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Application of Alginate and Chitosan in smart and active packaging: A review

Aplicación de alginato y quitosano en envases inteligentes y activos: una revisión

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Technological innovation: State of the art of the most recent works on two renewable, non-toxic and biodegradable polymers of natural origin and relatively low cost.

Industrial application area: Food industry. Useful to provide guidance to researchers interested in applying these polymers in food packaging that are environmentally friendly and provide food safety.

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Resumen

Debido al interés por prolongar la vida útil de los alimentos para reducir el desperdicio. Aunado al creciente interés por desarrollar empaques respetuosos con el medio ambiente, se realizó una revisión de los polímeros de origen natural utilizados en el envasado de alimentos con aplicación en envases inteligentes y activos. Dada la extensión del tema, la búsqueda se centró en los dos materiales más reportados: alginato y quitosano. Ambos se han utilizado en el desarrollo de envases inteligentes y activos debido a sus propiedades específicas. El alginato se obtiene de diversos productos marinos, lo que lo hace un recurso renovable. Su aplicación en el envasado de alimentos va desde películas modificadas con compuestos bioactivos y la inclusión de nanopartículas, hasta la mezcla con otros polímeros. Esas mezclas y síntesis, pueden mejorar sus propiedades mecánicas, sin dejar de ser un material degradable. Por su parte, el quitosano se obtiene principalmente del exoesqueleto de productos marinos. Este material se obtiene de los residuos agroindustriales, lo que le otorga un valor agregado. El quitosano se ha utilizado para desarrollar envases activos e

inteligentes. Sus características como película mejoran al incluir partículas, combinarlo con otros materiales y agregar indicadores que le otorgan una función de sensor en tiempo real. Finalmente, se realizó una comparación entre los dos polímeros de origen natural, con el fin de facilitar la orientación de futuras investigaciones. Dado los resultados de la revisión, la recomendación sería evaluar las ventajas y las desventajas de cada polímero para elegir el indicado según la necesidad de conservación del alimento. Se concluye que a pesar de todo el trabajo reportado para lograr un mejor empaque de alimentos y reducción de desperdicios, existe una clara necesidad de llevar cada investigación a una aplicación práctica. Se recomendaría implementar tecnologías de producción para que estos materiales sean aprovechados, ya que su naturaleza es adecuada para ser utilizados en cadenas industriales de producción más límpias.

Palabras clave: Biopolímeros, Empaques alimentarios, Polímeros inteligentes, Seguridad alimentaria.

Abstract

Due to the interest in extending the shelf life of food to reduce waste. In addition to the growing interest in developing environmentally friendly packaging, a review of the polymers of natural origin used in food packaging with applications in intelligent and active packaging was carried out. Given the extension of the topic, the search focused on the two most reported materials: alginate and chitosan. Both have been used in the development of smart and active packaging due to their specific properties. Alginate is obtained from various marine products, which makes it a renewable resource. Its application in food packaging ranges from films modified with bioactive compounds and the inclusion of nanoparticles, to blending with other polymers. These blends and synthesis can improve its mechanical properties, while remaining a degradable material. Chitosan is obtained mainly from the exoskeleton of marine products. This material is obtained from agro-industrial waste, which gives it added value. Chitosan has been used to develop smart and active packaging. Its characteristics as a film are improved by including particles, combining it with other materials and adding indicators that give it a real-time sensor function. Finally, a comparison was made between the two polymers of natural origin, in order to facilitate the orientation of future research. Given the results of the review, the recommendation would be to evaluate the advantages and disadvantages of each polymer to choose the indicated one according to the need for food preservation. It is concluded that despite all the work reported to achieve better food packaging and waste reduction, there is a clear need to bring each research to a practical application. It would be recommended to implement production technologies so that these materials can be used, since their nature is suitable for use in cleaner industrial production chains.

Keywords: Biopolymers, Food packaging, Food safety, Smart polymers.

1. Introduction

Foods, both naturally and processed, are exposed to environmental factors that can affect their quality and expose the consumer to diseases. Consequently, food packaging is in constant development to protect the product from external and internal

