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Review

Edible Packaging: A Technological Update for the Sustainable Future of the Food Industry

Surya Sasikumar Nair [1], Joanna Trafiałek [1] and Wojciech Kolanowski [2,*]

1 Department of Food Gastronomy and Food Hygiene, Institute of Human Nutrition Sciences, Warsaw University of Life Sciences—WULS, Nowoursynowska Str. 166, 02-787 Warsaw, Poland; surya_nair@sggw.edu.pl (S.S.N.); joanna_trafialek@sggw.edu.pl (J.T.)
2 Faculty of Health Sciences, Medical University of Lublin, Staszica Str. 4, 20-400 Lublin, Poland
* Correspondence: wojciech.kolanowski@umlub.pl

Abstract: This review aims to address the current data on edible packaging systems used in food production. The growing global population, changes in the climate and dietary patterns, and the increasing need for environmental protection, have created an increasing demand for waste-free food production. The need for durable and sustainable packaging materials has become significant in order to avoid food waste and environmental pollution. Edible packaging has emerged as a promising solution to extend the shelf life of food products and reduce dependence on petroleum-based resources. This review analyzes the history, production methods, barrier properties, types, and additives of edible packaging systems. The review highlights the advantages and importance of edible packaging materials and describes how they can improve sustainability measures. The market value of edible packaging materials is expanding. Further research on and developments in edible food packaging materials are needed to increase sustainable, eco-friendly packaging practices that are significant for environmental protection and food safety.

Keywords: edible packaging; edible coatings; environmental pollution; food safety; sustainability

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1. Introduction

Food packaging systems play a crucial role in the global food business [1]. Effective packaging reduces food waste and guarantees adequate quality during storage.

Plastics, such as polyethylene, polypropylene, and polyethylene terephthalate, are the most frequently used packaging materials for food packaging because they are inexpensive, quite simple to shape, and weigh less than glass or metal materials; however, plastics are petroleum-based and not sustainable, increasing carbon footprints and worsening the environment. Non-biodegradable packaging materials are not sustainable and provide package-waste-based pollution to the environment [2]. With increasing concern about the environmental impact of packaging waste, consumers are expecting high-quality, natural, eco-friendly, and safer food packaging materials. This presents a significant challenge for the food industry to produce sustainable packages while minimizing environmental pollution. To meet these demands, the food industry is focusing on developing biodegradable, edible, and sustainable materials that can enhance food safety and quality, leading to increased research and industry attention on this issue [3].

In recent years, edible packaging research has expanded rapidly due to greater consumer interest in health, food safety, nutrition, and environmental protection with respect to packaging waste [4]. Edible packaging is an essential part of sustainable packaging. It will significantly broaden its sources of packaging materials, minimizing the demand for non-renewable petroleum resources and thereby decreasing food losses and waste [5]. Such developments in packaging can decrease carbon footprints and benefit the environment. Edible packaging is also an emerging approach that could help to optimize food quality.

What differentiates edible packaging from traditional packaging is the fact that it is integrated with the food product it encases. So, consumers may consume the food product without removing it from its packaging, or they can throw the package away [6].

Therefore, this review aims to address the current information available on the edible packaging systems used in food production.

2. Materials and Methods

A systematic search of published articles related to the topic from internationally available databases such as Google Scholar, PubMed, Scopus, Web of Science, and Science Direct was conducted. The search parameters were based on a few specific keywords, such as edible film, edible coating, wet process, dry process, environmental sustainability, food packaging, pollution, history, food safety, food waste, polysaccharides, proteins, lipids, etc. The timeline for the literature study was set to range from 2013 to 2023. However, we also discussed some historical aspects of the review topic. Upon reviewing each study's article titles and abstracts, duplicates were eliminated. Only studies on edible packaging, sustainability, food safety, and food waste were considered for inclusion. Research and review articles, short communications, peer-reviewed conference materials, book chapters, patents, and, to a smaller extent, websites of recognized institutions describing research on edible packaging and some companies actively involved in the research and development of edible packaging materials were the selected sources of evidence included.

3. Results

3.1. Edible Packaging

Edible food packaging may not interact with the product or can be active or intelligent packaging [7]. In active packaging, active components such as vitamins, antioxidants, and antimicrobials are added; these components are controlled in their release into the product and can increase food durability and other characteristic features like sensory features or product safety [3,6]. Intelligent packaging has some sensors inserted within the films and coatings that can induce responses or changes that alter the freshness, weight, safety, and/or quality of packaged food products. These sensors are usually colorimetric indicators. Anthocyanin and curcumin are some examples of natural pigments that can be used as pH indicators. These sensors are mainly used for the preservation of seafood and meat products [7].

The materials used to package food are made from compounds that humans can eat without posing any health risks. By simply altering their thicknesses with only a small intervention in the material composition and structure, they can convert these materials into various types of films and coatings. Thickness is a very important physical property for making edible films, and the optimal thickness is considered to be less than 0.3 mm [8].

A typical edible film should be non-toxic; have good sensory qualities, microbial stability, and good mechanical properties; be safe for human consumption and non-pollutive; and low-cost. Edible food packaging materials, such as the conventional types, have to be tested to verify whether they are safe for ingestion based on certain quality requirements. One critical factor to assess the safety of edible packaging is its microbiological quality.

3.2. History of Edible Packaging

Edible packaging may seem like a new innovation, but it is a very ancient technology that has been used for centuries for food preservation. It started in the 12th century in China for the preservation of oranges and lemons by coating them with wax to prevent water loss during transportation and storage [6]. The practice of preservation was called "larding" [6]. Boiling soy milk proteins in pans and further air-drying created the first edible films, known as "Yuba" films, in Japan at the beginning of the 15th century [9]. During the 16th century, the larding of fruits, vegetables, meats, and fish was common in England to prevent moisture loss, similar to waxing. The first gelatin film patent was granted in the United States in the 19th century to safeguard several meat products. To limit gas transport through edible coatings, sucrose and sugar derivatives were used as protective coatings on nuts to prevent oxidative rancidity [10,11]. In the 1930s, commercial waxing and lipid coatings were applied to vegetables and fruits, allowing natural respiration and preventing dehydration during transport. This business has grown a lot in the last century. Its primary use was to keep water from leaking out of fruits and vegetables and to give them a shine. In the first two decades of the 21st century, the development of edible packaging remained stagnant due to the widespread use of plastic as a cost-effective packaging material [8]. Today's rising customer standards for quality, freshness, and sustainable packaging choices are facilitating a rise in commercial edible packaging materials. Moreover, increasing awareness of the necessity of environmental protection requires the widespread introduction of non-polluting food packaging as edible packaging.

