Fishery Technology 62 (2025) : 16 - 31

Chitosan and Sodium Alginate: The Potential of Natural Biopolymers of Marine Origin in Development of Biodegradable Packaging Material

Reshma C. S[1,2]*, Remya S.[2] and Bindu J.[2]

[1] *Faculty of Ocean Science and Technology, Kerala University of Fisheries and Ocean Studies, Panangad, Kerala, 682506, India*

[2] *Fish Processing Division, ICAR - Central Institute of Fisheries Technology (CIFT), Cochin, Kerala, 682029, India*

Abstract

Chitosan and sodium alginate are important natural polymers that are abundant in marine sources. Chitosan is generated from chitin by chemical N-deacetylation and is made up of poly-β-(1→4)-2-amino-deoxy-D-glucopyranose. It is found in the shells of crustaceans, insects, fungi, and also in the scales of fishes. Sodium alginate is a derivative of alginic acid found mostly in marine brown algae, made up of 1,4-β-d-mannuronic (M) and α-l-guluronic (G) acids. Chitosan and sodium alginate are natural, non-toxic, biocompatible and biodegradable polysaccharides. Thus, they have a wide range of uses in food packaging, biomedical applications, and are used to make biodegradable films in various compositions. This review covers chitosan and sodium alginate-based films with various combinations of polysaccharides, protein, essential oil, plant extract and synthetic materials. The incorporation of these materials has improved the physical, mechanical, barrier, antioxidant and antimicrobial properties of the films.

Keywords: Chitosan, sodium alginate, packaging

Introduction

Food packaging refers to the protection of all forms of food and raw materials against oxidative and microbiological degradation, as well as increasing the storage-life properties. The increased utilization of synthetic packaging materials like polystyrene, polypropylene, polyethylene, and polyethylene terephthalate, has caused serious environmental problems. Being non-biodegradable, these materials can take hundreds of years to decompose leading to environmental pollution (Tharanathan, 2003). Biodegradable materials can be degraded by bacteria, fungi, or by other biological means. Consumers are now demanding natural, environmentally friendly and biodegradable packaging material for food preservation (Tan, Lim, Tay, Lee, & Thian, 2015). The source of the polymer, its chemical composition, and environmental conditions all influence biodegradability (Vroman & Tighzert, 2009). Food packaging industries are increasingly using biodegradable films and coating to extend the storage life and quality of food by avoiding changes in flavor, odour, and texture. Biodegradable packaging has another benefit of acting as a soil conditioner when decomposed (Tharanathan, 2003).

Chitosan is a natural polymer that is chemically prepared by N-deacetylation of chitin. Chitin is the second most abundant naturally occurring polysaccharide, found in the shells of crab, krill, shrimps, insects, and also in fungi. Chitosan can be widely obtained from the by-products of marine resources like shells, crabs and fish scales (Aboudamia et al., 2020). Chitosan is a polymer made up of repeating units of β-(1→4)-2-amino-2-deoxy-D-glucopyranose. It is non-toxic, biodegradable and biocompatible. Chitosan can form viscous solution in various organic acids and these solutions can be used to make functional films (Bhuvaneshwari, Sruthi, Sivasubramanian, Kalyani, & Sugunabai, 2011). Chitosan has the capability to form good films and

Received 5 July 2024; Revised 27 December 2024; Accepted 2 January 2025

Handling Editor: Dr. B. Madhusudana Rao

**Email:* *reshmacsalila@gmail.com*

membranes, and it is employed for packaging, particularly as an edible packaging. Chitosan films have excellent oxygen and carbon dioxide barrier properties and antimicrobial properties (Bangyekan, Aht-Ong, & Srikulkit, 2006).

Sodium alginate is mainly found in the cell walls of marine brown algae, where it constitutes 30-60% of alginic acid. It is a linear polysaccharide that can be dissolved in water, and is harmless, biodegradable and biocompatible in nature. It is an alginic acid derivative containing 1,4-β-d-mannuronic (M) and α-l-guluronic (G) acids (Ahmad et al., 2021). Sargassum is a rich source of sodium alginate and others include *Ascophyllum nodosum, Laminaria digitata* etc. Sodium alginate has widespread use in the food and pharmaceutical industries (Sachan, Pushkar, Jha, & Bhattcharya, 2009).

Chitosan and sodium alginate are abundant in marine sources and are widely used to make biodegradable films. In this review chitosan and sodium alginate-based films combined with various polysaccharides, protein, essential oil, and plant extract are discussed along with its properties

Chitosan film

Neat chitosan film is made without the addition of any other polymers, and the packaging applications of these films were studied by some researchers. However, for the formation of the film several ingredients such as emulsifiers, plasticizers, and diluted acid are added. Chitosan films can be used to preserve fish, meat, fruits, and vegetables. It is also found that chitosan film can prevent microbial growth, oxidation and increase the shelf life (Ali, Zahid, Manickam, Siddiqui, & Alderson, 2014). Pure chitosan films are suitable for food and active packaging due to their mechanical and barrier properties. With the addition of plasticizers, other proteins, lipids, and polysaccharides, the properties of the chitosan film are enhanced. It is useful in increasing food shelf life by maintaining the quality and being biodegradable (Cazón & Vázquez, 2019). Table 1 shows the major findings of various chitosan-based films, while Fig 1 illustrates the various applications of chitosan based packaging films.

