polysaccharides

Review

Polysaccharide-Based Biodegradable Films: An Alternative in Food Packaging

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Abstract: Packaging can mitigate the physical, chemical, and microbiological phenomena that affects food products' quality and acceptability. However, the use of conventional packaging from non-renewable fossil sources generates environmental damage caused by the accumulation of non-biodegradable waste. Biodegradable films emerge as alternative biomaterials which are ecologically sustainable and offer protection and increase food product shelf life. This review describes the role of biodegradable films as packaging material and their importance regarding food quality. The study emphasizes polysaccharide-based biodegradable films and their use in foods with different requirements and the advances and future challenges for developing intelligent biodegradable films. In addition, the study explores the importance of the selection of the type of polysaccharide and its combination with other polymers for the generation of biodegradable films with functional characteristics. It also discusses additives that cause interactions between components and improve the mechanical and barrier properties of biodegradable films. Finally, this compilation of scientific works shows that biodegradable films are an alternative to protecting perishable foods, and studying and understanding them helps bring them closer to replacing commercial synthetic packaging.

Keywords: polysaccharides; biodegradable films; food packaging; food preservation; food quality

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1. Introduction

Packaging is one of the most important issues in the food industry [1] because its functional capacity protects against gases (e.g., oxygen, nitrogen, and carbon dioxide), humidity, and possible mechanical damage [2]. Additionally, it provides the information needed about the product and allows its commercialization and distribution [3–5]. Although packaging characteristics depend on the food product they protect, the materials most used are paper, cardboard, metal, glass, and plastic [6]. However, these synthetic materials have been restricted because they consume finite resources and they are not biodegradable, reusable, or recyclable [7]. According to data from 2018, about 102,895 tons of waste is generated per day in Mexico, including cardboard, paper, metals (aluminum), and glass [8], which contributes to the global problem of solid waste distribution in the environment [9]. Furthermore, only 10% of total synthetic materials are recycled [8,10], and the degradation treatment of them is considered dangerous and harmful to human health and economically unprofitable. As a result, synthetic material packaging is used once before being discarded [11].

Recently, food packaging has been directed toward the development of technologies for the generation of packaging with biodegradable materials which can serve as emerging materials or as substitutes for traditional packaging [2]. For example, films with biodegradable characteristics (biodegradable films) are considered a food packaging alternative [12] because they can preserve quality and extend the shelf life of minimally processed products [13,14]. Therefore, its study has been increasing in the last decade, as shown in Figure 1. This review offers an overview of food packaging and its characteristics and properties and the characteristics that biodegradable films must meet to be considered food packaging materials.

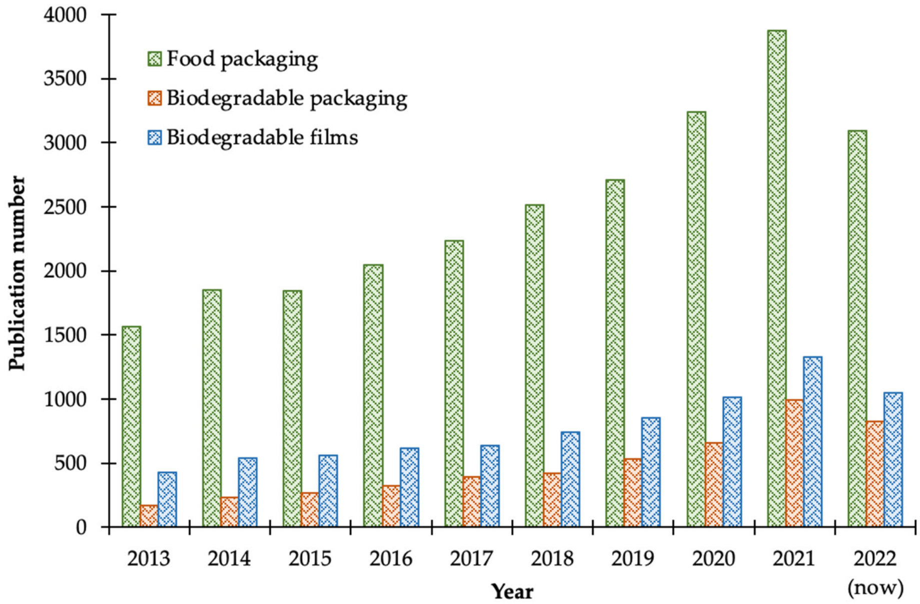

Figure 1. The number of publications related to food packaging and biodegradable films (Source: Scopus. Keywords: food packaging, biodegradable packaging, and biodegradable films. Accessed: 27 September 2022).

2. Food Packaging

Food packaging is any wrapper whose function is to protect food from physical, chemical, and biological contamination and preserve its quality (Figure 2) [15]. Physical contamination is any external material (e.g., bumps or pieces of glass, plastic, and wood) that are is part of the food and that is normally associated with unhygienic conditions during the preparation, production, storage, and distribution of food products. In contrast, chemical contamination can occur from the addition of food additives (e.g., flavors, colors, and sweeteners) or other chemicals (e.g., antibiotics, sanitizers, pesticides, and lubricants) during processing, food preparation, and storage. Biological contamination is related to any micro-organisms (e.g., *Salmonella* sp., *Clostridium* sp., and *Escherichia coli*) or harmful fauna (e.g., rats, mice, and cockroaches) that produce toxins (e.g., aflatoxins, citrinin, and alternariol) or cause consumer illness [16,17].

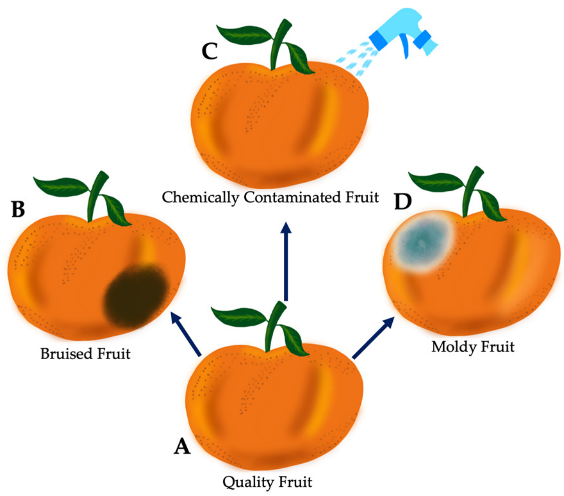

Figure 2. Example of food contamination. (**A**) without contamination, (**B**) physical, (**C**) chemical, and (**D**) biological.

Characteristics of Food Packaging

Traditional food packaging must be inert to the stored product, which means it must not interact with the product [18]. For this reason, they are considered passive containers because their only function is to create physical protection against mechanical, chemical, and biological damage and a barrier against gases and humidity [2]. However, the study of the adverse effects in food caused by the environment gave guidelines to intentionally incorporate compounds or substances in the container and achieve an active container [19,20]. This type of packaging intentionally modifies the environmental conditions to ensure the sensory and microbiological properties of the food, thus eventually extending its shelf life [18]. Active packaging can be classified into absorbers and emitters. Absorbers capture substances produced by food, such as steam, ethylene, and carbon dioxide, and release them into the environment, while emitters release bioactive substances, such as microbial and antioxidants [18–20].

The increase in the demand for food in the market stimulated the innovation of food packaging to improve the characteristics of traditional and active packaging that were used until a few years ago. Subsequently, packaging with new characteristics was conceptualized, or so-called intelligent packaging. This type of packaging is made up of a system influenced by the physicochemical properties, temperature, exposure time, or enzymatic reactions of foods that monitor, generate, and display the information [21]. Intelligent packaging uses chemical sensors or biosensors to monitor food quality, including ripeness, freshness, temperature, oxygen levels, moisture, or other gases [18].

Active packaging is more studied than intelligent packaging since there are many extracts and essential oils extracted from natural sources that have an antioxidant or antimicrobial nature and can be added as a biological additive [22]. Nevertheless, active packaging and intelligent packaging are not mutually exclusive since both can work synergistically together [23], as shown in Figure 3. There are even authors who contradict the idea of using the terms intelligent packaging and smart packaging as synonyms because they establish that smart packaging is active–intelligent packaging in which the characteristics of both are added [18].

