Polysaccharides based materials as active packaging for food applications: A review

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Abstract. In the food sector, one way to support the achievement of the SDGs goals responsible consumption and production is to implement edible or biodegradable food packaging. Food packaging has the main function of protecting food items. Based polysaccharides are one source of material that used to food packaging. Materials of polysaccharide based such as cellulose, hemicellulose, pectin, chitin, starch, and alginate. Polysaccharide based packaging has the potential to be used as active packaging with the addition of active ingredients which can increase the shelf life of the product. Polysaccharides have great potential to be used as active packaging materials for food. Polysaccharides as active packaging materials play an active role in the quality and durability of food either by acting as scavengers or inactivating harmful compounds through the release of desired components, which have antimicrobial or antioxidant properties. However, further research is needed to optimize their performance and overcome production and processing issues to facilitate their commercialization.

1 Introduction

This earth has abundant natural resources. However, we have not used it effectively, and we are currently consuming highly more than can be supplied. Therefore, we must learn how to use and produce it, following SDGs goal number 12, which is ensuring sustainable consumption and production patterns [1]. In the food sector, one way to support this is by implementing edible or biodegradable food packaging. Food packaging serves to shield food from contaminants such as microorganisms and water vapor generators, as well as harmful oxygen scavengers and UV radiation [2].

Currently, the food packaging material that is widely used is synthetic packaging. Concerns about the environment and human health promote the use of biodegradable packaging over synthetic packaging [2]. Biopolymers are one of the most popular natural packaging materials due to their non-toxic, biodegradable, biocompatible, and environmentally friendly nature [3]. Biopolymer-based resources can be used to develop biodegradable bioplastics that are more economical, renewable, and available in abundance

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[4]. In addition to improving the sensory quality and nutritional value of packaged goods, biopolymer materials can function as carriers of antibacterial substances, antioxidants, coloring and flavoring agents, vitamins, or other nutrients [5][6][7]. Biopolymers such as proteins, lipids, and polysaccharides are used frequently to create packaging materials [8].

Polysaccharides are the most common raw material for biopolymers, which come from the biomass of plants or marine organisms [9]. Several sources of polysaccharide materials used in food packaging are animals, plants, microbial organism, and algae. Polysaccharides are essential macromolecules that found in almost all biological forms. Polysaccharides are promising components for biodegradable food packaging due to their natural properties and phytochemical characteristics and can produce active ingredients that increase product value and extend shelf life [10]. Edible or biodegradable materials can be sprayed, dipped, or panned directly onto a food surface [11].

Consumers preference for safe food and good quality products with a longer shelf life led us to explore emerging food preservation techniques, including active food packaging [12]. Active food packaging works by delivering active ingredients into the food, providing a stable increase in food quality. Active ingredients in food packaging systems have an active role in food quality and shelf-life, either through scavenging or inactivation of harmful compounds by releasing desired components with antimicrobial or antioxidant properties [13]. Polysaccharides have received increasing attention due to their broad range of biological properties, including antimicrobial, antioxidant, anticoagulant and anti-diabetic properties [14]. This makes them one of the most promising candidates of materials to be used as active packaging materials.

Active packaging has several functions, including helping to extend the shelf-life of a product by using a system to absorb and diffuse various substances such as carbon dioxide, oxygen and ethanol (Figure 1). However, there are several important issues regarding this new technology such as costs, customer acceptability, marketability, food safety, organoleptic quality, and environmental safety [13]. Therefore, this paper reviews the potential use of polysaccharide materials as potential active food packaging materials. In the future, studies should be carried out to resolve remaining issues and develop advanced packaging innovations and their uses in the food sector.

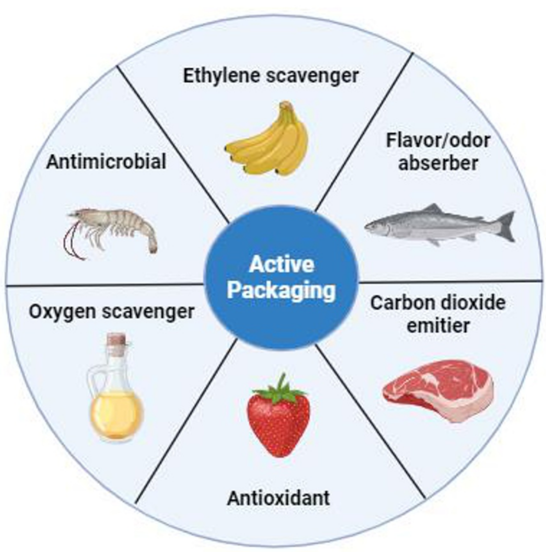

Fig. 1. Function of active food packaging.

2 Methods

This systematic review adheres to the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Figure 2 presents PRISMA flow diagram of the article selection. This review aims to examine scientific articles on the use of polysaccharides based for active food packaging. Strategic keyword selection was employed to search leading research databases, including PubMed, Scopus, Science Direct, Google Scholar, Springer, and Taylor and Francis. The study conducted searches using quotation marks and Boolean moderators (i.e., "AND" and "OR") to identify relevant articles. The keywords used in each database were "food packaging" OR "active packaging" AND "polysaccharides". The selection of the articles was based on criteria, as follows articles report the application of polysaccharides based for active food packaging and written in English.

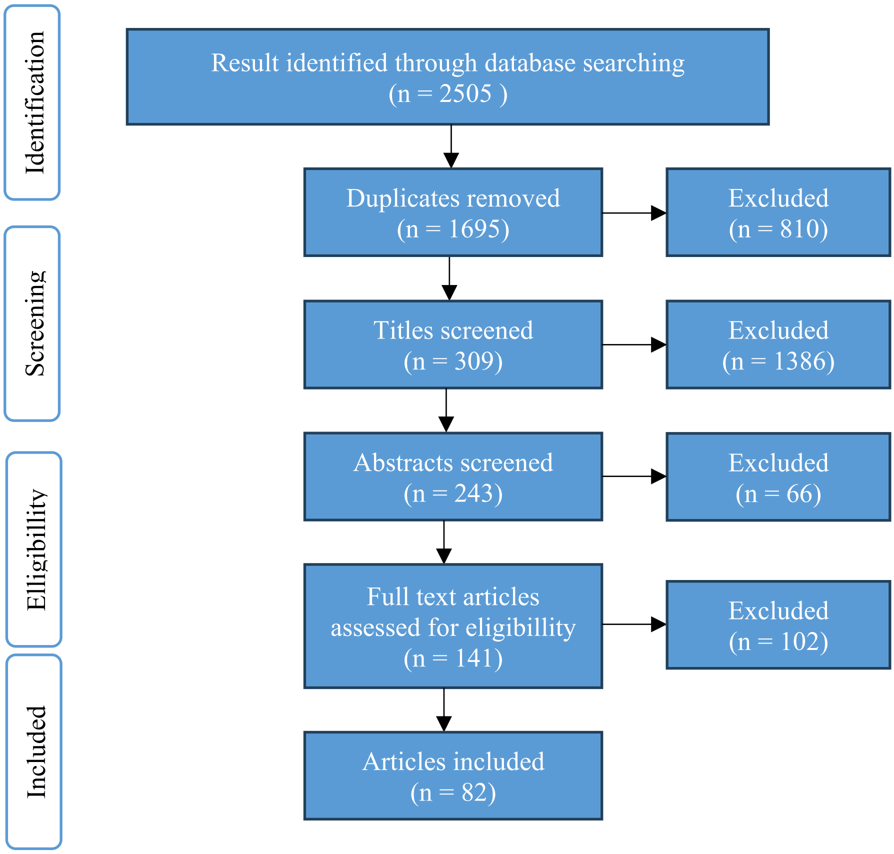

Fig. 2. PRISMA flow diagram of the article selection.

