Review Paper

Technological, applications, and characteristics of edible films and coatings: a review

Ahmed R. A. Hammam[1]

Abstract
In the last 2 decades, food packaging and packaging industry have received considerable attention from those who interested in manufacturing edible films and biodegradable packaging materials. The interest in whey proteins has increased because of their environmental benefits, availability in large quantities as residues, non-toxicity, low price, high nutritional values, and suitability for the packaging and protecting foods from damage. The purpose of this work is to highlight and review the importance of using edible films and coatings. This work also emphasizes the benefits of using edible films in the packaging industry. Finally, this work presents the most popular varieties of edible films, such as whey protein films and lipid films and their characteristics.

Keywords Edible film · Coatings · Food packaging · Whey protein films · Lipid films

1 Introduction

The packaging is an essential part of the food industry to keep the product fresh and its physiochemical properties during transportation and until consumption. The plastic packages are used widely, with approximately 70% of the total packaging materials [1]. Most of the plastic materials are non-biodegradable and are derived from non-renewable materials. However, their presence in the environment with the persistence and difficulty of disposing of their residues has become one of the significant problems that threaten the environment. Some of the plastic packages are used to improve the quality of the product as well as colored materials, which have recently proven that some of these substances have a negative impact on human health due to the interaction of food with the packages. These residues (heavy metals e.g. cadmium, mercury) cause health problems, such as poisoning or cancer. Furthermore, these substances affect the environment adversely, thus burning these materials lead to produce contaminated gases with sulfur oxides, nitrogen oxides, and carbon oxides [2].

In the past 2 decades, food packaging and packaging industry have received significant attention from those who interested in the food safety and environmental conservation. As a result, the food packaging industry tried to innovate edible films and biodegradable packaging materials. Proteins are generally considered suitable polymers for the formation of edible and biodegradable films due to their abilities to preserve moisture, gas, and aromatic flavors. Moreover, proteins have many advantages, such as acting as a buffer to inhibit the microorganism, carrying food additives, and improving the appearance of products by adding color or gloss to attract the consumers [3].

Proteins have a unique structure, consisting of 20 monomers, which gives a wide range of properties to films. Protein films, therefore, have good preservation characteristics of gases compared to lipid and polysaccharides films. However, they have less water preservation and mechanical strength properties than industrial polymers which limit their use in dietary applications. As a result,

Ahmed R. A. Hammam, Ahmed.Hammam@sdstate.edu | [1]Dairy and Food Science Department, South Dakota State University, Brookings, SD 57007, USA.

SN Applied Sciences (2019) 1:632 | https://doi.org/10.1007/s42452-019-0660-8

Received: 22 February 2019 / Accepted: 21 May 2019 / Published online: 24 May 2019

enzymatic, chemical, and physical improvements have been applied on proteins to increase their binding abilities and to improve the mechanical and preservation properties of these films [4].

The recycling of industrial waste has become a feature of progression in many countries to preserve the environment. Whey protein, which is a by-product derived from making cheese, has been used as one of the ingredients of functional foods. Whey protein is considered one of the modern trends in the manufacture of the films as well as its uses for the production of new polymeric materials capable of biodegradation due to its exceptional ability to interact and form sticky plastic [5]. Over the last 2 decades, the interest in whey proteins has increased because of their environmental benefits, their availability in large quantities as residues, non-toxicity, their low price, their high nutritional values, and their suitability for the packaging and protecting foods from damage [6].

The new standards of research and protection of the environment and consumers claimed to obtain a safe food and clean environment. The importance of whey proteins nutritional and industrial values led to increasing the possibility of their using in making edible films for food packaging.

2 Packaging and coatings

The process of packaging is an important stage in the food industry as it helps in preserving food and facilitating its circulation during marketing. The marketing of the products depends on the quality of the packaging material and its efficiency in preserving the food products from the physiochemical and biological damages after manufacturing and during the storage period. The primitive humans used animal skins, broad leaves, and dried fruits, such as coconut to preserve their food from damage. With the development of time; fabrics, then glassware, and followed by pottery have been used to preserve and foods. In recent years, researches have focused on the development of food preservation to increase the storage period and transport to long distances, such as cans, metal drums and flexible metals (e.g. aluminum, tin and glass, as in the case of bottles), solid and semi-solid plastics and various types of elastomers paper, cardboard, and wood [1].

Food packaging is divided into three types depending on their proximity or contact with the food, and their function. The first film is directly contacted with the food which should provide protection during storage and distribution. Followed by the secondary film that is not directly in contact with the food and used for the physical protection of food products, such as plastic boxes and flexible bags. Then the third film (outer layer or film), such as pallets and stretch foils, incorporates secondary films into the coated material transport system to protect it from mechanical damage and environmental or air conditions. Edible packaging is similar to primary or initial packaging functions [7].

Plasticizer materials were commonly used in the food packaging due to their availability, low prices, and flexibility of their use, as well as their hardness and formability. However, their residues were increased around the world due to the decline of the lands allocated for the landfill in industrial areas. Some of their substances have harmful effects when they are in direct contact with the food, as it has been shown to cause brain cancer in particular if the food is placed hot [2]. On the other hand, biomaterials such as natural substances, sugars, renewable fats, biodegradation, and plant or animal materials, such as proteins which are environmentally friendly [8, 9].

3 Biopolymers materials

The use of biopolymers or bio-packaging materials in the protection of food from the damage to increase the shelf-life is back to the ancient Egyptians era. Then the plastic materials have been discovered which have played a critical role in the food packaging except for cellulose that was used as a natural material derived from petrochemicals (traditional polymers). Biopolymers derived from natural components by chemical reactions to form compounds with long chains. The chemical composition gives the method of collocation occurring between the polymer chains which determine the properties of the final formed film [1]. Regalado et al. [1] reported that microorganisms completely transform biopolymers into compounds, such as carbon dioxide, water, and biomass.

Biopolymers have been divided into three categories: (1) Polymers are derived directly from living substances, such as polysaccharides (starch, cellulose and derivatives, plant gum, such as Arabic gum, etc.) and fats (beeswax, vegetable fats, animal fats, fatty acids, and their derivatives), and proteins, such as casein, whey proteins, and soy proteins [10]. (2) Polymers are originated by conventional chemical synthesis using biological substances of polylactate, which is resulted from sugar fermentation, cellulose, and cellulose nitrate. (3) Polymers are produced by selective microorganisms or genetically modified bacteria, such as gill, xanthan, and bacterial cellulose [11].