3.3. Production of Edible Films and Coatings

Generally, edible films and coatings are the primary forms of edible food packaging. The differences between edible films and coatings lie in their physical form and application process. Edible films are obtained as solid laminated sheets and then used as a food wrap that can be removed or consumed with food, whereas coatings are applied to foods in liquid form by coating, spraying, and immersion. After drying, an edible layer over the food is formed, and it can either be removed or consumed [3]. There are basically two processes for making edible films: wet and dry processes [6]. The main components used for the production of edible films and coatings include a film-forming material, a solvent, and additives (e.g., plasticizers, emulsifiers, antimicrobials). The specifications of these components are important; film-forming materials should be polymer-like polysaccharides, proteins, lipids, or composites, and they must have filmogenic properties. Solvents and plasticizers are selected on the basis of their compatibility with the selected polymer. Solvents can dissolve polymers and also modify their mechanical and barrier properties, which include alcohol, water, citric acid, acetic acid, lactic acid, and hydrochloric acid. Plasticizers can reduce brittleness, increase flexibility, decrease porosity, and improve the mechanical properties of films. However, the selection of each component will depend on the food product being used, and it does not alter the organoleptic properties of food. The effectiveness of edible films and coatings depends on the chemical composition of the polymer and the final properties of the films [12].

3.3.1. Wet Process

The wet process, mainly comprising the casting method (or solvent casting), is the most commonly used method for the production of films on a laboratory or pilot scale. In the wet process, the film-forming contents are homogenized with a solvent and dried to obtain a film. This process involves three steps. Dissolving or dispersing the biopolymers in solvents is typically the first step that needs to be carried out to generate films. Additives like antimicrobial agents, plasticizers, and flavoring or coloring agents [11] are added to the matrix material to boost these materials' durability and flexibility [3]. Adjusting the pH and heating the solutions above their melting point to increase their solubility is a possible requirement. This film-forming solution is then cast onto a flat surface and dried at the proper temperature and relative humidity; the resulting film can then be used to wrap the food products [6]. In the casting step, the film-forming solution is poured into a predefined mold or Teflon-coated glass plate. The drying step allows for solvent evaporation, which makes a mold-attached polymer film. In this step, air driers like hot air ovens, tray dryers, microwaves, and vacuum dryers are used for the casting of films [13]. Figure 1 shows a schematic representation of the casting process for edible film production.

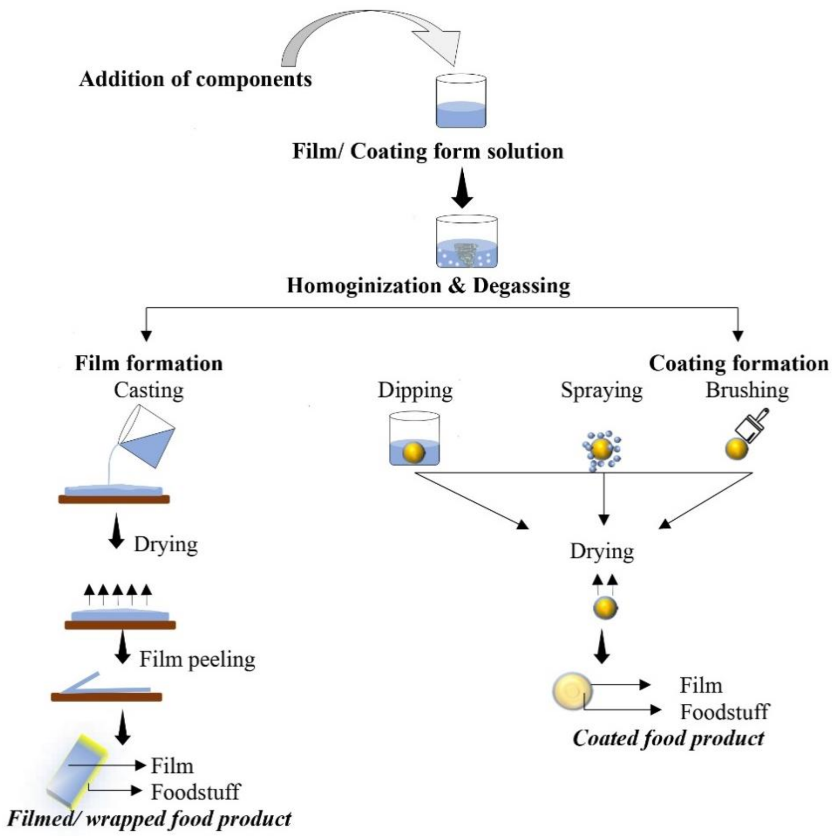

Figure 1. Schematic representation of the production of edible films (Casting method) and coatings.

A significant advantage of the casting method is that it can be easily employed without special equipment. Additionally, as many food-processing materials cannot withstand higher temperatures, lower temperatures during the processing steps can be beneficial. The casting process, on the other hand, has drawbacks such as a longer drying time, which makes it unsuitable for commercial manufacturing. In addition, moving film production from the laboratory to large-scale production presents a challenge due to the possibility of variations in quality and a risk of limiting the constant development of commercial operations caused by factors like heating, speed, and temperature [13].

3.3.2. Dry Process

In the dry process, added contents are converted into films by using the thermoplastic behavior at low moisture levels [14]. The dry process is more varied and consists of the extrusion method, compression molding, injection molding, etc. [3].

The extrusion process is a method of producing edible films on a commercial scale that consists of three zones: feeding, kneading, and heating. This method can change the structural properties and improve the physicochemical characteristics of extruded films [15]. In the feeding zone, film components are mixed, and air compression is applied to minimize the moisture content of these components. This process is also known as a "dry process" because it functions best with a small amount of water or solvents. As the ingredients move through the kneading zone, the strain, temperature, and density of the mixture rise. Then, these materials are heated above their glass transition temperature to facilitate a conversion into a melt form, which is extruded through a suitably shaped nozzle by the rotating force of an extrusion screw. The resulting materials are then subjected to cooling to form the film [16]. Mechanical and thermal energy are used in this process for the production of extruder-based films. Screw speed also has a role in specific mechanical energy. Different screw speeds alter film properties such as shear rate, homogeneity, and stress, as well as the control of residence time, which allows for the addition and removal of additives like stabilizers. As the screw speed increases, the torque value of the extrusion method to obtain films decreases. Other factors such as screw speed, barrel temperature, feed moisture content, die diameter and pressure, energy input, etc., are necessary to ensure that the extrusion process affects the final products. Figure 2 shows a schematic representation of the extrusion process of edible film production [13,14].

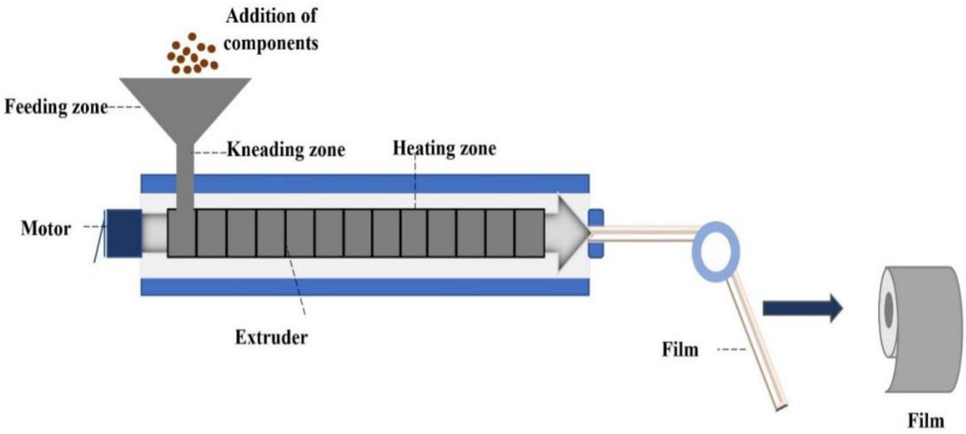

Figure 2. Schematic representation of the production of edible films via the extrusion method.