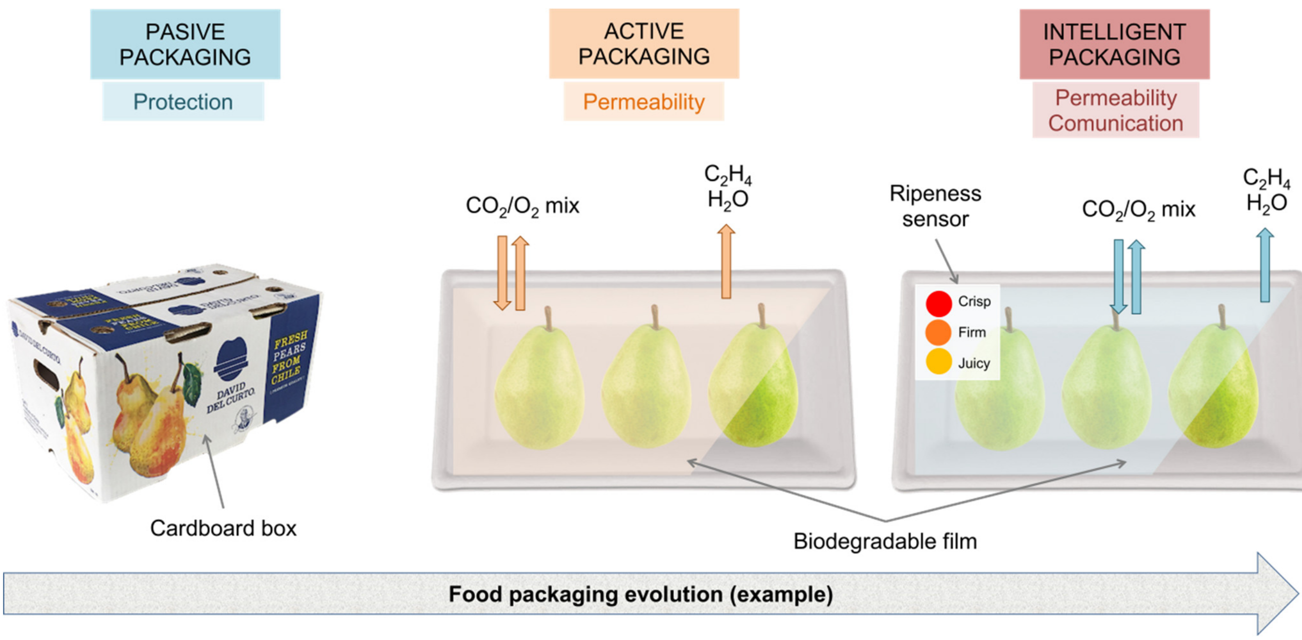

Figure 3. Schematization of the evolution of food packaging.

3. Biodegradable Films

Biodegradable films are solid matrices with a thickness of less than 0.3 mm [24] which are formed with biopolymer material [25,26] using casting, extrusion, or electrospinning techniques [27]. Biodegradable films are considered active packaging as their protective function includes the addition of bioactive compounds [2]. Biodegradable films present greater benefits than conventional packaging since in addition to meeting the main objectives of food passive packaging (i.e., protection against mechanical, chemical, and biological damage), they can also reduce UV light interaction [28], control the absorption of gases (e.g., oxygen, ethylene, carbon dioxide, and water vapor) [28,29], and control the release of bioactive components (e.g., antioxidants, antimicrobials, and flavors) [30–32]. These objectives create benefits, including the reduction of lipid oxidation and the increase in the nutritional value of food and its shelf life [33,34].

3.1. Polysaccharides in Biodegradable Films Formulations

The formation of biodegradable films is carried out due to the interaction between polymers (i.e., polysaccharides, lipids, and proteins), and polysaccharides are the most widely used biopolymers for biodegradable films due to their accessibility [35]. The main natural sources of polysaccharides are plants (e.g., cellulose, starch, and pectin), animals (e.g., chitin, chitosan, and hyaluronic acid), algae (e.g., alginate, agar, and carrageenan), fungi (e.g., glucans and pullans), and bacteria (e.g., dextran, xanthan, and gellan) [35]. According to the Scopus database, more than 50% of biodegradable film reports are based on plant polysaccharides, with cellulose being the most widely used polymer [36]. This is justifiable because it is the most abundant polysaccharide in nature, it is inexpensive, and it is obtained using simple methods, such as alkaline hydrolysis [37]. Chitosan and chitin (ca. 30%) are the most used animal polysaccharides for the generation of biodegradable films [36], and their extraction is based on the demineralization, deproteination, and distillation of residues from the shells of crustaceans [38]. These animal polysaccharides are appreciated due to their antimicrobial activity caused by their cationic characteristics [35]. In contrast, algae polysaccharides represent around 11% of the natural polymers reported for the generation of biodegradable films [36]. Alginate stands out because its extraction is traditionally carried out from brown algae using hydrolysis acid–alkaline [39]. Less than 10% of the rest of the studies report biodegradable films based on fungi and bacteria [36]. This is because bacteria and fungi need strictly controlled conditions of temperature, substrate, and exposure times so that the production yield is high [40]. However, the production of a polysaccharide by fermentation or by culture cannot be compared with the extraction yield of a polysaccharide from a plant or an animal.

3.2. Additives in Biodegradable Films Formulations

Additives, such as plasticizers, crosslinkers, or bioactive components, improve their characteristics and properties [25,26]. In the compilation made by Suderman et al. [41], it was stipulated that the most used plasticizers in biodegradable films are glycerol, sorbitol, xylitol, and fructose because they influence the microstructure and consequently improve mechanical (e.g., brittleness and flexibility), physicochemical (e.g., solubility), thermal (e.g., thermal decomposition), and barrier (e.g., gas absorption) properties. However, the interaction between polymer and plasticizer depends on the nature of both. For example, Sanyang et al. [42] concluded that adding plasticizers (i.e., glycerol and sorbitol) to the formulation of sugar palm starch films reduced brittleness and water absorption and increased solubility and moisture. Kaewprachu [43] reported higher elongation, moisture, and water vapor permeability in fish protein films by adding plasticizers (i.e., glycerol, sorbitol, and polyethylene glycol). The use of lipids in the formulation of biodegradable films has been carried out only in composite films, including some lipids (e.g., oils, waxes, and resins) mixed with polysaccharides and/or proteins, because their hydrophobic nature hinders the formation of cross-linking [44]. For example, Hassan et al. [45] formulated sugar palm starch/chitosan films with olive oil and noted that the lipid acted as a plasticizer that improved the elasticity and brittleness of the biodegradable films and stabilized the thermal and barrier properties. Additionally, Da Silva E Silva et al. [46] noted an increase in mechanical strength and a decrease in water vapor permeability when buriti oil was added to fish gelatin films.

Biodegradable films can use crosslinking agents, such as stimuli (e.g., pH and electrical charges) or components (e.g., ions and enzymes) to generate physical, chemical, or enzymatic changes and improve the interaction between polymeric components [47–52]. Chitosan is an acetylated polysaccharide that necessarily needs a cross-linking agent (an acid such as acetic, formic, or lactic acid) [53] to acidify its medium and increase its protonation [20] so it can interact with other molecules and eventually form biodegradable gels and films [54]. In amino polysaccharides or proteins, it is common to use genipin as a crosslinking agent because it produces nucleophilic reactions between amino and carboxylic groups in a neutral-acid medium [55] so they can generate biodegradable films due to intermolecular interactions [56]. Other protein cross-linking agents are enzymes (e.g., transglutaminases) because they can catalyze isopeptide bonds and improve the three-dimensional network of biodegradable films [57,58]. In contrast, the use of radioactive waves (e.g., electron beam, gamma radiation, and ultraviolet light) in starches can cause hydrolysis and linear restructuring of the chains, which then cause an increase in the hydrogen bonds and the crystallinity of the film [59,60].

In addition, biodegradable films may contain bioactive substances or components (molecules that can affect health) [61] extracted from natural sources (e.g., plant extracts, natural oils, or essential oils) which have an antimicrobial [62], antifungal [63], antioxidant [64], or probiotic effect [65]. However, regardless of the additives, polysaccharides (e.g., starches, gums, celluloses, agars, and pectins) are the most widely used polymers in the formulation of biodegradable films due to their hydrophilic nature, accessibility (i.e., sources and costs), and characteristics (e.g., non-toxic, biodegradable, and bioactive) [35].

4. Biodegradable Films in Food Packaging

Foods are susceptible to spoilage due to physical, enzymatic, chemical, or microbiological effects, which accelerate maturation and senescence and consequently modify product quality [66] (Figure 2). Food quality is based on sensory characteristics and its nutritional and functional properties which allow their acceptability. For direct consumers, sensory characteristics, such as color, appearance, texture, shape, size, odor, and taste demarcate the degree of product acceptability [67]. Therefore, packaging is important as it protects and maintains food quality from post-harvest until it reaches the consumer. Table 1 shows recent reports of the application of biodegradable films in food protection. As can be seen, biodegradable films have been tested on vegetables, fruits, cereals, grains, seeds, dairy and bakery products, meats and sausages, and seafood, and their requirements are varied due to the characteristics of the food product.

Table 1. Application of biodegradable films in food products.