4 Edible films and coatings

Wax coating for vegetables and fresh citrus to prevent moisture loss and maintain the strength and quality of vegetables during storage has been known since the twelfth century in China [3]. In 1930, paraffin was used first to protect citrus in the United States, while carnauba wax was used in 1950 as an emulsifier to protect fresh fruits and vegetables [11]. Also, the edible films elaborated from animal intestine have been used since 1900 to preserve sausage, wax capsules, and gelatin capsules as well as using resins to improve the appearance [12].

Technology has developed carbohydrates and proteins which are vital polymers that can be shaped like wax but are more cohesive, flexible, and have better gas barrier properties [13]. Many studies have been conducted on the use of wheat gluten, soy protein, casein, starch, and cellulose. The films and coatings made from these organic polymers are edible and have the ability for degradation and formation. These films have received special privileges for being used in packaging, which reduce the traditional packaging materials from non-renewable sources [14].

The edible films (Fig. 1) can be defined as a thin (0.050–0.250 mm thickness) and cohesive layer formed from a matrix of bioactive polymers [3] or thin layers of edible materials used to roll, immerse, coat or spray the foods to provide selective barrier that prevents the passage of gases, water vapor, dissolved solids or fats, as well as mechanical protection [11, 15]. These films prevent the loss of volatile flavor compounds from the food and consider as a barrier to preserve the product from microorganisms, as well as their ability to carry additives. These films also improve the appearance of the product by adding colors or gloss to be more attractive to consumers [3]. Biofilms enhance the nutritional value of foods, especially protein-based films, such as casein, whey proteins, and wheat gluten due to their content of amino acids [4].

Packaging process has functional properties other than preserving moisture, gases, and solvents, by incorporation of components within the packaging system and to maintain the quality of the product to extend its shelf-life [16]. Also, these components should be able to displace the carbon dioxide scavenging and oxygen scavenging and to work as moisture control and antimicrobial agents. These oxygen scavenging films are used in meat packaging to preserve the meat color during storage. It was found that the meat discoloration could be controlled by packaging with less than 1% oxygen concentrations [17].

Intelligent packaging is an advanced function, which monitors the status of packaged foods to provide information regarding their qualities during transportation and storage, such as containing a sensor or an indicator that is sensitive to any change occurred in the foods. Indicators may address these changes, such as freshness; thus the product directly provides the information resulting from microbiological growth or chemical changes through the interaction between the indicator and the metabolites of the microbes. Moreover, these indicators detect the chemical compounds, which led to the deterioration of food during storage [18, 19]. Currently, the barcode, which is being developed to detect pathogens in the packed food, has been used to detect and interact with the biosensor and giving a signal of toxicity [17].

5 Types of edible films

Edible films are divided into simple films and composite films according to the nature of the materials used in preparing them.

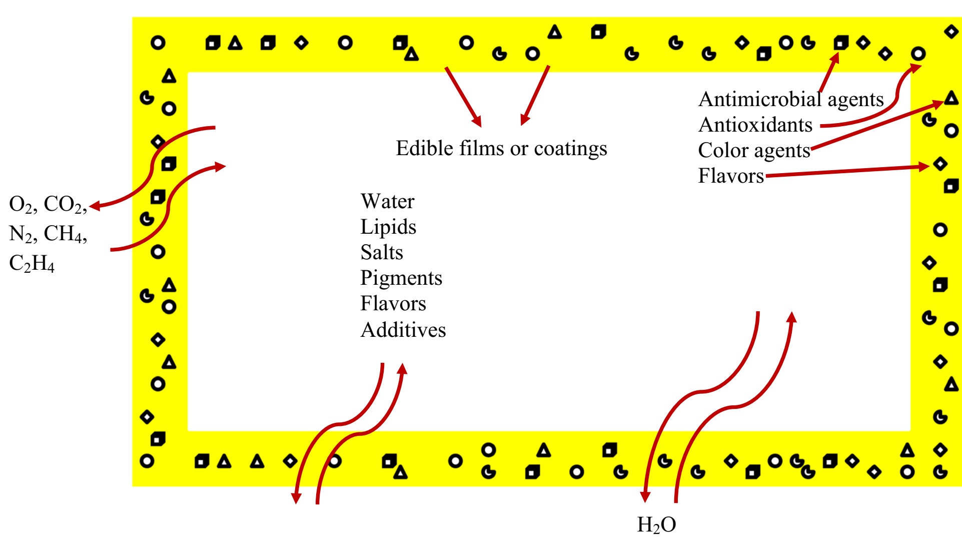

Fig. 1 The composition of edible films and coatings

5.1 Simple films

5.1.1 Protein films

Proteins are essential organic polymers in the manufacture of edible films, as well as their abundance and their renewable nature. Proteins are distinguished because of their content of amino acids, which vary in their numbers (polar and non-polar) and the sequence of amino acids that play a role in the formation of bonds between molecules [2]. There is an interest in the manufacturing of edible films from natural renewable polymers, such as protein. These films are used to decrease the moisture loss, limit the permeability of oxygen, reduce fat loss, improve mechanical properties, enhance the sensory properties of food, keep the degradability consistent with environmental requirements, and increase the nutritional value of foods [4]. Proteins also have the ability to carry antimicrobial substances, flavors, and colors that improve the functionality of packaging materials [3].

Protein films which made from polysaccharides and fats have superior mechanical properties due to the unique structure of the protein (containing 20 different monomers). These different monomers give a massive range of the functional characteristic, especially the presence of high voltage within the molecules. Consequently, these films can form links between high voltage sites to make the cross-linking [20]. Although protein films have low permeability of water vapor and low tensile strength compared with other polymers used in packaging, many studies have done to improve the functional properties of these films by using chemical, enzymatic, and physical methods, or by combining them with water-soluble substances or some polymers [2, 20]. Many protein sources were used in the manufacture of films, such as casein and whey proteins in cheese packaging [21], corn zein and wheat gluten in egg packaging [22], gelatin in cheese and cake packaging [23], and wheat gluten in cheese packaging [24].

Nemet et al. [8] used chicken meat proteins in the manufacture of edible films after dissolution in acid and base solutions at pH 3 and 11, respectively. The permeability of films to water vapor increased to 0.21, 0.26, and 0.28 with the addition of 35, 50, and 65% of plasticizers, respectively. In the two solutions, films strength decreased while elongation increased. The film which made in the acid solution was more transparent than the base solution film. It has been reported that the gelatin extracted from tuna resulted in producing yellow and dark films with a strength of 48.57 MPa, elongation of 15.2%, the permeability of evaporated water was 110 g/m^2 per day, the permeability gases was 5.3 cm^3/m^3 per day, the thermal properties were 56.30 °C as the degree of glass transition, and thermal stability of 260 °C [25].