The extrusion method has better mechanical and optical properties than the casting process, and it also requires less energy and time to process the material. Extrusion processing is also a widely employed commercial technique in the food industry that offers high performance at a reasonable cost. However, the extrusion method has some drawbacks, which are limited to materials with low temperature tolerance and low moisture levels. For example, chitosan is not a thermoplastic material and cannot be extruded [14].

Compression molding is one of the oldest methods and is considered a sustainable process due to its low energy requirement and rapid formation. Here, the film-forming contents are heated under high pressure in the mold until they solidify. Processing time is also a critical parameter for determining the properties of films. This step is usually used in combination with the extrusion method to prepare the film-forming material before its main thermoforming process. Ceballos et al. [17] developed an edible film from starch and yerba mate extract using extrusion and compression molding. Their study revealed that films produced via the compression-mold technique with yerba mate extract can improve the shelf life of foods, providing a promising active food packaging material.

The injection molding method is mainly used to make plastic items, but it is also appropriate for the mass production of edible films. This method consists of three stages, namely, filling, packing, and cooling, and its parameters are injection pressure, molding temperature, and pre-injection pressure temperature [18]. This method can be used in conjunction with the extrusion method to obtain a film. Studies on the injection molding method are scarce [14].

3.3.3. Production of Edible Coatings

The film-forming solution can be directly applied to food surfaces as coatings in the form of liquid suspension, emulsion, or powder. Methods like dipping, spraying, brushing, fluidized bed processing, and the panning method are used to apply edible coatings to food products, followed by drying. Figure 1 is a schematic representation of the process used to produce edible coatings.

The dipping method is the oldest and most common method used to coat edible coatings on foods such as meat products, fruit, and vegetables [13]. This method is one of the ideal choices for coating irregular food surfaces [15]. The surface tension, density, and viscosity of the coating solution are significant in estimating the thickness of the film. The dipping method involves dipping a product directly into an aqueous coating solution, removing it, and subsequently subjecting it to air drying to produce a delicate membranous film that envelops the product's surface. Another method for coating formation is the foam application method. Emulsions are typically used in this method. The foam breaks through a lot of tumbling so that the coating solution can be uniformly applied throughout the product's surface [19].

The spraying method is preferred when only one surface needs to be coated and a thin layer of coating is necessary. Compared to pan or fluidized bed coating, it is a more precise form of coating application, wherein the solution is applied to the food surface using pressure (60–80 psi) [18]. However, in this method, after coating and drying one/the upper surface of the product, the product needs to be rotated or spun to cover the other lower surface. This method is mostly preferred for products with large surfaces. In this coating process, the spray nozzle plays a crucial role as it can influence factors like droplet size, surface tension, spray distance and angle, flow rate, overlap speed, viscosity, temperature, and pressure of the coating fluid [15,19].

Fluidized bed processing is a process that involves applying a very thin coating to dry particles of extremely low size and/or density. In this method, the small particles that are to be coated are added to a rotating fluidized bed. A centrifugal force pushes the coated particles towards the equipment's wall. Also, the equipment is designed to allow for airflow; thus, the combined effects of airflow and centrifugal force effectively counter the total force acting on the food particles [15,19].

The pan-coating method is used to cover hard, almost-spherical particles in thin or thick layers [13]. This coating can prevent the loss of moisture and lipids and can provide additional flavors to the coated product. The pharmaceutical and confectionery industries both use the pan-coating method to cover the products with this coating material. In this method, the pan is a large, rotating bowl in which the item to be coated is placed. A ladle or spray is used to add the coating solution to a rotating pan. To apply the coating solution throughout the food's surface, the product is rotated in the pan [19].

3.4. Barrier Functions of Edible Packaging Materials

The protective barrier effect of an edible film helps to enhance the shelf life of food products. However, in the case of vegetables and fruit, there is some degree of respiration, and it is crucial that the packaging is not completely gas, water, and ethylene barrier-proof. Edible packaging materials must meet several specific functional requirements that depend on the material type, its production, and its application.

The edible films and coatings act as an environmental barrier and control the mass transfer between the food and the external environment [3]. When choosing edible materials for packaging, permeability is perceived to be a crucial consideration. The impact of moisture and temperature on film determines its intended use. Therefore, before employing it as a food packaging material, the permeability must be measured under specific circumstances [20].

For many kinds of applications, edible films and coatings should have an adequate moisture barrier. Reducing the transfer of moisture between compartments of heterogeneous food products like pizza is crucial for maintaining their various crunchy and soft textures. Variations in packaged food water activity (a_w) can lead to microbiological development, deteriorating chemical and enzymatic interactions, and undesirable textural changes. Edible films and coatings with good a_w gradients can significantly reduce the water migration between food compartments, thereby maintaining a crispy crust texture [21].

Water activity (a_w) is a critical factor in determining the shelf life and quality of food. Water vapor barrier functions are vital for fresh produce products, such as vegetables, and are crucial to preventing dehydration in dry foods such as bread, where it is necessary to prevent moisture absorption from the environment. The amount of water vapor transmitted through a unit area, time, and pressure is known as water vapor permeability (WVP) [22,23].

Oxygen-sensitive foods can have their shelf life extended and their quality preserved by using low-oxygen-permeability (OP) edible packaging. Additionally, the adoption of edible packaging will contribute to a reduction in the use of certain pricey and luxurious, non-recyclable, oxygen-barrier plastics. Edible films have a different range of OP values. Liu et al. [24] suggested that curcumin-treated chitosan-bacterial cellulose-based films have good barrier properties like increased hydrophobicity and oxygen permeability. Starch-based films have good oxygen barrier properties due to their hydrogen–hydrogen bond structure [25]. It is important that every type of food has specific packaging requirements. For example, in the case of fruit and vegetables, packaging must not be absolutely water, gas, and ethylene barrier-proof because fruit and vegetables have a certain degree of respiration [26]. However, regarding the packaging of slices of cheese and ham, this requirement is not applicable, and the porosity should be much lower [27].

Another way to address consumer preferences and health concerns is to minimize the fat content of fried food products like potato chips with oil barrier coatings using hydrophilic macromolecules. This may cause oil barrier coatings to develop into a viable substitute for reducing oil absorption during frying. Casein-based edible films and coatings can reduce the moisture losses and cooking losses regarding meat products during frying [21]. The mechanical and barrier qualities of a coating, which are influenced by its composition and microstructure, as well as the parameters of the substrate, determine how effective it is [28]. The utilization of fluorinated oil repellents in food packaging, especially for fast food, has raised concerns due to its potential to harm humans and the environment. Liu et al. [29] have presented an eco-friendly solution for the substitution of fluorine-free oil repellents, with microcrystalline wax emulsion serving as an alternative to paper-based oil repellents.

