Edible Packaging: An Overview

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Abstract

Food packaging exhibits a significant role in chain supply and also is considered one amongst the essential steps in final process. The increased demand of customers for high-quality products with natural ingredients has forced the food and packaging industry to introduce the concept of edible packaging in the market. Till date, a number of techniques have been optimized to preserve the food either by means of adding preservatives or by changing the nature of packaging material. Edible packaging aims to conserve the food quality along with increased shelf life. These are produced either from edible biopolymers, which can be proteins, lipids, polysaccharides (gums and carbohydrates), plasticizers or from food-grade additives. Edible packaging materials include edible coatings, films, pouches and sheets. Depending on the type of final edible packaging material, these can be used either alone or in combination as per the requirement of the food product to be stored in it. For instance, lipids or resins can be combined with polysaccharides or proteins to obtain the edible packaging material having properties that resist water penetration. The best edible film must be a good oxygen barrier, moisture barrier and aroma barrier. The edible film made of protein can be derived from various plant and animal sources such as grains, oilseeds, milk, eggs and other animal tissues. The mechanism of film forming includes drying and extensive interaction of polymer network either with dry or wet casting. At present, various active compounds like antioxidants,

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colouring agents, antimicrobials, flavours and nutraceuticals are being incorporated into the films to enhance its quality and stability. The concept of edible packaging seems to be one of the best alternatives to old synthetic plastics that cause severe environmental pollution. The present chapter explores the fundamental understanding about edible packaging and its construction. It highlights the kind of material employed for the construction of edible packaging and the considerations involved in its fabrication. Further, the chapter enlightens the current advancements of edible packaging research and industrial approach towards it.

Keywords

Edible packaging · Preservation · Environmental sustainability · Antioxidants · Food packaging

1.1 Introduction

Utilization of edible packaging is increasing rapidly by using various edible compounds like lipids, polysaccharides, resins and proteins originating from various renewable sources. These packaging are considered as a fundamental fragment of food and can be eaten along with food; therefore, these must be biodegradable in nature (Krochta 2002). The edible packaging usually comprises of sheets or edible films, pouches and coatings. The thickness of edible films is usually less than 254 μm, whereas that of sheets is more than 254 μm. These structures (sheets and films) are manufactured separately from food and are later on placed either on food components or are sealed as edible pouches. The edible coatings are usually the reedy layers made from edible material that are placed directly over food products (Krochta and De Mulder-Johnston 1997). Various examples of edible packaging may include tablet coatings, microcapsules made of edible material, soft and hard gel capsules, etc. There is an increased interest and various researches are in existence because of high purchaser demand for better quality and safe food along with increased storage life. Edible packaging due to their unique properties such as its ability to protect food due to its mechanical and barrier properties, increased sensory characteristics, controlled mass transfer among heterogeneous foods and controlled release of active ingredients are considered to be one amongst the best alternatives for various applications. Despite the fact that conventional packaging cannot be entirely replaced by edible packaging, the edible packaging can, however, improve the efficacy of preservation of food, when combined with other non-edible packaging that acts as additional secondary packaging and protects the edible packaging along with food from the outer environment containing foreign particles. Its use results in enhanced recyclability of packaging along with lesser use of packaging material that too with increased protective functions (Krochta 2002).

Apart from this, these edible packaging can be employed for non-edible packaging, where it acts as an oxygen or gas barrier and, thus, enhances the protective ability along with degradability of the packaging material (Han and Krochta 2001; Hong and Krochta 2003; Lee et al. 2008). The benefits of edible packaging material stand unique and versatile such as providing product stability, variety, better quality and more safety along with convenience to consumers.

1.2 Concept of Edible Films and Coatings

Various coatings and edible films, for instance, wax on fruits were being used since centuries in order to prevent the moisture loss and to increase the aesthetic appeal of the product by glossy appearance. Such practices were carried out since long, even before the chemistries associated with them came into existence, and are still under use at present. The term, 'edible-film' came into existence for food products since past half century. Mostly, the terms coatings and films can be used in either means, which indicates the coated surface of the food by some composition. However, coating and film can be sometimes differentiated by notion that film is a wrapping material, whereas coating can be applied directly onto the surface of the food product. During 1967, the commercialization of edible films was restricted and limited only to use as wax on fruits. In 1986, few companies started growing and their numbers increased up to 10; however, there was drastic increase in companies manufacturing edible packaging from 10 to 600 in 1996. At present, the use of edible film is increasing due to its wide range of benefits such as retaining quality of product and many others, with annual revenue that exceeds by $100 million (Janjarasskul and Krochta 2010).

Any material that enrobes (wraps or coats) different food to increase the shelf life of product, which can be eaten along with the product without removing any of its layer, is considered as coating or edible film. The edible films not only act as coating but also fortify the natural coatings or layers of product, which aid in preventing the loss of moisture from the food and allow only selective gases such as ethylene, carbon dioxide and oxygen to pass in and out through it that participates in the process of respiration. The coating or film with thickness of less than 0.3 mm can also act as surface sterilizer, thereby preventing the loss of various other important components (Janjarasskul and Krochta 2010).

1.3 Properties of Edible Packaging Materials

Packaging serves various functions such as preservation, distribution, marketing of foods, etc. Its dumping and disposal leads to various ecological problems, especially the non-biodegradable ones. Also, recycling of the same requires additional cost. Therefore, in this fast-moving era, edible packaging proves to be a wonderful natural alternative that not only act as packaging but, at the same time, it extends the storage stability of the product as well as hails various other benefits such as acting as barrier against transmission of gases (Álvarez 2000), reduces the process of maturation, increases aesthetic appeal, etc. (Souza et al. 2010).

1.3.1 Functional Properties

Edible packaging serves various functional properties such as environmental barrier, water barrier, oxygen barrier, aroma barrier, oil barrier, etc.

1.3.2 Environmental Barrier

The coatings and edible films serve as environmental barrier and are responsible for controlling the mass transfer between ambient atmosphere and the food. Permeability is considered to be an important factor while selecting the edible material for packaging. The effect of moisture and temperature on film reflects its condition of intended use. Therefore, conducting the measurement of permeability must be done under specific conditions before using it as a packaging material.

1.3.3 Water Barrier

The application of edible packaging has been widely used for food packaging and in various conditions where moisture exchange should be inhibited. The inhibition of moisture exchange results in curbing microbial growth owing to lowered waster activity, averting any change in texture or adverse chemical reactions. Films produced from edible waxes and plastics have fairly less WVP as compared to the hydrocolloid-based films due to substantial polarity, water vapour permeability of hydrophilic films increase at high relative humidity (RH) and high plasticizer concentration. Therefore, for short period duration and in low moisture foods, these films can solely be utilized as shielding barriers against moisture exchange. On the other hand, lipid based hydrophobic compounds are often used to enhance the water barrier properties of the films through low polarity and low affinity densely structured molecular matrices.

1.3.4 Oxygen Barrier

The major factors contributing to food spoilage or food deterioration include discoloration of myoglobin pigment in freshly cut meat pieces, oxidation of lipids and food ingredients or enzymatic browning of the fresh-cut produce. For foods that are sensitive to oxygen, an edible packaging can be used with low oxygen permeability (OP), which aids to preserve quality and extends the shelf life of oxygen-sensitive foods. Moreover, it also helps to reduce the utilization of various expensive and affluent, non-recyclable, oxygen barrier plastics. At the same time, a modified atmosphere can be created by the development of various advancements involved in the formulation of edible films. Such advanced techniques can also help in suppressing the respiration rate of horticultural products and the ethylene production of physiologically active climacteric produce during storage as well as distribution (Rahman 2007).