Food Application	Polymer(s)	Additive(s)	Main Result(s)	Reference
		Vegetables, Fruits, and Derivates		
Cherry tomatoes	Starch/Carrageenan	Gly	Films prolonged shelf life	[68]
Edible mushrooms	Dextran/Chitosan	Gly/Acetic acid	Films prolonged shelf life	[69]
Fresh-cut apples	Whey protein	Gly/Citric acid/Montmorillonite clay	Films prolonged shelf life	[70]
Fresh-cut apples	Starch/Carnauba wax	Gly/Stearic acid	Films prolonged shelf life	[71]
Fresh-cut apples	Soybean gum/Jojoba gum/Arabic gum	Gly/Paraffin oil	Films maintained quality	[72]
Grapes	Starch/Pectin	Gly/Feijoa extract	Films showed strong antimicrobial activity against *Escherichia coli*, *Salmonella*, and *Shigella* and prolonged shelf life	[73]

Table 1. *Cont.*

Food Application	Polymer(s)	Additive(s)	Main Result(s)	Reference
Grapes	Chitosan	ZnO NPs/Ag NPs/Citronella essential oil	Films showed strong antimicrobial activity against *Candida albicans*, *Staphylococcus aureus*, and *Escherichia coli* and prolonged shelf life	[74]
Grapes	Chitosan/CAP	Gly/ZnO NPs	Films exhibited excellent UV shielding ability and antimicrobial properties and prolonged shelf life	[75]
Orange	Bacterial cellulose	Ag NPs	Films showed strong antimicrobial and antifungal activity against *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Candida albicans*, and *Trichosporone* sp., and prolonged shelf life	[76]
Powdered juice	Methylcellulose	Gly	Films serve as container material	[77]
Spinach	Agar/K-carrageenan/Konjac	Gly	Films prolonged shelf life	[78]
Strawberries	Chitosan	Acetic acid/Tween 60/Canola oil/Cinnamon essential oil/ Roselle extract	Films incremented the antioxidant capacity and the microbial inhibition and prolonged shelf life	[79]
Tomatoes	Bacterial cellulose	Ag NPs	Films showed strong antimicrobial and antifungal activity against *Escherichia coli*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Candida albicans*, and *Trichosporone* sp. and prolonged shelf life	[76]
		Cereals, Grains, Seeds, and Derivates		
Powdered coffee	Methylcellulose	Gly	Films served as container material	[77]
Rice	Methylcellulose	Gly	Films served as container material	[77]
Rice noodles	Starch/PBAT	Benzoate/Sorbate	Films delayed antimicrobial activity against *Penicillium* sp., and *Aspergillus niger*. and extended the shelf life	[80]
Soybean oil	Methylcellulose	Gly	Films served as container material	[77]
Sunflower oil	Alginate	Gly/Norbixin salts	Films decreased the formation of oxidation products	[81]
		Bakery and Dairy Products		
Bread	Starch/Pectin	Gly/Feijoa extract	Films showed strong antimicrobial activity against *Escherichia coli*, *Salmonella* and *Shigella*, and prolonged shelf life	[73]
Cookies	Methylcellulose	Gly	Films serve as container material	[77]
Fresh milk	Alginate	Gly/*Clitoria ternatea*	Films retarded spoilage and served as indicators of freshness	[82]
		Meats		
Chicken thigh	Pectin	Kiwifruit peel extract	Films decreased lipid oxidation	[83]
Chicken meat	Gum Arabic/PVA	Sorbitol/*Zanthoxylum rhetsa* extract	Films incremented the bioactive compounds and prolonged shelf life	[84]
Chicken meat	Cyclodextrin/Gelatin/PVA	Gly/Mango peel extract	Films prolonged shelf life	[85]
Ground beef	Starch/Pectin	Gly/Feijoa extract	Films showed strong antimicrobial activity against *Escherichia coli*, *Salmonella*, and *Shigella* and prolonged shelf life	[73]
Lamb meat	Carrageenan	Olive leaf extract	Films delayed antimicrobial activity against *Escherichia coli*	[86]
Pork	Starch/PBAT	Gly/ZnO nanofillers	Films showed high efficiency for the total viable count, lactic acid bacteria, yeast, and mold and prolonged shelf life	[87]
Pork	Starch/PBAT	Nisin/EDTA	Films retained quality	[88]
Pork	Alginate	Gly/*Clitoria ternatea*	Films retarded spoilage and served as indicators of freshness	[82]
Pork	Cellulose/PLA/PET	–	Films prolonged shelf life	[89]
		Sausages and Derivates		
Ham slices	Starch/Chitosan	Gly/Gallic acid	Films prolonged shelf life	[90]
Sausages	Maltodextrin/Sodium alginate/CMC	Gly/Calcium chloride/Terminalia arjuna capsular	Films delayed the oxidation, incremented the antioxidant capacity, and prolonged shelf life	[91]
		Sea Products		
Carp burgers	Chitosan/Alginate/Gelatin	*Salvia officinalis* essential oil/Lactoperoxidase system	Films reduced spoilage changes and maintained quality	[92]
Fish burger	Alginate/Chitosan/Gelatin	Gly/Sage essential oil	Films exhibited several positive effects, mainly on psychrotrophic, *Pseudomonas* and *Shewanella*, and preserved quality	[93]

Table 1. *Cont.*

Food Application	Polymer(s)	Additive(s)	Main Result(s)	Reference
Fish burger	Alginate/Chitosan/Gelatin	Gly/Lactoperoxidase system	Films exhibited several positive effects, mainly on psychrotrophic, *Pseudomonas* and *Shewanella*, and preserved quality	[93]
Salmon	Starch	Gly/*Heterochlorella luteoviridis* extract	Films decreased lipid oxidation rate and prolonged shelf life	[94]
Salmon	Starch	Gly/*Dunaliella tertiolecta* extract	Films decreased lipid oxidation rate and prolonged shelf life	[94]
Shrimps	Alginate	Gly/*Clitoria ternatea*	Films retarded spoilage and served as indicators of freshness	[82]

Ag: silver; CMC: carboxymethyl cellulose; CAP: cellulose acetate phthalate; EDTA: ethylenediaminetetraacetic acid; Gly: glycerol; NPs: nanoparticles; PBAT: poly(butylene adipate terephthalate); PET: tereftalato de polietileno; PVA: polyvinyl alcohol; and ZnO: zinc oxide.

4.1. Polysaccharide-Based Biodegradable Films for Wet and Fatty Foods

Foods with high moisture content and nutritional composition rich in proteins and lipids, such as meat, are highly perishable [95]. For example, the most consumed meats (i.e., chicken, beef, lamb, pork, and fish) have moisture content between 65–80%, with chicken meat being the one with the highest protein content (~31%) and the least amount of fat (~4%), whereas beef has the highest amount of fat (~8%) and the lowest protein content (~27%) [96]. Some research has proposed the use of biodegradable films for the protection of various types of meat, such as the case of Muppalla and Chawla [84] and Kanatt and Chawla [85] who tested biodegradable films of gum Arabic/polyvinyl alcohol (PVA) and cyclodextrin/gelatin/PVA, respectively, in the protection of chicken breast. Kanatt and Chawla [85] increased the antioxidant and antimicrobial activity against *Staphylococcus aureus* and fecal coliforms in their films by adding mango skin extract, which prolonged the meat shelf life up to 10 days (at 3 °C). Muppalla and Chawla [84] added the seed cover extract of *Zanthoxylum rhetsa* to their films, and they noted an increase in bioactive components, antioxidant activity, and antimicrobial activity against *Staphylococcal* up to 15 days (at 4 °C). The bioactive activity of natural extracts is related to the presence of phenolic components, which unleash oxidation-reduction reactions (redox), donate hydrogens, reduce components, and act as chelating agents [97]. In addition, the redox mechanism affects the proteins of the cell membranes of micro-organisms and causes partial or total damage [98].

Phothisarattana et al. [87] and Leelaphiwat et al. [88] protected pork with starch/poly (butylene adipate terephthalate) (PBAT) films with different additives. Initially, the study by Phothisarattana et al. [87] reported a decrease in lipid oxidation after day 9 and up to day 12 (at 4 °C), attributing the result to the vaporization of oxidized products due to the effect of the three-dimensional conformation of the film. The authors stipulated that the content of zinc oxide (ZnO) nanofillers in the biodegradable films promoted their permeability as increasing the ZnO lowered the formation of oxidized components was lower and increased their release. In addition, the study [87] reported that the increase in ZnO in the films statistically decreased the number of micro-organisms (i.e., total count, lactic acid bacteria, yeast, and mold) in the meat for 12 days (at 4 °C) due to its antimicrobial effect; however, it was remarkable that when using 3–5% of ZnO, the lowest count was obtained, and there was no significant variation between the increase in the additive. The antimicrobial effect of ZnO is related to its ability to penetrate the cell membrane and trigger redox reactions within the micro-organism [99]. Leelaphiwat et al. [88] used nisin and ethylenediaminetetraacetic acid (EDTA) as additives in starch/PBAT films and observed that the antibacterial effect of the additives retarded the proliferation of total bacteria and lactic acid bacteria in meat stored for 12 days (at 4 °C) which was attributed to the concentration and functional release of nisin-EDTA and the exposure of pathogens with them. The combination of nisin and EDTA has already been reported previously due to the synergy of its antimicrobial activities [100]. Nisin has antimicrobial activity due to its ability to enlarge the pores of the membrane and cause egress from cell organelles and inhibit cell wall biosynthesis [101], while EDTA modifies the pH of the medium and denatures the proteins of the cell membrane [102].