It is crucial for the organoleptic properties of edible packaging materials to have a high degree of neutrality. They are designed to be clear, transparent, tasteless, odorless, etc., so that they will not be noticed when eaten. Enhancing the surface's appearance (like brilliance) and tactile properties (like decreased stickiness) is necessary. The ideal flavor, color, spiciness, acidity, sweetness, saltiness, and other qualities can also be preserved through the use of films and coatings [30]. Compared to films made from lipids, waxes, or their derivatives, which frequently exhibit characteristics such as opacity, slipperiness, and a distinct waxy flavor, films derived from hydrocolloids typically have a flavor that is more neutral. In any case, it is feasible to accomplish materials with positive tangible properties by guaranteeing similarity with the particular food contents. Candies, biscuits, certain cakes, and ice cream products (like wafer coatings) frequently employ sugar coatings, chocolate layers, and starch films [31].

3.5. Categories of Edible Packaging Materials

Edible films and coatings can be categorized into proteins, polysaccharides, lipids, and composites (Figure 3). Selecting edible films or coatings requires the consideration of the substance from which they are made, the kind of food to apply them to, and how they will be applied. To enhance their flexibility and elasticity, a plasticizer can be incorporated into the solution [12]. Depending on the final application, additional additives, like coloring, flavorings, and antimicrobial agents, can be added to the solution to yield specific functionality and film properties.

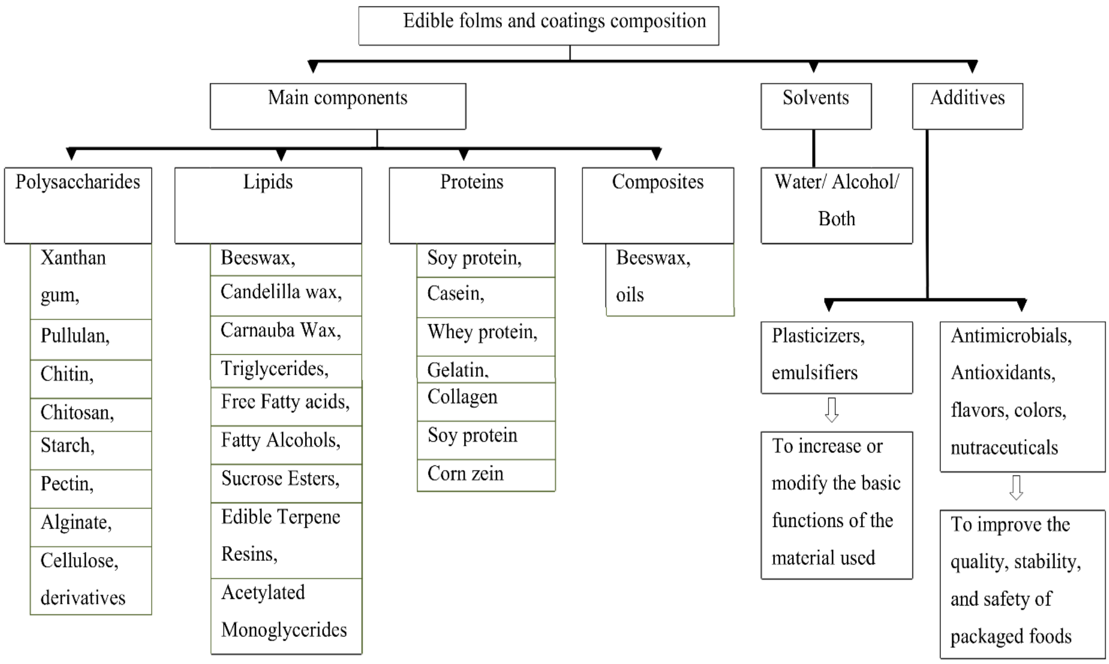

Figure 3. A compositional overview of edible films and coatings (according to the authors of [4,32–39]).

3.5.1. Polysaccharide-Based Packaging Materials

Polysaccharide is the most abundant natural macromolecule in nature [5] and it consists of long chains of polymeric carbohydrate bound together by glycosidic bonds which are widely used in the production of edible packaging. Polysaccharides can originate from many different sources, namely, microbial (such as xanthan gum and pullulan), plant (such as cellulose, starch, and pectin), animal (like chitin, chitosan), and marine sources (such as alginate). Films and coatings made from polysaccharides can be oil-free, tasteless, and colorless, have better chemical stability, and have better processing adaptability when compared to protein- and lipid-based packing materials. They can reduce dehydration, surface darkening, and oxidative rancidity, thereby potentially enhancing the shelf life of vegetables, fruit, meat products, or shellfish [5,26]. Polysaccharide-based film coatings are effective barriers against O_2 and CO_2 at low and medium relative humidities due to their intermolecular structure [26,40,41]. Thus, due to their selective permeability, polysaccharide-based materials can be used to improve the shelf life of fresh-cut fruits and vegetables by reducing the respiration rate and gas exchange [40]. However, polysaccharide-based materials provide a low barrier to moisture due to their hydrophilic nature [37]. In addition, packaging materials based on them have a high sorption ability; therefore, when they are consumed, they can adsorb and remove radionuclides, metal ions, and other toxic chemicals from the body [41]. Table 1 groups edible packaging materials based on different polysaccharides.

Cellulose Films

Cellulose is a linear-chain homopolysaccharide with anhydrous β1-4 glycosidic bonded glucose rings. It exhibits specific properties such as low cost, low density, durability, high mechanical strength, non-toxicity, biocompatibility, biodegradability, renewability, good film-forming performance, chemical stability, and ease of making chemical derivatives [9]. Nevertheless, cellulose's applicability in the production of edible films is limited because of its inability to dissolve in water and most organic solvents. This is due to its tightly packed hydrogen bonds, high crystallinity, and structural complexity [42]. One way to overcome this limitation is through derivatization by applying an alkali treatment and then acidification by using hydrophilic agents such as methyl chloride, chloroacetic acid, or propylene oxide to produce thermoplastic and hydroplastic cellulose derivatives. Various cellulose derivatives that are mostly employed in the creation of edible food packaging include ethers such as methylcellulose, carboxymethylcellulose, hydroxy-propyl methylcellulose, and hydroxypropyl cellulose, as well as esters like cellulose acetate. Methylcellulose and hydroxypropyl cellulose and films are very efficient O_2, CO_2, and lipid barriers, but have a low resistance to water vapor transfer [37]. However, the water vapor barrier characteristics can be increased by including hydrophobic elements such as lipids in the film-forming solution. The FDA has approved cellulose acetate as being generally recognized as safe (GRAS), prompting the food-packaging sector to develop and test new applications for this polymer. Cellulose acetate is mostly used to wrap fresh and baked items [42].

Chitosan Films

Chitosan is a linear polysaccharide composed of β-linked N-acetyl-glucosamine and N-glucosamine units. It is derived from alkaline N-deacetylation of chitin, which is the second most prominent natural polysaccharide after cellulose [42]. The main sources of chitin are the exoskeletons of crustaceans and several insects and fungi. Chitosan is biodegradable, non-toxic, and biocompatible [37]. Chitin is insoluble in water or other common solvents, but by applying high alkaline and warm conditions, this chitin can convert into chitosan. After this treatment, produced chitosan becomes soluble in acidic mediums such as diluted hydrochloric, formic, and acetic acids [26,32].