At low RH value, hydrocolloid-based films generally exhibit remarkable gas barrier properties. Whereas, at high RH conditions, plasticized hydrocolloid based films and hydrophilic EVOH films are used to have good barrier properties.

1.3.5 Aroma Barrier

In food packaging, aroma or volatile flavour and migration of flavours from outside create a problematic situation for any of the food packaging, which must be prevented during storage and distribution. In general, the barrier efficiency of packaging material is improved when a migrating compound has low affinity to film materials and low diffusivity across the polymer matrix. To identify some suitable barriers, include hydrophilicity of protein- and polysaccharide-based edible films for non-polar aroma compounds. Encapsulation of flavour and aroma has been proposed by carbohydrate and protein emulsion-based films (Pegg and Shahidi 2007; Hambleton et al. 2009; Fabra et al. 2009). The chief objective of using this technology is to preserve the hydrophobic organic aroma compounds in a non-polar lipid dispersed phase, whereas the matrix made of hydrophilic polymer prevents aroma loss to the environment or due to oxidation. Further research is still required in order to reveal the various aspects related to the aroma permeability of the edible films (Debeaufort and Voilley 1995).

1.3.6 Oil Barrier Properties

Any sort of lipid-containing food products can be provided resistance against grease by using edible packaging. Zein and whey protein based films have been reported to exhibit excellent resistance against grease owing to the inherent hydrophilicity of protein-based films.

1.4 Food Surface Properties

1.4.1 Wettability

The ability of a given liquid to spread over a solid surface is known as spreading coefficient or wettability (Ws). Higher the value of wettability, more is the coating material suitable for use. The major factors taken into consideration while determining spreading coefficient are the coefficient of adhesion (Wa) and cohesion coefficient (Wc). The former represents force promoting expansion of liquid over a solid surface, while the latter represents force promoting contraction of liquid over a solid surface (Lima et al. 2010).

1.4.1.1 Contact Angle of Coatings in the Surface of Foods

The association between water molecules offers a good understanding of the hydrophobic effect. In order to determine the hydrophobic or hydrophilic property of edible films, contact angle is measured. Studies have revealed that with increase in the number of lipid molecules, the contact angle is also increased (Tang and Jiang 2007; Ramos et al. 2013; Galus and Kadzińska 2016). Similarly, the hydrophilic nature of edible films is related to the solubility of film surface that might come in contact with water. This property is used to validate the ability of outer surface of fruits (like apple and mango) to either participate or not participate in interactions (non-polar) (Medeiros et al. 2012; Ramírez et al. 2012).

1.5 Comparison Between Edible Packaging Films and Synthetic Polymers

The various changes in the properties of various food products result due to the interaction or contact of food and materials used for packaging. Recent reports generated by the government have revealed that food is susceptible to get contaminated due to the possible leaching of chemical components of the cardboard, used for packaging, into the food products like boxes used for packing cereals and pizza. Earlier, phthalates were used while manufacturing cling film but these phthalates contain certain toxic chemicals that could lead to health hazards. But taking this point into consideration, the cling films are now manufactured without using phthalates and, hence, are found to be much safer for use in food industry. The quality of the food commodities is no longer compromised by the use of cling films and reaches the consumer in a very safe form as it aids in protecting as well as preserving the food product till distribution process. A number of factors are considered while choosing the appropriate material for food packaging so that the food is safely delivered to the consumer and any sort of contamination (internal or external) avoided. The most frequently used synthetic films in food industry are low- and high-density polyethylene, polyethylene terephthalate and polyvinylidene chloride, which provide strength, toughness, flexibility, sealability, stiffness and barrier properties against moisture, gas and humidity. Such synthetic packaging materials are extensively used in food industries as plastic bags, container lids, squeezing and juice bottles, etc. (Malhotra et al. 2015).

Synthetic polymers generally being used for packaging material are non-biodegradable and, moreover, their production cost is also very high. The need of the hour is to develop natural polymer-based cling films or edible films from the materials that are biodegradable and get readily converted into carbon dioxide, water and biomass on microbial action. These edible films do not lead to any sort of environmental hazard. Other than these advantages, the shelf life and stability of these natural polymer-based films can be increased by preventing food spoilage caused by microorganisms. Different materials used for manufacturing edible films are polysaccharides, proteins, lipids, nucleic acids and composite materials. Out of all these natural polymers, protein-based films have been accepted wholeheartedly owing to their advantages and use as compared to the synthetic polymer-based films (Malhotra et al. 2015).

1.6 Various Types of Edible Packaging Materials Used in Food and Pharmaceutical Industries

1.6.1 Protein-Based Edible Packaging Materials

Proteins have been widely used for the formation of edible films that involves its denaturation by means of heat treatment, pH change or one or the other solvents. Intermolecular interactions are established between the extended peptide chains, followed by the formation of protein film matrices. The formation of these protein matrices majorly depends on the type of protein chain, denaturation treatment as well as the fabrication conditions, which further leads to the formation of protein films having modified properties. Protein films are reported to have very good optical as well as mechanical properties. These protein-based films are also potent against the transport of aroma, carbon dioxide, oxygen and lipid, but it is not effective to serve as a barrier for moisture due to its innate hydrophilic nature.

For the sake of upgrading the quality and properties of protein-based edible films, many methods have been investigated based on various treatments including chemical, physical and enzymatic. To bring about a change in the physical, structural and chemical properties, different varieties of proteins have been reported to be modified, namely formation of intermolecular cross linking by breaking intramolecular disulphide bonds using heat denaturation; adjustment of pH of protein film-forming solution and modification of protein side chains by either changing solvent or adding salt (Gontard et al. 1992; Avena-Bustillos and Krochta 1993; Brandenburg et al. 1993; Pérez-Gago et al. 1999). And employing physical modifications like lamination, composite formation, ageing, heat curing, annealing and addition of emulsions and nanoparticles (Gennadios et al. 1996; Kim et al. 2002). Usage of enzymatic treatments and irradiation technique is also feasible as it helps in the formation of covalent cross linkage between aromatic amino acids (Gennadios et al. 1998; Vachon et al. 2000). Another research study has reported the use of microfluidization and ultrasound techniques to improve molecular order and enhance intermolecular interactions at the same time (Banerjee et al. 1996).

1.6.1.1 Wheat Gluten

These films are formed by preparing casting solutions with acidic or basic conditions in the presence of reducing agents and alcohol (Cuq et al. 1998). The change in pH caused by acidic and basic conditions of the medium leads to the disruption of hydrophobic, hydrogen and ionic interactions. By the dispersion of wheat gluten in alkaline or acidic environments (addition of reducing agents), the intra- and intermolecular disulphide bridges are cleaved and are reduced to thiol (functional groups). Wheat gluten becomes concentrated after drying of film-forming solution and evaporation of volatile solvents. This results in the formation of new intermolecular interactions as the active sites become free for the sake of bond formations. The cohesive network formed during film formation is contributed by the hydrogen and disulphide bonds as well as hydrophobic interactions.