3 Results and Discussion

3.1 Polysaccharides

Polysaccharides are the most prevalent macromolecules in the biosphere. Complex carbohydrates called polysaccharides, which are joined by glycosidic linkages, are fundamental parts of the exoskeletons of animals and plants (such as chitin and cellulose), and they are crucial for the storage of plant energy in the form of starch [15]. Figure 3 illustrates a several sources of polysaccharide polymers used in food packaging. Many polysaccharides and their derivatives are used to create smooth membranes and biodegradable films that can be used in the food, pharmaceutical, and medical industries, as well as in certain industrial processes like pervaporation [16]. Polysaccharide-based membranes, particularly in the food industry, are preferred because of their excellent mechanical strength and ability to effectively block oxygen and carbon dioxide in low to moderate humidity environments. Ongoing research efforts focus on improving polysaccharide films to exhibit desirable packaging characteristics and to be suitable for industrial use [17]. Table 1 shows the use of polysaccharide-based materials as active packaging for several food products.

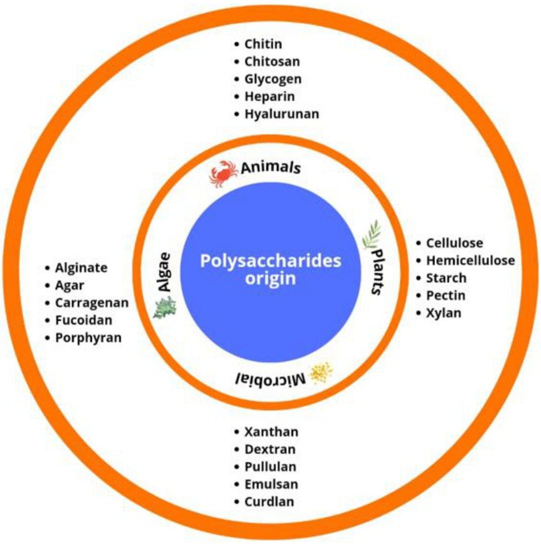

Fig. 3. Polysaccharides based material.

3.1.1 Cellulose

Cellulose represents the most prevalent biopolymer in nature and has been observed in the cell walls of a diverse array of plant species, fungi, algae, select marine organisms, including members of the tunicate family, invertebrates, and certain gram-negative bacteria [15]. A linear homopolysaccharide, cellulose is made up of d-glucopyranosyl units connected by β-(1,4) glycosidic linkages. Recent research highlights alternative cellulose sources such as vegetable waste materials, including peel, husks, shells, and bagasse, which offer economic and ecological advantages [18]. Cellulose is renowned for its film-forming ability, strong chemical stability, and ease of derivatization [19], but also faces important challenges because its limited solubility in water and most organic solvents, thus hindering its direct utilization [20]. However, derivatization is emerging as an important solution, not only increasing water solubility but also improving the compatibility of cellulose with thermoplastics. Regenerated cellulose, denoted by plastic, has wide application in real-world scenarios, especially in food packaging. Known for its transparency, mechanical rigidity, and dimensional stability, plastic serves as a staple for a variety of consumables such as candy, cheese, cookies, coffee, and chocolate. Additionally, efforts to incorporate antimicrobial agents such as nisin into plastics further underscore their utility in meat packaging [21].

Composite materials combining cellulose and lignin show UV-protective and antimicrobial properties, making them promising as next-generation food packaging materials [22]. By exploiting the various hydroxyl groups present along the cellulose chain, researchers are exploring various derivatization routes to tailor cellulose derivatives for specific applications, including food packaging. For instance, combining carboxymethyl cellulose (CMC) and polyvinyl alcohol yields packaging films with excellent mechanical qualities. Adding extracts, like rosemary oil, boosts the material's effectiveness as an active packaging ingredient, as seen by the fact that mold does not grow on it even after prolonged storage [23]. Likewise, layer-by-layer coating using CMC and chitosan showed efficacy in maintaining the freshness and quality of perishable ingredients such as strawberries [24]. A noteworthy advance is cellulose acetate films integrated with bacteriophages, showing promising antimicrobial potential for food packaging [25]. ellulose cinnamate has been identified as a viable packaging material for fruits, due to its superior mechanical qualities, thermal stability, and limited permeability to moisture, oxygen, and oils [26]. However, it's imperative to discern that while both cellulose-based polymers and paper share a common chemical composition, their distinct properties and performance characteristics warrant careful consideration in food packaging applications.

3.1.2 Hemicellulose

Hemicelluloses are polysaccharides derived from plant materials or generated as byproducts during different wood and plant processing techniques. The presence of hydrogen bonds and lignin, ester, and ether-linked lignin-carbohydrate complexes within the plant cell wall matrix makes hemicellulose extraction extremely difficult [27]. These compounds exhibit notable diversity in composition and structure, influenced by factors such as biological source and localization. Hemicelluloses are composed of β-(1,4)-linked backbones of glucose, mannose, or xylose in an equatorial configuration. They are generally characterized by shorter chains, a lower molecular mass, and a non-crystalline structure when compared to cellulose. These hemicelluloses are categorized into four main groups: xyloglycans (xylans), mannoglycans (mannans), β-glucans, and xyloglucans [27].

The configuration of side chains within hemicellulose has a considerable impact on its physical, chemical, and functional attributes, including solubility, interaction with other cell wall components, susceptibility to enzymatic degradation, as well as gelatinous behaviour. Despite their inherent capacity for gelling and film formation, the hydrophilic nature of hemicelluloses presents challenges for their direct application, necessitating chemical modification to enhance properties such as solubility, crystallinity, film-forming ability, and hydrophobicity [28]. Various techniques, including esterification, etherification, acetylation, and graft polymerization, have proven effective in tailoring hemicellulose molecules to achieve desired characteristics [29] [30]. In the realm of food packaging, xylans, glucomannans, and β-glucans have garnered significant attention due to their promising features. For example, xylan-based films exhibit good grease and oxygen barrier qualities, and blends of galactomannan and xyloglucan have the potential to be edible, biodegradable, and environmentally acceptable packaging materials [31]. However, in order to improve performance, issues like low mechanical strength and sensitivity to moisture must be addressed through chemical modification or mixing with other polymers. Techniques like adding antioxidants, blending with nanocellulose, and intercalation with montmorillonite have demonstrated the ability to improve the functionality, hydrophobicity, and mechanical characteristics of hemicellulose-based packaging materials, emphasizing their appropriateness for active food packaging applications [32] [33].

