

Review

Novel Materials in the Preparation of Edible Films and Coatings—A Review

Sabina Galus ^{1,*}, Emine Aytunga Arik Kibar ², Małgorzata Gniewosz ³
and Karolina Kraśniewska ³

¹ Department of Food Engineering and Process Management, Institute of Food Sciences, Warsaw University of Life Sciences-SGGW (WULS-SGGW), 02-776 Warsaw, Poland

² TÜBİTAK Marmara Research Center, Food Institute, Baris Mah Dr.Zeki Acar Cd No:1 PK:21, Kocaeli 41470, Turkey; aytunga.kibar@tubitak.gov.tr

³ Department of Biotechnology, Microbiology and Food Evaluation, Institute of Food Sciences, Warsaw University of Life Sciences-SGGW (WULS-SGGW), 02-776 Warsaw, Poland; malgorzata_gniewosz@sggw.edu.pl (M.G.); karolina_krasniewska@sggw.edu.pl (K.K.)

* Correspondence: sabina_galus@sggw.edu.pl; Tel.: +48-22-593-7579

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Abstract: The development of edible films and coatings has seen remarkable growth in recent decades and is expected to have an important impact on the quality of food products in the coming years. This growth is attributed to the increasing knowledge of edible films and edible coating technology, as well as advances in material science and processing technology. Packaging is used in order to reduce synthetic packaging and can play a role as an eco-friendly biodegradable package or a protective coating on the food surface. A large amount of bio-based polymers have been used in the production of edible films and coatings. Novel sources of edible materials, as well as the novel processing techniques, are a subject of great interest due to their promising potential as innovative food packaging systems. This paper presents the concept and potential for application of new film-forming materials and management of food wastes from the fruit and vegetable industry, which can encounter problems in appropriate disposal. It summarizes the extensive knowledge about the new film-forming materials such as plant residues, flours and gums to show their protective effectiveness and suitability in various types of foods.

Keywords: edible films; edible coatings; biopolymers; shelf life; food quality

1. Introduction

An edible coating is a thin layer of edible material, which is formed as a protective coating on foods and can be consumed together with those products. These layers are applied in liquid form onto the food surface, usually by immersing the product in a film-forming solution formed by the structural matrix. Edible films are self-standing structures in nature whereas edible coatings adhere to the food surface [1]. Various bio-based polymers have been investigated in order to produce a continuous structure of films or coatings. Hydrocolloids, both polysaccharides and proteins, are the most common group of biopolymers used in the production of edible materials. They can be obtained from sources such as plants, animals or microorganisms. Cellulose derivatives, starches, alginates, pectins, chitosans, pullulan, and carrageenans are the most popular polysaccharides used in the production of edible films and coating, whereas among proteins the most popular are soybean proteins, wheat gluten, corn zein, sunflower proteins, gelatin, whey, casein and keratin [2]. However, those materials are hydrophilic in nature. Therefore, different types of oils and fats are incorporated into hydrocolloid matrix in order to enhance their water vapour barrier properties. The most popular are waxes, triglycerides, acetylated monoglycerides, free fatty acids, and vegetable oils [3].

For a long time, biopolymers were applied mostly as a one-component film or coating formulation, and this tendency is still observed. However in recent times, extensive research has been conducted on two-component and multicomponent edible materials providing improved functional properties. In this context, composite films or coatings are prepared from the combination of two or more film-forming substances in order to obtain structures with modified physical, mechanical and barrier properties which are better than the one-component material. Thus in film-forming formulation various substances such as plasticizers, crosslinking agents, emulsifiers, and reinforcements are used to improve or modify the basic functionality of the material.

Moreover, different active compounds such as antimicrobials, antioxidant, colour agents, flavours, and nutraceuticals are incorporated into film-forming solution in order to improve the quality, stability, and safety of packed foods. In addition, those ingredients may provide antibacterial, antifungal or antioxidant properties of edible material [4,5].