1.6.1.2 Zein

Zein films are formed by preparing warm casting solutions by dissolving it in aqueous ethyl alcohol or isopropanol. Ethyl alcohol from the film surface is evaporated and it results in the formation of hydrogen, hydrophobic interactions and disulphide bonds within film matrix (Padua and Wang 2002). Zein film acts as a potent barrier against oxygen, moisture and lipid and finds its application in foods like confectioneries, nuts and candies. It is used commercially as a finishing agent that tends to impart surface gloss to the food products. Zein coating is also extensively used in pharmaceutical industry for the controlled release of the active drug ingredients and also to guise the taste of orally administered drugs (Meyer and Mazer 1997). It is also reported that the oil uptake by fried foods and moisture loss is reduced by using zein-based coating materials (Park et al. 1994; Mallikarjunan et al. 1997).

1.6.1.3 Soy Protein Isolate

It is also used for the preparation of film-forming solutions that are formed via hydrophobic interactions as well as intermolecular disulphide when the casting solution is denatured by heat. These films can be used to control lipid oxidation in precooked meat products and also helps to limit moisture loss from the external surface of food commodities (Wu et al. 2000). These films also act as potent carriers for the transport of antioxidants, antimicrobial compounds as well as flavouring agents (Kunte et al. 1997). Soy protein isolate films are used on products like meat pies, cakes containing high moisture content, cheese and coating of fruits and vegetables; where these protective films are used as microencapsulating agents and are highly permeable to water vapours (Petersen et al. 1999).

1.6.1.4 Collagen

Collagen is reported to have high solubility as it tends to swell in polar solvents due to its hydrophilic proteinaceous nature owing to the occurrence of amino acids such as proline, hydroxyproline, glycine, etc. Studies have reported that overwrapping collagen films on refrigerated and thawed beef significantly reduced the colour changes and oxidative changes followed by exudation (Farouk et al. 1990). In order to increase juiciness, reduce shrink loss, absorption of fluids exudates and for the easy removal of nets post-cooking, these collagen-based films have been used for processed meats and meat products.

1.6.1.5 Gelatin

Gelatin coatings are widely used for encapsulating low moisture food products or oil-based foods. It is also used for dietary supplements as it acts as a carrier of bioactive ingredients and oil, and also acts as a barrier against oxygen and moisture.

Gelatin films are used in pharmaceutical industry as an encapsulating agent in forming either soft or hard capsules (Rahman 2007).

1.6.1.6 Casein

Casein films are known to be excellent barriers of oxygen as well as moisture and find its application in retarding lipid oxidation. It also acts as a potent carrier of bioactive ingredients, flavouring agents and nutrients present in food products. Its property of low water activity has been shown to act as a water barrier for fresh produce, frozen foods, water-soluble pouches and dry fruits (Gennadios 1994).

1.7 Carbohydrate-Based Packaging Materials

Carbohydrate-based or polysaccharide coatings are known to act as excellent barriers against oxygen, oil and odour and, at the same time, it provides a little resistance against water migration. For the formation of polysaccharide films, the interactions among long-chain polymeric segments are disrupted and then new bonds are established such as hydrogen bonds and hydrophilic bonds. The solvent is then evaporated in order to obtain a film matrix. These films are known to provide good structural integrity as well as strength. Polysaccharide films help to increase the shelf life of the coated food products as it play a major role in delaying the ripening process of fresh produce. Its hydrogen bonded network contributes to the exceptional oxygen barrier property of these films (Saklani et al. 2019).

1.7.1 Cellulose

Various derivatives of cellulose such as carboxymethyl cellulose, hydroxypropyl methyl cellulose, hydroxypropyl cellulose and methyl cellulose are used as edible packaging materials owing to their excellent film-forming properties. The permeability, solubility, structural and mechanical properties depend upon various factors like the type and degree of substitution for functional group, chain length of the polymer, etc. Cellulose-based coatings are effective barriers against oxygen, moisture as well as oil and are, therefore, applied to a number of food products (Balasubramaniam et al. 1997).

1.7.2 Starch

Starch is composed of two components, namely amylose and amylopectin. These components (amylose and hydroxypropyl amylose) are used for the formation of edible food coatings as well as encapsulating agents. These starch-based films are most commonly used for coating confectionery products, batters, bakery items and meat products owing to its property to act as a barrier against oxygen and lipids. They also help to improve the texture, appearance as well as handling practices.

1.7.3 Chitosan

Properties and viscosity of chitosan films are majorly affected by the type of organic solvent used as these films are formed by casting aqueous acidic solutions. The post-harvest life of fresh fruits and vegetables can be increased by using such chitosan films that are semipermeable in nature. The cationic group (contributed by the amino group) present on chitosan films can easily react with negatively charged groups like ions, cholesterol, fats and proteins. These reactions bring about a good chance of chemical modification. These films exhibit properties like antioxidant, antimicrobial and act as a carrier of bioactive ingredients. It has also been reported in some studies that coatings of chitosan help in delaying enzymatic browning in fresh fruits (Zhang and Quantick 1997; Coma et al. 2002).

1.7.4 Pectin

Water from the pectin gel is evaporated for the formation of edible pectin films. Pectin films act as sacrificing agents by retarding water loss from the food product and prevents it from getting dehydrated; instead the moisture gets lost from the gel matrix. These coatings aid to improve the texture, appearance and handling of food products by retarding water loss and oil migration (Kester and Fennema 1986).

1.7.5 Alginate

Solvent from alginate gels is evaporated to form alginate films. There is another procedure in which the alginate solution is dried and then treated with solution of calcium salt in order to establish cross linkage. Different factors like temperature, pH, time of exposure, concentration of cations and presence of composite constituents play a vital role in the alteration of permeability as well as the strength of alginate films. In similar line with pectin films, the gelatinous alginate films also act as sacrificing agent and, thus, prevent the desiccation or dehydration of enrobed meat. These films are used as encapsulating agents in food and pharmaceutical industries. It also helps to prevent the process of oxidation in foods due to their potent oxygen barrier properties (Hambleton et al. 2009).

1.7.6 Gums

The most widely used gums as coating material for encapsulation are heteropolysaccharides, which have a complex structure including gum ghatti, gum arabic, gum tragacanth and gum karaya. Among them, guar gum is used as a good coating material owing to its properties like solubility (in both hot as well as cold water) and viscosity. It forms a gel-like consistency on binding with calcium. Another example of gum (polysaccharide) is locust bean gum that is neutral in nature and is quite soluble in hot water; thereby producing highly viscous solutions ideal for forming coating material and are also stable at variable temperature and pH (Pegg and Shahidi 2007).

1.8 Lipid-Based Packaging Materials

For many years, lipid-based compounds have been used as wrapping material for protection of food products. Lipid-based coatings are highly fragile, lack cohesiveness and are not self-supporting due to the inability of lipids to form polymers. Lipids lack covalent bonds and do not form long chains as they lack repeating units. These coatings act as a protective barrier against moisture and oxygen. It has been reported that wax films are much more resistant to the migration of water as compared to lipid or non-lipid films used as edible packaging materials. There are various applications of different types of lipid-based coatings. In order to impart a glossy and attractive appearance to food commodities, edible resins like wood resin, terpene resin and shellac are widely used. Shellac possesses low polarity and is used for confectionery and freshly produced food commodities (Saklani et al. 2019). Lipids are used to form composite films as they act as an excellent barrier against water migration. Besides having various advantages as discussed above, the use of lipid-based edible packaging materials is sometimes disadvantageous also due to the greasy surface, possible rancidity as well as their waxy texture and taste (Janjarasskul and Krochta 2010).