Chitosan and polysaccharide-based packaging films

Chitosan based films are made with various polysaccharides such as starch, cellulose, pectin etc. Starch is an important polysaccharide obtained from plant which is low in cost, abundant and biodegradable in nature. Starch blended with chitosan is regarded as an excellent material for preparing active packaging films for food. Various researchers have studied the properties of the chitosan films with starch obtained from different sources. In a study chitosan/corn starch-based films found to have excellent mechanical property. In addition to that, the increasing concentration of chitosan have increased the water vapour permeability, moisture and solubility. The obtained films can act as an active packaging material for food and pharmaceutical packaging (Ren, Yan, Zhou, Tong, & Su, 2017). In chitosan-brown rice starch-based films, it was noted that the increasing concentration of extra virgin olive oil (2.0% w/w) increased the tensile strength and thermal stability of the film but decreased the film's water uptake. The balanced ratio of starch and chitosan showed good water resistance and the lowest water absorption among all the films (Hasan et al., 2020). The chitosan-based films made with rice starch have excellent water barrier and mechanical property. The properties of the film varied with different ratio of chitosan and starch. The incorporation of chitosan improved the tensile strength and water vapour permeability but reduced solubility and elongation at break of the film (Bourtoom & Chinnan, 2008). Purple yam starch-chitosan film has a homogenous surface and the amount of chitosan determines the thickness of the film. The film improved shelf life of apples for about 4 weeks at room temperature (27 ± 1°C) (Da Costa, Miki, Ramos, & Costa, 2020).

Cellulose is another polysaccharide obtained from plants. Chitosan-cellulose blend film exhibited good mechanical properties and some antibacterial properties (Xiao, Xu, Liu, Hu, & Huang, 2013). Chitosan-carboxymethyl cellulose film enhanced storage life of cut wheat bread and cheese (Youssef, El-Sayed, El-Sayed, Salama, & Dufresne, 2016; Noshirvani, Ghanbarzadeh, Mokarram, & Hashemi, 2017). Microfibrillated cellulose, hydroxypropyl methylcellulose, methylcellulose and quaternized hemicellulose are mixed with chitosan to obtain composite films (Gol, Patel, & Rao, 2013; Chen et al., 2016). Methylcellulose, chitosan and sodium benzoate or potassium sorbate (4%) films remarkably exhibited antimycotic activity against *Rhodotorula rubra* and *Penicillium notatum.* The inclusion of preservatives had no effect on the mechanical qualities of methylcellulose-chitosan films (Chen, Yeh, & Chiang, 1996). Chitosan hydroxypropyl methylcellulose films exhibited improved mechanical properties while increasing film barrier properties (De Moura, Avena Bustillos, McHugh, Krochta, & Mattoso, 2008).

Alginates are linear anionic polysaccharides that are naturally produced from algae. Chitosan-alginate films are highly effective for food packaging due to their excellent gas exchange capabilities (Liu et al., 2013; De Silva, Iamanaka, Taniwaki, & Kieckbusch, 2013; Poverenov et al., 2014). Pectin is an anionic polysaccharide found in plants. Chitosan-pectin film can be used to make environment friendly bioplastic film having better mechanical and permeability properties, and can replace petroleum-based packaging material (Porta, Mariniello, Di Pierro, Sorrentino, & Giosafatto, 2011). Other polysaccharides such as xylan, cyclodextrin, glucose, kefiran etc. were also combined with chitosan (Gao, Zhu, & Zhang, 2013; Sun et al., 2014; Kamdem, Shen, Nabinejad, & Shu, 2019; Salmanian et al., 2019).

Chitosan and protein-based packaging film

Chitosan films can be developed with different proteins extracted from plants, animals or microorganisms. Proteins obtained from animals have good ability to form films. They have high nutrient value and are biocompatible. Caseinate is a good thermoplastic protein which have the ability to form films. Chitosan-caseinate films obtained by the exchange of ions showed improved water vapour barrier properties (Khwaldia, Basta, Aloui, & El-Saied, 2014). Collagen is a major protein used as a substitute for synthetic polymer. Chitosan-collagen films exhibited good thermal stability, adhesion and compatibility (Ahmad, Nirmal, Danish, Chuprom, & Jafarzedeh, 2016). Chitosan-acid soluble collagen (extracted from jumbo squid, *Dosidicus gigas*) films are transparent and brittle, have high elongation at break and low tensile strength than chitosan film (Uriarte-Montoya et al., 2010). Eggs coated with lysozyme-chitosan film improved shell strength, increased freshness and maintained the internal quality during long term storage (Yuceer & Caner, 2014). Gelatin-chitosan film modified with high molecular weight or degree of deacetylation showed excellent mechanical properties and high thermal stability (Liu et al., 2012).

Chitosan films incorporated with plant and animal proteins acts as natural extracts or antimicrobial agents. Films made from kidney bean protein isolate and chitosan, generated at an acidic pH were less rigid and elastic. By the addition of chitosan, the film's surface hydrophobicity improved, and are utilised as antimicrobial food packaging (Ma, Tang, Yang, & Yin, 2013). Chitosan-whey protein films with a high protein content at an acidic pH revealed that the polymer's miscibility and solubility in the film were affected by the polymer's concentration and pH. Even though the functionality of the film may be reduced due to the incompatibility between the polysaccharide and protein components in the matrix, the blended films with moderate amount of protein can be beneficial for food systems where the edible films need to dissolve during cooking or mastication process. The films have shown good antimicrobial properties as it contains chitosan (Ferreira, Nunes, Delgadillo, & Lopes-da-Silva, 2009). Edible chitosan-whey protein films were prepared with different concentrations of protein with or without microbial transglutaminase. The addition of enzyme into the film lowered the solubility at different pH and the degree of swelling. Films with transglutaminase improved the mechanical resistance and reduced their deformability (Da Pierro et al., 2006). Protein isolated from microorganisms play a good role in packaging films. Nisin is a protein obtained from *Lactococcus lactis.* Chitosan-nisin film can help to keep packaged foods to stay fresh for a longer duration (Imran, Klouj, Junelles, & Desobry, 2014).