Edible materials may be produced by wet or dry methods. Among wet processing, both films and coatings may be obtained by evaporation of the solvent. The main difference is the fact that films are produced by a casting method where the film-forming solution is dried over a solid surface. This casting method is the most popular techniques on a laboratory scale, although there is also some industrial scale application. Drying may be done by heat conduction or convection and infrared heating. On the other hand, edible coatings are also created by drying the film-forming solution over food products. The coating method may involve dipping (immersing), spraying, spreading or brushing. However, dry processing such as thermopressing/thermoforming or extrusion is used only in the production of edible films, especially in order to apply them as edible packages. Those conventional methods may be modified in order to control different functional properties of edible materials which depends on several factors [6]. Nevertheless, novel methods and techniques are investigated as a response to consumer preferences to healthier food with maintained quality and eco-friendly packaging.

Edible and biodegradable films are a very fast emerging technology providing an alternative to conventional synthetic plastics, which cause serious pollution of the environment. The main advantages associated with environmentally friendly composites are that they are renewable and biodegradable. Therefore recently, the development of edible coatings has increasingly attracted the attention of researchers and consumers, mainly due to the large variety of applications afforded by these materials. There is a great research effort focused on developing and investigating the new materials in which new components are used as building materials. In addition, the new processing systems are tested in order to optimize the composition, functional properties and costs of edible films and coatings. An important research trend is the investigation of novel sources as potential new edible films and coatings. Those materials may be among the available food compounds that exists but have not been tested as edible packaging components or industrial by-products and waste which find a sustainable application. New edible films and coatings, especially multicomponent, with and without lipids, as well as those incorporated with different active compounds were reviewed by López et al. [7]. However, a large amount of novel edible materials has been developed lately; therefore the most recent investigations carried out on the topic are described in this review. The main objectives of this paper are to discuss various new and innovative film-forming materials and techniques developed to show their protective effectiveness and suitability in various types of foods. This review provides interesting information for the food industry about new edible films and coatings that could be considered as sustainable.

2. Novel Materials

2.1. Whole Grain Flours

Edible films and coatings based on polysaccharides or proteins from conventional crops and roots have been extensively studied. Several researchers have described their properties and the different techniques used for production of such materials [1,2]. Some studies have shown the

film-forming potential of flours obtained from whole grain materials such as amaranth [8], quinoa [9] and chia [10]. In the same context, Tóth and Halász [11] noted that both, psyllium husk and its flour, are suitable components for film formation. However, Nouraddini et al. [12] developed edible composite films based on eggplant flour and corn starch. The authors observed that although eggplant flour showed excellent film-forming capacity, its mechanical and water vapour properties were impaired in comparison to films obtained with the addition of corn starch. It was attributed to the presence of other components such as lipids, fibres and proteins. The films showed complete biodegradation after 14 days.

Legume flours have been demonstrated to be a good film-forming material due to their high content of starch and protein. In addition, some legume flours contain a significant amount of lipids. They are generally cheap and provide a good source of nutritional protein, vitamins, and minerals. Furthermore, films of flours from grass peas [13], lentils [14], chickpeas [15], and mung beans [16] have also been successfully produced and evaluated. Montalvo-Paquini et al. [17] investigated edible films based on bean protein concentrate as a protein source from different Mexican popular beans, including alubia, flor de mayo, garbancillo, peruano, pinto, mantequilla, and negro. Ochoa-Yepes et al. [18] developed cassava starch films with addition of fibre-rich lentil flour obtained from the residue of lentil protein production. Composites were characterised as more resistant to water and mechanical damage. All films were easily biodegraded in vegetal compost and thermally stable up to 240 °C.