environmental conditions, such as heat, light, humidity, microorganisms, vibrations, and gaseous emissions. Unfortunately, a single material cannot fulfill all these functions at the same time. Therefore, smart packaging can be a solution to these deficiencies in food packaging [1]. Likewise, the food industry, in addition to ensuring food safety, must seek solutions to increase shelf life and reduce food waste. The options that have been developed include the addition of components in the packaging (nanoparticles, antibiotics, oils, and other active compounds), thus creating the so-called active packaging that intentionally interacts with the food to protect it against microbial deterioration, moisture, or oxidative damage [2]. Smart packaging, meanwhile, is a potential option, as it allows monitoring food quality in real-time, combining it with sustainability, ensuring food safety, and providing economic and environmental benefits [3]. Smart packaging refers to packaging systems that can be used in food, beverages, pharmaceuticals, and many other products, which have integrated sensor technology in response to external and internal stimuli. In the food field, smart packaging is used to monitor freshness, extend shelf life, display quality information, to improve product safety and consumer health [4]. In addition, smart packaging can control the quality and safety of food from producers to consumers by using various sensors to monitor the quality and safety of food [5]; for example, they detect and analyze freshness, presence of pathogens, losses, carbon dioxide, oxygen, pH level, packaging time, and temperature. The solutions provided by each smart package vary depending on the function for which they were designed and the product being packaged [6]. Similarly, the exact condition to be monitored, transported, or adjusted varies accordingly. Smart packaging makes it possible to detect and track a product throughout its life cycle by analyzing and monitoring the environment inside or outside the package, detecting changes to inform the manufacturer, the retailer, and the final consumer about the condition of the product at any given moment [4].

These types of active and smart packaging are developed from edible films and coatings made from natural polymers. These can be lipids, proteins and polysaccharides [7]. The manufacture of active films from non-toxic biological sources has increased in demand, due to the fact that the use of plastic films has been associated with health damages[8], among them, the leaching of phthalate [9]. Alginate is a polysaccharide that has the property of forming hydrogels and films. It is a biopolymer of economical production, biocompatible, non-toxic and capable of forming capsules to confine other compounds [10]. The variety of the alginate chemical composition gives it physical and chemical properties that make it very versatile for the development of various products in food packaging. Another polysaccharide that is widespread in practically all fields is chitosan. The use of chitosan for the creation of edible films and hydrogels has been very widespread, so there are abundant articles to analyze. These works have involved the use of natural products with an antimicrobial, antioxidant and, in some cases, improving their nutritional and organoleptic quality [11]. Another advantage of this polysaccharide is that it is obtained from chitin, which is the second most abundant biopolymer, after cellulose. Its degradability is also considerably high, so its use in food packaging represents a reduction in environmental contamination.

It cannot be ignored that the change from linear production to a circular economy also includes the food industry. Being able to transform waste products from food industries into raw material for food packaging industries would represent an

effort towards a sustainable economy [12]. For this reason, the aim of the review was to disseminate information on the development and application of edible films based on alginate and chitosan for all their characteristics that can be directed to creation of technological processes for cleaner production, with support for industrial ecology.

2. Active and smart packaging

Traditionally, the purpose of food packaging is containment, protection, convenience, and information about the content. Active packaging inhibits bacterial growth, by interacting directly with the food or with the upper area of the container, thus extending shelf life and/or the preservation of the sensory characteristics of the food [13]. Among the most efficient methods to develop antimicrobial food packaging, the combination of metal nanoparticles embedded in polymers has proven to be effective, as they can be combined with degradable and edible polymers to create active food packaging [14].

The functionalities of smart food packaging refer to active coatings and specific sensors (physical or chemical) that are included in the packaging material. But unlike active materials, smart antimicrobial coatings respond to microbial growth. Changes in the environment, cause them to release their active compounds, thus prolonging the shel life of the products. Sensors, on the other hand, are capable of reflecting food quality by monitoring the physical and chemical conditions that influence spoilage. These supplements have positive health, the environmental and socio-economic setting, which can be amplified if smart functions are achieved using renewable natural materials with robust technologies [15].

3. Biopolymers in food packaging

During the evolution of food packaging, it became evident that the use of petroleum-derived materials was causing the collateral damage of pollution. The preference of consumers towards disposable containers, led to the need to replace conventional, highly polluting and non-renewable plastic materials [16]. Consequently, the adaptation of biopolymers qualities, to redesign active food packaging, offers a new and sustainable alternative (Figure 1).