1.8.1 Glycol Esters

The properties of edible ingredients for coating food commodities depend upon the degree of saturation, physical state as well as length of chain of fatty acids. Coating films based on glycol esters are either used alone or in combination with other ingredients like fatty alcohols, fatty acids, etc. There are some problems associated with glycol ester coatings like bitter aftertaste, acidic mouthfeel, cracking and flaking during storage (Bourlieu et al. 2008).

1.8.2 Waxes

Wax coatings are much more resistant to water migration as compared to lipid or non-lipid edible films. These are either used alone or in combination with other ingredients. Examples of natural or synthetic edible wax-based coatings include candelilla wax, beeswax, carnauba wax, rice bran wax, paraffin wax, petroleum wax, etc. (Kester and Fennema 1986; Rahman 2007).

1.8.3 Resin

Such coatings like shellac, wood resin and terpene resin are used to give a glossy appearance to food commodities. Shellac consists of aleuritic acid and shellolic acid that are complex polymers of alicyclic and aliphatic -OH acids. Resin coatings are extensively employed in food and pharmaceutical industry as a coating material for fresh produce as well as confectionery food items. They are soluble in alkaline and organic solvents.

1.8.4 Composite Packaging Materials

In general, the fabrication of composite films is done by either of the two methods including lipid emulsion or hydrocolloid bilayer, which is made of a lipid component. The lipid globules are homogenously dispersed by using an emulsifier followed by entrapping into a matrix of hydrocolloid component to provide support. There are two different techniques to form bilayer film, namely emulsion and coating technique. The former comprises of lamination or casting of the molten lipid film-forming solution over a preformed protein-based or polysaccharide-based film for the preparation of final bilayer film, while the latter (emulsion technique) involves the solubilization of lipid in film-forming solution prior to film casting. Post-drying, the bilayer film is formed as a result of phase separation (Pérez-Gago et al. 1999).

Studies have revealed that bilayer films are more efficient as compared to stable emulsion films in terms of exhibiting water vapour barrier properties due to the presence of continuous hydrophilic layer in the film (Debeaufort and Voilley 1995). Besides having advantages, there are certain disadvantages associated with coating technique that the bilayer structure is highly susceptible to get cracked and delaminated. Moreover, two types of castings are required for the coating technique. On the other hand, there are multiple factors that need to be taken into account while fabricating stable emulsion films including melting temperature of the liquid, cross linkage and volatilization of the solvent (Pérez-Gago et al. 1999).

Significant advances have been made in the field of composites and it seems to be correlated with the evolution of nanotechnology. For improving the mechanical barrier properties of edible packaging materials, bio-nanocomposite materials are known for their promising properties (Azeredo et al. 2009; de Moura et al. 2009). Nanoparticles are used in the form of a homogenous dispersion to form a large matrix that further contributes to the thermal and mechanical properties of the material by changing their molecular mobility, nanostructure and relaxation behaviour. Moreover, nanocomponents also aid in refining the barrier properties of the composite films (Dalmas et al. 2007).

1.9 Utilization of Edible Packaging as a Carrier of Bioactive Compounds

The edible packaging is applied on to the food materials by layers that have good impact on preservation, marketing and distribution of foodstuffs by protecting it from microorganisms and physical and chemical damage. Different types of compounds are used to making edible packaging materials including antimicrobials, antioxidants, additives, nutraceuticals and flavouring compounds, which helps to improve the quality of packaging materials and handling (Tavassoli-Kafrani et al. 2016). The use of certain types of antioxidants in edible packaging helps to prevent oxidation of food containing lipids and proteins, which cause a change in flavour and colour (Robertson 2012). The incorporation of antimicrobial compounds into edible packaging materials can help to increase the shelf life of food products and prevents the growth of microorganisms (Bagheripoor et al. 2018; Lappa et al. 2019). The additives also help to improve the bioactive properties of packaging materials; it includes herbs and spices (essential oils, plant extracts and organic compounds) as well as natural antioxidants (Silva-Weiss et al. 2013). In Table 1.1, the role of different bioactive compounds used in edible packaging is shown.

1.10 Formulation of Edible Packaging

The edible packaging formulations involve at least one natural polymer, which is able to formulate a structural matrix that is sufficiently cohesive. The application and functional properties of edible packaging mostly depend on certain cohesion forces, including covalent bonds, ionic bonds and hydrogen bonding, between film-forming polymer molecules. The biopolymer cohesive strengthens it, depending upon the film-making process and parameters, structure and chemistry, plasticizers and additives concentration. In edible coatings, solid fats, resins and waxes are formed by melting and solidification process; for the solubilization, evaporate the solvent with organic solvent followed by the preparation of emulsion by adding water and again evaporating it. The wet and dry processes technology is used to achieve the formation of hydrocolloid-based biopolymer. The wet process also known as solution casting is based on coacervation mechanism. It can also result from the coagulation or thermal gelation process after cooling it in case of gelatin or agar. Based upon the number of biopolymers, the coacervation could be either simple or complex. The fatty substance material and possibly a surfactant is incorporated into the biopolymer solution required if the film formulation is based on an emulsion. This solvent mixture is heated above the melting temperature of fats, homogenized and cast or directly applied while melted or after cooling. For developing film, the different types of solution casting techniques are developed including microwave, air drying, hot surface and infrared. The thermal properties of the film's biopolymer are based on dry thermoplastic extrusion process (Janjarasskul and Krochta 2010).

The several important characteristics of edible packaging are as follows: it does not contain toxic, non-digestible allergic component; it should prevent structural

Table 1.1 The role of different bioactive compounds used into edible packaging

Bioactive compound	Foods	Role of bioactive compound	References
Semi-refined κ-carrageenan and water extract of germinated fenugreek seeds	Chicken breast	• Increase in phenolics content and antioxidant activity • Control the growth of microorganisms	Farhan and Hani (2020)
Lactic acid bacteria and Sodium carboxymethyl cellulose	Banana	• Reduce water vapour and light transmission rates • Prevent lipid oxidation and improve shelf life	Li et al. (2020)
Mango leaf extract	Cashew nuts	• More resistance to oxidation	Rambabu et al. (2019)
Vitamin C and citric acid	Fresh-cut mangoes	• Prevent browning • Increase antioxidant property	Robles-Sánchez et al. (2013)
Clove and oregano oils	Iceberg lettuce	• Effective against coliform bacteria • Reduce discoloration • Improve overall freshness and odour	Wieczyńska and Cavoski (2018)
Limonene	Cucumber	• Possesses weight loss properties, firmness, colour, pH, Tg and organoleptic properties • Reduces fungal growth	Maleki et al. (2018)
Grape seed extract	Rainbow trout fillet	• Maintains the sensorial quality • Extend the shelf life	Hassanzadeh et al. (2018)
Nisin, thymol and lauric arginate	Chicken	• Reduce food-borne pathogens *E. coli, Salmonella spp., L. monocytogenes* and *S. aureus* over 28 days refrigeration condition.	Hassan and Cutter (2020)
Garlic essential oil	Roasted peanuts	• Inhibited growth of *Aspergillus flavus* • Prevents lipid oxidation	Orsuwan and Sothornvit (2018)

stability during handling and display and transportation; the material should uniformly cover the whole surface of food materials; the food materials maintain moisture content and, hence, prevent water transmission rate; the internal environment of foods is maintained during storage like aerobic and anaerobic gases, in addition to the sensory properties, nutritional and organoleptic properties; it should prevent the growth of microbes in food and packaging materials and stop the degradation of compounds; it should provide the micronutrients, flavour and also the colour; the antioxidants and antimicrobial compounds should prevent oxidation of fats and proteins as well as stop the enzymatic activity; the cost of packaging materials should be less and environment friendly as well as the process of manufacturing should be easy (Dinika et al. 2020).