Several studies have reported chitosan use in food packaging due of its physicochemical properties. Chitosan has good mechanical and film-forming properties and selective permeability to O_2 and CO_2 [42]; it also possesses antimicrobial and antioxidant properties [43]. So, the chitosan-based film and coatings can be used in products like apples, pears, strawberries, cucumbers, bell peppers, peaches, and plums. However, chitosan films have some limitations for use in food products. Chitosan is hydrophilic; thus, it shows poor moisture barrier properties. Several strategies can be applied to enhance the functional qualities of chitosan, like modifying solvent type, pH, adding plasticizers [44], and incorporating lipid components [9]. Another main challenge to chitosan-based films and coatings is that they are not thermoplastic, which results in degradation before reaching the melting point. Therefore, chitosan is difficult to extrude, and the films cannot be heat-sealed, which limits their production at the commercial level [45].

Starch Films

Starch has been vastly studied because of its abundance, biodegradability, low cost, and edible nature. Starch is a polysaccharide that consists of amylose and amylopectin, of which amylose is responsible for the starch's film-forming abilities. The crystalline portion consists of amylopectin's short-branched chains, whereas the amorphous regions are made of amylose and amylopectin branching points. Starch granules are insoluble in cold water; thus, when they are heated in water, their crystalline structure becomes disrupted and causes water molecules to interact with the hydroxyl groups of amylose and amylopectin, which results in partial solubilization. To obtain a homogeneous film-forming solution, gelatinization is required [44]. High tensile strength values and low elongation percentages result in the starch films having poor mechanical properties. Also, starch films are brittle due to the presence of the amorphous regions created by amylose. However, this problem can be solved by adding a plasticizer, which results in improved flexibility and extensibility [46].

Alginate Films

Alginate is an edible, natural hetero-polysaccharide extracted from marine brown seaweed (*Phaeophyceae*), where they occur in the form of calcium, sodium, and magnesium salts of alginic acid [27]. Alginate consists of a linear anionic polysaccharide polymer of β-(1–4)-D mannuronic (M-blocks) and α-L-guluronic acid (G-blocks). Alginate can exhibit gelling properties because of the large number of GM blocks and their interchain interactions. They are biodegradable, biocompatible, biostable, non-toxic, and hydrophilic [47]. Sodium alginate has been listed as a GRAS substance by the U.S. Food and Drug Administration (FDA) in Title 21 of the Code of Federal Regulations (CFR) [48], and it can form good films with good mechanical strengths, moisture barriers, and cohesiveness [49,50]. Alginate edible films are uniform, highly water-soluble, and transparent. The use of divalent cations such as Ca^{2+} to cross-link alginate during film synthesis results in ionic interaction, which improves water insolubility and strengthens films [51].

Table 1. Edible packaging materials.

Category	Material	Food Product	Method	Properties	References
Polysaccharides	Cactus mucilage-agar blend	Low-moisture foods	Casting	Good water barrier properties and antioxidant activity.	[35]
	Tapioca starch	Fresh cut cauliflower	Dipping	Reduced the weight loss of the product.	[40]
	Chitosan	Sliced mango fruit	Dipping	Effectively improves the quality attributes and extends shelf life.	[52]
	Chitosan-beeswax blend	Fresh strawberries	Casting	Prolongs shelf life and decreases the senescence and weight loss of fruit.	[53]
	Chitosan-poly-vinyl-pyrrolidine combined with salicylic acid blend	Guava	Dipping	Reduce browning on the fruit skin.	[54]
	Mango kernel starch	Tomato	Dipping	Delayed ripening processes extend shelf life.	[55]
	Sodium alginate-agar blend	Slices of meat and cheese	Casting	Extended shelf life from 3 to 5 months.	[27]
	Sodium alginate-lemongrass essential oil blend	-	Casting	The sodium alginate/LEO films exhibited the highest inhibition against *E. coli*, *B. subtilis*, *S. aureus*, and *P. aeruginosa*, and the shelf life of the food can be enhanced with the films incorporated with LEO.	[51]
	Pectin	Lime fruit	Dipping	Longer shelf life and improved product safety.	[56]
		Plum fruit	Dipping	Increased antioxidative properties and shelf life and quality of plum fruit.	[57]
		Avocado fruit	Dipping	Extension of shelf life over a month at 10 °C, delaying changes in the texture and color of fruit.	[58]

Table 1. *Cont.*

Category	Material	Food Product	Method	Properties	References
Proteins	Whey protein isolates-nano-emulsions of *Grammosciadium ptrocarpum* Bioss. essential oil blend	Meat products, nuts, fruit and vegetables	Casting	Improved mechanical properties and lower water vapor permeability promote the antimicrobial activity of films.	[59]
	Whey protein concentrate	Cheddar cheese	Casting	Possibly extending the shelf life of milk products.	[60]
	Gelatin-hitosan-Ferulago Angulate essential oil blend	Turkey meat	Casting	Inhibits microbial growth and increases the shelf life of Turkey meat.	[61]
	Whey protein isolate-oregano oil blend	Fresh beef cuts	Casting	Increases the shelf life and reduces color change.	[62]
	Ultra-sound treated whey protein blend	Frozen Atlantic salmon	Dipping	Delayed lipid oxidation.	[63]
	Gelatin-starch-ε-Polylysine hydrochloride blend	Fresh bread	Extrusion blow	Increased film flexibility, antimicrobial effect, and shelf life.	[64]
Lipids	Alginate-lipid blend	Ready-to-eat foods	Casting	Exhibits strong antioxidant and antiviral activities.	[65]
	Chitosan-beeswax-pollen grain blend	Le Conte pear fruits	Casting	Decrease in weight loss, maintain quality.	[66]
	Cassava starch-beeswax-ethanolic propolis extract blend	Minimally processed foods	Casting	Decrease in moisture content and WVP; antifungal activity.	[67]

3.5.2. Protein-Based Packaging Materials

Proteins are complex polymers whose amino acids are linked by covalent peptide bonds, which have a broad range of mechanical and physical characteristics, making them good for coating diverse food products. Proteins exist as fibrous (water-insoluble) or globular proteins (water-soluble proteins). Collagen, gelatin, casein, whey protein, soy protein, bean protein, wheat gluten, and peanut protein are examples of common proteins from animal and plant sources used for edible packaging [14]. Protein coatings have relatively high mechanical properties and provide effective barriers to gases like CO_2, O_2 [68], lipids, and aromas [36], but they have low water barrier properties [14]. Table 1 groups edible packaging materials based on different proteins.

Milk Protein Films

Milk proteins consist of ca. 80% casein and 20% whey protein and have the properties of malleable, transparent, and tasteless films [36]. These proteins also serve as carriers of additives like antimicrobials, antioxidants, and colorants, thereby enhancing the organoleptic properties of the packed products. The type of biopolymer and also the type and concentration of plasticizers employed in the preparation of the film has a significant impact on the thickness, barrier properties, and tensile strength of casein and whey protein films [60].

Casein-based films are the most transparent of the protein-based films and also exhibit good elasticity and firmness, moderate surface hydrophobicity, thermal persistence, and low oxygen permeability. The main drawback of casein-based films, like most other protein-based films, is their low resistance to water vapor [69], and it is better to combine them with lipids to form composite films [70]. Picchio et al. [71] suggested the possibility of using tannic acid as a crosslinking agent to improve the physiochemical properties of casein-based films. Caseinate is the most common form of casein, which is highly water-soluble [33], but gets insoluble when subject to a buffer solution at pH 4.6 [72]. Calcium caseinate (CaCAs) and Sodium caseinate (NaCAs) are the most commercially available caseinates. Caseinates are made via casein precipitation by decreasing the pH to 4.6, either by adding a microbial culture or diluting mineral acid. After that, the casein curd is washed in water and then dissolved in an alkali appropriate to bring the pH up to approximately 7.0 before being spray-dried. If NaOH is selected to change the pH, sodium caseinate will be made, whereas if $Ca(OH)_2$ is selected, calcium caseinate will be produced [73].