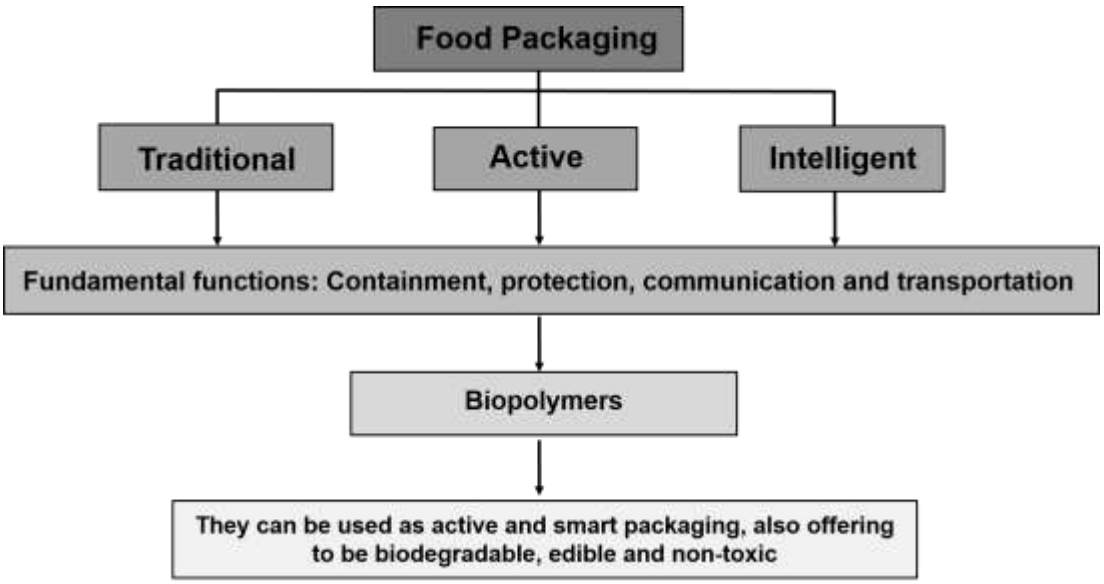


Figure 1. Biopolymers in food packaging.

Biopolymer-based edible packaging can be used as a coating applied directly onto the food product or as a preformed film wrapped it [17]. The application of a thin layer of edible coatings, on the surface of the fresh product, creates a semi-permeable barrier to respiratory gases and water vapor between the surrounding atmosphere and the fruit, and also develops a modified atmosphere around the product, which slows down the respiration, senescence and enzymatic processes [18]. The first coatings were developed based on natural waxes that were applied to lemons and oranges to protect them from microbial spoilage [19]. Currently, many natural polymer-based coatings have been developed as novel packaging systems that can be safely applied directly to foods and serve as vehicles for functional and bioactive additives [20]. These polymeric materials are produced from renewable raw materials. Therefore, they have special properties such as biodegradability, renewability, abundance in nature, non-toxicity, biocompatibility and are relatively low cost to obtain [21].

It is also possible to develop coatings and films with good barrier properties to gas transport and to prevent the transmission of food pathogens [22]. In addition, essential oils and plant extracts can be included, giving the packaging antibacterial and antifungal properties [23,24]. The simultaneous use of different polymers of biological and synthetic origin to induce the desired functionality is also a new area of research [25]. The characteristics and functionality of two of the most commonly used poymers of natural origin are described below, with a focus on active and smart food packaging.

4. Alginate

This polysaccharide is of great commercial interest due to its ability to form coatings and films with good flexibility, gloss, water solubility, and low permeability to oil and oxygen [26]. Alginate is a polyanionic heteropolymer that is easily obtained from brown seaweed and some genera of bacteria [27]. The most commercially exploited species for the production of this structural polysaccharide, are *Laminaria hyperborea*, *Macrocystis pyrifera*, and *Ascophyllum nodosum* [28]. Its most common form of extraction is with aqueous alkali (sodium hydroxide or sodium carbonate), after filtering and precipitating with calcium, it is acidified to form alginic acid [29]. The biopolymer chain is composed of β-D-mannuronate (M) and α-L-guluronate (G) linked through 1-4-glycosidic bonds (Figure 2). These G and M residues are arranged in polyguluronate (GG), polymannuronate (MM), and mixed GM domains distributed along the alginate chains. Although alginic acid is not soluble in water, its salts, such as sodium or potassium alginates, can dissolve to form viscous aqueous solutions [30].

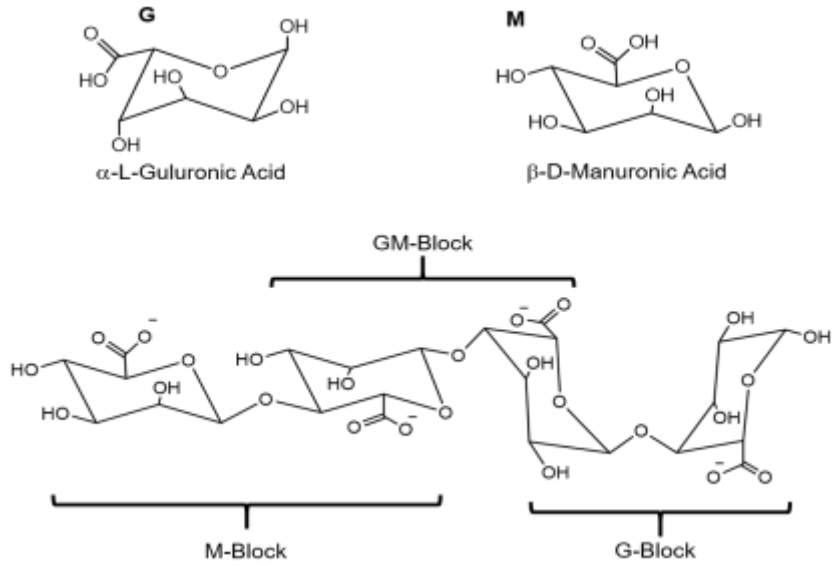


Figure 2. Chemical structures of the G and M alginate subunits and their arrangement in the biopolymer chain.