Table 1. Application of polysaccharides for active packaging in food products.

Polysaccharide (s)	**Food Product**	**Active agent(s)**	**Main result(s)**	**Reference**
Alginate	Tomatoes	Aloe vera and garlic oil	This edible film has mechanical, thermal, antibacterial, and UV barrier qualities were all enhanced by active agents.	[34]
Alginate	Fresh cut apples	Thyme oil	The research results showed that thyme oil edible coating could inhibit weight loss, microbial growth, respiration, hardness, and browning in freshly cut 'Red Fuji' apples.	[35]
Starch	Lard	Onion Skin	The films have enhanced their biological activities and physicochemical characteristics, making them suitable for use as an active packaging material to extand food shelf life.	[36]
Starch	Carrot	Cinnamon and turmeric essential oils	Overall, the films showed potent antioxidant activity and thermal stability.	[37]
Cellulose	Fresh fruit	Glucose	The films provided high UV-blocking properties, high antioxidant activity, antimicrobial activity, antibacterial and antifungal activity, and low cytotoxicity are extending their shelf life	[38]
Cellulose	Fresh beef	Garlic extract	The antibacterial properties of packaging can help prevent fresh meat from spoiling too soon.	[39]
Hemicellulose	Fatty foods	Mango peel	The film can enhance physicochemical properties and antioxidant’s slow release	[40]
Hemicellulose	Cherry tomato	Potassium cinnamate	The composite film shows moderate oxygen barrier properties, high film flexibility, as well as having good antibacterial UV barrier properties.	[41]
Pectin	Beef meat	Olives	The meat samples wrapped in antioxidant-containing film decreased the amount of oxidation products.	[42]
Pectin/chitosan	Epigallocatechin gallate, natamycin	Strawberry	The results show that it can block UV rays in the outer layer, and provide long-lasting and sustainable bacterial inhibition.	[43]
Chitin	Chicken breast meat	Curcumin	The film has total phenolic content, radical scavenging activity, and light barrier properties were all enhanced by the addition of curcumin.	[44]
Chitin/Chitosan	Fresh cut bananas	Scallion flower extract	The film exhibits enhanced physical and biological properties, with the potential to function as an oxygen barrier and possess antibacterial qualities.	[45]

3.1.3 Chitin

Chitin is a biopolymer that is more prevalent on Earth than cellulose. It is found in the exoskeletons of crustaceans and insects, as well as the cell walls of fungi and yeast. Chitin is a structural substance that functions similarly to cellulose in plant cells. It is produced annually in 1011 metric tons and is mainly composed of (1-4) bonded 2-acetamido-2-deoxy-β-D-glucose monomers [46]. However, only 150,000 tonnes of this vast quantity are commercially exploited [47], making it the most numerous biopolymer derived from animals and the second most frequent biopolymer on Earth after cellulose. Chitosan, the deacetylated derivative of chitin, is distinguished by its nitrogen content and is composed primarily of (1-4)-linked 2-amino-2-deoxy-β-D-glucose monomers. Chitotin is deacetylated to produce chitosan, a cationic biopolymer. Its hydroxyl and amino group-rich structure confers antibacterial action against both gram-positive and gram-negative bacteria. Functional characteristics are conferred upon chitosan by the presence of amino groups. Several chemical, physical, and biological properties of chitosan are caused by the positive charge that is produced when protons are accepted by electronegative amino groups.

Chitosan is a versatile polymer with applications in food packaging research due to its soluble, film-forming, viscous, ion-binding, and antibacterial qualities [48]. Chitosan films exhibit antimicrobial and antioxidant properties crucial for food packaging [49]. In addition, chitosan has been combined with different kinds of biopolymers, synthetic polymers, functional extracts, and nanomaterials to improve food packaging's mechanical, thermal, and barrier qualities [48][49]. Furthermore, chitosan's three reactive functional groups—two hydroxyl groups at locations C-3 and C-6 and one amino group at position C-2—allow for additional functionalization, producing a range of derivatives with enhanced qualities for food packaging [48]. The barrier qualities of food packaging materials can be improved by the addition of water-soluble chitosan derivatives including alkyl, quaternary, and carboxymethyl chitosan [50]. Many techniques have been used to create chitosan-based films/coatings to increase the shelf life of fruits, vegetables, fish, and meat, including solution casting, layer-by-layer assembly, extrusion, and spraying/coating/dipping [49]. Integration with specific indicators, such as anthocyanins, enables chitosan films to function as sensing films for monitoring meat freshness [51]. Chitosan hydrogel films, developed for microbial sensing in food quality and safety monitoring, represent an innovative alternative to conventional dry films [52].

3.1.4 Pectin

Pectin is a heterogeneous polysaccharide found in plant cell walls. It consists of D-galacturonate units linked to α-(1,4) [53]. Plant origin and processing circumstances can have an impact on the degree of methyl esterification of pectin, which is a common ingredient in packaging sheets [54]. Pectin is a good material for food packaging due to its biodegradability, biocompatibility, gelation qualities, and non-toxicity. However, its high hydrophilicity and moderate barrier, thermal, and mechanical properties may limit its uses [55]. In order to enhance the functional properties of pure pectin films, blending with other polymers or incorporating nanosized fillers has been employed, resulting in improved physicochemical, barrier, thermal, and mechanical properties [56].

Pectin films, made via thermo-compression casting or molding, have shown promising results in food packaging applications. Furthermore, pectin demonstrates compatibility with other biopolymers, such as proteins, lipids, and polysaccharides. Glycerol is a common plasticizing agent for pectin films. Food decomposition can be slowed down by using pectin composite coating, which combines maize starch and beet powder. It has been demonstrated to alter the oxygen content of food, modify the atmosphere surrounding it, and prevent ethylene emissions [57]. The application of pectin coating directly to cut fruit and vegetables has been demonstrated to delay the oxidation of soybean oil for up to 30 days and to preserve tomatoes' freshness for an extended period. This coating may also act as an encapsulation agent in active packaging, with controlled release of active compounds, thus extending the shelf life of food products [58]. The integration of clove essential oil into pectin films has been shown to enhance the barrier, mechanical, antimicrobial, and antioxidant properties of the film [59]. Conversely, encapsulation of marjoram essential oil via a Pickering emulsion has resulted in a slowed release, thus extending the shelf life of foods [60]. Films containing pectin, starch, and chitosan, in conjunction with mint and rosemary essential oils and nisin, have been observed to exhibit improved antimicrobial properties, barrier properties, tensile strength, and thermal stability [61]. Furthermore, red cabbage extracts have been used in pectin films as smart packaging for fish and meat, changing color as a sensor in response to protein degradation with increasing pH [62]. Similarly, the incorporation of tea extracts has improved the mechanical, antioxidant, and antimicrobial properties of pectin [63]. Composite films comprising pectin and nanomaterials, including silver, titanium dioxide, gold, and copper nanoparticles, have demonstrated enhanced mechanical, barrier, antimicrobial, and ultraviolet-screening properties for food packaging applications [64][58].