Recent research tried to find alternatives to traditional biological sources, such as plant proteins (wheat gluten, corn zein, and soy protein) and animal protein (casein, whey protein, gelatin, albumin of the egg) which are important sources of protein. Insects proteins are a good source of proteins and nutritional ingredients [26] compared to 15% protein in plants [27], and research is examining the safety of these proteins in terms of toxic, microbial, and parasitic hazards, as well as the sensitivity and communities acceptability to these sources of proteins [28, 29].

It has been reported that the possibility of improving the functional properties of whey protein isolate (WPI) with adding 0.03, 0.06, 0.1, 0.15, 0.2, and 0.4% of sericin extracted from silkworm Bombyx mori to 10% whey protein in presence of cholesterol as a plasticizer with 2:1 protein: cholesterol. Increasing the concentration of sericin resulted in decreasing the mechanical tensile and increasing the elongation of films due to increasing the molecules aggregation and their ability to bind protein with the hydrogen bonds of the crosslink. The permeability of the films to water increased with increasing the sericin concentration, as well as being antioxidant and antibacterial.

5.1.1.1 Whey protein films Whey protein is a yellowish-green color by-product derived from cheese manufacturing using acid or enzyme as coagulants (acid whey and sweet whey). As a result, the composition of whey (Table 1) differs depending on the coagulation methods [30]. Thus the acidity of acid whey is > 0.4% and pH < 5.1, while the acidity of sweet whey is ranged from 0.1 to 0.2% and pH > 5.9 [30].

The percentage of whey protein in milk protein is 20% and has approximately 54% β-Lactoglobulin and 21% α-lactalbumin, in addition to a small amount of serum albumin, immunoglobulin, and proteose peptone [30]. Whey proteins are found in separate molecules with different combinations of cross-sulfur bonds, and they are more sensitive to heat and less sensitive to calcium [1, 30].

Table 1 The chemical composition of sweet and acid whey [30]

Composition	Sweet whey (g/L)	Acid whey (g/L)
Total solids	63.0–70.0	63.0–70.0
Lactose	46.0–52.0	44.0–46.0
Protein	6.0–10.0	6.0–8.0
Calcium	0.4–0.6	1.2–1.6
Phosphate	1.0–3.0	2.0–4.5
Lactate	2.0	6.4
Chloride	1.1	1.1

Whey protein is highly nutritious, containing essential amino acids, vitamins, minerals, and a good source of essential acids, such as leucine, isoleucine, and valine. These acids aid protein synthesizing in muscles, so whey protein used in athletes' foods. As well as tryptophan which regulates appetite, growth rates, the pain sensation and it also has interesting functionalities in industrial applications, such as solubility, whisk ability, the ability to retain water, and the development of viscosity [31]. Whey protein is considered antioxidant due to its ability to inhibit the free radicals and antimicrobial properties because of its protective proteins, such as lactoferrin and derived peptides e.g. lactoperoxidase. Lactoperoxidase has the ability to decrease cholesterol levels, prevent high blood pressure, and counteract cancer tumors due to its content of sulfuric amino acid which synthesis of glutathione and thereby, reduces the risk of many diseases, such as cancer, atherosclerosis, acquired immunodeficiency, hepatitis, and cardiovascular disease, osteoporosis, and stomach problems [30]. This promotes the growth of beneficial bacteria in the gastrointestinal tract, increase the desired colon fermentation which called prebiotic, provides an environment that is not suitable for harmful bacteria, improves digestive function, and enhance mineral absorption [32]. The chemical and physiological properties of whey protein fractions are shown in Table 2. Whey protein is available in the market as whey protein concentrate (WPC) and whey protein isolate (WPI) which have approximately 35–85% and 90% protein, respectively, and whey protein has many applications as animal feed, beverages, bread, baby food, and diet [5].

There are many procedures to produce edible films from whey protein, such as using temperatures ranging from 70 to 100 °C and the irradiation process to make cross-linking for flexibility. The protein is composed of a series of amino acids, and these amino acids polymerize when they are heated due to oxidation of disulfide and sulfhydryl groups, which are found in the main components of the whey. As a result, the whey protein produces transparent films with a high nutritional value, flexible, odorless, and has good functional properties [1]. The properties of the films are influenced by the protein components of amino acids, their sequencing, polarity, and conditions that affect ionic cross-linking between amino acids and carboxylic groups by the hydrogen bonds and disulfide bonds [2, 33].

It has pointed out the importance of balancing between the accumulated and aggregated proteins in the preparation of solutions for films manufacturing. This balance prevents the formation of hydrophobic residue due to the protein-to-protein interaction, especially at pH 5.2. This balance is affected by pH and temperature [34]. It has been reported that the use of temperature 68, 70.5 and 76.5 °C at pH 9, 8, and 7, respectively, and the heating rate of 6 °C/min had the most significant effect of making the balance and obtaining good films with high reservation and mechanical properties [35].

The whey proteins are characterized by medium permeability of water vapor because they are hydrophilic, which are considered a good barrier to oxygen as well as they reduce food oxidation and decrease the hydrolysis. It has been found that whey protein films containing sorbitol as a plasticizer are less oxidized than glycerol in a 50% humidity due to the behavior of glycerol to bond with water molecules than sorbitol which resulted in decreasing the hydrogen bonds between the polymer chains [36]. Whey protein films are also used as carriers for additives and antioxidants; therefore, vitamin E is used with whey proteins to protect the products from the oxidation and to extend their shelf-life. The addition of ascorbic acid in whey protein films reduces food oxidation (increased the stability of the films against oxygen) [37], as well as reduced the changes in films color during storage. Furthermore, whey protein films are able to carry antimicrobial substances, flavors, and colors which improve the functionality of packaging materials [3].