The ability of alginate to form strong gels is due to its ability to react with polyvalent metal cations, especially calcium ions [31]. The gelling mechanism is known as the egg-box model. It begins when calcium Ca^{2+} ions in the crosslinking solution produce an exchange with Na^{+} ions that are attracted to the carboxylic acids of the G blocks [32]. The G-block of one of the chains forms junctions with the G-block of an adjacent polymeric chain, thus obtaining the characteristic "egg-box" structure [33]. Alginate can also form gels with many other monovalent, divalent, or trivalent cations, and its gelation may have different mechanisms than Ca^{2+} induced gelation [34]. Its schematic representation is shown in figure 3.

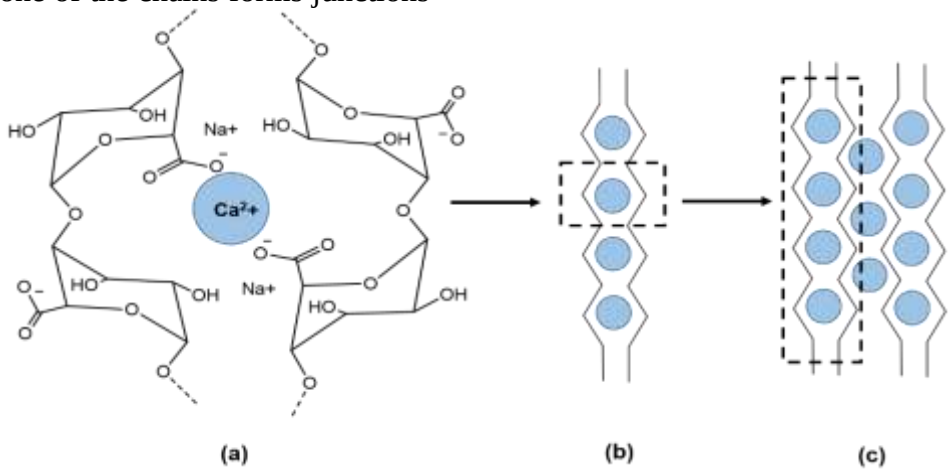


Figure 3. Schematic of the junctional zones of alginate/calcium gels: (a) Ca^{2+} coordination in a cavity created by a pair of guluronate sequences along alginate chains; (b) dimer of associated guluronate chains and (c) laterally associated egg case multimer. Circles represent Ca^{2+} ions.

4.1 Alginate for active and smart packaging.

Sodium alginate-based materials were initially used as coatings for pre-cut or perishable fruits and vegetables, but their properties increased their application in the food range, with emphasis on the meat industry. This is because sodium alginate films prevent loss of mass and degradation of

color and texture when used to protect meat products. In addition to its use in food processing and biotechnology, its attractive properties have broadened its application to the biomedical and pharmaceutical industries [35]. Specifically, the ability of alginate to form films and coatings, makes it a good material for food packaging, as glossy films, good water solubility, emulsification capacity, and low oil and oxygen permeability are obtained [7]. Due to their particular structure, alginate gels have the ability to encapsulate essential oils. Encapsulation allows their fragrance to be stabilized and to protect them from the harmful effects of oxygen, humidity, ultraviolet radiation and microorganisms [36]. Some oils in particular, prevent the contamination of some microorganisms such as *Escherichia coli*, *Salmonella enterica*, *Listeria monocytogenes* or *Botrytis cinerea* [16].

Alginate films can produce active packaging when used as a carrier for bioactive components. When such bioactive components are released, lipid oxidation and microbial growth in foods during storage are reduced [24]. Regarding this application, researchers have developed several strategies. Recently, Santos et al., incorporated purple onion peel extracts into alginate-based films. Filmogenic solutions with a content of 0, 10, 20, and 30% of the extract were prepared, using glycerol as the plasticizer. When the extract was added to the alginate matrix, opaque red films were formed, which presented a concentration of phenolic compounds 43 times higher than the films without extract, increasing their oxidizing capacity and the thickness of the films. The results indicated that sodium alginate films, incorporated with various concentrations of the extract, have the potential to be used in active packaging to apply to foods susceptible to lipid oxidation or with high presence of water to preserve and extend shelf life [37].