Ehsani et al. [93] evaluated two types of polysaccharides (i.e., alginate and chitosan) mixed with glycerol and two additives (sage essential oil and lactoperoxidase) for the generation of biodegradable films to protect fish burgers. The authors [93] report that biodegradable films decreased the concentration of the total viable count, the psychrotrophic bacteria count, *Pseudomonas* spp., and *Shewanella* spp. in fish burgers stored for 20 days (at 4 °C); however, the chitosan/lactoperoxidase films presented the most outstanding results. In addition, the combination of chitosan and lactoperoxidase controlled meat oxidation during a longer storage time (20 days at 4 °C). The sensory evaluation showed that the fish burger affected the smell, color, and acceptability; however, the products preserved in the chitosan/lactoperoxidase films maintained their acceptability during the study period (20 days, 4 °C) [93]. The success of the results is closely related to the characteristics and synergy of chitosan and lactoperoxidase. Chitosan naturally has an antimicrobial effect due to the amino groups (-NH_2) present in its structure that trigger redox reactions in cell membranes [20]. Lactoperoxidase is a multicomponent system (lactoperoxidase enzyme, hydrogen peroxide, and thiocyanate) that produces hypothiocyanite [103], which crosses the cell membrane through porins and prevents the absorption of substrates (e.g., sugars and minerals) through the release of these to the outside of the cell [104].

4.2. Polysaccharide-Based Biodegradable Films for Post-Harvest Foods

The qualities of natural foods, such as fruits, vegetables, cereals, and grains refer to intrinsic characteristics (e.g., color, size, and firmness), sensory parameters (e.g., taste and smell), and nutrients (e.g., vitamins, minerals, fiber, and phytochemicals). These qualities can be negatively affected by physiological (e.g., dehydration, aging, and softening) or microbiological (e.g., bacteria, yeast, or mold) deterioration [105]. For this reason, the application of biodegradable films as a method of post-harvest foods protection has been proposed as an alternative.

The use of natural extracts as natural additives in biodegradable films is a current area of study due to the characteristics that it adds. For example, Sganzerla et al. [73] incorporated feijoa (*Acca sellowiana* (Berg) Burret) extract into the formulation of starch/pectin films for grape protection over 30 days (at 20 °C). The results of the study [73] show that the firmness of the peel and the pH of the fruits were maintained, and pulp firmness, weight, phenolic content, and antioxidant activity decreased by ~40, 47, 24, and 70%, respectively, while the acidity and the soluble solids increased (~19 and 18%, respectively). Indumathi et al. [75] coated grapes with biodegradable films of chitosan and cellulose acetate phthalate for 28 days (at room temperature) and reported that the addition of ZnO nanoparticles in the formulation improved the properties of the films (e.g., tensile strength and elongation). The films allowed the preservation of up to ~70% of the weight of the grapes and reduced the bacterial load by ~30% compared to fruits without protection, and as a consequence, the shelf life increased [75]. The incorporation of essential oils in biodegradable films has been studied, particularly for their pharmacological effects, such as anti-inflammatory, anticancer, and antioxidant [106]. Motelica et al. [74] combined citronella essential oil with ZnO and silver nanoparticles in chitosan films to pack grapes for 14 days (at 30 °C). The results demonstrated the preservation of the fruits since moisture leakage was reduced and bacterial growth (*Candida albicans*, *Staphylococcus aureus*, and *Escherichia coli*) was controlled [74]. The loss in the production of fruits and vegetables is 25% worldwide because fruit and vegetable shelf life is very low after harvest and their quality standards are very demanding [107]. For this reason, innovation in additives and polysaccharides for the formulation of biodegradable films is considered a viable alternative to reduce the quality and loss of this type of natural food.

Lipid oxidation is the main source responsible for the degradation (i.e., loss of nutrients and bad odors) of fatty foods and foods with a high content of fatty acids, which is a consequence of the enzymatic and non-enzymatic formation of hydroperoxides and propanal [108]. Silva Filipini et al. [77] made biodegradable films of methylcellulose and glycerol to test them in different food matrices, such as soybean oil. The results indicated that the films presented greater resistance to the attractive force, elongation, thermostability, and solubility compared to films of different polymers (i.e., collagen and whey protein), whose characteristics were suitable for the manufacture of container bags to store oil without leaks or disintegration of the biodegradable film [77]. De Farias et al. [81] made biodegradable alginate films with glycerol and norbixin salts to store sunflower oil and evaluate lipid oxidation products. The authors [81] reported an increase in the mechanical properties of tensile strength and elongation with an increase in the concentration of salts. In addition, the quantification of peroxides in the oil showed that on day 6 of storage (at 30 °C), the control (stored in a glass container) presented higher levels than that recommended by the *Codex Alimentarius*, while the oil stored in the film remained below the norm, and it exceeded what was recommended on day 12. The quantification of conjugated dienes also indicated that on day 15 of storage (at 30 °C), the content increased slightly, which was similar to the control; therefore, the authors [81] considered that biodegradable alginate films with norbixin salts are an alternative for oil conservation. The protection of oils in polysaccharide materials, such as methylcellulose and alginate, depends on their intrinsic characteristics as methylcellulose is highly hydrophobic due to its methyl groups (-CH_3) [109], while alginate (anionic polysaccharide) transforms into an amphiphilic component with hydrogel properties by covalently interacting with the salts [110].

Cereal-based food products (e.g., bread, cookies, and muffins) can suffer two types of deterioration (dryness and rancidity) when exposed to high levels of temperature, light, humidity, and oxygen. Dryness occurs when the products lose moisture, which then causes a change in texture as the texture becomes soft, while rancidity occurs when lipids are oxidized or hydrolyzed (by lipases) and phenolic acids are degraded, causing a bitter taste [111,112]. That is why the containers of these products must be able to maintain adequate humidity that can preserve the crispy texture but not provide a medium for the development of micro-organisms (e.g., bacteria and fungi). For example, in some research that uses biodegradable films to preserve bakery products, such as cookies and bread, the use of hydrophobic materials, such as methylcellulose, reportedly prevents the transfer of water or water vapor from inside the packaging to the outside and vice versa. [77]. Other studies have chosen to incorporate natural extracts containing bioactive components with antimicrobial characteristics against pathogens, such as *Escherichia coli*, *Salmonella*, and *Shigella* [73]. In both proposals, the methodologies demonstrate the preservation of the quality of the products and the extension of their shelf life.

5. Regulatory and Safety Issues of Polysaccharide-Based Biodegradable Films

Food products or products that are in contact with food as packaging must meet various requirements according to the place of production, sale, or marketing. However, each country has national bodies that have basic regulations that can be implemented in a general way. The Food and Drug Administration (FDA) in the United States stipulates that food ingredients and packaging must be Generally Recognized As Safe (GRAS) [113]. The GRAS label can be acquired in various ways; for example, (1) the FDA has a list of products that meet GRAS standards, (2) the characterization of a product by experts outside the FDA, (3) and the publication of a study about a new GRAS food, substance, or packaging [114,115]. All food products marketed must prove the use of food additives (e.g., colors, flavors, or flavor enhancers) only as allowed by national bodies. For example, the national standards of the European Union (European Union Standards) and Mexico (Official Mexican Standards: NOM) require that food products have approved additives and that these be reported on their labeling [34]. Additionally, if products contain allergens, such as proteins, they also must be reported. In the case of biodegradable films based on polysaccharides, the polysaccharides must be classified as GRAS substances. Failing that, they must be synthesized by organisms classified as GRAS. In addition, the additives used in their formulation must individually comply with ingredient standards. If the biodegradable films use proteins or derivatives as part of their ingredients, they must also be reported as part of the allergens, while the biodegradable films under the designation "bioactive" must ensure that added substances, such as antioxidants, antimicrobials, or oils, do not cause toxicity problems in the doses used [34,113]. If classified as packaging, biodegradable films must also comply with regulations for food packaging [116].

6. Challenges and Perspectives

As seen throughout the sections, the characteristics of polysaccharide-based biodegradable films depend specifically on the manufacturing materials (e.g., polysaccharide type, plasticizers, and additives). However, while applied studies in food have shown that they can decrease pathogens, supply bioactive components, or extend shelf life, their commercial use as food packaging has not been explored enough because most food research has been directed toward synthetic materials [117].

Despite this, some researchers are moving forward and conducting studies on intelligent polysaccharide-based biodegradable films. For example, Maciel et al. [118] generated biodegradable films by immersing a card paper in a film-forming of chitosan and anthocyanin, and their results showed that exposure to temperatures above 40 °C caused an irreversible change from light violet to light yellow due to the sensitivity of anthocyanins. Veiga-Santos et al. [119] generated cassava starch films with spinach and grape extracts to detect the pH change by the color variation; however, their results described a visible color only at extreme pH (0 and 14), especially a yellow color at basic pH attributed to the grape anthocyanins. Similarly, Yoshida et al. [120] made chitosan films with grape anthocyanins, and they noted a reversible color change depending on the pH (i.e., pink at acid pH, blue at neutral pH, and yellow at basic pH). These authors considered the induction of pH change by pathogenic micro-organisms, and their results could be used to offer a future alternative for the quality of food products.

Although the development of intelligent packaging is accelerating, the application of biodegradable films in that area is still under development. However, there is a large number of bioactive components (e.g., metabolites) from natural and biological sources (e.g., micro-organisms) that have a promising future as part of sensors (e.g., gases, firmness, color, and temperature) in polysaccharide-based biodegradable films [23].