3.1.5 Starch

Starch, a polymeric carbohydrate, comprises two distinct components: linear and helical amylose, and branched amylopectin. Starch film is a semi-crystalline polymer, therefore it doesn't naturally have the flexibility needed for food packing. Numerous techniques, such as plasticization, enzymatic treatment, and chemical or physical modification, have been employed to improve the flexibility of starch films. Gelatin and citric acid have both been demonstrated to be useful in enhancing the characteristics and composition of starch films. Furthermore, starch derivatives with strong water vapor barrier and resistance to other gases pertinent to food packing, like starch acetate, have been employed as coatings on paper. Sulfur hexafluoride plasma treatment was utilized to diminish the hydrophilicity of starch, resulting in contact angles as high as 140°. Moreover, starch can be combined with additives like cellulose nanofibers (CNF), zinc oxide (ZnO), magnesium oxide (MgO), and nanoclay to create coating materials with outstanding barrier, antibacterial, and UV protection qualities. enhanced [50]. Lemongrass essential oil and pectin emulsion-containing starch composite films have shown good thermal stability, an outstanding water vapor barrier, and mechanical qualities appropriate for food packaging [65]. While there is considerable potential for starch-based materials to serve as environmentally friendly and sustainable alternatives to synthetic packaging in the food industry, their widespread production is currently constrained by the fact that they are unable to match the optical, barrier, and mechanical properties of conventional synthetic materials. In order to overcome this challenge, various efforts are underway to adapt and enhance conventional thermoplastic processing techniques and to explore the physical and chemical modification of starch, in addition to blending it with other biopolymers, plasticizers, and functional nanomaterials and microcapsules. The latter strategy also seeks to create intelligent or active packaging that can increase food shelf life or serve as a sensor while food is being transported and stored. Though starch-based polymers are biodegradable, it's crucial to remember that some chemical additions used to enhance their functionality may unintentionally prolong the life of material [66].

3.1.6 Alginate

Alginate is primarily derived from brown seaweeds, such as Laminaria species, Macrocystis pyrifera, Fucus species, and Ascophyllum nodosum [67]. It constitutes approximately 20–40% of the dry matter [68]. Alginate is composed chemically of α-l-guluronic acid and β-d-mannuronic acid connected units (1,4) [69]. As an anionic biopolymer derived primarily from brown algae, alginate is considered safe for use as a material in contact with food. Alginate has been used to improve paperboard's oil resistance and barrier qualities in combination with calcium chloride ($CaCl_2$). Composites of sodium alginate (SA) and sodium carboxymethyl cellulose (CMC) or sodium alginate (SA) and propylene glycol alginate (PGA) have been shown to be highly effective as paper coating materials, exhibiting improved water resistance, oil barrier and mechanical properties [50].

Alginates are a type of polysaccharide commonly used in the manufacture of edible coatings due to their exceptional film-forming properties, biocompatibility and edibility [70][71]. The alginate structure is derived from marine brown algae and consists of L-guluronic acid and D-mannuronic acid. In the presence of multivalent cations, such as calcium ions, alginate readily gels to form an insoluble cross-linked structure. Alginate-based coatings have been successfully used to delay post-harvest ripening of sweet cherries. [72]. owever, coatings made exclusively from alginate face challenges such as poor mechanical strength, low barrier properties, and limited antimicrobial efficacy [73]. Alginate is being mixed with other polymers, such as chitosan or its derivatives, like biguanidine chitosan or carboxymethyl cellulose, in an attempt to overcome this obstacle [71][74]. Good results were also observed when nanofillers such silver-montmorillonite nanoparticles, chitin whiskers, and titanium oxide nanoparticles were added [75][76][77]. Additionally, in order to enhance the physical and biological characteristics of alginate formulations, the addition of extracts such green tea, grape seed, rhubarb, and black chokeberry has been investigated [78][79][80].

3.2 Active packaging for food application

Food quality is stabilized through the release of active substances into the food by active food packaging. Active food packaging is a modern preservation technique that can meet consumer demand for safe and high-quality food products. Food packaging systems contain active ingredients that contribute to food quality and durability. These ingredients can function as scavengers or neutralize harmful molecules by releasing beneficial components with antioxidant or antibacterial properties. Active packaging provides an environmentally friendly way to address food preservation issues by utilizing antioxidants and antimicrobials. A long-term solution to this issue can be offered by active packaging with chemical additions or natural additives like natural antioxidants and antibacterial agents. Active compounds from natural sources have recently been utilized to develop active packaging materials. Natural sources such as animals, plants, fungi, enzymes, and microorganisms provide the active components for these packaging materials [12]. Currently, food quality, safety, and shelf life are all maintained in large part by active packaging. There are several kinds of active packaging materials that can be utilized in food goods, including moisture absorbers, ethanol generators, antioxidants, and antibacterial packaging.

The increasing variety of food products on the market and the need for long-term quality maintenance have driven the development of active packaging technology. Product shelf life is increased by this technology, which also includes systems for the absorption and dispersion of gases like oxygen and carbon dioxide. However, challenges such as cost, consumer acceptance, food safety, and environmental concerns remain important considerations. Considering these challenges, active packaging is essential for ensuring food safety, quality, and shelf life. Various types of active packaging materials, including antimicrobials, antioxidants, moisture absorbers, and ethanol producers, contribute to preserving food products [13]. In summary, active packaging represents a significant advancement in food preservation, offering innovative solutions to meet evolving consumer needs and improve food safety.

3.3 Future use application for food

Food product packaging follows progress along with the development of many types of food products. The selection of food packaging materials is a challenging process, requiring the consideration of a multitude of factors. These factors encompass the specific characteristics of the food product in question, the necessity of sustainable practices, and the surrounding environmental conditions. The food packaging that is currently widely used uses synthetic packaging materials. However, sustainable use of synthetic packaging can face environmental problems. Therefore, many bio-packages are starting to be produced that can replace synthetic packaging on the market. Additionally, polysaccharide-based materials have the potential to facilitate the future expansion of edible films and the development of smart and active sensors in food packaging. This is due to their proven gas barrier properties and biological activity. The primary drawback of materials based on polysaccharides is that they are weak in mechanics and sensitive to moisture, requiring the addition of another component to the system, which can increase the cost of the final product [81].

Currently, several types of active packaging are starting to be developed for food products. This application has amazing results and has the potential to protect food product safety and quality. However, several challenges remain in the application of active packaging to food products. These include the potential for an increase in food prices, the necessity for adequate labelling information, and the need to consider microbial ecology [82]. This is by possible directly influencing consumer behaviour and acceptance. Therefore, further research and development are required in order to facilitate the application of active packaging in the food industry.