Also, Priyadarshi et al., formed active alginate films incorporated with sulfur nanoparticles (SNP), using the casting method. They dissolved the biopolymer using glycerol as the plasticizer and added the SNP suspension dropwise. The films were formed by casting them onto glass plates. The addition of 2 wt% SNP showed the best results in water vapor barrier properties (increase of 41%) and tensile properties (increase of 12%). Furthermore, they reported that there was a decrease in the film transparency with the addition of SNP; however, the UV barrier properties increased to 99% and film hydrophobicity also increased. Finally, the activity against *L. monocytogenes* was found to be highly bactericidal at the highest content of nanoparticles, where 100% bacterial elimination was observed after 12 h of exposure. Therefore, they concluded that the alginate/SNP composite film has potential for application in the packaging of frozen meat products that have high moisture content and are susceptible to contamination by *L. monocytogenes* [38].

Hydrolyzed cotton protein has also been incorporated into alginate films to evaluate its antioxidant and antimicrobial properties for the preservation of fatty foods. The investigation reported that the incorporation of hydrolyzed protein kept the same oil barrier properties, moisture content, solubility, or biodegradability of the films. Antioxidant activity and total phenolic content increased with the incorporation of the hydrolyzed protein. As for the inhibitory effect, the composite films had an effect against *Staphylococcus aureus*, *Colletotrichum gloeosporioides* and *Rhizopus oligosporus* but not against *Escherichia coli*. The authors concluded that, due to the properties of the developed materials, the films could have applications as bioactive packaging for fatty foods

susceptible to oxidation and microbial growth [39].

Regarding research using nanoparticle incorporation, Wang and Rhim (2015) prepared agar/alginate/collagen (A/A/C) ternary mixture hydrogel films with silver nanoparticles (AgNP) and grapefruit seed extract nanoparticles (GSE). The A/A/C ternary films were highly transparent, and especially the ternary film loaded with grapefruit nanoparticles exhibited high UV protection without sacrificing transmittance. Both films, incorporated with the two types of nanoparticles, exhibited strong antimicrobial activity against Gram-positive (*Listeria monocytogenes*) and Gram-negative (*Escherichia coli*) food pathogenic bacteria. Packaging tests were carried out on fresh potatoes, finding that the composite films prevented the potatoes from greening during storage. The results indicated that blended hydrogel films, incorporated with AgNP or GSE are useful for packaging fresh products as an active food packaging system with strong antimicrobial activity [40].

Regarding for edible coatings, sodium alginate is widely used because it has the property of forming films with characteristics such as flexibility, resistance, water-solubility, brightness, low permeability to gases (O_2 and CO_2), as well as being tasteless and odorless. Therefore, this natural material is considered the packaging of the future [16]. Xu et al. developed sodium aligante coating films enriched with cyclopopeptides (CL) from *Bacillus subtilis* for the preservation of vulnerable berries. Their films exhibited potent antifungal and freshness-keeping properties of blueberries during storage. A 3% LC film reduced the total fungal count at the end of the storage period [41]. This work revealed that the addition of CL improved the antifungal effect and freshness-keeping ability of the alginate coating film on blueberries, as the film evenly covered the surface of the berries and blocked the stomata, thus inhibiting berry respiration The study also showed that ionic interactions and hydrogen bonds between alginate and CL stabilized the coating film and that these hydrophobic interactions negatively affected the strength and crystallinity of the coating film. It was concluded that the inclusion of CL in an alginate film provides a coating film for berries, with characteristics of being multifunctional and also easy to wash [41].

To assess the quality of carp fillets at refrigeration temperature (4+/-1°C), a sodium alginate coating enriched with peppermint (*Mentha balsamea*) essential oil (MEO) was developed. They coated carp fillets with sodium alginate containing 0.5 and 1% MEO and pure sodium alginate. They found that fillets coated with the MEO-loaded alginate showed lower TVB-N (Total Volatile Basic Nitrogen) content and lower lipid oxidation compared to pure alginate. A significant reduction in microbial spoilage was also detected when the treated coating was used compared to pristine alginate [42].

Considering the particular preference of some consumers for raw meat, it is even more important to control spoilage and production of microorganisms in this type of meat. Oh et al. developed and evaluated a hydrogel with the antimicrobial potential to decrease the cell count of pathogens on the surface of raw beef and fish. The hydrogel was formulated with sodium alginate, agar, $CaCl_2$, and glycerol. Subsequently, 0.5% grapefruit seed extract or 0.5% citrus extract was loaded. The hydrogel reduced surface counts of *Listeria monocytogenes* and *Escherichia coli* in raw beef and surface counts of *Vibro parahaemolyticus* in raw fish. Additionally, they carried out sensory tests in which they demonstrated that the hydrogel has the potential to improve the safety of beef and fish, without altering their sensory aspects, when preparing foods based on raw meat [43].