2.2. Fruit and Vegetable Residues

In previous studies fruit and vegetable purees have been widely used as components of hydrocolloid films and coatings. However, they are still a subject of research. For example, Pelissari et al. [19] investigated the physical properties of flour and starch edible films based on plantain bananas. A large volume of solid residues is produced every year by the food industry. Moreover, these residues are a rich source of nutrients and bioactive compounds, as well as primarily biopolymers such as polysaccharides or dietary fibres. In addition, peel, pomace and seed fractions of some fruits possess higher antioxidant activity than the pulp fractions. Since plant residues are an excellent source of nutrients and readily available, they have already been used as components in the development of functional food products [20]. Biopolymers based on food industry by-products are known for their film-forming capacity, which has been a subject of recent studies. Among them, fruit and vegetable residues, usually processed into flour, demonstrated promising potential for their applications as film-forming components. In addition, the energy cost of processing residues is not high, similar to processing of fruits or vegetables, since new technologies are not applied, and so, the processing variations are based on the established techniques [21]. In the last decades, the use of fruits and vegetables as a components of edible films and coatings has been a subject of many research papers [22–25]. However, the use of residues from processing of fruit or vegetables in the preparation of edible films and coatings has recently been of great importance. In this context, Andrade et al. [21] studied new edible films based on flour composed of different residues, including those from orange, passion fruit, watermelon, lettuce, courgette, carrot, spinach, mint, taro, cucumber, and rocket. The authors obtained homogeneous, flexible films without addition of plasticizers, which showed promising characteristics. Moreover, the incorporation of potato skins residue flour resulted in enhanced mechanical resistance. Arquelau et al. [26] developed and characterised films based on flour made from ripe banana peels and corn starch. Another good example is the use of by-products from citrus fruits. A grapefruit albedo was investigated as a film-forming material, which showed good functional properties of manufactured films [27]. Similar observations were made for films obtained from pomelo peel flour [28].

Brito et al. [29] obtained edible films based on solid residues which remained after preparation of isotonic drink, including both, fruits (sweet orange, passion fruit, watermelon) and vegetables (zucchini, lettuce, carrot, spinach, mint, yams, cucumber, and arugula). The films were homogeneous, yellowish and malleable with high water solubility. The formulation enriched with pectin showed great

technological and functional potential to produce biodegradable films. Moreover, films containing small amounts of pectin provided better colour, mechanical and barrier properties, and significantly lower film hygroscopicity. In general, plant residues are complex materials, thus different residue fractions could have different applications depending on their composition and particle size, either as a dietary fibre or as main components for edible films and coatings.

2.3. Root Plants

Tuber and root starches such as cassava, potato and sweet potato have shown promising results as edible films and coating. However, flour or starches from less popular root plants are being investigated in order to apply them as edible film or coating. In this context, new film-forming materials were evaluated using achira flour [30] or starches from canna [31], yam [32], ulluco [33] or water chestnut [34]. Gutiérrez et al. [35] obtained starch from guinea arrowroot tuber which showed a good film-forming capacity. The authors also investigated composite films incorporated with the wastes from wine manufacture (grape waste flour and extract). These natural fillers caused cross-linking reactions which resulted in a higher content of resistant starch and a decrease in the hydrophilic nature of films.

According to the previous studies, most of the films obtained from flours have a heterogeneous structure with rather poor mechanical and water vapour resistance compared to those developed from popular polysaccharides or proteins. Therefore, their practical applications may depend on the product properties and the function achieved. For some usage, a combination of flours with other film-forming materials may be needed.

2.4. Plant Gums

A large number of natural, plant origin gum exudates have been discovered in the last decades such as gum arabic, gum karaya, gum ghatti, mesquite and tragacanth gum. Gum Arabic (or acacia gum) is one of the best-known among all natural gums and the oldest, since its usage dates back to 5000 years ago. Regarding emulsifying, stabilizing, thickening, and binding attributes, gum Arabic has found broad utility in the food industry as well as in the paint and textile industry [36]. Moreover, gum Arabic has potential as a protective edible coating for shelf life extension of food products, including pecan nuts to eliminate their moist and oily appearance [37,38]. Ali et al. [39] observed that tomatoes coated with gum Arabic showed a significant delay in changes of colour, weight loss, firmness, soluble solid concentration, titratable acidity, ascorbic acid content, and decay percentage. Similar results were obtained for coated apple [40] and strawberries [41].

Almond gum, also known as Persian gum, is a novel gum exudate collected from the trunk and branches of almond tree. Exudate gums are produced by trees, through the process known as gummosis, in response to various stress factors such as physical injury, insect attack, etc. Exudate gums are known to exhibit interesting physical, chemical and biological properties which make them suitable substrates for utilization as various food additives. Bashir and Haripriya [42] conducted a comparative study between gum arabic and almond gum and concluded that almond gum exhibited better physical properties such as bulk density, oil holding capacity, flowability and mineral content than gum arabic. Robles-Flores et al. [43] developed the edible coatings from protein isolate and gum obtained from *Cajanus cajan* seeds which were successfully applied in enhancing the quality of coated strawberries. Flour and starch from pinhão tree seeds are good sources of complex carbohydrates which showed excellent film-forming properties [44].