1.11 Applications of Edible Packaging

The selection of appropriate material for fabrication of edible packaging is influence by the storgae conditions of the food that is packaged. The different types of materials used for film and coating of food products include carbohydrates, lipids, proteins and combination of two or more mixture of these. Edible packaging plays important role in extending the shelf life of food products (Falguera et al. 2011). The applications of edible packaging on various food products are explained below.

1.11.1 Fruits and Vegetables

The major cause of spoilage caused in fruits and vegetables is exchange of gas during storage and microbial growth (Bakar et al. 2020). For fruits and vegetables, mineral oils, paraffin, beeswax, candelilla shellac and waxes are used for edible packaging (Baldwin 1994). The main aim of edible coating is to improve the natural vegetable and fruit barrier. This coating material is eaten as food, it helps to increase the shelf life of foods as well as it is eco-friendly (Ali et al. 2010). The different types of processing technologies involved in the processing of fruits and vegetables increase the chances of nutrient loss. The 30% of spoilage of fruits and vegetables are due to action of microorganisms and insects during harvesting time, transportation and maintenance process, which lead to tissue damage and, hence, the integrity of the food products. Fruits and vegetables are becoming more susceptible to contamination, development of undesirable volatile compounds and changes in texture; all these reduce their health benefits (Ribeiro et al. 2020). These changes in fruits and vegetables are controlled by using artificial materials in the form of edible films or coatings (Senturk Parreidt et al. 2018). The application of edible packaging on fruits and vegetables and their effects are shown in Table 1.2.

1.11.2 Dairy Products

The dairy products are described as products that get through by processing of milk; it may contain ingredients or food additives. The demand of milk products has been observed to increase particularly in developing countries due to the increasing population and also change in dietary patterns (FAO 2019). The dairy products are good source of essential nutrients that are important for children's growth and also maintaining good health of adults (Cardador and Gallego 2016). The use of edible packaging material for cheese helps to minimize quality losses. These changes mostly happened due to action of microbes and enzymes, development of undesirable compounds, changes in sensory properties and moisture loss (Senturk Parreidt et al. 2018; Guitián et al. 2019). The application of edible packaging on dairy products and their effects are shown in Table 1.2.

Table 1.2 Application of edible packaging on different foods

Foods	Edible packaging materials	Outcomes and results obtained	References
Fruits and vegetable applications			
Strawberries	Pectin, lemongrass essential oil and cellulose nanocrystals	• The edible coating was effective to minimize weight loss without affecting the chemical parameters	Da Silva et al. (2019)
Orange	Salicylic acid and aloe vera gel	• It help to maintain the quality during cold storage and inhibits growth of microorganisms	Rasouli et al. (2019)
Tomatoes	Almond gum and gum arabic	• Increase the shelf life and affect changes in weight, firmness, titratable acidity, TSS, colour, vitamin C content and decay percentage of tomatoes	Mahfoudhi et al. (2014)
Soybean oil	Pomelo peel flour and tea polyphenol	• Oil oxidation reduces during storage	Wu et al. (2019)
Potato chips	Whey protein and rosemary extract	• The acrylamide and oil content during frying reduce, improve firmness and texture as well as sensory properties	Trujillo-Agudelo et al. (2020)
Dairy products applications			
Paneer	Casein and clove bud essential oil	• Maintain the sensory quality of paneer	Archana et al. (2020)
Cheddar cheese	Linalool, carvacrol and thymol	• Reduce the growth of *A. niger* on the surface of cheddar cheese after 35 days of storage at 15 °C	Kuorwel et al. (2014)
Cheeses	Agar and glycerol	• Control the growth of *L. monocytogenes* in cheeses	Guitián et al. (2019)
Kashar cheese	Sorbitol, whey protein isolate, alginate and ginger essential oil	• Decrease the growth of *E. coli* O157:H7 and *S. aureus*	Kavas et al. (2016)
Meats, poultry and seafood applications			
Beef	Heracleum lasiopetalum essential oil and *Lepidium sativum* seed mucilage	• Maintain the overall acceptance • Prevent microorganism growth and oxidation	Barzegar et al. (2020)
Fresh pork	Grape seed extract, nisin and chitosan alginate	• Inhibit pork oxidation and microbial spoilage	Xiong et al. (2020)
Beef	Basil extract and alginate	• Improve the antioxidant properties and reduced the lipid oxidation during storage	Alexandre et al. (2020)
Fish sausage	Papaya seed extract and sago starch-gelatine	• No colour changes during storage • Maintain overall quality	Bakar et al. (2020)

(continued)

Table 1.2 (continued)

Fruits and vegetable applications			
Foods	Edible packaging materials	Outcomes and results obtained	References
Smoked salmon	Gulfweed seed	• No effects on aroma	Kim et al. (2018)
Chicken breast fillet	Ginger essential oil and sodium caseinate	• Increase the shelf life • Decrease the level of aerobic bacteria under refrigeration storage for 12 days and no significant effect on TBARS value	Noori et al. (2018)
Chicken breast fillets	Black pepper seed extract, turmeric extract and carboxymethyl cellulose	• Good antimicrobial activity against total aerobic mesophilic bacteria and total aerobic psycrotrophic bacteria • Maintain colour, appearance, odour and overall acceptability during storage	Dalvandi et al. (2020)

1.11.3 Meats, Poultry and Seafoods

The quality of meat, poultry and seafood products is improved by using edible packaging as it helps to minimize the moisture loss, prevents oxidation, improves the overall appearance, improves sensory properties and increases the shelf life (Gennadios et al. 1997). The quality of meat is known to increase during storage, when packed with carbohydrate based edible films. The weak water barrier properties of carrageenan, when it is applied on fresh and frozen meat, poultry and fish compared to polysaccharides, help to prevent moisture loss (Debeaufort et al. 1998). The use of this packaging method involves different processes like spraying, dipping, foaming, casting, individual wrapping and rolling on to meats, poultry and seafood products. The application of edible packaging on meats, poultry and seafood products and their effects are shown in Table 1.2.

1.12 Regulations

The edible packaging is an integral part of the edible portion of the food items; therefore, it is necessary to follow all the regulations relevant to food ingredients (Guilbert and Gontard 1995). The edible packaging, depending on its role, could be classified as food contact substances, food packaging materials, food products or food ingredients (Debeaufort et al. 1998). While making edible packaging films or coating, ingredients must be generally recognized as safe (GRAS) for the intended use or approved by the FDA or U.S. Pharmacopoeia/National Formulary. One has to follow the good manufacturing practices (GMP) while using edible packaging materials and additives (Janjarasskul and Krochta 2010). The different types of edible packaging materials are made up of eggs, fish, milk (casein and whey), wheat, peanuts and soy proteins; therefore, taking it into account that some of these are allergens, it must provide all information to consumers according to Food Allergen Labelling and Consumer Protection Act of 2004 (Franssen and Krochta 2003; Janjarasskul and Krochta 2010).