Whey protein produces water-soluble films with low permeability to moisture and water vapor as well as the aroma. In addition, the manufactured films without

Table 2 The chemical and physiological properties of whey protein fractions and their relative molecular weight [30]

Whey protein fractions	Concentration (g/L)	MW (kDa)	Isoelectric point (pI)	Functional properties
β-Lactoglubilin	3.0–4.0	18.4	5.2	Pro-vitamin A transfer
α-Lactalbumin	0.7–1.5	14.2	4.7–5.1	Lactose synthesis
Bovine serum albumin	0.3–0.6	69.0	4.7–4.9	Fatty acid transfer
IgG, IgA, IgM	0.6–0.9	150–1000	5.5–9.8	Passive imunity
Lactoperoxidase	0.006	89.0	9.6	Antibacterial agent
Lactoferrin	0.05–0.35	78.0	8.0	Bateriostatic agent
Protease-peptone	0.5–1	4–20	3.3–3.7	Opioid activity
Caseinomacropeptide	0.0–1.5	7.0–32		Regulation of cell growth and differentiation

plasticizers are fragile and can be broken so the plasticizer should be added to increase the flexibility of the films; however, the permeability of the water vapor decreases. This is due to the reduction of hydrogen bonds within polymers chains which increase the molecular free movement of these chains. The functional properties and water vapor permeability are useful in the packaging of many foods but are not sufficient, so other proteins are added to improve these qualities [6] or mixing the protein with hydrophobic substances, such as fat. Addition of fat leads to changing the properties of films due to the molecular substitutions of fat in the film. Adding fat to whey proteins resulted in increasing the moisture resistance of films and reduces water vapor permeability. This reduction differs depending on the quality and size of lipid molecules and the length of the fatty acids and polar chains which affect the mechanical properties [2].

It has announced that increasing beeswax and free milk fat supplementation with films formation solution led to decreasing the tensile strength and increasing the elongation of the whey protein films [38]. Whey protein films are fragile because of bonding protein by hydrogen and disulfide bonds (hydrophilic). Plasticizers are used to overcome fragility while increasing water and oxygen permeability. Schmid et al. [6] confirmed that the use of hydrolyzed whey proteins with less plasticization alters the mechanical properties of films which reduce the tensile and elasticity while maintaining water vapor permeability.

Whey protein films are not antibacterial, so the solutions of the film could be mixed with antimicrobial substances, such as propionic acid, benzoic acid, sorbic acid, sodium benzoate, and sodium potassium. Furthermore, other materials such as ethylenediaminetetraacetic acid (EDTA) is mixed with edible whey proteins films to prevent bacterial and fungal growth [39] and natural antagonists (e.g. bacteriocins, lysosome, lactoferrin, and enzymes) [40].

Ramos et al. [5] reported that WPI and WPC films were transparent, flexible, and homogenous. WPI films had less moisture content and solubility, low permeability of water vapor and gas, more intense and tensile strength, more elongation and thermal stability than WPC for the same ratio of glycerol as a plasticizer due to the difference in lactose, fat, minerals, and total solids proportions that affecting the internal molecules of films. Thus decreasing the lactose content reduces the spacing between the polymers network and increases the films matrix, vice versa increasing the lactose resulted in increasing the permeability of the films because lactose acts as a plasticizer.

5.1.2 Polysaccharides films

The polysaccharides are biological substances found in plants, cells, and the outer structure of insects. Polysaccharides include starch, pectin, carrageen, alginate, gill, gum, chitosan, cellulose and its derivatives [41]. The functional properties of polysaccharides have made them suitable to be used in many applications in the food industry as stabilizers, thickening substances, gelling agents, and strengthening due to their high viscosity [10, 42]. Polysaccharides are used recently in the preparation of edible films because they are cheap and abundant natural substances in nature. Moreover, they are renewable and can form edible films with good mechanical properties to maintain the strength, flavor, and increase the longevity of the food during shelf-life due to their hydrophilic nature [43, 44].

The films of polysaccharides are characterized by excellent storage properties of gases, flavored compounds, and fatty substances due to their ability to form a cross-linking network between polymer chains by hydrogen bonds. This increases the reservation of films for gases while decreasing the water vapor barriers because of their hydrophilic properties [10, 44]. It has been reported that polysaccharides are colorless, tasteless, odorless, and non-toxic, as well as their ability to inhibit bacterial growth due to the reduction of water activity [45]. The researcher also noted that the starch is composed of amylose and amylopectin, which is found in grains, such as corn, wheat, sweet potato. Amylose is responsible for the ability of starch to form films, thus increasing the quantity of amylose increases the elasticity of the films. Amylose produces films with good reservation properties of fat and oxygen and high solubility. Thus the starch films are used in the potato packaging to prevent oxidation and to avoid color changing after frying [45, 46]. Corn starch has been utilized in the eggs packaging. These films maintained the functional properties of eggs and reduced their moisture loss during storage [47].

It has shown that alginates and carrageenans are water-soluble polymers found in algae, seaweed, respectively, and could be utilized in edible films because of their reservation and mechanical properties [48]. However, their resistance to gas passage is limited, so they are mixed with oil to improve the functional properties. They have been used in the packaging of frozen meat, poultry, fish, and fatty and dry foods to prevent dehydration [49, 50].

Skurtys et al. [39] reported that cellulose derivatives, such as hydroxypropyl, carboxymethylcellulose, and methylcellulose could be employed in making less effective edible films. They should be mixed with fats and fatty acids to develop their functional properties. Another type, such as chitosan, is extracted from crustaceans and is a non-toxic material which is abundant in nature and characterized by antifungal, antibacterial, and low solubility [51, 52]. The chitosan products are very sticky, like gum, and their films are cohesive with resistance to the transition of gases and fats [53].

On the other hand, their permeability to water vapor is limited, and it is utilized in strawberry packaging [54, 55]. The changes in the quality and microbial characteristics of the fish bream covered by 1.5% sodium gene films, 10% plasticizer cholesterol, plus 5% vitamin C and 0.3% tea polyphones as natural antioxidants were examined during storage at 4 °C for 21 days [56]. The results showed that the covered fish with films maintained their strength with no chemical damages [56].

5.1.3 Lipid films

Covering the fruits by waxes protects them from physiological damage; however, there are adverse effects, such as increasing of carbon dioxide which causes the growth of microorganisms (fungi), as well as increasing the total soluble solids, acetaldehyde, and ethanol and decreasing the total solids due to anaerobic respiration [57]. It has been reported that waxes are the most efficient substances in the retention of moisture from solid fats products, followed by saturated fatty acids. Several types of waxes are utilized in the formation of films, which vary in their ability to preserve moisture. Paraffin wax is more effective than beeswax due to paraffin is made up of a mixture of long hydrocarbon chains while beeswax consists of a mixture of hydrophobic substances (a long chain of esters with a hydrocarbon chain, and a chain of fatty acids) [58].