Other researchers such as Sutthasupa et al., focused on hydrogel-based systems to monitor pork spoilage. This group developed a hydrogel with a colorimetric ammonia sensor, which was synthetized with alginate and methylcellulose, to which bromothymol blue was incorporated as a colorimetric indicator. The hydrogel indicator presented a color change from orange to yellow on day 6, upon detection of TVB-N (Total Volatile Basic Nitrogen) accumulated in the package during storage of minced pork at 4 °C. The results showed that the color change and the pH change are correlated with the deterioration of the pork meat.

Thus, they demonstrated the potential application of the hydrogel as a deterioration indicator and its potential use in smart packaging [44].

5 Chitosan

Chitosan is a natural biopolymer, produced from chitin [45], which is obtained mainly from the shells of crustaceans, shrimp, crabs, and lobsters, discarded by the seafood processing industries. By deacetylating chitin, chitosan is obtained, which is a copolymer of β-(1–4)-2-acetamido-D-glucose and β-(1–4)-2-amino-D-glucose units (Figure 4). Chitosan is the only cationic polysaccharide of natural origin with high activity as an antioxidant, antitumor, anti-inflammatory, antimicrobial and with a low immune response [46], it is also biocompatible, non-toxic, biodegradable, and able to adsorb heavy metal ions [47]. According to Baranwal, chitosan has many applications in the food, pharmaceutical, biomedicine, environmental, and tissue engineering industries [48]. But its poor solubility in water caused by its rigid crystalline structure due to intermolecular and intramolecular hydrogen and the non-ionization of the amino group, limits its application [49].

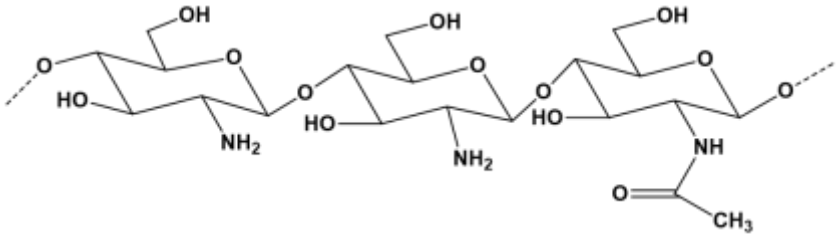


Figure 4. Chitosan structure.

5.1 Chitosan for active and smart packaging

In addition to the wide spectrum of biotechnological applications of this biopolymer, in the environmental, industrial, agricultural, and medical fields. In the food industry, it has been applied to water purification, food shelf-life extension, and preservation from microbial spoilage, food quality improvement, food additives, and the formation of biodegradable packaging film. Many researchers have obtained chitosan-based films that have been applied to different foods like meat, fruits, and vegetables, with excellent preservative effects showing their potential as an alternative means of food packaging. These films have been manufactured by casting, coating, layer-by-layer assembly, etc. In addition, by adding functional materials to chitosan, they have achieved composite films to increase the advantages of each material by modifying the characteristics, such as antimicrobial activity, barrier property, antioxidant activity, mechanical property, optical property, detection/indicator capacity, and thermal stability [50].

A combination of the antioxidant properties of essential oils and the antibacterial properties of chitosan is widely used in food preservation and the manufacture of cosmetics, antimicrobial textiles, and medications [36]. This blend with natural antioxidants has also been used to produce composite active films that extend shelf life, maintain the quality, and enhance nutrients of primary foods protected by the film [51]. For this purpose, Rambabu et al., developed chitosan films modified with mango leaf extract (MLE) to improve the chitosan antioxidant activity. Increasing the concentration of the extract resulted in films with greater thickness and lower moisture content. Application studies for 28-day cashew nut preservation indicated higher oxidation resistance (56%) for the 5% MLE film compared to a commercial film (polyamide/polyethylene). These results highlighted the potential that MLE-loaded chitosan films have as an alternative for food preservation, using the films as active packaging [8]. Also, Amor et al., designed a chitosan active packaging containing basil essential oils to prolong the shelf life of foods. These films were tested as a packaging system by wrapping samples of cooked ham during 10 days of storage to demonstrate their effective antimicrobial activity. Thus, these authors demonstrated that their active film can both control the bacterial growth of cooked ham and significantly inhibit the pH rise of packaged foods [52]. Thyme (*Artemisia campestris*) is another extract used for active packaging based on chitosan films**,** as shown by Moalla et al. Based on their results, it was clear that adding the extract improved the water-resistance of the chitosan films. The analysis indicated that interactions occurred between the film matrix and the active compounds of thyme, which was reflected in the physical and mechanical properties of the composite films. Furthermore, the addition of the extracts to the chitosan films was effective in significantly increasing the antioxidant and UV-Vis barrier and properties [53]. In another research, conducted by Jiang et al., chitosan nanoparticles were prepared to encapsulate lemon (*Citrus limon*) essential oil (CEO) by emulsification. They obtained spherical CEO nanoparticles, with a size of 58 ± 9 nm and very stable under the right conditions. FTIR spectra indicated that the nanoparticles were encapsulated in the films. By applying the films to pork meat, lipid oxidation microbial proliferation was effectively inhibited, and spoilage was delayd for 21 days [36].