4 Conclusion

This review summarizes the most recent research on advancements in food packaging. Food products evolve alongside advancements in the packaging process. Food packaging materials need to be carefully chosen according to the type of food product, standards of sustainability, and environmental responsibility. While synthetic packaging materials currently dominate the market, their environmental impact has sparked interest in biopolymer alternatives, particularly polysaccharide-based materials. Food packaging uses materials based on polysaccharides as films, coatings, hydrogels, emulsions, and aerogels. Despite challenges such as sensitivity to moisture and mechanical strength, polysaccharides show promise for future development in food packaging materials, especially in active packaging applications. Various properties are involved in their application to active packaging, such as mechanical qualities, gas barrier performance, and antibacterial and antimicrobial qualities in food packaging materials. It is important to consider a range of factors when examining the practical application of polysaccharides in active food packaging. Suitable active ingredients must be selected and adapted to the food ingredients being packaged. However, further research is required to optimise their performance and overcome production and processing issues to facilitate their commercialization.

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Data will be made available on request.

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References

[1] Project Everyone, "The 17 Goals: Responsible Consumption and Production," *The Global Goals*. https://www.globalgoals.org/goals/12-responsible-consumption-and-production/ (accessed May 14, 2024).

[2] D. Dutta and N. Sit, "Application of natural extracts as active ingredient in biopolymer based packaging systems," *J. Food Sci. Technol.*, vol. 60, no. 7, pp. 1888–1902, Jul. 2023, doi: 10.1007/s13197-022-05474-5.

[3] A. Ali and S. Ahmed, "Recent Advances in Edible Polymer Based Hydrogels as a Sustainable Alternative to Conventional Polymers," *J. Agric. Food Chem.*, vol. 66, no. 27, pp. 6940–6967, Jul. 2018, doi: 10.1021/acs.jafc.8b01052.

[4] M. Asgher, S. A. Qamar, M. Bilal, and H. M. N. Iqbal, "Bio-based active food packaging materials: Sustainable alternative to conventional petrochemical-based packaging materials," *Food Res. Int.*, vol. 137, p. 109625, Nov. 2020, doi: 10.1016/j.foodres.2020.109625.

[5] S. D. F. Mihindukulasuriya and L.-T. Lim, "Nanotechnology development in food packaging: A review," *Trends Food Sci. Technol.*, vol. 40, no. 2, pp. 149–167, Dec. 2014, doi: 10.1016/j.tifs.2014.09.009.

[6] C. G. Otoni *et al.*, "Recent Advances on Edible Films Based on Fruits and Vegetables—A Review," *Compr. Rev. Food Sci. Food Saf.*, vol. 16, no. 5, pp. 1151–1169, Sep. 2017, doi: 10.1111/1541-4337.12281.

[7] D. C. Vodnar, O. L. Pop, F. V. Dulf, and C. Socaciu, "Antimicrobial Efficiency of Edible Films in Food Industry," *Not. Bot. Horti Agrobot. Cluj-Napoca*, vol. 43, no. 2, pp. 302–312, Dec. 2015, doi: 10.15835/nbha43210048.

[8] K. Kraśniewska and M. Gniewosz, "Substances with Antibacterial Activity in Edible Films – A Review," *Polish J. Food Nutr. Sci.*, vol. 62, no. 4, pp. 199–206, Dec. 2012, doi: 10.2478/v10222-12-0059-3.

[9] H. P. Ramesh and R. N. Tharanathan, "Carbohydrates—The Renewable Raw Materials of High Biotechnological Value," *Crit. Rev. Biotechnol.*, vol. 23, no. 2, pp. 149–173, Jan. 2003, doi: 10.1080/713609312.

[10] S. A. Mir, B. N. Dar, A. A. Wani, and M. A. Shah, "Effect of plant extracts on the techno-functional properties of biodegradable packaging films," *Trends Food Sci. Technol.*, vol. 80, pp. 141–154, Oct. 2018, doi: 10.1016/j.tifs.2018.08.004.

[11] S. Ahmed *et al.*, "Research progress on antimicrobial materials for food packaging," *Crit. Rev. Food Sci. Nutr.*, vol. 62, no. 11, pp. 3088–3102, Apr. 2022, doi: 10.1080/10408398.2020.1863327.

[12] R. K. Deshmukh and K. K. Gaikwad, "Natural antimicrobial and antioxidant

compounds for active food packaging applications," *Biomass Convers. Biorefinery*, vol. 14, no. 4, pp. 4419–4440, Feb. 2024, doi: 10.1007/s13399-022-02623-w.

[13] M. Soltani Firouz, K. Mohi-Alden, and M. Omid, "A critical review on intelligent and active packaging in the food industry: Research and development," *Food Res. Int.*, vol. 141, p. 110113, Mar. 2021, doi: 10.1016/j.foodres.2021.110113.

[14] A. S. A. Mohammed, M. Naveed, and N. Jost, "Polysaccharides; Classification, Chemical Properties, and Future Perspective Applications in Fields of Pharmacology and Biological Medicine (A Review of Current Applications and Upcoming Potentialities)," *J. Polym. Environ.*, vol. 29, no. 8, pp. 2359–2371, Aug. 2021, doi: 10.1007/s10924-021-02052-2.

[15] A. Ferreira, V. Alves, and I. Coelhoso, "Polysaccharide-Based Membranes in Food Packaging Applications," *Membranes (Basel).*, vol. 6, no. 2, p. 22, Apr. 2016, doi: 10.3390/membranes6020022.

[16] F. Freitas, V. D. Alves, M. A. Reis, J. G. Crespo, and I. M. Coelhoso, "Microbial polysaccharide-based membranes: Current and future applications," *J. Appl. Polym. Sci.*, vol. 131, no. 6, Mar. 2014, doi: 10.1002/app.40047.

[17] J.-W. Rhim, H.-M. Park, and C.-S. Ha, "Bio-nanocomposites for food packaging applications," *Prog. Polym. Sci.*, vol. 38, no. 10–11, pp. 1629–1652, Oct. 2013, doi: 10.1016/j.progpolymsci.2013.05.008.

[18] A. L. M. P. Leite, C. D. Zanon, and F. C. Menegalli, "Isolation and characterization of cellulose nanofibers from cassava root bagasse and peelings," *Carbohydr. Polym.*, vol. 157, pp. 962–970, Feb. 2017, doi: 10.1016/j.carbpol.2016.10.048.

[19] C. S. Dzah *et al.*, "The effects of ultrasound assisted extraction on yield, antioxidant, anticancer and antimicrobial activity of polyphenol extracts: A review," *Food Biosci.*, vol. 35, p. 100547, Jun. 2020, doi: 10.1016/j.fbio.2020.100547.

[20] D. Wei *et al.*, "Antimicrobial paper obtained by dip-coating with modified guanidine-based particle aqueous dispersion," *Cellulose*, vol. 24, no. 9, pp. 3901–3910, Sep. 2017, doi: 10.1007/s10570-017-1386-7.