1.13 Advantages and Disadvantages of Edible Packaging

Edible packaging is biodegradable, it prevents moisture loss and helps to stop chemical reaction in foods like one of the enzymatic reactions (Osorio et al. 2011). The edible packaging materials help to increase the shelf life of foods by minimizing loss of oxidation, gas permeation rate, inhibit the growth of microorganisms and oxidative rancidity (Dhanapal et al. 2012). Edible packaging materials do not contain any harmful chemical substances, instead it contain natural and biodegradable substances that are obtained from agricultural sources and, thus, help to protect the environment (Debeaufort et al. 1998). These packaging materials can be directly consumed with food products and do not cause any harm to the animals (Shit and Shah 2014). Edible packaging acts as a carrier with the addition of some naturally available bioactive compounds and agents in accordance with internationally induced dose release of antimicrobial, antioxidants and vitamins to the specific alimentary matrix. It also helps to increase the quality and reduce microbial load of foods (Suhag et al. 2020).

The thick coating is applied onto any type of food products, which prohibit oxygen exchange and development of off flavour in the food products. The edible coating plays an important role as a gas barrier so it causes anaerobic respiration in fruits and vegetables, which results in causing a delay in the ripening process. In addition, some edible packaging materials are present into hygroscopic form so it helps to hinder microorganism growth (Raghav et al. 2016).

1.14 Consumer Acceptance and Commercialization

The consumer acceptance includes properties like sensory properties, marketing, safety as well as cultural and religious restrictions associated with the use of new materials and applications, and is also significantly affected by potential uses of edible materials. The cost of edible packaging materials is another factor that influences consumer acceptance. It has been revealed that the cost of edible packaging is high as compared to the plastic packaging materials. During the manufacturing of edible packaging materials, major focus is kept on reducing the cost of packaging materials so that the consumers are attracted more towards edible packaging materials.

1.15 Conclusion

The demand to use sustainable packaging solution has forced all manufacturing industries to amend their ways and thus, have significantly changed the packaging industry aswell. In the other side of packaging sectors, the edible packaging is recognized as healthy, biodegradable, low cost and sustainable as compared to the plastic packaging materials. The edible packaging (coatings, sheets, pouches and films) provides a good oxygen barrier, moisture barrier and aroma barrier properties. Different types of compounds are used to make edible packaging materials including antimicrobials, antioxidants, additives, nutraceuticals and flavouring compounds, which helps to upgrade the quality of packaging materials and handling. The edible packaging is used for different foods like fruits and vegetables, dairy products, meat, poultry, seafoods, nuts, cereals and confectionary products. The advantages of edible packaging material are unique and versatile such as providing product stability, variety, better quality, more safety along with convenience to consumers. The future research is required on reducing the cost of packaging materials, how to implement it on industrial scale, improve its functional properties and to evaluate the compatibility between packaging, final product along with human consumption.

References

Alexandre S, Vital AC, Mottin C, do Prado RM, Ornaghi MG, Ramos TR, Guerrero A, Pilau EJ, do Prado IN (2020) Use of alginate edible coating and basil (Ocimum spp) extracts on beef characteristics during storage. J Food Sci Technol 22:1–9

Ali A, Maqbool M, Ramachandran S, Alderson PG (2010) Gum arabic as a novel edible coating for enhancing shelf-life and improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruit. Postharvest Biol Technol 58(1):42–47

Álvarez MF (2000) Revisión: Envasado activo de los alimentos/review: active food packaging. Food Sci Technol Int 6(2):97–108

Archana S, Divya KB, Rajakumar SN, Aswin SW (2020) Evaluation of sensory quality of paneer with casein based edible coating incorporated with essential oil. Pharma Innovation 9(11):26–28

Avena-Bustillos RJ, Krochta JM (1993) Water vapor permeability of caseinate-based edible films as affected by pH, calcium crosslinking and lipid content. J Food Sci 58(4):904–907

Azeredo HM, Mattoso LH, Wood D, Williams TG, Avena-Bustillos RJ, McHugh TH (2009) Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. J Food Sci 74(5):31–35

Bagheripoor N, Khoshgozaran-Abras S, Sohrabvandi S, Khorshidian N, Mortazavian AM, MollaKhalili N, Jazaeri S (2018) Application of active edible coatings to improve the shelf-life of cheese. Food Sci Technol Res 24(6):949–962

Bakar J, Kadir NA, Mazlan AA, Ismail-Fitry MR (2020) Effect of edible coating of sago starch-gelatine incorporated with papaya seed extract on the storage stability of Malaysian fish sausage (keropok lekor). Int Food Res J 27(4):618–624

Balasubramaniam VM, Chinnan MS, Mallikarjunan P, Phillips RD (1997) The effect of edible film on oil uptake and moisture retention of a deep-fat fried poultry product. J Food Process Eng 20 (1):17–29

Baldwin EA (1994) Edible coatings for fresh fruits and vegetables: past, present, and future. Edible Coat Films Improve Food Qual 1:25

Banerjee R, Chen H, Wu J (1996) Milk protein-based edible film mechanical strength changes due to ultrasound process. J Food Sci 61(4):824–828

Barzegar H, Behbahani BA, Mehrnia MA (2020) Quality retention and shelf life extension of fresh beef using *Lepidium sativum* seed mucilage-based edible coating containing Heracleum lasiopetalum essential oil: an experimental and modeling study. Food Sci Biotechnol 29 (5):717–728

Bourlieu C, Guillard V, Vallès-Pamiès B, Gontard N (2008) Edible moisture barriers for food product stabilization. In: Food materials science. Springer, New York, pp 547–575

Brandenburg AH, Weller CL, Testin RF (1993) Edible films and coatings from soy protein. J Food Sci 58(5):1086–1089

Cardador MJ, Gallego M (2016) Origin of haloacetic acids in milk and dairy products. Food Chem 196:750–756

Coma V, Martial-Gros A, Garreau S, Copinet A, Salin F, Deschamps A (2002) Edible antimicrobial films based on chitosan matrix. J Food Sci 67(3):1162–1169

Cuq B, Gontard N, Guilbert S (1998) Proteins as agricultural polymers for packaging production. Cereal Chem 75(1):1–9

Da Silva ISV, Prado NS, De Melo PG, Arantes DC, Andrade MZ, Otaguro H, Pasquini D (2019) Edible coatings based on apple pectin, cellulose nanocrystals, and essential oil of lemongrass: improving the quality and shelf life of strawberries (Fragaria Ananassa). J Renew Mat 7 (1):73–87

Dalmas F, Cavaillé JY, Gauthier C, Chazeau L, Dendievel R (2007) Viscoelastic behavior and electrical properties of flexible nanofiber filled polymer nanocomposites. Influence of processing conditions. Compos Sci Technol 67(5):829–839