2.5. Wild Plants

Mainly, fruits and vegetables are subjected to post-harvest losses due to high moisture contents along with the natural ripening enzymes. Therefore edible coatings seem a promising solution for preserving perishable fruits and vegetables. So far, well-known polysaccharides used in this type of coating are generally starches and cellulose derivatives. Further studies focused on some wild plants that contain complex polysaccharides as a source of novel edible coating material. One of these is

Opuntia cactus, which is an interesting xerotrophyte that can be used to obtain an edible coating [45]. Polysaccharides extracted from *Opuntia cactus* were applied to citrus fruits as an edible coating, being stored up to 35 days at 5 °C and 90% RH. The results indicated that the cactus-based edible coating increased the shelf life of *Kinnow mandarin* with regard to its chemical and physical characteristics such as pH, acidity, aroma, colour, texture and general appearance.

Oliveira et al. [46] developed and characterised the properties of edible films based on hydrocolloids extracted from leaves of *Pereskia aculeata* Miller mucilage. The obtained films were flexible, with a smooth surface and dark coloration, which can be a desirable property when used as a protective coating for light-sensitive foods such as chocolate or coffee beans. Furthermore, Behbahani and Fooladi [47] used Shirazi balangu (*Lallemantia royleana*) seed mucilage to obtain an edible coating for extending the shelf life of beef slices. The results indicated that mucilage wrapping on beef enhanced the shelf life by preventing lipid oxidation and microbial spoilage and it could be used as an active packaging material. Recent studies revealed that seaweed and its extracted polysaccharides could be used as edible coating and film materials [48]. Similar to other polysaccharide materials, seaweed is also an environmentally friendly, economical and abundant source of polysaccharide, where alginate, carrageenan and agar can be regarded as common seaweed-derived products that exhibit promising film-forming properties. Kim et al. [49] developed edible films using gulfweed in both forms of film and coating for application to smoked salmon. Their study revealed that coating smoked salmon with gulfweed suspension enhanced the redness without altering its texture and volatile properties.

In general, many new polymers are being investigated as potential edible packaging, as presented in Figure 1 together with well-known biopolymers. In addition, edible films and coatings produced from only one type of natural film-forming biopolymer provide both, advantages and disadvantage. Therefore, most studies focus on blending several polymers or incorporation of different components in order to obtain edible materials with appropriate functional properties.