Whey protein is a by-product or waste product of the dairy industry, which is another reason why it is selected as a component for producing edible films. The availability of whey protein and its potential applications in the production of gels, emulsions, and foams have attracted interest in the packaging industry. Because of this interest, whey protein is used to create films or coatings that protect food surfaces from chemical or microbial decay. As a result, this helps products maintain their high-quality standards and extend their shelf life [74]. Whey proteins consist of whey protein isolates (WPI) and whey protein concentrates (WPC) and have differences in protein concentration. WPIs are the most prevalent protein-based materials utilized in films and coatings [75]. This whey protein film is gaining more attention than polysaccharide-based films and other protein-based films because of its biodegradable, edible nature as well as its mechanical and barrier properties [74]. WP-based edible packaging is colorless, odorless, flexible, and transparent, with distinguishing features such as conformation, denaturation, amphiphilic nature, and electrostatic charges, which can be produced by methods like casting, extrusion, enrobing, dipping, fluidization, spraying, and foaming. WP films can limit the amount of water vapor condensation in fruit and vegetable packaging, thereby preventing microbial spoilage [23].

Collagen Films

Meat proteins are classified as sarcoplasmic, stromal, or myofibrillar. Sarcoplasmic proteins include enzymes, myoglobulins, and cytoplasmic proteins. Collagen and elastin are stromal proteins, whereas myosin, actin, tropomyosin, and troponins are myofibrillar proteins. For the production of edible films and coatings, stromal and myofibrillar proteins can be used. Collagen is a fibrous protein extracted from various sources like skin, tendons, bones, connective tissue, and the vascular system. These sources are typically by-products of meat processing [30] and are used as edible films for meat products. This type of coating has the advantage of preventing humidity loss and gives the product a uniform appearance, boosting its structural qualities [32].

Gelatin Films

Gelatin is a tasteless, water-soluble, transparent high protein with a faint yellow color that is produced as a result of the hydrolysis of the fibrous protein collagen [37]. Pork, fish, and bovine are sources of collagen for gelatin production [36]. Depending on its method of synthesis, gelatin can be categorized as (I) Type A—derived from acid-treated collagen—and (II) Type B—obtained from alkali-treated collagen [42,76]. Gelatin is utilized in the adjustment, gelling, texturization, and emulsification of bakery, confectionary, beverages, and dairy items in the food industry. However, its limited mechanical and thermal stability has prevented it from being used in many applications [76]. The gelatin-based film shows low O_2 permeability and good mechanical properties but is highly moisture-sensitive and water vapor permeable because of its hygroscopic nature [42].

Zein Films

Zein is a prolamin protein present in corn that is insoluble in water but soluble in 60–90% ethanol solutions and also in alkaline solutions with pH greater than 11 [77,78]. It has thermoplastic behavior and hydrophobic, antioxidant, and antibacterial properties [79]. Zein-based films are thermally stable, smooth, and have selective barriers to O_2, CO_2, and oils. Hence, it has good film-forming properties due to its hydrophobic nature and barrier properties. Despite this, zein-based films exhibit fragility and poor mechanical properties. However, the addition of plasticizers or combining them with other polymers as composite films can improve their structural properties [30,42]. Pavlátková et al. [80] developed zein-chitosan-based blend systems enhanced with cinnamon, thymol, thyme, and oregano and studied their physicochemical properties and antimicrobial efficiency with a specific focus on their potential application in the active packaging of fresh strawberries. The result showed that the zein-chitosan blend is appropriate as a bioactive compound carrier to prevent moisture loss, make barriers, ensure microbial food quality, and prolong the shelf life of fruits. These systems can be used for sustainable active food packaging.

3.5.3. Lipid-Based Packaging Materials

Lipids are naturally hydrophobic polymers that come from plants, animals, or insects. Natural waxes, acetylated monoglycerides, and resins are the most frequently utilized edible packaging lipids. Lipids cannot form independent and cohesive films. Therefore, they can be used for packaging as composite films. Lipids can make films and coatings that are excellent at keeping out moisture [38]. Coatings of wax are considerably more impervious to the migration of water when compared with other lipid-based or non-lipid edible films. These can be used by themselves or with other ingredients [26]. Table 1 groups edible packaging materials based on different lipids.

Waxes are made of esters of a long-chain alcohol and a long-chain fatty acid, and they have a larger molecular weight. Waxes have animal and vegetal origins and serve as protective covering tissues. Due to their strong hydrophobicity, waxes made from esters aid in minimizing moisture permeability, which is why they are utilized in edible packaging [32,81]. Both natural and synthetic waxes have been employed as protective coatings either alone or in combination with other materials. Natural waxes include carnauba wax [82], candelilla wax [83], rice bran wax [84], and beeswax [85], all of which can used to prevent fungal growth and extend the shelf life of fruits [86]; synthetic waxes include paraffin wax [87] and petroleum wax [88].

Essential oils have good antimicrobial and antioxidant properties and can reduce lipid oxidation, improving the shelf life of foods [89]. Chitosan films supplemented with active agents have potential applications in meat preservation because of their antimicrobial properties. Tan et al. [90] developed a chitosan film with Chrysanthemum morifolium essential oil to enhance the storage period of fresh raw beef and chicken. The developed active chitosan film seemingly inhibited the activity of S. aureus, and the authors of this study recommended using the film as a substitute for plastic bags.

3.5.4. Composite Films

Composite films are complex systems that consist of multiple components and combine several hydrophobic and hydrophilic compounds to improve functional qualities [20]. In these kinds of edible packaging, the approach is to use a combination of at least two constituents, wherein the weakness of an individual substance is compensated for by the presence of the other component. For example, the water vapor permeability of polysaccharides and proteins can be enhanced by incorporating lipids, resulting in an edible composite that possesses both hydrophilic and hydrophobic properties [6]. A study by Sanchez-Gonzalez et al. [90] presented an edible coating with hydroxypropylmethylcellulose and chitosan with and without bergamot essential oil (EO) for the cold storage of grapes. They suggested that HPMC coating with bergamot EO was the most effective formulation, in comparison to chitosan alone with bergamot EO, in displaying effective antimicrobial action and great control over respiration rates, with reduced weight loss during postharvest cold storage. The extension of ivy gourd (*Coccinia Indica*) shelf life was studied with composite films with a blend of gum acacia pectin and pullulan using plasticizers like sorbitol and glycerol. To evaluate the efficiency of the coating solution, titrable acidity (TA), antioxidant, weight loss, total soluble solids (TSS), total phenolic content (TPC), and storage time measurements were taken. According to the study's results, the ivy gourd's shelf life increased by 35% throughout the 23-day storage period. The anti-microbial test suggested that the prepared film/coating is more resistant to *Pseudomonas aeruginosa* because of the presence of pullulan [91].