Chitosan and synthetic polymer-based packaging films

Film with improved properties and characteristics can be developed from chitosan and synthetic polymer blends. Poly vinyl alcohol (PVA) is a harmless synthetic polymer that can be dissolved in water with excellent mechanical properties. Chitosan-PVA blend films exhibited homogenous and compatible structures. Incorporation of PVA in blend increased the intermolecular interactions and mechanical properties, but decreased the antioxidant activity and antibacterial activity against various gram-positive and gram-negative bacteria (Hajji et al., 2016). In chitosan-PVA film, concentration of chitosan reduced crystallinity and stretchability of film, but improved the resistance to fracture and rigidity of the film (Bonilla, Fortunati, Atarés, Chiralt, & Kenny, 2014). Chitosan-PVA films have gained wide spread interest because of its feasible film-forming capacity, but they have poor mechanical property. The films are developed with SiO_2 to increase the mechanical properties. The developed film increased the tensile strength by 45%, reduced oxygen and moisture permeability, and extended the preservation time (Yu, Li, Chu, & Zhang, 2018). In a study, chitosan-PVA-fish gelatin-based film was made to develop a new material with excellent physiochemical property and these films were apt for food packaging purposes (Ghaderi, Hosseini, Keyvani, & Gómez-Guillén, 2019).

Antimicrobial chitosan film was prepared with low density polyethylene (LDPE) and different percentages of chitosan. The obtained films have inhibited 85-100% of *Escherichia coli.* In chilled storage, tilapia (*Oreochromis mossambicus*) wrapped with these films have antibacterial activity, and improved the shelf life of tilapia than virgin LDPE film (Reesha, Panda, Bindu, & Varghese, 2015). Chitosan-polyethylene terephthalate/polypropylene (PET/PP) films were prepared with different preservatives. Antimicrobial activity was found in the films against foodborne microorganisms such as *E. coli* and *Bacillus subtilis*. The inhibition against *B. subtilis* and *E. coli* was almost 100%, while *Staphylococcus aureus* was lower than 85% (Lei et al., 2014).

Chitosan and nano-particle based packaging films

Silver nanoparticles exhibited antimicrobial activity against various harmful microorganisms. When silver nanoparticles are incorporated into the chitosan film, they act as active food packaging (Lopez-Carballo, Higueras, Gavara, & Hernaìndez-MunÞoz, 2013). Chitosan silver oxide encapsulated nano-composite film exhibited antibacterial activity against various harmful bacteria such as *B. subtilis, Pseudomonas aeruginosa,* and *E. coli* (Tripathi et al., 2011). In chitosan film, the addition of zinc oxide nanoparticles improved the solubility and water contact angle but reduced the swelling by 80%. It was also noted that the zinc oxide completely inactivated the multiplication of micro-organisms (Al-Naamani, Dobretsov & Dutta, 2016). Chitosan films containing zinc oxide and silver nanoparticles showed antibacterial activity against various harmful bacteria such as *B. subtilis, Listeria monocytogenes, Staphylococcus aureus*, and *B. cereus* (Youssef, Abou-Yousef, El-Sayed, & Kamel, 2015).

Chitosan films with titanium dioxide enhanced the physiochemical properties of the film, and can be used as active packaging material. It is also noted that the films have excellent antimicrobial activity against various microorganisms like *Salmonella typhimurium E. coli*, *P. aeruginosa*, *S. aureus, Aspergillus* and *Penicillium* (Siripatrawan & Kaewklin, 2018). Chitosan-nanosized titanium dioxide film delayed ripening process and increased the life span of tomato (Kaewklin, Siripatrawan, Suwanagul, & Lee, 2018). Chitosan-graphene oxide composite film was prepared with aqueous solution of acetic acid as solvent. The film exhibited high mechanical and thermal properties in dry and wet state. The film also showed high storage modulus up to 200ºC, making it suitable for use as biomaterials or packaging materials (Han, Yan, Chen, & Li, 2011). Incorporation of graphene oxide to the chitosan film improved the drug delivery profiles of chitosan (Justin & Chen, 2014).

Chitosan, essential oils and plant extracts-based packaging film

Various researches have been conducted with chitosan film containing different type of essential oil and plant extract. Chitosan film containing apricot kernel (*Prunus armeniaca*) essential oil exhibited excellent barrier properties against moisture and water. The apricot kernel essential oil significantly increased mechanical, antioxidant and antimicrobial properties of the film. The storage life of bread slices packaged in the film improved by preventing the growth of fungus (Priyadarshi et al., 2018). According to Gómez-Estaca, López de Lacey, Gómez-Guillén, López-Caballero, and Montero (2009) the incorporation of clove essential oil to chitosan film inhibited pathogenic and spoilage bacteria, and increased the storage life of fish during chilled storage. Ojagh, Rezaei, Razavi, & Hosseini, (2010) found that the addition of cinnamon essential oil decreased the film's solubility, moisture content, elongation at break, and water vapour permeability.

Active films for food preservation are made with chitosan and rosemary essential oil (Abdollahi, Rezaei, & Farzi, 2012). Chitosan film with *Eucalyptus globulus* essential oil can also act as active packaging film with better antimicrobial and antioxidant activity. However, the addition of essential oil reduced moisture content and water solubility (Hafsa et al., 2016). Antimicrobial active packaging films were developed with chitosan and different amount of ginger (*Zingiber officinale*) essential oil. Inclusion of ginger essential oil up to 0.3% to the film enhanced antimicrobial properties without affecting mechanical properties, and was effective against gram-positive bacteria. Fish steak packed with the film was sensorily acceptable till the 20th days of storage and 12 days for unwrapped fish steak (control). The active films help in increasing the storage life of food while packaging (Remya et al., 2016). The chitosan (CH) and tea tree essential oil (TTO) composite film prepared at 1:2 ratio, showed antibacterial properties and completely inhibited microbial growth. TTO:CH ratios higher than 1 exhibited limited antibacterial activity against *Penicillium* and reduced after 3 days of storage (Sánchez-González, Martínez, Chiralt, & Cháfer, 2010). Chitosan films are prepared with different amounts of citronella essential oil and cedarwood oil. The incorporation of essential oil at the lowest concentration (10% w/w) had no effect on the film's properties. An improvement is observed for highest concentration (30% w/w) of both essential oils particularly in citronella essential oil which resulted in better barrier properties in chitosan film than in control (Shen & Kamdem, 2015).