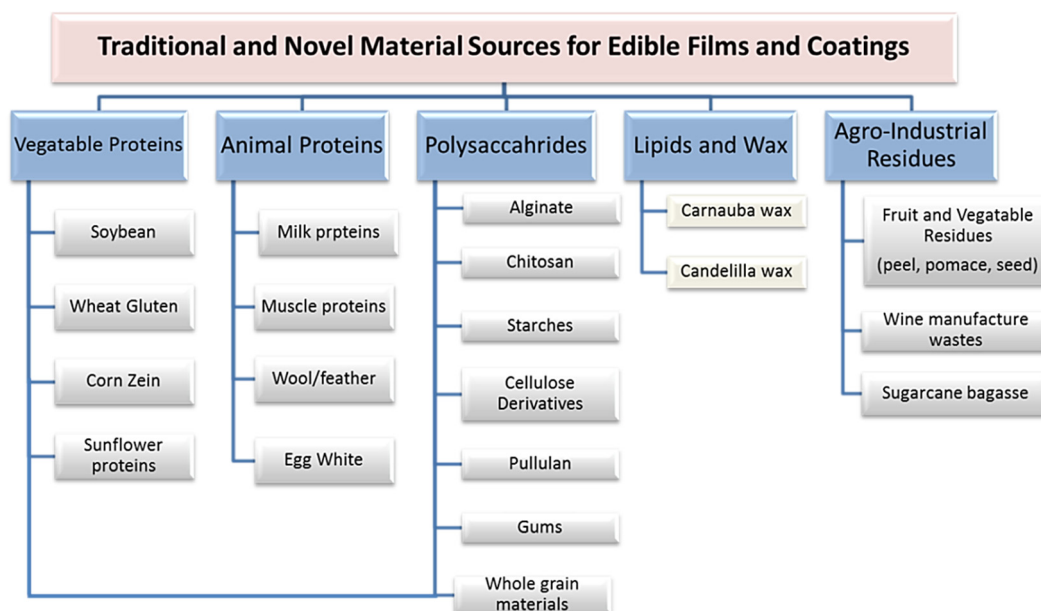


Figure 1. Classification of edible coating and film sources.

3. Physical Properties

Characteristics of biopolymer-based packaging materials are dependent on a large number of different factors. The main ones are those including the original biopolymer source, structural organization of the polymer chain, processing technology (preparation method and drying conditions), and degree of cross-linking or crystallinity. Therefore, in the application of edible films and coatings

for food, it is necessary to take into account both the physical characteristics of biopolymer materials and their functional properties [50].

In general, the physical properties of novel biopolymer films and coatings depend on the characteristics of the main ingredients. Regarding the multi-component formulations, chemical composition and miscibility of all ingredients are crucial and affect most physical properties of biopolymers materials. The most common measured physical properties are water vapour permeability and mechanical resistance (tensile strength, Young's modulus and elongation at break). The results of water vapour permeability and mechanical properties for selected biopolymer films and synthetic polymers are presented in Tables 1 and 2, respectively. Regarding water vapour permeability analysis, the most important parameters are relative humidity and temperature. The higher the differentials in water humidity are, the greater is the amount of water vapour that can migrate through a polymeric film. In general, biopolymer films show higher water vapour permeability values than synthetic films, which is attributed to the origin and process parameters. Most hydrocolloid films are characterised as hydrophilic materials and the improvement of water resistance of those materials has been of great interest to scientists in recent decades. In addition, the water resistance depends on film thickness, which also affects other physical properties of films.

Table 1. Water vapour permeability (WVP) of selected biopolymer and plastic films.

Polymer	T (°C)	ΔRH (%)	WVP (10 ⁻¹¹ g·m ⁻¹ ·Pa ⁻¹ ·s ⁻¹)	References
Low density polyethylene.	38	0–90	0.09	[51]
Bocaiuva (<i>Acromonia aculeata</i>) flour	25	0–75	0.17–0.20	[52]
Grapefruit Albedo	25	0–84	2.52	[27]
Pinhão (<i>Araucaria angustifolia</i>) starch and flour	25	0–100	1.14–2.80	[44]
Chia flour	25	0–75	1.58–3.90	[10]
Ulluco starch	25	75–100	4.14–4.84	[33]
Celophane	25	22–84	5.60	[53]
Methylcellulose	25	0–52	8.7–14.0	[54]
Whey protein isolate	25	0–100	17.3	[55]
Starch-lentil flour	25	0–70	16.1–18.7	[18]
Mixture of fruit and vegetable residue flour	25	0–100	16.5–20.0	[21]
Banana flour	25	0–100	21.0	[19]
Bean protein concentrate from seven mexican beans: <i>alubia, for de mayo, garbancillo, peruano, pinto, mantequilla, and negro</i>	–	33–100	20.6–26.8	[17]
Chitosan	25	30–100	34.5	[56]
Lentil flour	25	0–50	24.5–35.2	[14]
Achira flour	25	0–100	53.0	[30]
Wheat starch	25	58–100	130	[57]
Quinoa starch	25	0–100	450	[9]
Cheakpea flour	20	0–100	3480–8870	[15]

Abbreviations: T—temperature; ΔRH—relative humidity differentials.

Table 2. Mechanical properties of selected biopolymer and plastic films.