Dalvandi F, Almasi H, Ghanbarzadeh B, Hosseini H, Karimian Khosroshahi N (2020) Effect of vacuum packaging and edible coating containing black pepper seeds and turmeric extracts on shelf life extension of chicken breast fillets. J Food Bioprocess Eng 1(3):69–78

de Moura MR, Aouada FA, Avena-Bustillos RJ, McHugh TH, Krochta JM, Mattoso LH (2009) Improved barrier and mechanical properties of novel hydroxypropyl methylcellulose edible films with chitosan/tripolyphosphate nanoparticles. J Food Eng 92(4):448–453

Debeaufort F, Voilley A (1995) Effect of surfactants and drying rate on barrier properties of emulsified edible films. Int J Food Sci Technol 30(2):183–190

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

Dhanapal A, Sasikala P, Rajamani L, Kavitha V, Yazhini G, Banu MS (2012) Edible films from polysaccharides. Food Sci Quality Manag 3(0):9

Dinika I, Verma DK, Balia R, Utama GL, Patel AR (2020) Potential of cheese whey bioactive proteins and peptides in the development of antimicrobial edible film composite: a review of recent trends. Trends Food Sci Technol. https://doi.org/10.1016/j.tifs.2020.06.017

Fabra MJ, Hambleton A, Talens P, Debeaufort F, Chiralt A, Voilley A (2009) Influence of interactions on water and aroma permeabilities of ι-carrageenan–oleic acid–beeswax films used for flavour encapsulation. Carbohyd Polym 76(2):325–332

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

Farhan A, Hani NM (2020) Active edible films based on semi-refined κ-carrageenan: antioxidant and color properties and application in chicken breast packaging. Food Packag Shelf Life 24:100476

Farouk MM, Price JF, Salih AM (1990) Effect of an edible collagen film overwrap on exudation and lipid oxidation in beef round steak. J Food Sci 55(6):1510–1512

Food and Agricultural Organization of the United Nations (2019) Milk and milk products. http://www.fao.org/economic/est/est-commodities/dairy/milk-and-milk-products/en/. Accessed 25 Dec 2020

Franssen LR, Krochta JM (2003) Edible coatings containing natural antimicrobials for processed foods. In: Natural antimicrobials for the minimal processing of foods. Woodhead Publishing, pp 250–262

Galus S, Kadzińska J (2016) Whey protein edible films modified with almond and walnut oils. Food Hydrocol 52:78–86

Gennadios A (1994) Edible and coating and films to improved food quality. In: Edible coating and film based on proteins, pp 201–277

Gennadios A, Ghorpade VM, Weller CL, Hanna MA (1996) Heat curing of soy protein films. Trans ASAE 39(2):575–579

Gennadios A, Hanna MA, Kurth LB (1997) Application of edible coatings on meats, poultry and seafoods: a review. LWT-Food Sci Technol 30(4):337–350

Gennadios A, Rhim JW, Handa A, Weller CL, Hanna MA (1998) Ultraviolet radiation affects physical and molecular properties of soy protein films. J Food Sci 63(2):225–228

Gontard N, Guilbert S, Jean-Louis CUQ (1992) Edible wheat gluten films: influence of the main process variables on film properties using response surface methodology. J Food Sci 57 (1):190–195

Guilbert S, Gontard N (1995) Edible and biodegradable food packaging. In: Ackermann P, Jägerstad M, Ohlsson T (eds) Foods and packaging materials—chemical interactions. The Royal Society of Chemistry, England, UK, pp 159–168

Guitián MV, Ibarguren C, Soria MC, Hovanyecz P, Banchio C, Audisio MC (2019) Anti-*Listeria monocytogenes* effect of bacteriocin-incorporated agar edible coatings applied on cheese. Int Dairy J 97:92–98

Hambleton A, Debeaufort F, Bonnotte A, Voilley A (2009) Influence of alginate emulsion-based films structure on its barrier properties and on the protection of microencapsulated aroma compound. Food Hydrocol 23(8):2116–2124

Han JH, Krochta JM (2001) Physical properties and oil absorption of whey-protein-coated paper. J Food Sci 66(2):294–299

Hassan AH, Cutter CN (2020) Development and evaluation of pullulan-based composite antimicrobial films (CAF) incorporated with nisin, thymol and lauric arginate to reduce foodborne pathogens associated with muscle foods. Int J Food Microbiol 320:108519

Hassanzadeh P, Moradi M, Vaezi N, Moosavy MH, Mahmoudi R (2018) Effects of chitosan edible coating containing grape seed extract on the shelf-life of refrigerated rainbow trout fillet. Vet Res Forum 9(1):73

Hong SI, Krochta JM (2003) Oxygen barrier properties of whey protein isolate coatings on polypropylene films. J Food Sci 68(1):224–228

Janjarasskul T, Krochta JM (2010) Edible packaging materials. Ann Rev Food Sci Technol 1:415–448

Kavas N, Kavas G, Saygili D (2016) Use of ginger essential oil-fortified edible coatings in Kashar cheese and its effects on *Escherichia coli* O157: H7 and *Staphylococcus aureus*. CyTA-J Food 14(2):317–323

Kester JJ, Fennema OR (1986) Edible films and coatings: a review. Food Technol (USA). https://agris.fao.org/agris-search/search.do?recordID=US8836195

Kim KW, Ko CJ, Park HJ (2002) Mechanical properties, water vapor permeabilities and solubilities of highly carboxymethylated starch-based edible films. J Food Sci 67(1):218–222

Kim SY, Kang JH, Jo JH, Min SC (2018) Development of a gulfweed-based edible coating using high-pressure homogenization and its application to smoked Salmon. J Food Sci 83 (12):3027–3034

Krochta JM (2002) Proteins as raw materials for films and coatings: definitions, current status, and opportunities. Protein-Based Films Coat 1:1–40

Krochta JM, De Mulder-Johnston C (1997) Edible and biodegradable polymer films: challenges and opportunities. Food Technol 51(2):61–73

Kunte LA, Gennadios A, Cuppett SL, Hanna MA, Weller CL (1997) Cast films from soy protein isolates and fractions. Cereal Chem 74(2):115–118

Kuorwel KK, Cran MJ, Sonneveld K, Miltz J, Bigger SW (2014) Evaluation of antifungal activity of antimicrobial agents on cheddar cheese. Packaging Technol Sci 27(1):49–58

Lappa IK, Papadaki A, Kachrimanidou V, Terpou A, Koulougliotis D, Eriotou E, Kopsahelis N (2019) Cheese whey processing: integrated biorefinery concepts and emerging food applications. Foods 8(8):347

Lee DS, Yam KL, Piergiovanni L (2008) Food packaging science and technology. CRC Press

Li S, Ma Y, Ji T, Sameen DE, Ahmed S, Qin W, Liu Y (2020) Cassava starch/carboxymethylcellulose edible films embedded with lactic acid bacteria to extend the shelf life of banana. Carbohyd Polym 248:116805

Lima ÁM, Cerqueira MA, Souza BW, Santos ECM, Teixeira JA, Moreira RA, Vicente AA (2010) New edible coatings composed of galactomannans and collagen blends to improve the postharvest quality of fruits–Influence on fruits gas transfer rate. J Food Eng 97(1):101–109

Mahfoudhi N, Chouaibi M, Hamdi S (2014) Effectiveness of almond gum trees exudate as a novel edible coating for improving postharvest quality of tomato (*Solanum lycopersicum* L.) fruits. Food Sci Technol Int 20(1):33–43