Many fatty compounds, such as plant fats, animal fats, and waxes (beeswax, carnauba wax, paraffin wax, and acetomonoglycerides) have been used in the preparation of edible films because of their high moisture retention capacity as hydrophobic substances and their good appearance. As a result, they prevent the water permeability from the foods, especially fresh foods e.g. fruits and vegetables [16, 59–61]. Lipid films are characterized by misty, brittle, and unsteady due to they are oxidized easily and have the lipid taste in foods. These characteristics affect the sensory characteristics of the food and thus, reduce their marketing [62].

Some types of oils, such as cottonseed oil, soybean oil, flaxseed oil, corn oil, olive oil, and fish oil are used to cover many fruits because they have excellent holding properties of water vapor due to their low polarity which extends the shelf-life of the fruits and preventing their wilt [16, 63, 64]. The addition of monoglycerides to whey protein decreased the permeability of water vapor from 0.5 to 70 times compared to using only whey proteins [65]. On the other hand, adding stearic acid to whey proteins led to decreasing the permeability of water vapor from the film, which reduced its mechanical properties [66].

5.2 Composite films

The films made from proteins or polysaccharides are known for their appropriate mechanical and reservations properties; however, they are permeable to moisture. While the lipid films (wax, fats, and oils) have less permeable characteristics to water vapor, but their mechanical resistance is weak and highly permeable to oxygen. The properties of these films could be improved by combining these components to obtain films with good properties [67]. The plasticized whey proteins films with glycerol have been manufactured by addition of candelilla wax and lipids. These films were flexible and soluble at 20 °C/24 h. Thus mixing fats with protein reduced the solubility and permeability of films to water vapor [68].

It has been reported that the addition of lipids (50% beeswax and 50% oleic acid), commercial vegetable oil, and lecithin of sodium caseinates films led to increasing the reduction of water vapor permeability with increasing three concentration of fatty acids (4.88–22.56%, 12.20–48.14%, and 61.59–15.85%) of the dry weight of casein [69]. This reduction related to the role of lipids in restricting the movement of water molecules through the polymer because they are hydrophobic substances, as well as the role that sodium caseinate plays in stabilizing the film's solution. The tensile strength of films decreased from 4.12 to 3.34 MPa, and 2.97 to 2.75 MPa when mixing the lipids with vegetable oils and lecithin, respectively. This is due to the penetration of fatty substances which have less structural cohesion that reduces the strength and cohesion of the protein films network.

Some researchers were able to manufacture films from WPC, kappa carrageen, and gum. They concluded that tensile strength increased from 4.67 MPa to 23.89 MPa when two or more compounds were mixed compared to one compound film, while elongation increased from 0.16% in one film compound to 3.03% for the composite films [70]. The composite films of wheat gluten and fatty substances were characterized by good texture and low transparency, which proportional to the concentration of the fatty substances. The water vapor permeability of the films was also reduced from 1.59 to 1.31 g mm/°C h KPa with increasing the concentration of olive oil and sunflower oil from 10 to 30% compared to 3.99 g.mm/°C h KPa of simple gluten films. The solubility of composite films (olive oil and sunflower oil) in water decreased from 22.91 and 20.01 compared with 30.35 of the simple gluten films. Also, tensile strength decreased from 1.78 to 2.42 MPa for oils compared to 2.88 MPa of simple gluten films. The elongation ratio was high in composite olive oil and sunflower oil films (50.25% and 44.16%) compared to 35.33% of simple gluten films [24].

Zahedi et al. [62] reported that the permeability of water vapor decreased from 37 to 34%; also, oxygen permeability and tensile strength have decreased. The elongation decreased from 70 to 35% with an increase in the mist of films. Also, the thermal stability of films was 127 °C by adding stearic acid and palmitic acid to pistachios. The tensile strength and thermal stability increased with the addition of the dialdehyde carboxymethyl, while the permeability of water vapor and the proportion of elongation have decreased [71].

6 The retention characteristics of edible films

The use of edible films with appropriate reservation properties is required in a large number of food applications [1]. The efficiency of films depends strongly on the properties of gas reservation, water and lipid permeability, and odor which in turn depend on the chemical composition, polymers structure, product characteristics, and storage conditions [39]. The mechanisms of water permeability, gas, fat, odor and flavor compounds are done one three steps (Fig. 2); adsorption (where the permeable material is adsorbed on the surface of the films), followed by the diffusion (the transfer of components through the polymers), then desorption (which is driven by the concentration gradient and evaporates from the other surface of the films).

Chemical composition, method of preparation, polarity, degree of entanglement, polymers, plasticizers, and additives affect the susceptibility of films reservations [1, 72]. Most of the films made from polysaccharides and proteins have low moisture retention properties, especially under high relative humidity and good gas barriers, as well as good transparency and luster properties. Lipid films have excellent properties in moisture retention and high oxygen permeability, so the composite films made up of proteins and polysaccharides have good characteristics [3].

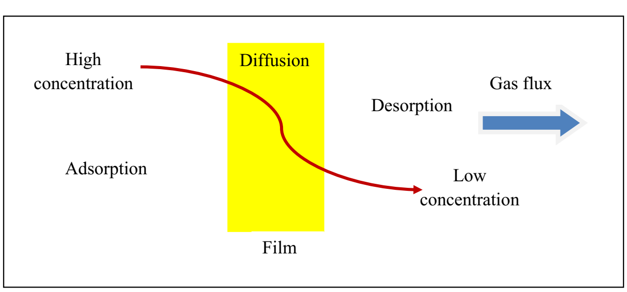

Fig. 2 Mechanical diagram of the movement of molecules through the film

7 Improvement of retention characteristics

The functional properties of films can be improved by adding food additives, such as antioxidants, microbiological substances, plasticizers, or networking agents to the films solutions. Janjarasskul et al. [37] reported that the addition of ascorbic acid had increased the oxygen retention of whey protein films [73]. Nisin and glucose oxidase were utilized to increase the inhibitory ability of the whey protein films against the gram-positive and negative bacteria. Mixing of niacin and enzyme was less inhibitory compared to the enzyme only at pH 5, as well as a decrease in the water vapor retention. The recent trends in the improvement of the functional properties of edible films are to mix nano-particles and nano-fibers [74] to strengthen the mixture and improve the functional properties of the films [75].

It has been shown that the permeability of water vapor decreased to 2.95, 3.03, 2.33, and 1.90 g mm/°C h KPa for a 4.5% banana puree mixture, 4.5% banana puree with 0.2% pectin, 4.5% banana puree with 0.5% pectin, and 4.5% banana puree with 0.2% chitosan nanoparticles, respectively due to the increase of molecules cross-linking [76]. There are several ways to increase the cohesion between protein chains which improve the reservation properties of films. Enzymes such as transglutaminase are increasing the cross-linking more than physical processes (e.g. irradiation) with the addition of chemicals such as formaldehyde [4].