Health hazards related with the use of plastic led to the development of active films from nontoxic and antioxidant rich bio-sources. Mango leaf extract-chitosan composite films were thicker, denser and hydrophobic in nature. The incorporation of mango leaf extract to the film enhanced antioxidant and tensile strength properties. The obtained film showed better performance than commercial plastic film for cashew nut preservation (Rambabu, Bharath, Banat, Show, & Cocoletzi, 2019). In chitosan film the incorporation of purple-fleshed sweet potato extract (PSPE) improved the thickness, water solubility, UV–vis light barrier performance and thermal stability, but reduced elongation at break, moisture and crystallinity of the film. PSPE integration had an effect on the physical, structural, antioxidant, and pH-sensing properties of the film (Yong et al., 2019).

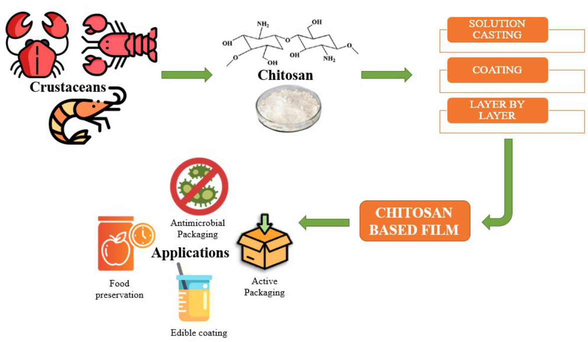

Fig 1. Different applications of chitosan based packaging films

Chitosan films were incorporated with extracts from jujube leaves, peanut shells, and pine nut shells. The shells were dried and cleaned to a constant weight, then ground into a powder to prepare the extracts. These extracts were added to the films to enhance their gas permeability and antioxidant properties. Incorporation of plant extracts decreased the homogeneity and caused porous structure in the films. Among all the films, chitosan-peanut shell film exhibited highest thermal stability (Zhang, Lian, Shi, Meng, & Peng, 2020). In another study, banana peel extract was added to the chitosan films. The extract was prepared using the peels of ripe bananas. The peels were washed, dried, and pulverized to obtain a powder for the ethanolic extraction of banana peels. The addition of extract to films affected their physical, mechanical and structural properties. The film with 4% extract exhibited better performance. Chitosan-banana peels extract composite film exhibited good antioxidant activity in different food simulants (Zhang, Li, & Jiang, 2020). Chitosan-pine needle (*Cedrus deodara*) extract films were greenish in colour. Addition of pine needle extract to the film improved antioxidant property, reduced transparency, improved water vapour and oxygen permeability, and also used as active packaging for oxygen-sensitive food (Kadam, Singh, & Gaikwad, 2021).

Sodium alginate films

Sodium alginate obtained from seaweeds were originally used as coatings for whole or sliced vegetables and fruits. It can be used on wide variety of foods, mainly in the meat industry as it prevents mass loss, colour and texture deterioration (Gheorghita, Gutt & Amariei, 2020). The incorporation of various components (Table 2) can increase the physical, antioxidant, mechanical and antimicrobial properties of the sodium alginate film. Different properties and application of sodium alginate based films are shown in Fig. 2.

Sodium alginate and polysaccharide-based packaging films

Sodium alginate films are incorporated with various polysaccharides such as carboxymethyl cellulose, cellulose, chitosan, carageen etc. to make composite films with different properties. In a study, sodium alginate/carboxymethyl cellulose/chitosan composite films prevented the growth and multiplication of various micro-organisms such as *S. aureus* and *E.*

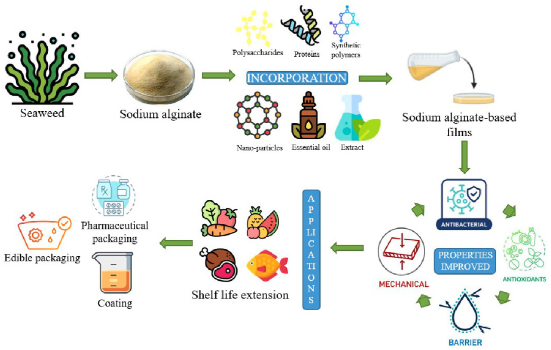

Fig. 2. Properties and application sodium alginate-based packaging film

coli. It is found that the composite films have excellent mechanical properties and can be used as antibacterial packaging material (Lan et al., 2018). Layer by layer films are made in combination with chitosan and sodium alginate films, which have excellent mechanical and hydrophobic characteristics. The structural results indicated that the film interacted with non-covalent bonds rather than covalent bonds (Li, Zhu, Guan, & Wu, 2019). In other study, a bio-composite film was made with sodium alginate/carboxymethyl cellulose and scrap paper (reinforcement). These films have excellent mechanical properties, can replace currently used non-biodegradable and costly biodegradable packaging materials (Kale, Maurya, & Potdar, 2018). Sodium alginate/ carboxymethyl cellulose films were also made from chitosan biguanidine hydrochloride, a biodegradable multifunctional polymer with outstanding antibacterial and water-soluble characteristics. The film prevented spoilage of tomatoes during the storage period and reduced the mass loss of tomatoes (Salama, Aziz, & Alsehli, 2019). Sodium alginate-methyl cellulose film improved the shelf life of peaches and maintained the quality by decreasing transpiration and respiration. The coated samples were acceptable up to 21-24 days of storage at 15°C (Maftoonazad, Ramaswamy, & Marcotte, 2008).