7. Concluding Remarks

Polysaccharides have become the most widely used polymeric material for the formulation of biodegradable films due to their accessibility in terms of costs and sources of production, but even more so because of their ease in modifying characteristics (e.g., solubility, charges, and structure) with variations in pH, temperature, salts, and charged components. Polysaccharide-based biodegradable films are currently being studied, and they have been successfully used in food products. However, the introduction of this type of packaging to the market is still under development, and they cannot compete against the synthetic packaging market. For this reason, researchers are conducting further research to show that soon, polysaccharide-based biodegradable films can be a real alternative as primary packaging but also as intelligent packaging.

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References

1. Peelman, N.; Ragaert, P.; De Meulenaer, B.; Adons, D.; Peeters, R.; Cardon, L.; Van Impe, F.; Devlieghere, F. Application of Bioplastics for Food Packaging. *Trends Food Sci. Technol.* **2013**, *32*, 128–141. [CrossRef]
2. Masuelli, M.A.; Zanon, M. State of the Art. In *Biopackaging*; Masuelli, M.A., Ed.; Taylor & Francis Group, LLC.: Boca Raton, FL, USA, 2018; pp. xv–xx, ISBN 9781498749688.
3. Han, J.H. *Innovations in Food Packaging*; Elsevier Ltd.: London, UK, 2005.
4. Davis, G.; Song, J.H. Biodegradable Packaging Based on Raw Materials from Crops and Their Impact on Waste Management. *Ind. Crop. Prod.* **2006**, *23*, 147–161. [CrossRef]
5. Raheem, D. Application of Plastics and Paper as Food Packaging Materials-An Overview. *Emir. J. Food Agric.* **2013**, *25*, 177–188. [CrossRef]
6. Kishimoto, A. New Food Packaging Materials: An Introduction. In *Food Packaging*; Kadoya, T., Ed.; Academic Press Inc.: San Diego, CA, USA, 1990; pp. 47–51, ISBN 0123935903.
7. Siracusa, V.; Rocculi, P.; Romani, S.; Rosa, M.D. Biodegradable Polymers for Food Packaging: A Review. *Trends Food Sci. Technol.* **2008**, *19*, 634–643. [CrossRef]
8. SEMARNAT. Informe de La Situación Del Medio Ambiente En México. Available online: https://apps1.semarnat.gob.mx:8443/dgeia/informe15/tema/pdf/Informe15_completo.pdf (accessed on 2 September 2019).
9. Joaquid, D.D.F.; Villada, C.H.S. Propiedades Ópticas Y Permeabilidad De Vapor De Agua En Películas Producidas a Partir De Almidón. *Biotecnol. Sect. Agropecu. Agroind.* **2013**, *11*, 59–68.
10. SEMARNAT. Inventario de Residuos Sólidos de La Ciudad de México. Available online: https://sedema.cdmx.gob.mx/programas/programa/residuos-solidos (accessed on 8 October 2019).
11. Briassoulis, D. An Overview on the Mechanical Behaviour of Biodegradable Agricultural Films. *J. Polym. Environ.* **2004**, *12*, 65–81. [CrossRef]
12. Bourtoom, T.; Chinnan, M.S. Preparation and Properties of Rice Starch-Chitosan Blend Biodegradable Film. *LWT-Food Sci. Technol.* **2008**, *41*, 1633–1641. [CrossRef]
13. Acevedo-Fani, A.; Soliva-Fortuny, R.; Martín-Belloso, O. Nanoemulsions as Edible Coatings. *Curr. Opin. Food Sci.* **2017**, *15*, 43–49. [CrossRef]
14. Tahir, H.E.; Xiaobo, Z.; Mahunu, G.K.; Arslan, M.; Abdalhai, M.; Zhihua, L. Recent Developments in Gum Edible Coating Applications for Fruits and Vegetables Preservation: A Review. *Carbohydr. Polym.* **2019**, *224*, 115141. [CrossRef]
15. Dwi Ariyanto, H.; Loon Neoh, T.; Yoshii, H. Active Packaging. In *Gases in Agro-Food Processes*; Cachon, R., Girardon, P., Voilley, A., Eds.; Academic Press, Inc.: San Diego, CA, USA, 2019; pp. 363–372, ISBN 9780128124659.
16. Singh, P.K.; Singh, R.P.; Singh, P.; Singh, R.L. Food Hazards: Physical, Chemical, and Biological. In *Food Safety and Human Health*; Singh, R.L., Mondal, S., Eds.; Elsevier Inc.: London, UK, 2019; pp. 15–65, ISBN 9780128163337.
17. Alexandre, E.M.C.; Pinto, C.A.; Moreira, S.A.; Pintado, M.; Saraiva, J.A. Nonthermal Food Processing/Preservation Technologies. In *Saving Food: Production, Supply Chain, Food Waste and Food Consumption*; Galanakis, C.M., Ed.; Elsevier Inc.: London, UK, 2019; pp. 141–169, ISBN 9780128153574.
18. Stoma, M.; Dudziak, A. Eastern Poland Consumer Awareness of Innovative Active and Intelligent Packaging in the Food Industry: Exploratory Studies. *Sustainability* **2022**, *14*, 13691. [CrossRef]
19. Martínez-Tenorio, Y.; López-Malo, A. Envases Activos Con Agentes Antimicrobianos y Su Aplicación En Los Alimentos. *Temas Sel. Ing. Aliment.* **2011**, *5*, 1–12.
20. Díaz-Montes, E.; Castro-Muñoz, R. Trends in Chitosan as a Primary Biopolymer for Functional Films and Coatings Manufacture for Food and Natural Products. *Polymers* **2021**, *13*, 767. [CrossRef] [PubMed]
21. Wilson, C.L. *Intelligent and Active Packaging for Fruits and Vegetables*, 1st ed.; Taylor & Francis Group, LLC.: Boca Raton, FL, USA, 2007; ISBN 9780849391668.
22. Shinde, R.; Rodov, V.; Krishnakumar, S.; Subramanian, J. Active and Intelligent Packaging for Reducing Postharvest Losses of Fruits and Vegetables. In *Postharvest Biology and Nanotechnology*; Paliyath, G., Subraamanian, J., Lim, L.-T., Subramanian, K.S., Handa, A.K., Mattoo, A.K., Eds.; John Wiley & Sons, Inc.: New York, NY, USA, 2018; pp. 171–189, ISBN 9781119289470.
23. Vanderroost, M.; Ragaert, P.; Devlieghere, F.; De Meulenaer, B. Intelligent Food Packaging: The next Generation. *Trends Food Sci. Technol.* **2014**, *39*, 47–62. [CrossRef]
24. Embuscado, M.E.; Huber, K.C. *Edible Films and Coatings for Food Applications*; Springer Science & Business Media: New York, NY, USA, 2009; ISBN 9780387928234.
25. Montalvo, C.; López-Malo, A.; Palou, E. Películas Comestibles de Proteína: Características, Propiedades y Aplicaciones. *Temas Sel. Ing. Aliment.* **2012**, *6*, 32–46. [CrossRef]
26. Shit, S.C.; Shah, P.M. Edible Polymers: Challenges and Opportunities. *J. Polym.* **2014**, *2014*, 427259. [CrossRef]
27. Li, M.; Ye, R. Edible Active Packaging for Food Application: Materials and Technology. In *Biopackaging*; Masuelli, M.A., Ed.; Taylor & Francis Group, LLC.: Boca Raton, FL, USA, 2018; pp. 1–19, ISBN 9781498749688.
28. Debeaufort, F.; Quezada-Gallo, J.-A.; Voilley, A. Edible Films and Coatings: Tomorrow's Packagings: A Review. *Crit. Rev. Food Sci. Nutr.* **1998**, *38*, 299–313. [CrossRef] [PubMed]
29. Falguera, V.; Quintero, J.P.; Jiménez, A.; Muñoz, J.A.; Ibarz, A. Edible Films and Coatings: Structures, Active Functions and Trends in Their Use. *Trends Food Sci. Technol.* **2011**, *22*, 292–303. [CrossRef]