[21] N. P. Guerra, C. L. Macias, A. T. Agrasar, and L. P. Castro, "Development of a bioactive packaging cellophane using NisaplinR as biopreservative agent," *Lett. Appl. Microbiol.*, vol. 40, no. 2, pp. 106–110, Feb. 2005, doi: 10.1111/j.1472-765X.2004.01649.x.

[22] Guo *et al.*, "Transparent Cellulose/Technical Lignin Composite Films for Advanced Packaging," *Polymers (Basel).*, vol. 11, no. 9, p. 1455, Sep. 2019, doi: 10.3390/polym11091455.

[23] S. Nasibi *et al.*, "A review of Polyvinyl alcohol / Carboxiy methyl cellulose (PVA/CMC) composites for various applications," *J. Compos. Compd.*, vol. 2, no. 3, pp. 68–75, May 2020, doi: 10.29252/jcc.2.2.2.

[24] J. Yan *et al.*, "The effect of the layer-by-layer (LBL) edible coating on strawberry quality and metabolites during storage," *Postharvest Biol. Technol.*, vol. 147, pp. 29–38, Jan. 2019, doi: 10.1016/j.postharvbio.2018.09.002.

[25] D. M. Gouvêa, R. C. S. Mendonça, M. L. Soto, and R. S. Cruz, "Acetate cellulose film with bacteriophages for potential antimicrobial use in food packaging," *LWT - Food Sci. Technol.*, vol. 63, no. 1, pp. 85–91, Sep. 2015, doi: 10.1016/j.lwt.2015.03.014.

[26] X. Wei *et al.*, "Effects of temperature on cellulose hydrogen bonds during dissolution in ionic liquid," *Carbohydr. Polym.*, vol. 201, pp. 387–391, Dec. 2018, doi: 10.1016/j.carbpol.2018.08.031.

[27] N. M. L. Hansen and D. Plackett, "Sustainable Films and Coatings from Hemicelluloses: A Review," *Biomacromolecules*, vol. 9, no. 6, pp. 1493–1505, Jun. 2008, doi: 10.1021/bm800053z.

[28] J. P. de Oliveira, G. P. Bruni, M. J. Fabra, E. da Rosa Zavareze, A. López-Rubio, and M. Martínez-Sanz, "Development of food packaging bioactive aerogels through the valorization of Gelidium sesquipedale seaweed," *Food Hydrocoll.*, vol. 89, pp. 337–350, Apr. 2019, doi: 10.1016/j.foodhyd.2018.10.047.

[29] K. S. Mikkonen, C. Laine, I. Kontro, R. A. Talja, R. Serimaa, and M. Tenkanen, "Combination of internal and external plasticization of hydroxypropylated birch xylan tailors the properties of sustainable barrier films," *Eur. Polym. J.*, vol. 66, pp. 307–318, May 2015, doi: 10.1016/j.eurpolymj.2015.02.034.

[30] K. S. Mikkonen and M. Tenkanen, "Sustainable food-packaging materials based on future biorefinery products: Xylans and mannans," *Trends Food Sci. Technol.*, vol. 28, no. 2, pp. 90–102, Dec. 2012, doi: 10.1016/j.tifs.2012.06.012.

[31] F. R. S. Mendes *et al.*, "Preparation and evaluation of hemicellulose films and their blends," *Food Hydrocoll.*, vol. 70, pp. 181–190, Sep. 2017, doi: 10.1016/j.foodhyd.2017.03.037.

[32] G.-G. Chen, X.-M. Qi, Y. Guan, F. Peng, C.-L. Yao, and R.-C. Sun, "High Strength Hemicellulose-Based Nanocomposite Film for Food Packaging Applications," *ACS Sustain. Chem. Eng.*, vol. 4, no. 4, pp. 1985–1993, Apr. 2016, doi: 10.1021/acssuschemeng.5b01252.

[33] L. R. Mugwagwa and A. F. A. Chimphango, "Enhancing the functional properties of acetylated hemicellulose films for active food packaging using acetylated nanocellulose reinforcement and polycaprolactone coating," *Food Packag. Shelf Life*, vol. 24, p. 100481, Jun. 2020, doi: 10.1016/j.fpsl.2020.100481.

[34] M. S. Abdel Aziz and H. E. Salama, "Developing multifunctional edible coatings based on alginate for active food packaging," *Int. J. Biol. Macromol.*, vol. 190, pp. 837–844, Nov. 2021, doi: 10.1016/j.ijbiomac.2021.09.031.

[35] Sarengaowa, W. Hu, A. Jiang, Z. Xiu, and K. Feng, "Effect of thyme oil–alginate-based coating on quality and microbial safety of fresh-cut apples," *J. Sci. Food Agric.*, vol. 98, no. 6, pp. 2302–2311, Apr. 2018, doi: 10.1002/jsfa.8720.

[36] C. Wang, Y. Lu, Z. Li, X. An, Z. Gao, and S. Tian, "Preparation and Performance Characterization of a Composite Film Based on Corn Starch, κ-Carrageenan, and Ethanol Extract of Onion Skin," *Polymers (Basel).*, vol. 14, no. 15, p. 2986, Jul. 2022, doi: 10.3390/polym14152986.

[37] A. F. Rivera Leiva, J. Hernández-Fernández, and R. Ortega Toro, "Active Films Based on Starch and Wheat Gluten (Triticum vulgare) for Shelf-Life Extension of Carrots," *Polymers (Basel).*, vol. 14, no. 23, p. 5077, Nov. 2022, doi: 10.3390/polym14235077.

[38] P. Ezati, J.-W. Rhim, R. Molaei, R. Priyadarshi, and S. Han, "Cellulose nanofiber-based coating film integrated with nitrogen-functionalized carbon dots for active packaging applications of fresh fruit," *Postharvest Biol. Technol.*, vol. 186, p. 111845, Apr. 2022, doi: 10.1016/j.postharvbio.2022.111845.

[39] A. Dirpan, M. Djalal, and I. Kamaruddin, "Application of an Intelligent Sensor and Active Packaging System Based on the Bacterial Cellulose of Acetobacter xylinum to Meat Products," *Sensors*, vol. 22, no. 2, p. 544, Jan. 2022, doi: 10.3390/s22020544.

[40] L. R. Mugwagwa and A. F. A. Chimphango, "Physicochemical properties and potential application of hemicellulose/pectin/nanocellulose biocomposites as active

packaging for fatty foods," *Food Packag. Shelf Life*, vol. 31, p. 100795, Mar. 2022, doi: 10.1016/j.fpsl.2021.100795.

[41] J. Shi *et al.*, "Antimicrobial food packaging composite films prepared from hemicellulose/polyvinyl alcohol/potassium cinnamate blends," *Int. J. Biol. Macromol.*, vol. 222, pp. 395–402, Dec. 2022, doi: 10.1016/j.ijbiomac.2022.09.139.