Sodium alginate/starch films were prepared by solution casting. From Differential Scanning Calorimetry (DSC) analysis, single glass transition temperature up to 30% starch content indicated the compatibility and interaction between sodium alginate and starch molecules. Thermogravimetric analysis revealed that when the starch level increased, the thermal stability reduced. From Scanning Electron Microscopy (SEM) analysis, the film showed homogenous distribution of starch with rough cavities (Siddaramaiah, Swamy, Ramaraj, & Lee, 2008). Cationic starch/sodium alginate polyelectrolyte films exhibited excellent thermal stability, surface properties and antimicrobial activity (Şen, Uzunsoy, Baştürk, & Kahraman, 2017).

Pectin and sodium alginate are great materials for making edible films. These are continuous, transparent and homogenous films. The increasing amount of pectin will disturb the internal structure of films. The mechanical and barrier properties of the film are dependent on the compound and its compatibility (Galus & Lenart, 2013). Composite film from sodium alginate and high methoxyl pectin are made from natural resources, and used as biodegradable packaging material. The film showed low water vapour transmission rate (WVTR) in extreme condition at 38 °C and 90% relative humidity. The film has excellent water vapour barrier properties and degrades completely in soil, which made the film a better material for food and pharmaceutical packaging applications (Solak & Dyankova, 2014).

Sodium alginate films are also made with i-carrageenan and gum kondagogu, which have improved mechanical properties and can be used as excellent material for food packaging/coating (Hambleton, Voilley, & Debeaufort, 2011; Ramakrishnan, Wacławek, Černík, & Padil, 2021).

Sodium alginate and protein-based packaging film

Sodium alginate-collagen films were prepared with various amounts of sodium alginate and their physical, mechanical, and barrier properties were studied. DSC analysis showed that the thermal stability of film has increased, owing to the incorporation of sodium alginate. The incorporation of sodium alginate enhanced tensile strength but reduced WVTR and film elongation (Wang, Hu, & Wang, 2017).

Sodium alginate-gelatin film was prepared by adding graphene oxide. The addition of 0.5% of graphene oxide improved strength and ductility of the film. The film can be utilised as packing material due to its high strength and ductility (Yang et al., 2020). Active sodium alginate- gelatin film prepared with tea polyphenols improved antioxidant capacity, denseness, and mechanical properties. The films had a smooth and continuous surface and may be utilised as edible packaging film (Dou, Li, Zhang, Chu, & Hou, 2018). Sodium alginate-gelatin blend films with 4% by weight of sodium alginate and 5% by weight of aqueous gelatin solution and dried at room temperature for 2 days to obtain transparent films. The incorporation of sodium alginate decreased crystallinity but increased thermal stability, mechanical properties and solubility of the films (Xiao, Liu, Lu, & Zhang, 2001). Incorporation of freeze-dried powder of *Pseuderanthemum palatiferum* (Nees) Radlk to sodium alginate-gelatin film improved total phenolic, solubility, antioxidant and mechanical properties but decreased the film's water vapour permeability (Ho et al., 2020).

Feather keratin is a protein obtained from waste feathers and are biodegradable and renewable protein resource having capability in the field of materials such as keratin sponges, films and microcapsules. Sodium alginate/feather keratin film with different ratios were prepared. The film had compactible and homogenous structure. Incorporating sodium alginate into feather keratin improved the film's water vapor permeability while also increasing its strength but the water vapor permeability of the film decreased when the concentration of sodium alginate reached 30%. The films containing 30% sodium alginate showed a high level of transparency. It is also noted that increasing the concentration of sodium alginate to 50% enhanced the mechanical properties and moisture content of the film (He, Zhang, Dou, Yin, & Cui, 2017).

Sodium alginate and synthetic polymer-based packaging films

Sodium alginate-PVA blend films are used in agriculture as films for the solarization of the soils (Russo, Malinconico, Petti, & Romano, 2005). Bilayer films were prepared with PVA, chitosan film as outer layer and sodium alginate film as inner layer. The bilayer film improved mechanical and water barrier properties (Zhuang et al., 2018). Sodium alginate-poly sodium 4-styrenesulfonate (PSS) film have uniform and flat surfaces. The film was hydrophobic in nature and increasing concentration of PSS slightly varied hydrophobicity of film. The obtained film is a promising material and can be further studied for drug delivery behaviour (Sarwar, Ghaffar, & Huang, 2021). Addition of poly (ethylene glycol) monomethyl ether to sodium alginate film improved the hydrophobicity. Increasing amount of poly (ethylene glycol) monomethyl ether decreased roughness of the film. The obtained films can be utilised for drug delivery applications (Sarwar et al., 2020).

Sodium alginate and nano-particle based packaging films

Cellulose nanofibrils were obtained from sisal fibre. The increasing content of cellulose nanofibrils from 0-10% in sodium alginate film improved the tensile modulus value. The obtained film exhibited improved water resistance, mechanical properties and was found to have a longer biodegradation time than pure alginate films. Sodium alginate/cellulose nanofibrils film are a new biomaterial for packing and preserving foods (Deepa et al., 2016). Sodium alginate/cellulose nanofibrils nanocomposite films formed heterogeneous, porous, rough films, and are vulnerable to heat. But the addition of cellulose nanocrystals formed smooth, uniform and homogenous film (Deepa et al., 2020).