30. Salvia-Trujillo, L.; Soliva-Fortuny, R.; Rojas-Graü, M.A.; McClements, D.J.; Martín-Belloso, O. Edible Nanoemulsions as Carriers of Active Ingredients: A Review. *Annu. Rev. Food Sci. Technol.* **2017**, *8*, 439–466. [CrossRef]
31. Sánchez Aldana, D.; Contreras-Esquivel, J.C.; Nevárez-Moorillón, G.V.; Aguilar, C.N. Caracterización de Películas Comestibles a Base de Extractos Pécticos y Aceite Esencial de Limón Mexicano. *CYTA-J. Food* **2015**, *13*, 17–25. [CrossRef]
32. Kraśniewska, K.; Galus, S.; Gniewosz, M. Biopolymers-based Materials Containing Silver Nanoparticles as Active Packaging for Food Applications–A Review. *Int. J. Mol. Sci.* **2020**, *21*, 698. [CrossRef]
33. Tharanathan, R.N. Biodegradable Films and Composite Coatings: Past, Present and Future. *Trends Food Sci. Technol.* **2003**, *14*, 71–78. [CrossRef]
34. Díaz-Montes, E.; Castro-Muñoz, R. Edible Films and Coatings as Food-Quality Preservers: An Overview. *Foods* **2021**, *10*, 249. [CrossRef]
35. Díaz-Montes, E. Polysaccharides: Sources, Characteristics, Properties, and Their Application in Biodegradable Films. *Polysaccharides* **2022**, *3*, 29. [CrossRef]
36. Elsevier, B.V. Scopus. Available online: https://www.scopus.com (accessed on 14 November 2022).
37. Escamilla-García, M.; García-García, M.C.; Gracida, J.; Hernández-Hernández, H.M.; Granados-Arvizu, J.Á.; Di Pierro, P.; Regalado-González, C. Properties and Biodegradability of Films Based on Cellulose and Cellulose Nanocrystals from Corn Cob in Mixture with Chitosan. *Int. J. Mol. Sci.* **2022**, *23*, 10560. [CrossRef] [PubMed]
38. Varun, T.K.; Senani, S.; Jayapal, N.; Chikkerur, J.; Roy, S.; Tekulapally, V.B.; Gautam, M.; Kumar, N. Extraction of Chitosan and Its Oligomers from Shrimp Shell Waste, Their Characterization and Antimicrobial Effect. *Vet. World* **2017**, *10*, 170–175. [CrossRef]
39. Mohammed, A.; Rivers, A.; Stuckey, D.C.; Ward, K. Alginate Extraction from Sargassum Seaweed in the Caribbean Region: Optimization Using Response Surface Methodology. *Carbohydr. Polym.* **2020**, *245*, 116419. [CrossRef]
40. Osemwegie, O.O.; Adetunji, C.O.; Ayeni, E.A.; Adejobi, O.I.; Arise, R.O.; Nwonuma, C.O.; Oghenekaro, A.O. Exopolysaccharides from Bacteria and Fungi: Current Status and Perspectives in Africa. *Heliyon* **2020**, *6*, e04205. [CrossRef]
41. Suderman, N.; Isa, M.I.N.; Sarbon, N.M. The Effect of Plasticizers on the Functional Properties of Biodegradable Gelatin-Based Film: A Review. *Food Biosci.* **2018**, *24*, 111–119. [CrossRef]
42. Sanyang, M.L.; Sapuan, S.M.; Jawaid, M.; Ishak, M.R.; Sahari, J. Effect of Plasticizer Type and Concentration on Physical Properties of Biodegradable Films Based on Sugar Palm (*Arenga pinnata*) Starch for Food Packaging. *J. Food Sci. Technol.* **2016**, *53*, 326–336. [CrossRef]
43. Kaewprachu, P.; Osako, K.; Rawdkuen, S. Effects of Plasticizers on the Properties of Fish Myofibrillar Protein Film. *J. Food Sci. Technol.* **2018**, *55*, 3046–3055. [CrossRef]
44. Amin, U.; Khan, M.U.; Majeed, Y.; Rebezov, M.; Khayrullin, M.; Bobkova, E.; Shariati, M.A.; Chung, I.M.; Thiruvengadam, M. Potentials of Polysaccharides, Lipids and Proteins in Biodegradable Food Packaging Applications. *Int. J. Biol. Macromol.* **2021**, *183*, 2184–2198. [CrossRef]
45. Hasan, M.; Rusman, R.; Khaldun, I.; Ardana, L.; Mudatsir, M.; Fansuri, H. Active Edible Sugar Palm Starch-Chitosan Films Carrying Extra Virgin Olive Oil: Barrier, Thermo-Mechanical, Antioxidant, and Antimicrobial Properties. *Int. J. Biol. Macromol.* **2020**, *163*, 766–775. [CrossRef]
46. Da Silva, N.S.E.; Hernández, E.J.G.P.; Araújo, C.D.S.; Joele, M.R.S.P.; Lourenço, L.d.F.H. Development and Optimization of Biodegradable Fish Gelatin Composite Film Added with Buriti Oil. *CYTA-J. Food* **2018**, *16*, 340–349. [CrossRef]
47. Rouhi, M.; Razavi, S.H.; Mousavi, S.M. Optimization of Crosslinked Poly(Vinyl Alcohol) Nanocomposite Films for Mechanical Properties. *Mater. Sci. Eng. C* **2017**, *71*, 1052–1063. [CrossRef] [PubMed]
48. da Silva, M.A.; Bierhalz, A.C.K.; Kieckbusch, T.G. Alginate and Pectin Composite Films Crosslinked with Ca2+ Ions: Effect of the Plasticizer Concentration. *Carbohydr. Polym.* **2009**, *77*, 736–742. [CrossRef]
49. Delville, J.; Joly, C.; Dole, P.; Bliard, C. Solid State Photocrosslinked Starch Based Films: A New Family of Homogeneous Modified Starches. *Carbohydr. Polym.* **2002**, *49*, 71–81. [CrossRef]
50. Figueiró, S.D.; Góes, J.C.; Moreira, R.A.; Sombra, A.S.B. On the Physico-Chemical and Dielectric Properties of Glutaraldehyde Crosslinked Galactomannan-Collagen Films. *Carbohydr. Polym.* **2004**, *56*, 313–320. [CrossRef]
51. Su, J.F.; Yuan, X.Y.; Huang, Z.; Wang, X.Y.; Lu, X.Z.; Zhang, L.D.; Wang, S.B. Physicochemical Properties of Soy Protein Isolate/Carboxymethyl Cellulose Blend Films Crosslinked by Maillard Reactions: Color, Transparency and Heat-Sealing Ability. *Mater. Sci. Eng. C* **2012**, *32*, 40–46. [CrossRef]
52. Migneault, I.; Dartiguenave, C.; Bertrand, M.J.; Waldron, K.C. Glutaraldehyde: Behavior in Aqueous Solution, Reaction with Proteins, and Application to Enzyme Crosslinking. *BioTecniques* **2004**, *37*, 790–802. [CrossRef]
53. Sikorski, D.; Gzyra-Jagieła, K.; Draczyński, Z. The Kinetics of Chitosan Degradation in Organic Acid Solutions. *Mar. Drugs* **2021**, *19*, 236. [CrossRef]
54. Deshmukh, A.R.; Aloui, H.; Khomlaem, C.; Negi, A.; Yun, J.; Kim, H.; Kim, S.B. Biodegradable Fi Lms Based on Chitosan and Defatted Chlorella Biomass: Functional and Physical Characterization. *Food Chem.* **2021**, *337*, 1–10. [CrossRef] [PubMed]
55. González, A.; Strumia, M.C.; Alvarez Igarzabal, C.I. Cross-Linked Soy Protein as Material for Biodegradable Films: Synthesis, Characterization and Biodegradation. *J. Food Eng.* **2011**, *106*, 331–338. [CrossRef]
56. Roy, S.; Rhim, J.W. Genipin-Crosslinked Gelatin/Chitosan-Based Functional Films Incorporated with Rosemary Essential Oil and Quercetin. *Materials* **2022**, *15*, 3769. [CrossRef]