Regarding chitosan-based films, in which nanoparticles are included, work has been done seeking to enhance the properties of nanoparticles, such as that of Kızılkonca et al., who prepared chitosan-based composite films with cerium oxide nanoparticles by casting method. They used hydroxyethylcellulose (HEC) for the flexibility of the films and polyethylene glycol as the plasticizer. The incorporation of cerium oxide nanoparticles in the chitosan-based films improved the activity against *Escherichia coli* and *Staphylococcus aureus*. With these results, the authors proposed the composite film as a packaging or coating material due to its flexibility, antibacterial efficacy, and good mechanical resistance [54]. Although the inclusion of silver nanoparticles (AgNPs) in the food area is still under discussion, due to leakage cytotoxitiy, it has been evaluated whether, by immobilization and inclusion in a chitosan film, a controlled release of nanoparticles can be achieved and thereby reduce toxicity. For this reason, Wu et al, synthesized silver nanoparticles (AgNPs), which they immobilized in a film composed of laponite with chitosan. The nanoparticles were confined in the intermediate layer of laponite. The results show that only about 5.6% of the AgNPs were released from the films. The films presented very low toxicity to cells and exhibited good antimicrobial activity. Finally, when applied

to pack lychees, the films effectively extended the shelf life. Therefore, this research provides the potential application of AgNPs in the food field [55].

6. Polymer blends used to combine with alginate and chitosan

At this point in the review, it is already possible to outline the position that the two biopolymers occupy in the packaging of active and smart foods to preserve food health (Figure 5). To finalize the review, a comparative table of the blend of alginate and chitosan with other similar polymers, with extracts and with nanoparticles was made (Table 1). Polymer blends have been preferred over individual polymers because they improve their physicochemical properties and consequently lower their cost [56].

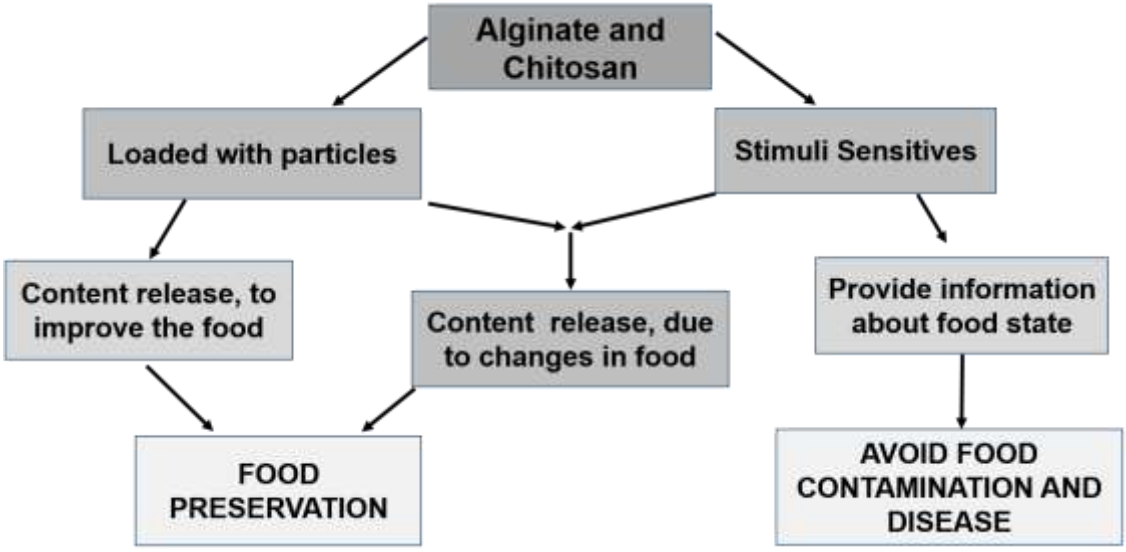


Figure 5. The use of alginate and chitosan have great potential to be used for food safety.

Table I. Different materials and compounds that have been used in combination with alginate and chitosan.