8 Mechanical properties

Mechanical properties of edible films are important because they are an indicator of the durability and cohesion of films. Mechanical properties of films are dependent on the structural cohesion to be useful for maintaining and enhancing the mechanical safety of food during manufacture and transportation [77]. The durability and consistency of films depend on the ability of polymers to form multiple molecular bonds between polymer chains. The length and polarity of the polymer chains and the regular distribution of polar groups increase cohesion due to the high pH and ions interactions between the chains. Increasing the cohesion reduced the flexibility of films and their ability to reserve gases, water vapors, and soluble substances [2, 78].

Mechanical measurements of edible films are protein-to-protein bonds in the polymer sequences to provide useful information for the properties of the mechanical film, such as tensile strength. This is the maximum force exerted on the film per unit across the section area before films cutting and elongation. Resiliency, which is reversible to solidity and can be measured by multiplying tensile strength in elongation, is an important measurement of the strength and elasticity of films in resisting the transport and handling conditions of the final product [3]. Polymers vary in strength and elasticity, which depend on molecular weight, polarization, and bonding strength. Milk proteins are made of strong polymers due to the dense interaction between protein chains and hydrogen bonds within protein-to-protein. This becomes fragmented and non-useful when no plasticizers are added to reduce this strength and hydrogen bonds [79]. Skurtys et al. [39] found that polysaccharides have a tensile strength of 10–100 MPa and elongation percentage is between 1 and 8%, while proteins have less tensile strength and more elongation [63, 80].

9 Conclusion

Traditional plastics do not degrade, leaving tons of plastic waste for years, and thereby, increasing environmental pollution. Some plastic wrappers suspected of leaking compounds may also be harmful to food. As a result, the packaging industry tried to manufacture many varieties of edible films made from polysaccharides, lipids, casein, and whey proteins in the marketing. The characteristics of these edible films are examined to extend the shelf-life of foods with functional properties. Researchers have recently incorporated vitamins, flavors, probiotics, and nutritional supplements into edible films.

Compliance with ethical standards

Conflict of interest The authors also declare that they have no conflict of interest.

References

1. Regalado C, Pérez-Pérez C, Lara-Cortés E, Garcia-Almendarez B (2006) Whey protein based edible food packaging films and coatings. In: Guevara-González RG, Irineo T-P (eds) Agricultural and food biotechnology, pp 237–261
2. Baldwin EA (1999) Surface treatments and edible coatings in food preservation. In: Rahman MS (ed) Handbook of food preservation, 2nd edn. Marcel Dekker, New York, pp 477–507
3. Jooyandeh H (2011) Whey protein films and coatings: a review. Pak J Nutr 10:296–301
4. Bourtoom T (2009) Edible protein films: properties enhancement. Int Food Res J 16:1–9
5. Ramos ÓL, Reinas I, Silva SI, Fernandes JC, Cerqueira MA, Pereira RN, Vicente AA, Poças MF, Pintado ME, Malcata FX (2013) Effect of whey protein purity and glycerol content upon physical properties of edible films manufactured therefrom. Food Hydrocoll 30:110–122
6. Schmid M, Hinz L-V, Wild F, Noller K (2013) Effects of hydrolysed whey proteins on the techno-functional characteristics of whey protein-based films. Materials 6:927–940
7. Weber CJ (2000) Biobased packaging materials for the food industry: status and perspectives, a European concerted action. KVL
8. Nemet NT, Šošo VM, Lazić VL (2010) Effect of glycerol content and pH value of film-forming solution on the functional properties of protein-based edible films. Acta Period Technol 31:57–67
9. Ferreira CO, Nunes CA, Delgadillo I, Lopes-da-Silva JA (2009) Characterization of chitosan–whey protein films at acid pH. Food Res Int 42:807–813
10. Dhanapal A, Sasikala P, Rajamani L, Kavitha V, Yazhini G, Banu MS (2012) Edible films from polysaccharides. Food Sci Qual Manag 3:9
11. Kokoszka S, Lenart A (2007) Edible coatings-formation, characteristics and use—a review. Polish J food Nutr Sci 57:399–404
12. Valencia-Chamorro SA, Pérez-Gago MB, del Río MÁ, Palou L (2009) Effect of antifungal hydroxypropyl methylcellulose (HPMC)–lipid edible composite coatings on postharvest decay development and quality attributes of cold-stored 'Valencia'oranges. Postharvest Biol Technol 54:72–79
13. Krochta JM (2002) Proteins as raw materials for films and coatings: definitions, current status, and opportunities. Protein-based Film Coat 1:1–40
14. Zhang H, Mittal G (2010) Biodegradable protein-based films from plant resources: a review. Environ Prog Sustain Energy 29:203–220
15. Blanco-Pascual N, Gómez-Estaca J (2016) Production and processing of edible packaging. Edible Food Packag Mater Process Technol 36:153
16. Yousuf B, Qadri OS, Srivastava AK (2018) Recent developments in shelf-life extension of fresh-cut fruits and vegetables by application of different edible coatings: a review. LWT 89:198–209. https://doi.org/10.1016/j.lwt.2017.10.051
17. Bhat ZF, Bhat H (2011) Recent trends in poultry packaging: a review. Am J Food Technol 6:531–540
18. Ščetar M, Kurek M, Galić K (2010) Trends in meat and meat products packaging—a review. Croat J Food Sci Technol 2:32–48
19. Kerry JP, O'grady MN, Hogan SA (2006) Past, current and potential utilisation of active and intelligent packaging systems for meat and muscle-based products: a review. Meat Sci 74:113–130
20. Wang J, Shang J, Ren F, Leng X (2010) Study of the physical properties of whey protein: sericin protein-blended edible films. Eur Food Res Technol 231:109–116
21. Shendurse AM, Gopikrishna G, Patel AC (2018) Milk protein based edible films and coatings–preparation, properties and food applications. J Nutr Heal Food Eng 8:219–226
22. Al-Bayati AAH (2005) Preparation of edible and biodegradable films and coatings from wheat gluten and corn zain. Ph. D. Thesis. Coll. Agriculture, Univ. Baghdad, 128 pp
23. Popović S, Peričin D, Vaštag Ž, Lazić V, Popović L (2012) Pumpkin oil cake protein isolate films as potential gas barrier coating. J Food Eng 110:374–379
24. Rocca-Smith JR, Marcuzzo E, Karbowiak T, Centa J, Giacometti M, Scapin F, Venir E, Sensidoni A, Debeaufort F (2016) Effect of lipid incorporation on functional properties of wheat gluten based edible films. J Cereal Sci 69:275–282
25. Kim J-Y, Jung C-K, Kim D-H, Kim S-B (2012) Properties of edible biofilm manufactured from yellowfin tuna (*Thunnus albacares*) skin gelatin. Korean J Chem Eng 29:786–791