57. Sabbah, M.; Giosafatto, C.V.L.; Esposito, M.; Di Pierro, P.; Mariniello, L.; Porta, R. Transglutaminase Cross-Linked Edible Films and Coatings for Food Applications. In *Enzymes in Food Biotechnology: Production, Applications, and Future Prospects*; Kuddus, M., Ed.; Elsevier Inc.: London, UK, 2019; pp. 369–388, ISBN 9780128132807.
58. Seiwert, K.; Kamdem, D.P.; Kocabaş, D.S.; Ustunol, Z. Development and Characterization of Whey Protein Isolate and Xylan Composite Films with and without Enzymatic Crosslinking. *Food Hydrocoll.* **2021**, *120*, 106847. [CrossRef]
59. Khan, B.; Khan Niazi, M.B.; Jahan, Z.; Farooq, W.; Naqvi, S.R.; Ali, M.; Ahmed, I.; Hussain, A. Effect of Ultra-Violet Cross-Linking on the Properties of Boric Acid and Glycerol Co-Plasticized Thermoplastic Starch Films. *Food Packag. Shelf Life* **2019**, *19*, 184–192. [CrossRef]
60. Yin, P.; Chen, C.; Ma, H.; Gan, H.; Guo, B.; Li, P. Surface Cross-Linked Thermoplastic Starch with Different UV Wavelengths: Mechanical, Wettability, Hygroscopic and Degradation Properties. *RSC Adv.* **2020**, *10*, 44815–44823. [CrossRef] [PubMed]
61. Kris-Etherton, P.M.; Hecker, K.D.; Bonanome, A.; Coval, S.M.; Binkoski, A.E.; Hilpert, K.F.; Griel, A.E.; Etherton, T.D. Bioactive Compounds in Foods: Their Role in the Prevention of Cardiovascular Disease and Cancer. *Am. J. Med.* **2002**, *113*, 71–88. [CrossRef] [PubMed]
62. Pérez-Vergara, L.D.; Cifuentes, M.T.; Franco, A.P.; Pérez-Cervera, C.E.; Andrade-Pizarro, R.D. Development and Characterization of Edible Films Based on Native Cassava Starch, Beeswax, and Propolis. *NFS J.* **2020**, *21*, 39–49. [CrossRef]
63. Díaz-Galindo, E.P.; Nesic, A.; Cabrera-Barjas, G.; Mardones, C.; Von Baer, D.; Bautista-Baños, S.; Garcia, O.D. Physical-Chemical Evaluation of Active Food Packaging Material Based on Thermoplastic Starch Loaded with Grape Cane Extract. *Molecules* **2020**, *25*, 1306. [CrossRef]
64. Medeiros Silva, V.D.; Coutinho Macedo, M.C.; Rodrigues, C.G.; Neris dos Santos, A.; de Freitas e Loyola, A.C.; Fante, C.A. Biodegradable Edible Films of Ripe Banana Peel and Starch Enriched with Extract of Eriobotrya Japonica Leaves. *Food Biosci.* **2020**, *38*, 100750. [CrossRef]
65. Khodaei, D.; Hamidi-Esfahani, Z.; Lacroix, M. Gelatin and Low Methoxyl Pectin Films Containing Probiotics: Film Characterization and Cell Viability. *Food Biosci.* **2020**, *36*, 100660. [CrossRef]
66. Tzia, C.; Sfakianakis, P.; Giannou, V. Raw Materials of Foods: Handling and Management. In *Handbook of Food Processing-Food Safety, Quality and Manufacturing Processes*; Varzakas, T., Tzia, C., Eds.; Taylor & Francis Group, LLC.: Boca Raton, FL, USA, 2016; pp. 1–40.
67. Tzia, C.; Giannou, V.; Lignou, S.; Lebesi, D. Sensory Evaluation of Foods. In *Handbook of Food Processing-Food Safety, Quality and Manufacturing Processes*; Varzakas, T., Tzia, C., Eds.; Taylor & Francis Group, LLC.: Boca Raton, FL, USA, 2016; pp. 41–72.
68. Abdillah, A.A.; Charles, A.L. Characterization of a Natural Biodegradable Edible Film Obtained from Arrowroot Starch and Iota-Carrageenan and Application in Food Packaging. *Int. J. Biol. Macromol.* **2021**, *191*, 618–626. [CrossRef] [PubMed]
69. Díaz-Montes, E.; Yáñez-Fernández, J.; Castro-Muñoz, R. Dextran/Chitosan Blend Film Fabrication for Bio-packaging of Mushrooms (*Agaricus bisporus*). *J. Food Process. Preserv.* **2021**, *45*, e15489. [CrossRef]
70. Azevedo, V.M.; Dias, M.V.; de Siqueira Elias, H.H.; Fukushima, K.L.; Silva, E.K.; de Deus Souza Carneiro, J.; de Fátima Ferreira Soares, N.; Borges, S.V. Effect of Whey Protein Isolate Films Incorporated with Montmorillonite and Citric Acid on the Preservation of Fresh-Cut Apples. *Food Res. Int.* **2018**, *107*, 306–313. [CrossRef]
71. Chiumarelli, M.; Hubinger, M.D. Stability, Solubility, Mechanical and Barrier Properties of Cassava Starch-Carnauba Wax Edible Coatings to Preserve Fresh-Cut Apples. *Food Hydrocoll.* **2012**, *28*, 59–67. [CrossRef]
72. El-anany, A.M.; Hassan, G.F.A.; Fm, R.-A. Effects OC Edible Coatings on the Shelf-LiCe and Quality OC Anna Apple (*Malus domestica* Borkh) During Cold Storage. *J. Food Technol.* **2009**, *7*, 5–11.
73. Sganzerla, W.G.; da Rosa, C.G.; da Silva, A.P.G.; Ferrareze, J.P.; Azevedo, M.S.; Forster-Carneiro, T.; Nunes, M.R.; de Lima Veeck, A.P. Application in Situ of Biodegradable Films Produced with Starch, Citric Pectin and Functionalized with Feijoa (*Acca sellowiana* (Berg) Burret) Extracts: An Effective Proposal for Food Conservation. *Int. J. Biol. Macromol.* **2021**, *189*, 544–553. [CrossRef]
74. Motelica, L.; Ficai, D.; Ficai, A.; Truşcă, R.D.; Ilie, C.I.; Oprea, O.C.; Andronescu, E. Innovative Antimicrobial Chitosan/Zno/Ag Nps/Citronella Essential Oil Nanocomposite—Potential Coating for Grapes. *Foods* **2020**, *9*, 1801. [CrossRef]
75. Indumathi, M.P.; Saral Sarojini, K.; Rajarajeswari, G.R. Antimicrobial and Biodegradable Chitosan/Cellulose Acetate Phthalate/ZnO Nano Composite Films with Optimal Oxygen Permeability and Hydrophobicity for Extending the Shelf Life of Black Grape Fruits. *Int. J. Biol. Macromol.* **2019**, *132*, 1112–1120. [CrossRef]
76. Atta, O.M.; Manan, S.; Ul-Islam, M.; Ahmed, A.A.Q.; Ullah, M.W.; Yang, G. Silver Decorated Bacterial Cellulose Nanocomposites as Antimicrobial Food Packaging Materials. *ES Food Agrofor.* **2021**, *6*, 12–26. [CrossRef]
77. da Silva Filipini, G.; Romani, V.P.; Guimarães Martins, V. Blending Collagen, Methylcellulose, and Whey Protein in Films as a Greener Alternative for Food Packaging: Physicochemical and Biodegradable Properties. *Packag. Technol. Sci.* **2020**, *34*, 91–103. [CrossRef]
78. Rhim, J.W.; Wang, L.F. Mechanical and Water Barrier Properties of Agar/κ-Carrageenan/Konjac Glucomannan Ternary Blend Biohydrogel Films. *Carbohydr. Polym.* **2013**, *96*, 71–81. [CrossRef] [PubMed]
79. Ventura-Aguilar, R.I.; Bautista-Baños, S.; Flores-García, G.; Zavaleta-Avejar, L. Impact of Chitosan Based Edible Coatings Functionalized with Natural Compounds on Colletotrichum Fragariae Development and the Quality of Strawberries. *Food Chem.* **2018**, *262*, 142–149. [CrossRef] [PubMed]