Silver nanoparticles were obtained from fruit industrial wastes such as persimmon seed, peel and calyx. The addition of silver nanoparticles to the sodium alginate film improved transparency of the film, showed good antioxidant activity and can be used as biodegradable packaging food (Ramachandraiah, Gnoc, & Chin, 2017). The addition of nano silicon dioxide to sodium alginate film improved mechanical properties as well as their resistance to water, UV light, and thermal stability (Hou et al., 2019). Composite sodium alginate-carboxymethyl cellulose film incorporated with zinc oxide exhibited antibacterial activity against *E. coli* and *S. aureus,* and it improved the tensile properties and water vapour resistance of the film (Wang et al., 2019). Sodium alginate/bismuth (III) oxide (Bi_2O_3) composite film have great extent of stretching before breaking than high-density polyethylene, poly vinyl chloride etc. These composite films are nontoxic and can be used as soft and biodegradable radiation shields (Prabhu, Bubbly, & Gudennavar, 2021).

Sodium alginate, essential oils and plant extracts-based packaging film

Sodium alginate films made by incorporating various essential oils and plant extract are discussed in this section. Sodium alginate film with 1.5% of *Origanum majorana* essential oil prevent growth of various bacteria like *B. cereus, E. coli, L. monocytogenes,* and *S. aureus,* as well as improved storage life of food products. *Dracocephalum moldavica L.* essential oil enhanced the mechanical qualities, thickness,

Table 1. Different chitosan-based packaging films and their major findings

Type of material	Material used	Major Findings	Reference
Polysaccharides	Corn starch	Films can act as an active packaging material for food and pharmaceutical packaging	Ren et al., 2017
	Brown rice starch	Balanced ratio of starch and chitosan showed good water resistance	Hasan et al., 2020
	Purple yam starch	The film improved shelf life of apples for about 4 weeks	Da Costa et al., 2020
	Carboxymethyl cellulose	Enhanced storage life of cut wheat bread	Youssef et al., 2016
	Pectin	Environment friendly bioplastic film having better mechanical and permeability properties	Porta et al., 2011
Proteins	Caseinate	Exhibited excellent water barrier properies	Khwaldia et al., 2014
	Acid soluble collagen	Films are transparent and brittle, have high elongation at break	Uriarte-Montoya et al., 2010
	Gelatin	Excellent mechanical properties and high thermal stability	Liu et al., 2012
	Nisin	The food stayed fresh for longer time	Imran et al., 2014
Synthetic polymer	Poly (vinyl alcohol)	Film increased the tensile strength by 45%, reduced oxygen and moisture permeability, and extended the preservation time	Yu et al., 2018
	Low density polyethylene (LDPE)	Improved the shelf life of tilapia, inhibited 85-100% of *Escherichia coli*	Reesha et al., 2015
Nano-particle	Silver nanoparticles	Showed antibacterial activity against various harmful bacteria such as *B. subtilis, L. monocyte, S. aureus*, and *B. cereus*	Youssef et al., 2015
	Titanium dioxide	Delayed ripening process and increased the life span of tomato	Kaewklin et al., 2018
Essential oils	Apricot kernel (*Prunus armeniaca*) essential oil	The storage life of bread slices packed in the film improved by preventing the growth of fungus	Priyadarshi et al., 2018
	Eucalyptus globulus essential oil	Act as active packaging film with better antimicrobial and antioxidant activity	Hafsa et al., 2016
	Ginger (*Zingiber officinale*) essential oil	The active films help in increasing the storage life of food while packaging	Remya et al., 2016
Extract	Mango leaf extract	Film showed better performance than commercial plastic film for cashew nut preservation	Rambabu et al., 2019
	Banana peel extract	Film exhibited good antioxidant activity oxygen-sensitive food	Zhang, Li et al., 2020
	Pine needle (*Cedrus deodara*)	Can be used as active packaging for extract	Kadam et al., 2021

water vapour barrier properties, and whiteness index of sodium alginate-hydroxypropyl methylcellulose films. The film also has antioxidant properties, making it suitable for use as an active food package (Amjadi, Nouri, Yorghanlou, & Roufegarinejad, 2020). The addition of essential oils from different sources has different effect on properties of the film. In a study, the addition of essential oils obtained from medicinal plants (*O. basilicum, R.officinalis, A. herba-alba,* and *M. pulegium*) to sodium alginate film exhibited antioxidant and antimicrobial activity against various harmful

Table 2. Different Sodium-based packaging films and their major findings

Type of material	Used material	Major Findings	Reference
Polysaccharides	Carboxymethyl cellulose/chitosan	Can be used as antibacterial packaging material	Lan et al., 2018
	Methyl cellulose	Improved the shelf life of peaches and maintained the quality by decreasing transpiration and respiration	Maftoonazad et al., 2008
	Starch	Film showed homogenous distribution of starch with rough cavities	Siddaramaiah et al., 2008
	Pectin	Increasing amount of pectin will disturb the internal structure of films	Galus & Lenart, 2013
	High methoxyl pectin	Film showed low WVTR in extreme condition at 38º C and 90% relative humidity	Solak & Dyankova, 2014
Proteins	Collagen	Enhanced tensile strength but reduced WVTR	Wang et al., 2017
	Gelatin	Films had a smooth and continuous surface and may be utilised as edible packaging film	Dou et al., 2018
	Feather keratin	Improved water vapour permeability	He et al., 2017).
Synthetic polymer	Poly (vinyl alcohol)	Improved the mechanical and barrier properties	Zhuang et al., 2018
	Poly (sodium 4-styrenesulfonate)	Increasing concentration of PSS slightly varied hydrophobicity of film	Sarwar et al., 2021
Nano-particle	Silver nanoparticles	Have excellent antioxidant property	Ramachandraiah et al., 2017
	Zinc oxide	Exhibited antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*	Wang et al., 2019
Essential oils	*Origanum majorana* essential oil	Improved storage life of food products	Amjadi et al., 2020
	O. basilicum, L R.officinalis L, A. herba alba Asso, and *M.pulegium L* essential oil	Exhibited antioxidant and antimicrobial activity against various harmful foodborne bacteria	Mahcene et al., 2020
Extract	Purple onion peel extract (*Allium cepa*)	Phenolic content of purple onion peel improved the antioxidant capacity and reduced water solubility	Santos et al., 2021
	Guava leaf extract	Improved the antioxidant, tensile strength, antibacterial and water-resistant properties.	Luo et al., 2019
	Gallnut extract	Bioactive packaging material which will prevent fat oxidation and spoilage caused by microbes	Aloui et al., 2021

