subsp. Viride essential oil as edible coating for fresh-cut apricots. Postharvest Biol Technol 125:26–34

Jiang T (2013) Effect of alginate coating on physicochemical and sensory qualities of button mushrooms (*Agaricus bisporus*) under a high oxygen modified atmosphere. Postharvest Biol Technol 76:91–97

Jongjareonrak A, Benjakul S, Visessanguan W, Tanaka M (2006) Effects of plasticizers on the properties of edible films from skin gelatin of bigeye snapper and brownstripe red snapper. Eur Food Res Technol 222(3–4):229–235

Kester JJ, Fennema OR (1986) Edible films and coatings: a review. Food Technology (USA)

Krochta JM, Mulder-Johnston CD (1997) Edible and biodegradable polymer films: challenges and opportunities. Food Technol 51(2):61–74

Kumins CA (1965) Transport through polymer films. In Journal of Polymer Science Part C: Polymer Symposia, vol. 10(1), 1–9. New York: Wiley Subscription Services, Inc., A Wiley Company

Martínez-Romero D, Castillo S, Guillén F, Díaz-Mula HM, Zapata PJ, Valero D, Serrano M (2013) Aloe vera gel coating maintains quality and safety of ready-to-eat pomegranate arils. Postharvest Biol Technol 86:107–112

Medina E, Caro N, Abugoch L, Gamboa A, Díaz-Dosque M, Tapia C (2019) Chitosan thymol nanoparticles improve the antimicrobial effect and the water vapour barrier of chitosan-quinoa protein films. J Food Eng 240:191–198

Mohebbi M, Ansarifar E, Hasanpour N, Amiryousefi MR (2012) Suitability of aloe vera and gum tragacanth as edible coatings for extending the shelf life of button mushroom. Food Bioproc Technol 5(8):3193–3202

Neves ACV Jr, Coneglian RCC, Soares AG, Freitas DGC, Fonseca MJO, Barreira FR et al (2012) Physical and sensory characterization of edible coatings applied to minimally processed persimmon. Acta Hortic 934:537–542

NHB (2017) Horticultural statistics at a glance. National horticulture board, India

Oms-Oliu G, Soliva-Fortuny R, Martín-Belloso O (2008a) Edible coatings with antibrowning agents to maintain sensory quality and antioxidant properties of fresh-cut pears. Postharvest Biol Technol 50(1):87–94

Oms-Oliu G, Soliva-Fortuny R, Martín-Belloso O (2008b) Using polysaccharide-based edible coatings to enhance quality and antioxidant properties of fresh-cut melon. LWT-Food Sci Technol 41(10):1862–1870

Perez-Gago MB, Serra M, Del Rio MA (2006) Color change of fresh-cut apples coated with whey protein concentrate-based edible coatings. Postharvest Biol Technol 39(1):84–92

Piccirilli GN, Soazo M, Pérez LM, Delorenzi NJ, Verdini RA (2019) Effect of storage conditions on the physicochemical characteristics of edible films based on whey protein concentrate and liquid smoke. Food Hydrocoll 87:221–228

Poverenov E, Danino S, Horev B, Granit R, Vinokur Y, Rodov V (2014) Layer-by-layer electrostatic deposition of edible coating on fresh-cut melon model: anticipated and unexpected effects of alginate–chitosan combination. Food Bioprocess Technol 7(5):1424–1432

Raybaudi-Massilia RM, Mosqueda-Melgar J, Martín-Belloso O (2008) Edible alginate-based coating as carrier of antimicrobials to improve shelf-life and safety of fresh-cut melon. Int J Food Microbiol 121(3):313–327

Robledo N, López L, Bunger A, Tapia C, Abugoch L (2018a) Effects of antimicrobial edible coating of thymol-nano-emulsion/quinoa protein/chitosan on the safety, sensorial properties, and quality of refrigerated strawberries (Fragaria ananassa) under commercial storage environment. Food Bioprocess Technol 11(8):1566–1574

Robledo N, Vera P, López L, Yazdani-Pedram M, Tapia C, Abugoch L (2018b) Thymolnanoemulsions incorporated in quinoa protein/chitosan edible films; antifungal effect in cherry tomatoes. Food Chem 246:211–219

Robles-Sánchez RM, Rojas-Graü MA, Odriozola-Serrano I, González-Aguilar G, Martin-Belloso O (2013) Influence of alginate-based edible coating as carrier of antibrowning agents on bioactive compounds and antioxidant activity in fresh-cut Kent mangoes. LWT-Food Sci Technol 50(1):240–246

Rojas-Graü MA, Tapia MS, Martín-Belloso O (2008) Using polysaccharide-based edible coatings to maintain quality of fresh-cut Fuji apples. LWT-Food Sci Technol 41(1):139–147