[42] A. Bermúdez-Oria, G. Rodríguez-Gutiérrez, F. Rubio-Senent, Á. Fernández-Prior, and J. Fernández-Bolaños, "Effect of edible pectin-fish gelatin films containing the olive antioxidants hydroxytyrosol and 3,4-dihydroxyphenylglycol on beef meat during refrigerated storage," *Meat Sci.*, vol. 148, pp. 213–218, Feb. 2019, doi: 10.1016/j.meatsci.2018.07.003.

[43] X. Fu *et al.*, "Development of a chitosan/pectin-based multi-active food packaging with both UV and microbial defense functions for effectively preserving of strawberry," *Int. J. Biol. Macromol.*, vol. 254, p. 127968, Jan. 2024, doi: 10.1016/j.ijbiomac.2023.127968.

[44] E. Kaya, L. N. Kahyaoglu, and G. Sumnu, "Development of curcumin incorporated composite films based on chitin and glucan complexes extracted from Agaricus bisporus for active packaging of chicken breast meat," *Int. J. Biol. Macromol.*, vol. 221, pp. 536–546, Nov. 2022, doi: 10.1016/j.ijbiomac.2022.09.025.

[45] C. Xie *et al.*, "Development and characterization of active packaging based on chitosan/chitin nanofibers incorporated with scallion flower extract and its preservation in fresh-cut bananas," *Int. J. Biol. Macromol.*, vol. 242, p. 125045, Jul. 2023, doi: 10.1016/j.ijbiomac.2023.125045.

[46] D. Elieh-Ali-Komi and M. R. Hamblin, "Chitin and Chitosan: Production and Application of Versatile Biomedical Nanomaterials.," *Int. J. Adv. Res.*, vol. 4, no. 3, pp. 411–427, Mar. 2016, [Online]. Available: http://www.ncbi.nlm.nih.gov/pubmed/27819009.

[47] G. Guan *et al.*, "Biological Effects and Applications of Chitosan and Chito-Oligosaccharides," *Front. Physiol.*, vol. 10, May 2019, doi: 10.3389/fphys.2019.00516.

[48] H. Wang, J. Qian, and F. Ding, "Emerging Chitosan-Based Films for Food Packaging Applications," *J. Agric. Food Chem.*, vol. 66, no. 2, pp. 395–413, Jan. 2018, doi: 10.1021/acs.jafc.7b04528.

[49] S. Kumar, A. Mukherjee, and J. Dutta, "Chitosan based nanocomposite films and coatings: Emerging antimicrobial food packaging alternatives," *Trends Food Sci. Technol.*, vol. 97, pp. 196–209, Mar. 2020, doi: 10.1016/j.tifs.2020.01.002.

[50] P. Nechita and M. Roman (Iana-Roman), "Review on Polysaccharides Used in Coatings for Food Packaging Papers," *Coatings*, vol. 10, no. 6, p. 566, Jun. 2020, doi: 10.3390/coatings10060566.

[51] X. Zhang, S. Lu, and X. Chen, "A visual pH sensing film using natural dyes from Bauhinia blakeana Dunn," *Sensors Actuators B Chem.*, vol. 198, pp. 268–273, Jul. 2014, doi: 10.1016/j.snb.2014.02.094.

[52] M.-M. Sadat Ebrahimi, Y. Voss, and H. Schönherr, "Rapid Detection of Escherichia coli via Enzymatically Triggered Reactions in Self-Reporting Chitosan Hydrogels," *ACS Appl. Mater. Interfaces*, vol. 7, no. 36, pp. 20190–20199, Sep. 2015, doi: 10.1021/acsami.5b05746.

[53] F. R. B. Marenda *et al.*, "Advances in Studies Using Vegetable Wastes to Obtain Pectic Substances: A Review," *J. Polym. Environ.*, vol. 27, no. 3, pp. 549–560, Mar. 2019, doi: 10.1007/s10924-018-1355-8.

[54] V. A. Cataldo, G. Cavallaro, G. Lazzara, S. Milioto, and F. Parisi, “Coffee grounds as filler for pectin: Green composites with competitive performances dependent on the UV irradiation,” *Carbohydr. Polym.*, vol. 170, pp. 198–205, Aug. 2017, doi: 10.1016/j.carbpol.2017.04.092.

[55] R. K. S. Khalil, M. R. Sharaby, and D. S. Abdelrahim, “Novel active edible food packaging films based entirely on citrus peel wastes,” *Food Hydrocoll.*, vol. 134, p. 107961, Jan. 2023, doi: 10.1016/j.foodhyd.2022.107961.

[56] M. R. Sharaby, E. A. Soliman, A. B. Abdel-Rahman, A. Osman, and R. Khalil, “Novel pectin-based nanocomposite film for active food packaging applications,” *Sci. Rep.*, vol. 12, no. 1, p. 20673, Nov. 2022, doi: 10.1038/s41598-022-25192-4.

[57] Sucheta, K. Chaturvedi, N. Sharma, and S. K. Yadav, “Composite edible coatings from commercial pectin, corn flour and beetroot powder minimize post-harvest decay, reduces ripening and improves sensory liking of tomatoes,” *Int. J. Biol. Macromol.*, vol. 133, pp. 284–293, Jul. 2019, doi: 10.1016/j.ijbiomac.2019.04.132.

[58] C. Mellinas, M. Ramos, A. Jiménez, and M. C. Garrigós, “Recent Trends in the Use of Pectin from Agro-Waste Residues as a Natural-Based Biopolymer for Food Packaging Applications,” *Materials (Basel).*, vol. 13, no. 3, p. 673, Feb. 2020, doi: 10.3390/ma13030673.

[59] T. Nisar, Z.-C. Wang, X. Yang, Y. Tian, M. Iqbal, and Y. Guo, “Characterization of citrus pectin films integrated with clove bud essential oil: Physical, thermal, barrier, antioxidant and antibacterial properties,” *Int. J. Biol. Macromol.*, vol. 106, pp. 670–680, Jan. 2018, doi: 10.1016/j.ijbiomac.2017.08.068.

[60] H. Almasi, S. Azizi, and S. Amjadi, “Development and characterization of pectin films activated by nanoemulsion and Pickering emulsion stabilized marjoram (Origanum majorana L.) essential oil,” *Food Hydrocoll.*, vol. 99, p. 105338, Feb. 2020, doi: 10.1016/j.foodhyd.2019.105338.

[61] R. Akhter, F. A. Masoodi, T. A. Wani, and S. A. Rather, “Functional characterization of biopolymer based composite film: Incorporation of natural essential oils and antimicrobial agents,” *Int. J. Biol. Macromol.*, vol. 137, pp. 1245–1255, Sep. 2019, doi: 10.1016/j.ijbiomac.2019.06.214.

[62] I. Dudnyk, E.-R. Janeček, J. Vaucher-Joset, and F. Stellacci, “Edible sensors for meat and seafood freshness,” *Sensors Actuators B Chem.*, vol. 259, pp. 1108–1112, Apr. 2018, doi: 10.1016/j.snb.2017.12.057.