foodborne bacteria. The obtained films have strong ability to absorb DPPH radicals and increased peroxide value (Mahcene et al., 2020). Sodium alginate films were encapsulated with chamomile blue, tea tree, cinnamon, peppermint, lemongrass, elicriso italico, lavender, lemon and eucalyptus essential oil. The films are stable at different humid environments, prevented the multiplication of bacteria and fungi based on the concentration and type of essential oils. These films can be utilized as a novel antibacterial wound dressing and food packaging material, according to the findings (Liakos et al., 2014).

The addition of cinnamon essential oil to sodium alginate-carboxymethyl cellulose films improved the thickness, water vapour permeability, oxygen permeability, elongation at break but reduced tensile strength and moisture content. Antibacterial action was found in the films against *E. coli* and *S. aureus*. The obtained film slows down rotting of bananas (Han, Yu, & Wang, 2018). A study conducted by Hashemi et al. (2019) found that the inclusion of *Zataria multiflora* essential oil and resveratrol in sodium alginate film improved antioxidant properties and declined oxidative reactions. So, the inclusion of *Z. multiflora* essential oil and resveratrol is a suitable way to delay the oxidative reactions. Chen et al. (2021) found that sodium alginate films containing thymol improved antibacterial, antioxidant and mechanical properties of the film. These films also increased the storage life of fresh cut apples.

Active sodium alginate films are made with extracts from purple onion (*Allium cepa*) peels. The peels used for extraction are dried, washed, and ground into a powder to produce the extract. The addition of the extract decreased the solubility of the films. The phenolic content of purple onion peels enhanced the antioxidant capacity and reduced water solubility. As a result, the films reduce oxidation and extend the storage life of food products (Santos, Silva, Gomes, & Martins, 2021). Composite corn starch–sodium alginate-rosemary extract film exhibited anti-*Escherichia coli* effect, reduced mechanical properties and improved water vapour permeability. The films surface was rough and improved shelf life of food materials (Yan, Zhang, Dong, Hou, & Guo, 2013). Sodium alginate/gelatin films containing rosemary extract showed good antioxidant activity and also provided excellent ultraviolet barrier for the film (Li et al., 2021). Sodium alginate/carvacrol film showed antimicrobial activity against *Trichoderma* sp. and improved the storage life of white mushrooms. The incorporation of carvacrol to the sodium alginate film improved light barrier and mechanical properties (Cheng et al., 2019). In a study, sausages covered with sodium alginate/cherry tomato powder film decreased the lipid oxidation and prevented microbial growth but increased the water holding capacity. During the storage, the film extended the storage life of low-fat meat products (Qiu & Chin, 2020).

Sodium alginate/guava leaf extract films were made with ethanolic or water extracts of guava leaf in various combinations. Comparing the composite films to a plain sodium alginate film, the guava leaf extracts considerably improved the antioxidant, tensile strength, antibacterial and water-resistant properties. Results from Fourier Transform Infrared (FTIR) Spectroscopy and SEM showed good intermolecular hydrogen bonding between sodium alginate and guava leaf extract (Luo, Liu, Yang, Zeng & Wu, 2019). Sodium alginate/carboxymethyl cellulose films was made with shallot onion waste extract, which is prepared from the peels and stalks of the onions. The peels and stalks were cleaned in running water to remove soil and unwanted materials. They were then dried and powdered to produce the extract. The films containing this extract exhibit excellent physical, optical, barrier, mechanical, and antioxidant properties, along with high phenolic content. The films made with shallot peel extract demonstrate better properties than those made with stalk extract. At 4°C storage, the films prevent browning and maintain the quality of fresh-cut potatoes and apples. From the study, it is found that the composite films can be used to pack fresh cut fruits and vegetables (Thivya, Bhosale, Anandakumar, Hema, & Sinija, 2021).

Sodium alginate/maltodextrin films are made by adding various amounts of phenolic extract of *Azolla pinnata* leaves. Wrinkles appeared on the film when the concentration of the extract was higher (1.6%). The quantity of extract has decreased the film's mechanical properties and changed film's thickness from 0.124 to 0.181 mm. Additionally, it decreased the films solubility, degree of swelling, and WVP (Eltabakh, Kassab, Badawy, Abdin, & Abdelhady, 2022). Sodium alginate films prepared with various ratios of gallnut extract have increased the mechanical and light barrier properties, but decreased WVP. The film has good antioxidant properties as the extract have high phenolic content. Films also exhibited excellent antibacterial property against various gram-positive and gram-negative bacteria. Developed film act as bioactive packaging material which will prevent fat oxidation and spoilage caused by microbes to preserve and to increase storage life of food (Aloui, Deshmukh, Khomlaem, & Kim, 2021).

Conclusion

The increased use of synthetic or petroleum-based material for packaging has led to serious environmental issues, which lead to the shift towards the use of biodegradable materials that break down into simple compounds once they reach the soil, thus reducing environmental problems. Among various biodegradable materials, chitosan has gained attention as a promising green polymer for food packaging due to its unique, versatile, and excellent characteristics, making it an ideal material for creating biodegradable and eco-friendly packaging. Chitosan-based films can protect food products from lipid oxidation, as well as undesirable flavours, odours, and the adverse effects associated with synthetic polymers. Sodium alginate films are also excellent film-forming materials; however, they have low mechanical strength, antioxidant, and antimicrobial properties. These properties can be improved or modified by adding various natural or synthetic materials to the films. Sodium alginate films have numerous applications in the food, medicine, and pharmaceutical industries. Furthermore, sodium alginate-based films with different additives help prevent water evaporation, colour loss, gas transfer, and microbial contamination.