Polymer	Tensile Strength (MPa)	Young's Modulus (MPa)	Elongation at Break (%)	References
Gum and protein isolate of <i>Cajanus Cajan</i> seed	0.002–0.046	0.014–0.044	0.74–4.60	[43]
Banana peel flour	0.14–0.70	3.0–33.1	9.84–19.6	[26]
Grass pea flour	0.70	26.2	32.2	[13]
Soy protein isolate	1.93	1.19	3.95	[58]
Mixture of fruit and vegetable residue flour	1.20–2.90	0.03–0.16	20–51	[29]
Eggplant flour and corn starch	2.36–4.29	42.7–65.5	19.7–37.3	[12]
Eggplant flour	5.33	92.24	65.09	[12]
Whey protein isolate	5.34	–	10.08	[59]
Chia flour	0.77–6.26	25.6–681.4	1.05–5.16	[10]
Starch-lentil flour	2.10–6.30	0.86–4.8	42–149	[18]
Achira flour	7.00	231.7	14.6	[30]
Quinoa starch	7.56	4.59	58.14	[9]
Cheakpea flour	0.94–9.15	0.71–15.69	4.87–30.9	[15]
Banana flour	9.20	583.4	24.2	[19]
Water chesnut starch	13.1	–	42.2	[34]
Ulluco starch	10.6–15.1	765.5–1155	4.44–4.95	[33]
Low density polyethylene	9–17	–	500	[60]
Mixture of fruit and vegetable residue flour	27–28	3.0	30.5–31.4	[21]
Pinhão (<i>Araucaria angustifolia</i>) starch and flour	1.60–46.5	19–2586	2.80–64.7	[44]
Methylcellulose	69.0	–	10	[54]
Chitosan	74.0	2451	4.60	[56]

Taking into account the mechanical properties of biopolymer films (Table 2), tensile strength values are similar to low-density polyethylene (LDPE), but the elongation at break is much lower for biopolymer films than for synthetic polymers. This is attributed to many factors, the most important being origin of film-forming materials and preparation methods.

4. Applications of Novel Edible Coatings in Improving the Quality and Shelf Life of Food Products

The novel film-forming materials discussed above have great potential for potential application in food preservation, which was presented in Table 3. In particular, they are used as an edible film or coating to cover the surface of various food products in order to enhance food shelf life while sustaining their nutritional and sensory quality [61,62].

Important factors causing the degradation of food are spoilage microorganisms and food-borne pathogens. The presence of spoilage microorganisms in food entails a number of undesirable changes, for example, it accelerates lipid oxidation, which contributes to changes in the organoleptic properties of the product. In turn, pathogenic microorganisms cause foodborne illness in humans [62].

Mali and Grossmann [63] employed yam starch films as packaging to extend the storage life of strawberries. The authors conclude that starch films reduced decay and microbiological contamination of stored samples. Additionally, the shelf life of coated strawberries was prolonged up to 21 days compared to 14 days of uncoated ones. The reason why the tested coating reduced the growth of spoilage microorganisms could be attributed to their good oxygen barrier properties. The coatings inhibited the growth of aerobic pathogens.

Bnuyan et al. [76] reported that gum Arabic exhibited good antimicrobial activity against various bacteria and fungi including *S. aureus*, *S. epidermidis*, *S. pneumoniae*, *Ps. aeruginosa*, *P. mirabilis*, *Acinetobacter*, *Enterobacter*, *Klebsiella pneumoniae*, *Serratia* spp., *E. coli*, *Salmonella* Typhi, and *C. albicans*. For this reason, several attempts have been made to use gum arabic as an edible coating to preserve fresh fruits and vegetables. For example, gum Arabic coating has been successfully used for preserving the quality and safety of Anna apples during cold storage. The coating significantly reduced decay compared to uncoated samples of apples [40]. Similar results were obtained by Mahfoudhi and Hamdi [38] who used almond gum and gum Arabic as an edible coating for sweet cherry fruits. The authors proved that the coatings delayed the ripening process and increased the shelf life of cherries without any spoilage or off-flavour. Also, other studies confirmed that using gum Arabic as packaging materials effectively inhibited fungal growth during storage in perishable food such as strawberries [41] or tomatoes [39].