Maleki G, Sedaghat N, Woltering EJ, Farhoodi M, Mohebbi M (2018) Chitosan-limonene coating in combination with modified atmosphere packaging preserve postharvest quality of cucumber during storage. J Food Measure Charact 12(3):1610–1621

Malhotra B, Keshwani A, Kharkwal H (2015) Natural polymer based cling films for food packaging. Int J Pharm Pharm Sci 7(4):10–18

Mallikarjunan P, Chinnan MS, Balasubramaniam VM, Phillips RD (1997) Edible coatings for deep-fat frying of starchy products. LWT-Food Sci Technol 30(7):709–714

Medeiros BGDS, Pinheiro AC, Carneiro-da-Cunha MG, Vicente AA (2012) Development and characterization of a nanomultilayer coating of pectin and chitosan–evaluation of its gas barrier properties and application on 'Tommy Atkins' mangoes. J Food Eng 110(3):457–464

Meyer GA, Mazer TB (1997) U.S. Patent No. 5,599,556. U.S. Patent and Trademark Office, Washington, DC

Noori S, Zeynali F, Almasi H (2018) Antimicrobial and antioxidant efficiency of nanoemulsion-based edible coating containing ginger (*Zingiber officinale*) essential oil and its effect on safety and quality attributes of chicken breast fillets. Food Control 84:312–320

Orsuwan A, Sothornvit R (2018) Active banana flour nanocomposite films incorporated with garlic essential oil as multifunctional packaging material for food application. Food Bioprocess Technol 11(6):1199–1210

Osorio FA, Molina P, Matiacevich S, Enrione J, Skurtys O (2011) Characteristics of hydroxy propyl methyl cellulose (HPMC) based edible film developed for blueberry coatings. Procedia Food Sci 1:287–293

Padua GW, Wang Q (2002) Formation and properties of corn zein films and coatings. In: Protein-based films and coatings. CRC Press, pp 43–67

Park HJ, Chinnan MS, Shewfelt RL (1994) Edible corn-zein film coatings to extend storage life of tomatoes. J Food Process Preserv 18(4):317–331

Pegg RB, Shahidi F (2007) Encapsulation, stabilization, and controlled release of food ingredients and bioactives. In: Handbook of food preservation. CRC Press, pp 527–586

Pérez-Gago MB, Nadaud P, Krochta JM (1999) Water vapor permeability, solubility, and tensile properties of heat-denatured versus native whey protein films. J Food Sci 64(6):1034–1037

Petersen K, Nielsen PV, Bertelsen G, Lawther M, Olsen MB, Nilsson NH, Mortensen G (1999) Potential of biobased materials for food packaging. Trend Food Sci Technol 10(2):52–68

Raghav PK, Agarwal N, Saini M (2016) Edible coating of fruits and vegetables: a review. Int J Sci Res Modern Edu 1(1):188–204

Rahman MS (ed) (2007) Handbook of food preservation. CRC Press

Rambabu K, Bharath G, Banat F, Show PL, Cocoletzi HH (2019) Mango leaf extract incorporated chitosan antioxidant film for active food packaging. Int J Biol Macromol 126:1234–1243

Ramírez C, Gallegos I, Ihl M, Bifani V (2012) Study of contact angle, wettability and water vapor permeability in carboxymethylcellulose (CMC) based film with murta leaves (*Ugni molinae* Turcz) extract. J Food Eng 109(3):424–429

Ramos ÓL, Reinas I, Silva SI, Fernandes JC, Cerqueira MA, Pereira RN, Malcata FX (2013) Effect of whey protein purity and glycerol content upon physical properties of edible films manufactured therefrom. Food Hydrocol 30(1):110–122

Rasouli M, Saba MK, Ramezanian A (2019) Inhibitory effect of salicylic acid and *Aloe vera* gel edible coating on microbial load and chilling injury of orange fruit. Sci Hortic 247:27–34

Ribeiro AM, Estevinho BN, Rocha F (2020) Preparation and incorporation of functional ingredients in edible films and coatings. Food Bioprocess Technol:1–23

Robertson GL (2012) Food packaging: principles and practice, 3rd edn. CRC Press, United States of America

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

Saklani PS, Nath S, Kishor Das S, Singh SM (2019) A review of edible packaging for foods. Int J Curr Microbiol Appl Sci 8(7):2885–2895

Senturk Parreidt T, Müller K, Schmid M (2018) Alginate-based edible films and coatings for food packaging applications. Foods 7(10):170

Shit SC, Shah PM (2014) Edible polymers: challenges and opportunities. J Polym. https://doi.org/10.1155/2014/427259

Silva-Weiss A, Ihl M, Sobral PDA, Gómez-Guillén MC, Bifani V (2013) Natural additives in bioactive edible films and coatings: functionality and applications in foods. Food Eng Rev 5 (4):200–216

Souza BW, Cerqueira MA, Ruiz HA, Martins JT, Casariego A, Teixeira JA, Vicente AA (2010) Effect of chitosan-based coatings on the shelf life of salmon (*Salmo salar*). J Agric Food Chem 58(21):11456–11462

Suhag R, Kumar N, Petkoska AT, Upadhyay A (2020) Film formation and deposition methods of edible coating on food products: a review. Food Res Int 136:109582

Tang CH, Jiang Y (2007) Modulation of mechanical and surface hydrophobic properties of food protein films by transglutaminase treatment. Food Res Int 40(4):504–509

Tavassoli-Kafrani E, Shekarchizadeh H, Masoudpour-Behabadi M (2016) Development of edible films and coatings from alginates and carrageenans. Carbohyd Polym 137:360–374

Trujillo-Agudelo S, Osorio A, Gómez F, Contreras-Calderón J, Mesías-Garcia M, Delgado-Andrade C, Vega-Castro O (2020) Evaluation of the application of an edible coating and different frying temperatures on acrylamide and fat content in potato chips. J Food Process Eng 43(5):e13198

Vachon C, Yu HL, Yefsah R, Alain R, St-Gelais D, Lacroix M (2000) Mechanical and structural properties of milk protein edible films cross-linked by heating and γ-irradiation. J Agric Food Chem 48(8):3202–3209

Wieczyńska J, Cavoski I (2018) Antimicrobial, antioxidant and sensory features of eugenol, carvacrol and trans-anethole in active packaging for organic ready-to-eat iceberg lettuce. Food Chem 259:251–260

Wu Y, Rhim JW, Weller CL, Hamouz F, Cuppett S, Schnepf M (2000) Moisture loss and lipid oxidation for precooked beef patties stored in edible coatings and films. J Food Sci 65 (2):300–304

Wu H, Lei Y, Zhu R, Zhao M, Lu J, Xiao D, Li S (2019) Preparation and characterization of bioactive edible packaging films based on pomelo peel flours incorporating tea polyphenol. Food Hydrocol 90:41–49

Xiong Y, Chen M, Warner RD, Fang Z (2020) Incorporating nisin and grape seed extract in chitosan-gelatine edible coating and its effect on cold storage of fresh pork. Food Control 110:107018

Zhang D, Quantick PC (1997) Effects of chitosan coating on enzymatic browning and decay during postharvest storage of litchi (*Litchi chinensis* Sonn.) fruit. Postharvest Biol Technol 12 (2):195–202