80. Wangprasertkul, J.; Siriwattanapong, R.; Harnkarnsujarit, N. Antifungal Packaging of Sorbate and Benzoate Incorporated Biodegradable Films for Fresh Noodles. *Food Control.* **2021**, *123*, 107763. [CrossRef]
81. de Farias, Y.B.; Coutinho, A.K.; Assis, R.Q.; Rios, A.d.O. Biodegradable Sodium Alginate Films Incorporated with Norbixin Salts. *J. Food Process. Eng.* **2020**, *43*, e13345. [CrossRef]
82. Santos, L.G.; Alves-Silva, G.F.; Martins, V.G. Active-Intelligent and Biodegradable Sodium Alginate Films Loaded with Clitoria Ternatea Anthocyanin-Rich Extract to Preserve and Monitor Food Freshness. *Int. J. Biol. Macromol.* **2022**, *220*, 866–877. [CrossRef]
83. Han, H.S.; Song, K. Bin Antioxidant Properties of Watermelon (*Citrullus lanatus*) Rind Pectin Films Containing Kiwifruit (*Actinidia chinensis*) Peel Extract and Their Application as Chicken Thigh Packaging. *Food Packag. Shelf Life* **2021**, *28*, 100636. [CrossRef]
84. Muppalla, S.R.; Chawla, S.P. Effect of Gum Arabic-Polyvinyl Alcohol Films Containing Seed Cover Extract of Zanthoxylum Rhetsa on Shelf Life of Refrigerated Ground Chicken Meat. *J. Food Saf.* **2018**, *38*, e12460. [CrossRef]
85. Kanatt, S.R.; Chawla, S.P. Shelf Life Extension of Chicken Packed in Active Film Developed with Mango Peel Extract. *J. Food Saf.* **2017**, *38*, 1–12. [CrossRef]
86. Martiny, T.R.; Raghavan, V.; de Moraes, C.C.; da Rosa, G.S.; Dotto, G.L. Bio-Based Active Packaging: Carrageenan Film with Olive Leaf Extract for Lamb Meat Preservation. *Foods* **2020**, *9*, 1795. [CrossRef]
87. Phothisarattana, D.; Wongphan, P.; Promhuad, K.; Promsorn, J.; Harnkarnsujarit, N. Blown Film Extrusion of PBAT/TPS/ZnO Nanocomposites for Shelf-Life Extension of Meat Packaging. *Colloids Surfaces B Biointerfaces* **2022**, *214*, 112472. [CrossRef] [PubMed]
88. Leelaphiwat, P.; Pechprankan, C.; Siripho, P.; Bumbudsanpharoke, N.; Harnkarnsujarit, N. Effects of Nisin and EDTA on Morphology and Properties of Thermoplastic Starch and PBAT Biodegradable Films for Meat Packaging. *Food Chem.* **2022**, *369*, 130956. [CrossRef] [PubMed]
89. Hawthorne, L.M.; Beganović, A.; Schwarz, M.; Noordanus, A.W.; Prem, M.; Zapf, L.; Scheibel, S.; Margreiter, G.; Huck, C.W.; Bach, K. Suitability of Biodegradable Materials in Comparison with Conventional Packaging Materials for the Storage of Fresh Pork Products over Extended Shelf-Life Periods. *Foods* **2020**, *9*, 1802. [CrossRef] [PubMed]
90. Zhao, Y.; Teixeira, J.S.; Gänzle, M.M.; Saldaña, M.D.A. Development of Antimicrobial Films Based on Cassava Starch, Chitosan and Gallic Acid Using Subcritical Water Technology. *J. Supercrit. Fluids* **2018**, *137*, 101–110. [CrossRef]
91. Kalem, I.K.; Bhat, Z.F.; Kumar, S.; Noor, S.; Desai, A. The Effects of Bioactive Edible Film Containing Terminalia Arjuna on the Stability of Some Quality Attributes of Chevon Sausages. *Meat Sci.* **2018**, *140*, 38–43. [CrossRef]
92. Ehsani, A.; Hashemi, M.; Aminzare, M.; Raeisi, M.; Afshari, A.; Mirza Alizadeh, A.; Rezaeigolestani, M. Comparative Evaluation of Edible Films Impregnated with Sage Essential Oil or Lactoperoxidase System: Impact on Chemical and Sensory Quality of Carp Burgers. *J. Food Process. Preserv.* **2019**, *43*, e14070. [CrossRef]
93. Ehsani, A.; Hashemi, M.; Afshari, A.; Aminzare, M.; Raeisi, M.; Zeinali, T. Effect of Different Types of Active Biodegradable Films Containing Lactoperoxidase System or Sage Essential Oil on the Shelf Life of Fish Burger during Refrigerated Storage. *Lwt* **2020**, *117*, 108633. [CrossRef]
94. Carissimi, M.; Flôres, S.H.; Rech, R. Effect of Microalgae Addition on Active Biodegradable Starch Film. *Algal Res.* **2018**, *32*, 201–209. [CrossRef]
95. Varzakas, T. Meat and Meat Products: Processing, Quality, and Safety. In *Handbook of Food Processing-Food Safety, Quality and Manufacturing Processes*; Varzakas, T., Tzia, C., Eds.; Taylor & Francis Group, LLC.: Boca Raton, FL, USA, 2016; pp. 425–486.
96. Kralik, G.; Kralik, Z.; Grčević, M.; Hanžek, D. Quality of Chicken Meat. In *Animal Husbandry and Nutrition*; Yucel, B., Taski, T., Eds.; IntechOpen: London, UK, 2018; pp. 63–94.
97. Farahmandfar, R.; Esmaeilzadeh Kenari, R.; Asnaashari, M.; Shahrampour, D.; Bakhshandeh, T. Bioactive Compounds, Antioxidant and Antimicrobial Activities of Arum Maculatum Leaves Extracts as Affected by Various Solvents and Extraction Methods. *Food Sci. Nutr.* **2019**, *7*, 465–475. [CrossRef]
98. Prasad, A.; Rossi, C.; Manoharan, R.R.; Sedlářová, M.; Cangeloni, L.; Rathi, D.; Tamasi, G.; Pospíšil, P.; Consumi, M. Bioactive Compounds and Their Impact on Protein Modification in Human Cells. *Int. J. Mol. Sci.* **2022**, *23*, 7424. [CrossRef]
99. Siddiqi, K.S.; ur Rahman, A.; Tajuddin; Husen, A. Properties of Zinc Oxide Nanoparticles and Their Activity Against Microbes. *Nanoscale Res. Lett.* **2018**, *13*, 141. [CrossRef] [PubMed]
100. Liu, J.; Huang, R.; Song, Q.; Xiong, H.; Ma, J.; Xia, R.; Qiao, J. Combinational Antibacterial Activity of Nisin and 3-Phenyllactic Acid and Their Co-Production by Engineered Lactococcus Lactis. *Front. Bioeng. Biotechnol.* **2021**, *9*, 1–10. [CrossRef]
101. Li, Q.; Manuel Montalban-lopez, O.P.; Manuel Montalban-lopez, O.P.K. Increasing the Antimicrobial Activity of Nisin-Based. *Am. Soc. Microbiol.* **2018**, *84*, 1–15.
102. Finnegan, S.; Percival, S.L. EDTA: An Antimicrobial and Antibiofilm Agent for Use in Wound Care. *Adv. Wound Care* **2015**, *4*, 415–421. [CrossRef] [PubMed]
103. Al-Baarri, A.N.; Damayanti, N.T.; Legowo, A.M.; Hayakawa, S.; Tekiner, I.H. Enhanced Antibacterial Activity of Lactoperoxidase-Thiocyanate-Hydrogen Peroxide System in Reduced-Lactose Milk Whey. *Int. J. Food Sci.* **2019**, *2019*, 22–27. [CrossRef]
104. Yassine, E.; Rada, B. Microbicidal Activity of Hypothiocyanite against Pneumococcus. *Antibiotics* **2021**, *10*, 1313. [CrossRef]
105. Ziv, C.; Fallik, E. Postharvest Storage Techniques and Quality Evaluation of Fruits and Vegetables for Reducing Food Loss. *Agronomy* **2021**, *11*, 1133. [CrossRef]
106. Elshafie, H.S.; Camele, I. An Overview of the Biological Effects of Some Mediterranean Essential Oils on Human Health. *Biomed. Res. Int.* **2017**, *2017*, 9268468. [CrossRef]

107. FAO. *Pérdidas y Desperdicio de Alimentos En El Mundo–Alcance, Causas y Prevención*; FAO: Düsseldorf, Germany, 2012.
108. Chiofalo, B.; Lo Presti, V. Sampling Techniques for the Determination of Volatile Components in Food of Animal Origin. In *Comprehensive Sampling and Sample Preparation*; Pawliszyn, J., Ed.; Academic Press, Inc.: Cambridge, MA, USA, 2012; Volume 4, pp. 61–85, ISBN 9780123813749.
109. Zhang, K.; Fang, K.; Sun, F.; Song, Y.; Qin, H. Progress in Organic Coatings The Hydrophobicity and Swelling of Methyl Cellulose Coating Synergistically Enhancing the Inkjet Printing Qualities of Cotton Fabric. *Prog. Org. Coatings* **2022**, *173*, 107187. [CrossRef]
110. Rastello De Boisseson, M.; Leonard, M.; Hubert, P.; Marchal, P.; Stequert, A.; Castel, C.; Favre, E.; Dellacherie, E. Physical Alginate Hydrogels Based on Hydrophobic or Dual Hydrophobic/Ionic Interactions: Bead Formation, Structure, and Stability. *J. Colloid Interface Sci.* **2004**, *273*, 131–139. [CrossRef]
111. Manzocco, L.; Romano, G.; Calligaris, S.; Nicoli, M.C. Modeling the Effect of the Oxidation Status of the Ingredient Oil on Stability and Shelf Life of Low-Moisture Bakery Products: The Case Study of Crackers. *Foods* **2020**, *9*, 749. [CrossRef] [PubMed]
112. Heiniö, R.-L. Sensory Attributes of Bakery Products. In *Bakery Products Science and Technology*; Zhou, W., Hui, Y.H., De Leyn, I., Pagani, M.A., Rosell, C.M., Selman, J.D., Therdthai, N., Eds.; John Wiley & Sons Ltd.: New York, NY, USA, 2014; pp. 391–407, ISBN 9781118792001.
113. Galus, S.; Kibar, E.A.A.; Gniewosz, M.; Kraśniewska, K. Novel Materials in the Preparation of Edible Films and Coatings-A Review. *Coatings* **2020**, *10*, 674. [CrossRef]
114. FDA. Food Ingredients & Packaging. Available online: https://www.fda.gov/food/food-ingredients-packaging (accessed on 12 November 2022).
115. MINCETUR. *Guía Para Reconocimiento de Una Sustancia GRAS En Estados Unidos*, 1st ed.; Ministerio de Comercio Exterior y Turismo: San Isidro, Lima, Perú, 2018.
116. Alamri, M.S.; Qasem, A.A.A.; Mohamed, A.A.; Hussain, S.; Ibraheem, M.A.; Shamlan, G.; Alqah, H.A.; Qasha, A.S. Food Packaging's Materials: A Food Safety Perspective. *Saudi J. Biol. Sci.* **2021**, *28*, 4490–4499. [CrossRef] [PubMed]
117. Pavli, F.; Tassou, C.; Nychas, G.J.E.; Chorianopoulos, N. Probiotic Incorporation in Edible Films and Coatings: Bioactive Solution for Functional Foods. *Int. J. Mol. Sci.* **2018**, *19*, 150. [CrossRef]
118. Maciel, V.B.V.; Yoshida, C.M.P.; Franco, T.T. Development of a Prototype of a Colourimetric Temperature Indicator for Monitoring Food Quality. *J. Food Eng.* **2012**, *111*, 21–27. [CrossRef]
119. Veiga-Santos, P.; Ditchfield, C.; Tadini, C.C. Development and Evaluation of a Novel PH Indicator Biodegradable Film Based on Cassava Starch. *J. Appl. Polym. Sci.* **2010**, *1120*, 1069–1079. [CrossRef]
120. Yoshida, C.M.P.; Maciel, V.B.V.; Mendonça, M.E.D.; Franco, T.T. Chitosan Biobased and Intelligent Films: Monitoring PH Variations. *LWT-Food Sci. Technol.* **2014**, *55*, 83–89. [CrossRef]