26. Belluco S, Losasso C, Maggioletti M, Alonzi CC, Paoletti MG, Ricci A (2013) Edible insects in a food safety and nutritional perspective: a critical review. Compr Rev Food Sci Food Saf 12:296–313
27. Premalatha M, Abbasi T, Abbasi T, Abbasi SA (2011) Energy-efficient food production to reduce global warming and ecodegradation: the use of edible insects. Renew Sustain Energy Rev 15:4357–4360
28. Ayuso R (2011) Update on the diagnosis and treatment of shellfish allergy. Curr Allergy Asthma Rep 11:309–316
29. Wales AD, Carrique-Mas JJ, Rankin M, Bell B, Thind BB, Davies RH (2010) Review of the carriage of zoonotic bacteria by arthropods, with special reference to Salmonella in mites, flies and litter beetles. Zoonoses Public Health 57:299–314
30. Hammam ARA, Tammam AA, Elderwy YMA, Hassan AI (2017) Functional peptides in milk whey: an overview. Assiut J Agric Sci 48:77–91. https://doi.org/10.21608/ajas.2017.19875
31. Walzem RL, Dillard CJ, German JB (2002) Whey components: millennia of evolution create functionalities for mammalian nutrition: what we know and what we may be overlooking. Crit Rev Food Sci Nutr 42:353–375
32. Marshall K (2004) Therapeutic applications of whey protein. Altern Med Rev 9:136–157
33. Le Tien C, Letendre M, Ispas-Szabo P, Mateescu MA, Delmas-Patterson G, Yu H-L, Lacroix M (2000) Development of biodegradable films from whey proteins by cross-linking and entrapment in cellulose. J Agric Food Chem 48:5566–5575
34. Hernandez-Izquierdo VM, Reid DS, McHugh TH, De Berrios J, Krochta JM (2008) Thermal transitions and extrusion of glycerol-plasticized whey protein mixtures. J Food Sci 73:E169–E175
35. Anker M, Stading M, Hermansson A-M (2000) Relationship between the microstructure and the mechanical and barrier properties of whey protein films. J Agric Food Chem 48:3806–3816
36. Osés J, Fernández-Pan I, Ziani K, Maté JI (2008) Use of edible films based on whey protein isolate to protect foods rich in polyunsaturated fatty acids. Eur Food Res Technol 227:623–628
37. Janjarasskul T, Min SC, Krochta JM (2011) Storage stability of ascorbic acid incorporated in edible whey protein films. J Agric Food Chem 59:12428–12432
38. Shellhammer TH, Krochta JM (1997) Whey protein emulsion film performance as affected by lipid type and amount. J Food Sci 62:390–394
39. Skurtys O, Acevedo C, Pedreschi F, Enronoe J, Osorio F, Aguilera JM (2014) Food hydrocolloid edible films and coatings. Nova Science Publishers, Incorporated, Hauppauge
40. Perez-Perez C, Regalado-González C, Rodríguez-Rodríguez CA, Barbosa-Rodríguez JR, Villaseñor-Ortega F (2006) Incorporation of antimicrobial agents in food packaging films and coatings. Adv Agric food Biotechnol 37:2
41. Han JH (2014) Chapter 9 - Edible films and coatings: a review. In: Han JH (ed) Food science and technology, 2nd edn. Academic Press, San Diego, pp 213–255
42. Stephen AM, Phillips GO (2016) Food polysaccharides and their applications. CRC Press, Boca Raton
43. Ma X, Chang PR, Yu J (2008) Properties of biodegradable thermoplastic pea starch/carboxymethyl cellulose and pea starch/microcrystalline cellulose composites. Carbohydr Polym 72:369–375
44. Cazón P, Velazquez G, Ramírez JA, Vázquez M (2017) Polysaccharide-based films and coatings for food packaging: a review. Food Hydrocoll 68:136–148. https://doi.org/10.1016/j.foodhyd.2016.09.009
45. Romero-Bastida CA, Bello-Pérez LA, García MA, Martino MN, Solorza-Feria J, Zaritzky NE (2005) Physicochemical and microstructural characterization of films prepared by thermal and cold gelatinization from non-conventional sources of starches. Carbohydr Polym 60:235–244
46. Pelissari FM, Ferreira DC, Louzada LB, dos Santos F, Corrêa AC, Moreira FKV, Mattoso LH (2019) Chapter 10 - Starch-based edible films and coatings: an eco-friendly alternative for food packaging. In: Silva Clerici MTP, Schmiele MBT (eds) Starches for food application. Academic Press, pp 359–420
47. Petersen K, Nielsen PV, Bertelsen G, Lawther M, Olsen MB, Nilsson NH, Mortensen G (1999) Potential of biobased materials for food packaging. Trends Food Sci Technol 10:52–68
48. Farhan A, Hani NM (2017) Characterization of edible packaging films based on semi-refined kappa-carrageenan plasticized with glycerol and sorbitol. Food Hydrocoll 64:48–58
49. Borchard W, Kenning A, Kapp A, Mayer C (2005) Phase diagram of the system sodium alginate/water: a model for biofilms. Int J Biol Macromol 35:247–256
50. Nunes EM, Silva AI, Vieira CB, Men de Sá Filho MS, Silva EM, Souza BW (2016) Edible coatings and films for meat, poultry, and fish. In: Cerqueira MAPR, Pereira RNC, Ramos OL da S, Teixeira JAC, Vicente AA (eds) Edible food packaging: materials and processing technologies. CRC Press, pp 432–448
51. Avila-Sosa R, Palou E, Jiménez Munguía MT, Nevárez-Moorillón GV, Navarro Cruz AR, López-Malo A (2012) Antifungal activity by vapor contact of essential oils added to amaranth, chitosan, or starch edible films. Int J Food Microbiol 153:66–72. https://doi.org/10.1016/j.ijfoodmicro.2011.10.017
52. Perdones Á, Vargas M, Atarés L, Chiralt A (2014) Physical, antioxidant and antimicrobial properties of chitosan–cinnamon leaf oil films as affected by oleic acid. Food Hydrocoll 36:256–264. https://doi.org/10.1016/j.foodhyd.2013.10.003
53. Alves VLCD, Rico BPM, Cruz RMS, Vicente AA, Khmelinskii I, Vieira MC (2018) Preparation and characterization of a chitosan film with grape seed extract-carvacrol microcapsules and its effect on the shelf-life of refrigerated Salmon (*Salmo salar*). LWT 89:525–534. https://doi.org/10.1016/j.lwt.2017.11.013
54. Leceta I, Guerrero P, De la Caba K (2013) Functional properties of chitosan-based films. Carbohydr Polym 93:339–346
55. Hajji S, Younes I, Affes S, Boufi S, Nasri M (2018) Optimization of the formulation of chitosan edible coatings supplemented with carotenoproteins and their use for extending strawberries postharvest life. Food Hydrocoll 83:375–392
56. Song Y, Liu L, Shen H, You J, Luo Y (2011) Effect of sodium alginate-based edible coating containing different anti-oxidants on quality and shelf life of refrigerated bream (*Megalobrama amblycephala*). Food Control 22:608–615
57. McHugh TH, Krochta JM (1994) Sorbitol-vs glycerol-plasticized whey protein edible films: integrated oxygen permeability and tensile property evaluation. J Agric Food Chem 42:841–845
58. Park HJ (1999) Development of advanced edible coatings for fruits. Trends Food Sci Technol 10:254–260
59. Sonti S (2003) Consumer perception and application of edible coatings on fresh-cut fruits and vegetables. Louisiana State University, Agricultural and Mechanical College. LSU Master's Theses. 2225. https://digitalcommons.lsu.edu/gradschool_theses/2225
60. Abdul Khalil HPS, Banerjee A, Saurabh CK, Tye YY, Suriani AB, Mohamed A, Karim AA, Rizal S, Paridah MT (2018) Biodegradable films for fruits and vegetables packaging application: preparation and properties. Food Eng Rev 10:139–153. https://doi.org/10.1007/s12393-018-9180-3
61. Montero-Calderón M, Soliva-Fortuny R, Martín-Belloso O (2016) Edible packaging for fruits and vegetables. In: Cerqueira MAPR, Pereira RNC, Ramos OL da S, Teixeira JAC, Vicente AA (eds) Edible food packaging: materials and processing technologies. CRC Press, pp 353–382