[63] Y. Lei *et al.*, “Investigation of the structural and physical properties, antioxidant and antimicrobial activity of pectin-konjac glucomannan composite edible films incorporated with tea polyphenol,” *Food Hydrocoll.*, vol. 94, pp. 128–135, Sep. 2019, doi: 10.1016/j.foodhyd.2019.03.011.

[64] M. Kumar *et al.*, “Emerging trends in pectin extraction and its anti-microbial functionalization using natural bioactives for application in food packaging,” *Trends Food Sci. Technol.*, vol. 105, pp. 223–237, Nov. 2020, doi: 10.1016/j.tifs.2020.09.009.

[65] J. F. Mendes *et al.*, “Correlating emulsion characteristics with the properties of active starch films loaded with lemongrass essential oil,” *Food Hydrocoll.*, vol. 100, p. 105428, Mar. 2020, doi: 10.1016/j.foodhyd.2019.105428.

[66] L. García-Guzmán, G. Cabrera-Barjas, C. G. Soria-Hernández, J. Castaño, A. Y. Guadarrama-Lezama, and S. Rodríguez Llamazares, “Progress in Starch-Based Materials for Food Packaging Applications,” *Polysaccharides*, vol. 3, no. 1, pp. 136–177, Jan. 2022, doi: 10.3390/polysaccharides3010007.

[67] O. Martínez, J. Salmerón, L. Epelde, M. S. Vicente, and C. de Vega, “Quality enhancement of smoked sea bass (Dicentrarchus labrax) fillets by adding resveratrol and coating with chitosan and alginate edible films,” *Food Control*, vol. 85, pp. 168–176, Mar. 2018, doi: 10.1016/j.foodcont.2017.10.003.

[68] R. K. ROCKOWER, J. C. DENG, W. S. OTWELL, and J. A. CORNELL, “Effect of Soy Flour, Soy Protein Concentrate and Sodium Alginate on the Textural Attributes of Minced Fish Patties,” *J. Food Sci.*, vol. 48, no. 4, pp. 1048–1052, Jul. 1983, doi: 10.1111/j.1365-2621.1983.tb09158.x.

[69] T. Senturk Parreidt, K. Müller, and M. Schmid, “Alginate-Based Edible Films and Coatings for Food Packaging Applications,” *Foods*, vol. 7, no. 10, p. 170, Oct. 2018, doi: 10.3390/foods7100170.

[70] H. E. Salama, M. S. Abdel Aziz, and M. Alsehli, “Carboxymethyl cellulose/sodium alginate/chitosan biguanidine hydrochloride ternary system for edible coatings,” *Int. J. Biol. Macromol.*, vol. 139, pp. 614–620, Oct. 2019, doi: 10.1016/j.ijbiomac.2019.08.008.

[71] M. S. Abdel Aziz, H. E. Salama, and M. W. Sabaa, “Biobased alginate/castor oil edible films for active food packaging,” *LWT*, vol. 96, pp. 455–460, Oct. 2018, doi: 10.1016/j.lwt.2018.05.049.

[72] H. M. Díaz-Mula, M. Serrano, and D. Valero, “Alginate Coatings Preserve Fruit Quality and Bioactive Compounds during Storage of Sweet Cherry Fruit,” *Food Bioprocess Technol.*, vol. 5, no. 8, pp. 2990–2997, Nov. 2012, doi: 10.1007/s11947-011-0599-2.

[73] M. S. Abdel Aziz, H. E. Salama, and G. R. Saad, “Diglycidyl ether of bisphenol A/chitosan- graft -polyaniline composites with electromagnetic interference shielding properties: Synthesis, characterization, and curing kinetics,” *Polym. Eng. Sci.*, vol. 59, no. 2, pp. 372–381, Feb. 2019, doi: 10.1002/pen.24933.

[74] H. E. Salama, M. S. Abdel Aziz, and M. W. Sabaa, “Novel biodegradable and antibacterial edible films based on alginate and chitosan biguanidine hydrochloride,” *Int. J. Biol. Macromol.*, vol. 116, pp. 443–450, Sep. 2018, doi: 10.1016/j.ijbiomac.2018.04.183.

[75] H. E. Salama and M. S. Abdel Aziz, “Optimized alginate and Aloe vera gel edible coating reinforced with nTiO2 for the shelf-life extension of tomatoes,” *Int. J. Biol. Macromol.*, vol. 165, pp. 2693–2701, Dec. 2020, doi: 10.1016/j.ijbiomac.2020.10.108.

[76] H. M. C. Azeredo, K. W. E. Miranda, M. F. Rosa, D. M. Nascimento, and M. R. de Moura, “Edible films from alginate-acerola puree reinforced with cellulose whiskers,” *LWT - Food Sci. Technol.*, vol. 46, no. 1, pp. 294–297, Apr. 2012, doi: 10.1016/j.lwt.2011.09.016.

[77] C. Costa, A. Conte, G. G. Buonocore, M. Lavorgna, and M. A. Del Nobile, “Calcium-alginate coating loaded with silver-montmorillonite nanoparticles to prolong the shelf-life of fresh-cut carrots,” *Food Res. Int.*, vol. 48, no. 1, pp. 164–169, Aug. 2012, doi: 10.1016/j.foodres.2012.03.001.

[78] M. J. Fabra, I. Falcó, W. Randazzo, G. Sánchez, and A. López-Rubio, “Antiviral and antioxidant properties of active alginate edible films containing phenolic extracts,” *Food Hydrocoll.*, vol. 81, pp. 96–103, Aug. 2018, doi: 10.1016/j.foodhyd.2018.02.026.

[79] X. Li, X. Du, Y. Liu, L. Tong, Q. Wang, and J. Li, “Rhubarb extract incorporated into an alginate-based edible coating for peach preservation,” *Sci. Hortic. (Amsterdam).*,

vol. 257, p. 108685, Nov. 2019, doi: 10.1016/j.scienta.2019.108685.

[80] S. Kim, S.-K. Baek, and K. Bin Song, “Physical and antioxidant properties of alginate films prepared from Sargassum fulvellum with black chokeberry extract,” *Food Packag. Shelf Life*, vol. 18, pp. 157–163, Dec. 2018, doi: 10.1016/j.fpsl.2018.11.008.

[81] A. Nešić, G. Cabrera-Barjas, S. Dimitrijević-Branković, S. Davidović, N. Radovanović, and C. Delattre, “Prospect of Polysaccharide-Based Materials as Advanced Food Packaging,” *Molecules*, vol. 25, no. 1, p. 135, Dec. 2019, doi: 10.3390/molecules25010135.

[82] M. Qian *et al.*, “A review of active packaging in bakery products: Applications and future trends,” *Trends Food Sci. Technol.*, vol. 114, pp. 459–471, Aug. 2021, doi: 10.1016/j.tifs.2021.06.009.