Much attention has been paid to enhancing and improving the antimicrobial properties of edible packaging materials. Therefore studies on the possibility of incorporation of active compounds with potential biological activity into films and coatings have been analysed. For example, coating based on apricot (*Prunus armeniaca*) gum with the addition of extract from *Satureja intermedia* showed an antifungal effect against *Penicillium citrinum*, *Fusarium oxysporum*, *Aspergillus flavus* and *Alternaria alternate*. Moreover, the application of these active materials has been tested in real food. This coating effectively inhibited the level of microbial contamination caused by fungi on wild almond kernels during storage for 60 days [64].

Maqbool et al. [65] investigated antifungal effects of gum arabic containing lemongrass oil and cinnamon oil for controlling postharvest anthracnose on banana and papaya. The results showed that using gum arabic with essential oils effectively reduced the growth of *Colletotrichum musae* and *Colletotrichum gloeosporioides* in response to anthracnose in tropical fruit. In other studies, potato peel waste film incorporated with oregano essential oil was found to effectively control the growth of *Listeria monocytogenes* on cold-smoked salmon stored for 30 days [66].

Table 3. Potential applications of novel edible coatings.

Coating Materials	Food Products	Main Advantages	References
Yam starch	Strawberries	Reduced decay, weight loss and firmness	[63]
Gum arabic	Anna apple	Reduced decay	[40]
Almond gum	Sweet cherries	Decrease in respiration rate and ethylene production; delayed the changes in colour, weight loss, firmness, titratable acidity and soluble solid concentration	[38]
Gum arabic	Strawberries	Inhibited fungal growth	[41]
Gum arabic	Tomatoes	Inhibited fungal growth	[39]
Apricot gum containing <i>Satureja intermedia</i> extract	Wild almond kernels	Lower fungal contamination, oxidative compounds content and fatty acid profile variation	[64]
Gum arabic with lemongrass and cinnamon essential oil	Banana and papaya	Antifungal effect; reduced the growth of <i>Colletotrichum musae</i> and <i>Colletotrichum gloeosporioides</i>	[65]
Potato peel waste with oregano essential oil	Salmons (Cold-smoked)	Reduced the growth of <i>L. Monocytogenes</i>	[66]
<i>Cordia myxa</i> gum	Artichoke bottoms	Delayed browning; overall shelf-life extension	[67]
Mucilage extract from <i>Opuntia ficus-Indica</i> cladodes	Figs	Maintained the fruit weight and firmness	[68]
<i>Opuntia cactus</i> polysaccharides	Kinnow mandarin	Increase shelf life with regard to its ph, acidity, aroma, colour, texture and general appearance	[45]
<i>Aloe vera</i> Gel	Apple	Maintained the bioactive compounds; reduces weight loss and firmness	[69]
Arabic gum with <i>Aloe vera</i> and garlic extract	Guava	Shelf-life extension; higher ascorbic acid content; lower content of total sugars	[70]
Fruit and vegetable residue flour from orange, passion fruit, watermelon, lettuce, courgette, carrot, spinach, mint, taro, cucumber, and rocket	Carrots (fresh-cut)	Delayed weight loss; maintained the colour	[71]
Fruit and vegetable residue flour from orange, passion fruit, watermelon, lettuce, courgette, carrot, spinach, mint, taro, cucumber and rocket with the addition of potato peel flour	Acerolas	Delayed weight loss	[72]
Protein isolate and gum from the <i>Cajanus cajan</i> seed	Strawberries	Decreased total soluble solid content, consumption of citric acid, mass loss; maintained sensorial acceptability	[43]
Almond gum exudate	Tomatoes	Delayed the changes in colour, weight loss, titratable acidity, soluble solid concentration, ascorbic acid content, firmness, and decay percentage	[73]
Almond gum	Bananas (slices)	Delayed the changes in weight loss; lower browning index	[74]
Pomelo peel flour with tea polyphenol	Soybean oil	Delayed oil oxidation	[28]
Quince seed gum, almond gum, tragacanth gum	Bananas (slices)	Reduced weight loss and changes in colour	[74]
Gulfweed seed	Smoked salmon	Enhance the redness of salmon without affecting its texture and scent.	[49]
Shirazi balangu (<i>Lallemantia royleana</i>) seed mucilage	Beef slices	Enhance the shelf life of beef by preventing lipid oxidation and microbial spoilage	[47]
<i>Lepidium sativum</i> seed mucilage with <i>Heracleum lasiopetalum</i> essential oil	Beef	Increased oxidative and microbiological stability; enhanced overall acceptance	[75]