Composite edible films can be classified as binary or ternary depending on the number of biopolymers. Combining pectin and zeolite Y results in a classic example of a binary edible film [91]. Such systems allow for a variety of protein–protein, carbohydrate–carbohydrate, and protein–carbohydrate combinations. There are a lot of studies on composite coatings and films created by combining two hydrocolloids; however, edible films or coatings created by combining three hydrocolloids are rare [92].

The field of composites has seen significant advancements closely related to that of the progress in nanotechnology. Bio-nanocomposite materials are renowned for their promising features that help to enhance the mechanical and barrier properties of edible packaging materials [20].

3.6. Additives in Edible Films

Film additives are compounds other than film-formers that are incorporated into films to improve their mechanical, structural, and handling qualities or to perform active functional properties.

3.6.1. Plasticizers

Most edible films made from biopolymers usually have poor mechanical properties; they are fragile and prone to cracking when drying. This is because of the cohesive forces in polymer films. These issues can be resolved by incorporating plasticizers into the film's composition [75]. Plasticizers are hydrophilic agents with a low molecular weight that are incorporated into film-forming preparations and aim to improve the film's mechanical properties [93]. The International Union of Pure and Applied Chemistry (IUPAC) defines a plasticizer as a substance or material that is added to a another material to enhance its workability, flexibility, or distensibility [94]. Films made from a variety of polysaccharides are often brittle in the absence of a plasticizer because of the interactions between polymer chains. Plasticizers reduce the intermolecular interactions between adjacent polymer chains within a film. By doing so, plasticizers decrease cohesion within the film network. Plasticizers alter or enhance the mechanical properties in this way [35,44,57]. Sucrose, glycerol, sorbitol, mannitol, propylene glycol, and polyethylene glycol are some of the plasticizers used in edible packaging [9,10]. Glycerol has been frequently used to maintain moisture in starch-based products [95]. In a study conducted by Makhloufi et al. and Panahirad et al. [35,57], glycerol was used as a plasticizer to enhance the mechanical properties of their polysaccharide-based film.

3.6.2. Emulsifiers

Emulsifiers possess both polar and nonpolar components, making them surface-active compounds capable of altering interfacial energy at the interface of immiscible systems, such as a water–lipid interface or a water–air surface. The presence of emulsifiers is necessary for the creation and stabilization of well-dispersed lipid particles in composite emulsion films. Also, emulsifiers contribute to achieving appropriate surface wettability, ensuring proper surface coverage and adhesion to the coated surface. Natural lecithins are important emulsifiers; glycerol monopalmitate, glycerol monostearate, acetylated monoglyceride, sodium lauryl sulfate, polysorbate 60, polysorbate 65, polysorbate 80, sodium stearoyl lactylate, sorbitan monostearate, and sorbitan monooleate are a few other common emulsifiers [37]. Because of their amphiphilic nature, many proteins exhibit emulsifying capabilities [96].

3.6.3. Antimicrobials

Edible coatings can be used as carriers of antibacterial and antifungal agents to prolong the storage life of food products and are also used as nutrient carriers to improve the nutritional profile of processed food items. As an alternative for limiting the growth of bacteria, both natural and synthetic antimicrobial agents have been created and added to various edible packaging materials [97]. The most commonly used antimicrobial substances introduced in films are nisin, enzymes, chitosan, oils, plant extracts and preservatives, bacteriocins, ethylenediaminetetraacetic acid (EDTA), metal nanoparticles, and different plant extracts and their essential oils [4,97]. Chitosan exhibits good antibacterial activity against yeast and mold and also against Gram-positive and Gram-negative bacteria [97]. García-Anaya et al. [12] discussed the few studies on bacteriophage-treated edible films and coatings. The phage-added edible films and coatings have good antibacterial properties and are suitable for the preservation of fruits, vegetables, cheese, and meats. Table 2 shows the effect of different antimicrobial agents on edible packaging materials.

Table 2. Antimicrobial properties of some edible packaging materials.

Type of Edible Packing Material	Antimicrobial Agent Used	Food Models	Target Microorganism	Result	References
Film	Chitosan thymol nanoparticles	Blueberries, tomato cherries	*Listeria innocua*, *Salmonella typhimurium*, and *Staphylococcus aureus*	Stronger antimicrobial action of chitosan-thymol nanoparticles than thymol alone.	[98]
Chitosan film	Bioactive extracts (tea tree, rosemary, pomegranate, resveratrol, and propolis)	Minimally processed broccoli	*E. coli*, *Listeria monocytogenes*	Slowed the growth of both psychotropic and mesophilic microorganisms; improved the color, texture, and sensory qualities of broccoli.	[99]
Whey proteins isolate films	Oregano oil	Fresh beef cuts	Spoilage flora	Increased shelf life of fresh beef.	[62]
Gelatin-based nanocomposite film	Chitosan nanofiber (CHINF) and ZnO nanoparticles (ZnONPs)	Chicken fillet and cheese	*E. coli*, *Staphylococcus aureus*, *P. aeruginosa*	Decreased the growth of inoculation bacteria and increased the organoleptic characteristics of both samples.	[100]
Polylactic acid (PLA) film	Sorbic acid and lyophilized alga (*Ficus spiralis*)	Megrim (*Lepidorhombus whiffiagonis*)	Aerobes, Enterobacteriaceae and psychrotrophs	Enhanced refrigerated fish quality and reduced the waste material content.	[28]

3.6.4. Plant Extracts

Plant-based essential oil extracts, such as cinnamon, clove, allspice, grapefruit seed, thyme, horseradish, rosemary, radish, onion, garlic, mustard, and oregano, are high in phenolic compounds like phenolic acids and flavonoids, which have a variety of biological effects with respect to antimicrobial and antioxidant activity [45]. Natural antimicrobial agents can be incorporated into foods without the need for antimicrobial agents or preservatives [101]. Numerous studies have reported beneficial effects on the properties of fish, meat, fruits, and vegetables after the introduction of plant extracts. These extracts have positive effects, including the inhibition of microbial growth, antioxidant activity, and preservation of sensory characteristics by effectively controlling quality deterioration [102]. Asian medicinal plants and spices can be used as food preservatives and flavorings. Their addition can improve the antioxidant and antimicrobial properties of edible films. Kong et al. [103] incorporated various Asian-based plant extracts and essential oils into an edible film, improving its mechanical and physiochemical properties and contributing to the antioxidant and antimicrobial activity of the edible film.

However, the structure and functional properties of films incorporated with active plant extracts can vary depending on their concentration, the polymer used, and the conditions (pH, temperature, etc.) applied for processing, posing challenges for film performance and quality. Also, the antioxidant activities of edible packaging materials incorporated with natural additives can decrease over time. Therefore, stability during processing and storage needs to be assessed [104].