62. Zahedi Y, Ghanbarzadeh B, Sedaghat N (2010) Physical properties of edible emulsified films based on pistachio globulin protein and fatty acids. J Food Eng 100:102–108
63. Atarés L, Chiralt A (2016) Essential oils as additives in biodegradable films and coatings for active food packaging. Trends Food Sci Technol 48:51–62. https://doi.org/10.1016/j.tifs.2015.12.001
64. Aguirre-Joya JA, Álvarez B, Ventura JM, García-Galindo JO, De León-Zapata MA, Rojas R, Saucedo S, Aguilar CN (2016) Edible coatings and films from lipids, waxes, and resins. In: Cerqueira MAPR, Pereira RNC, Ramos OL da S, Teixeira JAC, Vicente AA (eds) Edible food packaging: materials and processing technologies. CRC Press, pp 142–173
65. Anker M, Berntsen J, Hermansson A-M, Stading M (2002) Improved water vapor barrier of whey protein films by addition of an acetylated monoglyceride. Innov Food Sci Emerg Technol 3:81–92
66. Yoshida CMP, Antunes AJ (2004) Characterization of whey protein emulsion films. Braz J Chem Eng 21:247–252
67. Diab T, Biliaderis CG, Gerasopoulos D, Sfakiotakis E (2001) Physicochemical properties and application of pullulan edible films and coatings in fruit preservation. J Sci Food Agric 81:988–1000
68. Kim SJ, Ustunol Z (2001) Solubility and moisture sorption isotherms of whey-protein-based edible films as influenced by lipid and plasticizer incorporation. J Agric Food Chem 49:4388–4391
69. Saadi R (2003) Applications in the manufacture of edible films of milk proteins for cheese packaging. Ph.D. Thesis. Coll. Agriculture, Univ. Baghdad, 115 pp
70. Villagómez-Zavala DL, Gómez-Corona C, Martínez ESM, Pérez-Orozco JP, Vernon-Carter EJ, Pedroza-Islas R (2008) Comparative study of the mechanical properties of edible films made from single and blended hydrophilic biopolymer matrices. Rev Mex Ing Química 7:263–273
71. Mu C, Guo J, Li X, Lin W, Li D (2012) Preparation and properties of dialdehyde carboxymethyl cellulose crosslinked gelatin edible films. Food Hydrocoll 27:22–29
72. Miller KS, Krochta JM (1997) Oxygen and aroma barrier properties of edible films: a review. Trends Food Sci Technol 8:228–237
73. Murillo-Martínez MM, Tello-Solís SR, García-Sánchez MA, Ponce-Alquicira E (2013) Antimicrobial activity and hydrophobicity of edible whey protein isolate films formulated with nisin and/or glucose oxidase. J Food Sci 78:M560–M566
74. Azeredo HMC, Mattoso LHC, Wood D, Williams TG, Avena-Bustillos RJ, McHugh TH (2009) Nanocomposite edible films from mango puree reinforced with cellulose nanofibers. J Food Sci 74:N31–N35
75. Lorevice MV, de Moura MR, Aouada FA, Mattoso LHC (2012) Development of novel guava puree films containing chitosan nanoparticles. J Nanosci Nanotechnol 12:2711–2717
76. Martelli MR, Barros TT, de Moura MR, Mattoso LHC, Assis OBG (2013) Effect of chitosan nanoparticles and pectin content on mechanical properties and water vapor permeability of banana puree films. J Food Sci 78:N98–N104
77. Adedeji AA, Ngadi MO, Raghavan GSV (2009) Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. J Food Eng 91:146–153
78. Gontard N, Guilbert S (1994) Bio-packaging: technology and properties of edible and/or biodegradable material of agricultural origin. In: Mathlouthi M (ed) Food packaging and preservation. Springer, pp 159–181
79. Javanmard M (2009) Biodegradable whey protein edible films as a new biomaterials for food and drug packaging. Iran J Pharm Sci 5:129–134
80. Ojagh SM, Rezaei M, Razavi SH, Hosseini SMH (2010) Development and evaluation of a novel biodegradable film made from chitosan and cinnamon essential oil with low affinity toward water. Food Chem 122:161–166