Ruzaina I, Norizzah AR, Halimahton Zahrah MS, Cheow CS, Adi MS, Noorakmar AW, Mohd. Zahid, A (2013) Utilisation of palm-based and beeswax coating on the postharvest-life of guava (*Psidium guajava* L.) during ambient and chilled storage. J Int Food Res 20 (1):265–274

Salinas-Roca B, Soliva-Fortuny R, Welti-Chanes J, Martín-Belloso O (2016) Combined effect of pulsed light, edible coating and malic acid dipping to improve fresh-cut mango safety and quality. Food Control 66:190–197

Scope RK (1994) Separation by precipitation. In: Scope RK (ed) Protein purification; principles and practice. Springer-Verlag, New York, pp 71–101

Seydim AC, Sarikus G (2006) Antimicrobial activity of whey protein based edible films incorporated with oregano, rosemary and garlic essential oils. Food Res Int 39(5):639–644

Shewfelt RL (1987) Quality of minimally processed fruits and vegetables. J Food Qual 10(3):143–156

Shin YJ, Song HY, Song KB (2012) Effect of a combined treatment of rice bran protein film packaging with aqueous chlorine dioxide washing and ultraviolet-C irradiation on the postharvest quality of 'Goha' strawberries. J Food Eng 113(3):374–379

Sipahi RE, Castell-Perez ME, Moreira RG, Gomes C, Castillo A (2013) Improved multilayered antimicrobial alginate-based edible coating extends the shelf life of fresh-cut watermelon (Citrullus lanatus). LWT-Food Sci Technol 51(1):9–15

Song HY, Jo WS, Song NB, Min SC, Song KB (2013) Quality change of apple slices coated with Aloe vera gel during storage. J Food Sci 78(6):C817–C822

Sothornvit R, Krochta JM (2001) Plasticizer effect on mechanical properties of β-lactoglobulin films. J Food Eng 50(3):149–155

Souza M, Cerqueira M, Souza B, Teixeira J, Porto A, Vicente A, Carneiro-da-Cunha M (2010) Polysaccharide from *Anacardium occidentale* L. tree gum (Policaju) as a coating for Tommy Atkins mangoes. Chem Pap 64(4):475–481

Talens P, Pérez-Masía R, Fabra MJ, Vargas M, Chiralt A (2012) Application of edible coatings to partially dehydrated pineapple for use in fruit-cereal products. J Food Eng 112(12):86–93

Tao N-G, Ao T-T, Liu Y-J, Huang S-R (2012) Effect of sucrose-based polymers on quality of Satsuma mandarin fruit (Citrus unshiu Marc. cv. Miyagawa Wase). Int J Food Sci Technol 47(5):997–1003

Tapia MS, Rojas-Graü MA, Rodríguez FJ, Ramírez J, Carmona A, Martin-Belloso O (2007) Alginate-and gellan-based edible films for probiotic coatings on fresh-cut fruits. J Food Sci 72(4):E190–E196

Tien L, Vachon C, Mateescu MA, Lacroix M (2001) Milk protein coatings prevent oxidative browning of apples and potatoes. J Food Sci 66(2001):512–516

Tsai MJ, Weng YM (2019) Novel edible composite films fabricated with whey protein isolate and zein: Preparation and physicochemical property evaluation. LWT-Food Sci Technol 101: 567–574

USEPA (2015) Reducing wasted food & packaging: a guide for food services and restaurants. United States Environmental Protection Agency, 1200 Pennsylvania Avenue, N.W

Vásconez MB, Flores SK, Campos CA, Alvarado J, Gerschenson LN (2009) Antimicrobial activity and physical properties of chitosan–tapioca starch based edible films and coatings. Food Res Int 42(7):762–769

Viña SZ, Mugridge A, García MA, Ferreyra RM, Martino MN, Chaves AR, Zaritzky NE (2007) Effects of polyvinylchloride films and edible starch coatings on quality aspects of refrigerated Brussels sprouts. Food Chem 103(3):701–709

Vu KD, Hollingsworth RG, Salmier S, Takala PN, Lacroix M (2012) Development of bioactive coatings based on γ-irradiated proteins to preserve strawberries. Radiat Phys Chem 81(8):1211–1214

Xiao Z, Luo Y, Luo Y, Wang Q (2011) Combined effects of sodium chlorite dip treatment and chitosan coatings on the quality of fresh-cut d'Anjou pears. Postharvest Biol Technol 62(3):319–326

Yang L, Paulson AT (2000) Mechanical and water vapour barrier properties of edible gellan films. Food Res Int 33(7):563–570

Yousuf B, Srivastava AK (2017) A novel approach for quality maintenance and shelf-life extension of fresh-cut Kajari melon: Effect of treatments with honey and soy protein isolate. LWT-Food Sci Technol 79:568–578

Zhang C, Wang Z, Li Y, Yang Y, Ju X, He R (2019) The preparation and physiochemical characterization of rapeseed protein hydrolysate-chitosan composite films. Food Chem 272: 694–701