3.6.5. Antioxidants

Antioxidants are chemical compounds that, when added to edible packaging materials, can delay the start of or slow the rate of oxidation reactions. Examples of antioxidants include tocopherols, butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), propyl gallate, tertiary butylhydroquinone, citric acid, tartaric acid, ascorbic acid, ascorbyl palmitate, polyphenols, and carotenoids. Nogueira et al. [105] studied the antioxidant property of blackberry powder on an arrowroot starch-based edible film. The antioxidant property of blackberry and other plant extracts is related to polyphenol and anthocyanin content, which is maintained when added to the edible film. Assis et al. [106] created a cassava starch-based biodegradable film that encapsulated β-carotene and showed antioxidant properties. Edible packaging materials incorporated with natural antioxidants can inhibit or reduce lipid oxidation in meat products. However, edible packaging materials must be specially designed for meat products due to their specific methods of storage and processing and the increased risk of microbial contamination [7].

3.7. Regulations

Edible packaging is an integrated portion of the food product; ergo, edible packaging has to conform to food safety regulations. It is possible to create edible films and coatings using the food ingredients and additives that have been permitted by Codex Alimentarius, the US Food and Drug Administration, the EFSA (European Food Safety Authority), or other national food safety authorities [30]. Edible packaging materials may be categorized as food packaging materials, food products, food contact materials, or food ingredients depending on their function. Currently, the majority of non-plastic food contact materials are not regulated by European legislation, and the present regulations only cover a limited amount of edible packaging materials, with the exception of Directive 2007/42/EC, which pertains to the regenerated cellulose films and articles intended for use in food contact materials [107].

Several edible coatings and films contain components that might cause allergic reactions in some consumers. So, any coating that contains a recognized allergen should be properly labeled [30]. The use of organic solvents in the development of edible packaging materials is discouraged due to the risk of contamination of food products and increased toxicological concerns. Any edible packaging material must not harm human health and must be authorized by official food safety institutions to ensure compliance with food safety regulations.

Overall, edible packaging materials have to be developed and used in a way that complies with local and national food safety rules to ensure their safety and success. To attract customers, marketing strategies such as price discounts, awareness programs, and advertisements should be used. When using edible packaging materials and additives, it is necessary to follow good manufacturing practices (GMP) [20].

3.8. Market Examples

Various companies and start-ups are developing edible packaging materials on a commercial level, mostly in the U.S. The worldwide edible packaging market was valued at USD 0.84 billion in 2021 and is predicted to reach around USD 2.8 billion by 2030, recording a mean annual growth rate of 14.31% during the forecast period from 2022 to 2030 [108]. Market examples of edible packaging are shown in Table 3.

Table 3. Commercial brands that produce edible films and coatings.

Edible Material	Brand & Origin	Features	References
Ooho	Notpla (rebranded from Skipping Rocks Lab), London, UK	Edible bubble made from natural a renewable resource (brown seaweed). Consumer can gulp the drink and swallow the packaging or spit out the film; available in different flavors.	[109–111]
Lolistraw	Loliware, San Francisco, CA, USA	Edible, non-toxic, and eco-friendly straws made from alginate and agar from seaweed and red algae. Film-like membrane that provides double-layer protection around the liquid, foam, or solids it carries.	[112,113]
Wikicells	Wikicells Designs Inc., Cambridge, MA, USA	The first layer is soft skin made up of natural food particles, calcium, and a nutritive ion, which, together, form an electrostatic gel to keep water inside a food or drink, while the second layer is a protective shell made of isomalt or tapioca that is edible or biodegradable.	[114,115]
Ello Jello	Evoware, Jacarta, Indonesia	Edible cup and wrappers made from seaweed containing nutritious ingredients.	[116]
Edipeel	Apeel Sciences, Goleta, CA, USA	Spray-based edible coating derived from agricultural waste and by-products. Entirely plant-based, edible, colorless, odorless, and tasteless. Proven to be effective on bananas, lemons, limes, mangos, blueberries, tomatoes, strawberries, avocados, green beans, and raspberries.	[117]
Sandwich wraps	NewGem Foods, Allyn, OH, USA	Plant-based sandwich wraps; alternatives to bread and tortillas as they can easily damage. Each wrap is a serving of fruit/vegetable, making it easier to eat healthily. They have a one-year shelf life and do not need to be refrigerated.	[118]
Sushi wraps		Sushi Wraps made from fruits/vegetables.	
Edible carrier bags	Envigreen Biotech India Ltd., Karnataka, India	Biodegradable edible carrier bags; an alternative to plastic bags. The bags are made of tapioca, starch, vegetable oil, and flower oil.	[119,120]
Edible films	Amtrex Nature Care Pvt., Ltd., Mumbai, India	Edible films made of starch and cellulose; they are available in roll form in many colors and flavors.	[121]
Composite coating	National Agri-Food Biotechnology Institute, Mohali, India	Edible composite coatings based on wheat straw hemicellulosic polysaccharide and stearic acid-derivatized oat bran polysaccharide; they reduce fruit weight loss and softening, delay ripening, and maintain sensory qualities.	[122]

Table 3. *Cont.*

Edible Material	Brand & Origin	Features	References
Longevita(R) coating solution	BioEnvelop Technologies Corporation, Laval, QB, Canada	Biodegradable and edible protein-based coating treatment that prolongs shelf life and inhibits humidity transfer in fresh and frozen food products.	[123]
Lactips	Lactips, Saint-Paul-en-Jarez, France	This company has developed a water-soluble, biodegradable plastic substitute made from milk protein casein. It has a good oxygen barrier and is edible, but has not yet been exploited to design edible cutlery.	[124]

3.9. Advantages and Disadvantages of Edible Packaging

The main problem for the food sector is the loss of quality during storage, which ultimately increases waste. Using bio-packaging methods to increase a product's shelf life may effectively reduce costs associated with spoilage caused by natural ripening processes. Edible packaging can improve food quality and shelf life and thereby meet consumer demand for environmentally friendly products [125]. Other advantages of edible packaging over plastic packaging, include biodegradability, selective barrier properties, biocompatibility, edibility, non-toxicity, and non-polluting properties [4].

Edible packaging requires special care during shipping processes as they are sensitive to temperature fluctuations, and most edible films and coatings degrade or almost degrade at their melting point, negative affecting their ability to be formed via thermal processing methods like extrusion, compression molding, and injection molding [14,21]. A lot of edible packaging is primarily packed, and food products still need outer coverings for protection from chemical and biological contaminants. The oxygen barrier of edible packaging can block anaerobic respiration, thereby resulting in the delayed ripening of fruits and vegetables. Also, some consumers may have allergic reactions to edible food packaging (e.g., caseins). The cost of edible packaging materials is comparatively higher than conventional packaging materials. These factors may significantly affect consumer acceptance [20]. Another important limitation is the limited data on cytotoxic studies regarding edible films and coatings. Natural materials can also be toxic due to reactions or high-concentration formulations [86].

4. Conclusions

The growing global population, changes in the globe's climate and people's dietary patterns, and the increasing need for environmental protection have created an increasing demand for waste-free food packaging. The importance of durable and sustainable packaging materials has grown significantly to avoid food waste and environmental pollution. Edible packaging has emerged as a solution to prolong the shelf life of food products, reduce dependence on petroleum-based resources, and reduce the global amount of waste from used food packaging. This review has highlighted the advantages and importance of edible packaging materials and described how they can improve sustainability measures. To ensure the quality of these materials, it is important to consider factors such as appearance, organoleptic features, and labeling information. The market value of edible food packaging is expanding, which means that these materials need to be further developed and subjected to more in-depth research to increase sustainable, eco-friendly packaging practices that enhance environmental protection and food safety.

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