In general, the most popular products to be coated are fruits and vegetables. This is attributed to their nature as perishable food, which has a huge impact on the quality during storage. Therefore, coating technology is promising approach in order to prolong the consumer acceptability and shelf life of fruits and vegetables. Most of the materials described in this paper require a plasticizer to produce a flexible films and coatings. Using the appropriate amounts of plasticizers and choosing the appropriate film-forming material, the hydrophilic nature of the films can be adjusted to the practical usage of the films. Nevertheless, most studies on food applications are carried out on a laboratory scale. Therefore, future research is needed in order to optimize the production according to costs and practical applications on an industrial scale.

5. Regulatory and Safety Issues of Edible Films and Coatings

Edible films and coatings, since they are an integral part of the edible portion of food products, should follow all required regulations pertinent to food ingredients [77]. Druchta and Johnston [78] published a scientific status summary on edible films that includes their safety and health issues. They reported that to maintain product safety and eating quality, all film-forming components, as well as any functional additives in the film-forming materials, should be GRAS, and used within any limitations specified by the U.S. Food and Drug Administration (FDA). If the edible polymer film material used is not currently GRAS, but the manufacturer can demonstrate its safety, the manufacturer may either file a GRAS Affirmation Petition to the FDA or proceed to market the material without FDA concurrence (self-determination). Besides, edible coatings and films may contain several functional/nutritious ingredients, such as antioxidants, antimicrobials, colorings, etc. In European Union regulations, intended usage of food additives must be labelled on packaging according to the specific functional category with either their name or E-number.

There is another important topic within the regulatory statutes. Many edible films and coatings are made with ingredients that can cause allergic reactions in some consumers. The well-known allergens are usually sourced from milk, soybeans, fish, peanuts, nuts, and wheat. Several edible films and coatings are formed from milk (whey, casein), wheat (gluten), soy and peanut proteins. Therefore, a coating containing a well-known allergen must also be clearly declared to the consumer, no matter how small the amount used, with the appropriate warning about the allergenic ingredient [79].

In general, it is obvious that to achieve a commercial success all film-forming materials as well as different compounds used to increase the quality and shelf life of food products has to meet the sensory acceptance of the consumers. Further research should investigated sensory properties including sensory analysis on the actual products to explore whether the consumer may distinguish between coated products or preference test to determine which products is preferred by the consumers [80]. Along with this, there is another important aspect that should be taken into account during manufacturing, toxicity and allergenicity of edible films and coatings. In this context, essential oils which are usually used in edible coatings as antimicrobial compound, even though they are classified and registered by the European Commission as well as by United States as GRAS may present allergic effect. In addition, the consumption of higher doses of these natural compounds can induce serious problems of oral toxicity. It is necessary to find a balance between the effectiveness of essential oil or plant extract dose and the risk of their toxicity [81]. Overall, since edible films and coatings become part of the food to be consumed, all materials used in these products must be appropriately declared on the label. Regulations regarding incorporation of antimicrobials, antioxidants, essential oils, colour and other additives are the same as those that will be applicable to food formulations [61].

6. Conclusions

The benefits of edible films and coatings for the food industry are numerous, but just a few industrial applications have been developed. The replacement of conventional synthetic polymers by biodegradable films should be highlighted as a highly desirable approach. Many new materials have been investigated for their potential use in the production of edible films and coatings. The source of the

biopolymer is the most important factor in defining the final functional properties and characteristics of biopolymer films. Plant residues are readily available and low cost materials of edible packaging which also provide an excellent source of nutrients. Regarding edible coatings applied to food products, the advantages are also significant. The reduction of weight losses and the prolonged shelf life of food products have a big impact on the reduction of food wastes and, consequently, the costs of food production. Therefore, more research is required on edible films and coatings in order to provide innovative materials and techniques which are beneficial for global economics and the environment.

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