Blend with	Alginate	Reference	Quitosan	Reference
Starch	Polyelectrolyte films with antimicrobial properties, with good thermal and surface stability.	[57]	Thermally stable film. Good apple preservative for 4 weeks	[58]
Cellulose	Film with good UV barrier effect, prevented oxidative changes in chicken color.	[59]	Cellulose was impregnated with chitosan to obtain a gel that was used as a pH indicator for food spoilage.	[60]
Guar gum	Gels were formed that showed porosity without shrinkage during storage, showing high elasticity and stiffness.	[61]	Crosslinked with hydroxycitric acid, it improved the mechanical properties of active films with a hydrophobic surface. Decrease in water vapor permeability	[56]

			(WVP) and growth inhibition of *E. coli* and *S. aureus* bacteria.	
Silver nanoparticles	Nanocomposite films showed antimicrobial effect against *S. aureus*, *S. typhimurium* and *C. perfringens* and improved food quality and storage stability.	[62]	Films with antibacterial activity against gram-positive and gram-negative bacteria by including Ag nanoparticles.	[63]
Polyphenols	The films with polyphenols had better mechanical, physical and antioxidant properties than the alginate films. They also had strong antioxidant activity and anti-inflammatory properties, which may be useful for both food and medical applications.	[64]	A higher light barrier of the blend films was observed, which could improve the ability of the film to prevent lipid oxidation in foods but decreased the tensile strength and extensibility of the film.	[53]
Essential oils	Cinnamon oil alginate beads were created and proved to be effective agains: *B. cinerea*, *P. expansum*, *A. alternata* and *C. gloeosporioides*, in the vapor phase. They could be an alternative for the control of foodborne microorganisms inside food packaging.	[65]	Basil essential oil was encapsulated. It presented a marked antimicrobial activity against mesophilic aerobic bacteria and improved the pH of food during storage.	[52]

As alginate is derived from alginic acid, it has acidic character which is not good for food. To overcome this, alginate has been mixed with synthetic and natural polymers to improve its properties [66]. Another important drawback is that it is highly hydrophilic, so it has a poor barrier against moisture and increases water absorption by the packaging material [67]. In reference to chitosan, although it exhibits a good film forming ability, the mechanical and barrier properties are not promising, thus mixing chitosan with different polymers is a convenient approach to improve the properties of the final product [56]. Sodium alginate and chitosan are both ideal materials to create biodegradable hydrogel microcapsules, which have been used to encapsulate solid, liquid, or gaseous materials of extracts and essential oils to protect them from external factors and thus preserve food [68].

Regarding its combined use, in the review that was carried out, the development of films using a mixture of the two polymers has not been found, due to the aforementioned characteristics. What has been manufactured are multilayer packages, forming the alginate and chitosan films separately and joining them in a later step. This created packages with other properties like the work done by Wang et al. They developed multilayer films

incorporating carboxymethylchitosan-ZnO (CMCS-ZnO) nanoparticles. The chitosan film was the outer layer and the alginate film was the inner layer, which helped to overcome the weakness of chitosan. The addition of the CMCS-ZnO nanoparticles conferred higher tensile strength and better water vapor resistance. Antimicrobial tests of the films showed distinctive activity against S. aureus and E. coli [69]. In another study, a walnut-chitosan polypeptide bilayer was prepared by crosslinking it with genipin. That bilayer was combined with an alginate layer. The results showed that tensile property, oil absorption property and water vapor barrier property were improved with the presence of genipin. And that the ratio of chitosan and walnut peptide had significant effects on the color, transmittance, mechanical properties, barrier properties, and antioxidant properties of composite films [70].

7. Conclusions

Chitosan has antibacterial and antioxidant properties, it is capable of encapsulating particles and essential oils, which makes it suitable for use in active packaging. It is also capable of responding to physical and chemical stimuli, which makes it a suitable material for smart packaging, mainly as sensors. Alginate is suitable for encapsulating bioactive extracts, protecting their properties, so it can be used in active packaging, however, it does not respond well to external stimuli, so it is not as efficient as chitosan to apply as a sensor. During the review of this important topic, it was clear that it is the current trend to replace synthetic materials derived from petroleum that generate non-biodegradable waste. Another reason for the use of biopolymers is because of the added value, of using materials produced from agro-industrial waste. Chitosan, in particular, obtained from marine food waste, can already be considered a raw material instead of an alternative material due to its multiple benefits and applications. Alginate, on the other hand, is obtained from abundant and renewable natural resources, so it does not represent an impact on the environment.

8. Perspectives

The most relevant aspect detected during the review was that the properties of chitosan, as an antibacterial material and the ease of adaptation of its mechanical properties, depending on the type of packaging and food, place it in an distinguished place as a packaging material. In contrast, alginate does not show the same versatility for food packaging; however, it has been more widely tested in the biomedical area, precisely because it is an inert material, which does not interact with living organisms as chitosan. Consequently, the review of these two materials shows how the usefulness of each in its field. Chitosan is recommended for further development of smart and active packaging for food; whereas alginate is mainly used as a carrier for natural bioactive compounds in active packaging, but it is excellent for drug delivery and other applications in medicine and cell regeneration. For both materials, much remains to be researched and tested to implement the technology and bring them to a practical level.

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Conflict of interest

The authors declare no conflict of interest.

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