References

Abdollahi, M., Rezaei, M., & Farzi, G. (2012). Improvement of active chitosan film properties with rosemary essential oil for food packaging. *International Journal of Food Science & Technology*, *47*(4), 847-853. https://doi.org/10.1111/j.1365-2621.2011.02917.x.

Aboudamia, F. Z., Kharroubi, M., Neffa, M., Aatab, F., Hanoune, S., Bouchdoug, M., & Jaouad, A. (2020). Potential of discarded sardine scales (*Sardina pilchardus*) as chitosan sources. *Journal of the Air & Waste Management Association*, *70*(11), 1186-1197. https://doi.org/10.1080/10962247.2020.1813840.

Ahmad, A., Mubarak, N. M., Jannat, F. T., Ashfaq, T., Santulli, C., Rizwan, M., Najda, A., Bin-Jumah, M., Abdel-Daim, M. M., Hussain, S., & Ali, S. (2021). A critical review on the synthesis of natural sodium alginate based composite materials: An innovative biological polymer for biomedical delivery applications. *Processes*, *9*(1), Article 137. https://doi.org/10.3390/pr9010137.

Ahmad, M., Nirmal, N. P., Danish, M., Chuprom, J., & Jafarzedeh, S. (2016). Characterisation of composite films fabricated from collagen/chitosan and collagen/soy protein isolate for food packaging applications. *RSC Advances*, *6*(85), 82191–82204. https://doi.org/10.1039/C6RA13043G.

Ali, A., Zahid, N., Manickam, S., Siddiqui, Y., & Alderson, P. G. (2014). Double layer coatings: a new technique for maintaining physico-chemical characteristics and antioxidant properties of dragon fruit during storage. *Food and Bioprocess Technology*, *7*(8), 2366-2374. https://doi.org/10.1007/s11947-013-1224-3.

Al-Naamani, L., Dobretsov, S., & Dutta, J. (2016). Chitosan-zinc oxide nanoparticle composite coating for active food packaging applications. *Innovative Food Science & Emerging Technologies*, *38*, 231-237. https://doi.org/10.1016/j.ifset.2016.10.010.

Aloui, H., Deshmukh, A. R., Khomlaem, C., & Kim, B. S. (2021). Novel composite films based on sodium alginate and gallnut extract with enhanced antioxidant, antimicrobial, barrier and mechanical properties. *Food Hydrocolloids*, *113*, Article 106508. https://doi.org/10.1016/j.foodhyd.2020.106508.

Amjadi, S., Nouri, S., Yorghanlou, R. A., & Roufegarinejad, L. (2020). Development of hydroxypropyl methylcellulose/sodium alginate blend active film incorporated with *Dracocephalum moldavica L.* essential oil for food preservation. *Journal of Thermoplastic Composite Materials*, *35*(12), 2354-2370. https://doi.org/10.1177/0892705720962153.

Bangyekan, C., Aht-Ong, D., & Srikulkit, K. (2006). Preparation and properties evaluation of chitosan-coated cassava starch films. *Carbohydrate Polymers*, *63*(1), 61-71. https://doi.org/10.1016/j.carbpol.2005.07.032.

Bhuvaneshwari, S., Sruthi, D., Sivasubramanian, V., Kalyani, N., & Sugunabai, J. (2011). Development and characterization of chitosan film. *International Journal of Engineering Research and Applications*, *1*(2), 292-299.

Bonilla, J., Fortunati, E., Atarés, L., Chiralt, A., & Kenny, J. M. (2014). Physical, structural and antimicrobial properties of poly vinyl alcohol–chitosan biodegradable films. *Food Hydrocolloids*, *35*, 463-470. https://doi.org/10.1016/j.foodhyd.2013.07.002.

Bourtoom, T., & Chinnan, M. S. (2008). Preparation and properties of rice starch–chitosan blend biodegradable film. *LWT-Food Science and Technology*, *41*(9), 1633-1641. https://doi.org/10.1016/j.lwt.2007.10.014.

Cazón, P., & Vázquez, M. (2019). Applications of chitosan as food packaging materials. In G. Crini & E. Lichtfouse (Eds.), *Sustainable Agriculture Reviews 36* (pp. 81-123). Springer, Cham.

Chen, G. G., Qi, X. M., Guan, Y., Peng, F., Yao, C. L., & Sun, R. C. (2016). High strength hemicellulose-based nanocomposite film for food packaging applications. *ACS Sustainable Chemistry & Engineering*, *4*(4), 1985-1993. https://doi.org/10.1021/acssuschemeng.5b01252.

Chen, J., Wu, A., Yang, M., Ge, Y., Pristijono, P., Li, J., Xu, B., & Mi, H. (2021). Characterization of sodium alginate-based films incorporated with thymol for fresh-cut apple packaging. *Food Control*, *126*, Article 108063. https://doi.org/10.1016/j.foodcont.2021.108063.

Chen, M. C., Yeh, G. H. C., & Chiang, B. H. (1996). Antimicrobial and physicochemical properties of methylcellulose and chitosan films containing a preservative. *Journal of Food Processing and Preservation*, *20*(5), 379-390. https://doi.org/10.1111/j.1745-4549.1996.tb00754.x.

Cheng, M., Wang, J., Zhang, R., Kong, R., Lu, W., & Wang, X. (2019). Characterization and application of the microencapsulated carvacrol/sodium alginate films as food packaging materials. *International Journal of Biological Macromolecules*, *141*, 259-267. https://doi.org/10.1016/j.ijbiomac.2019.08.215.

Da Costa, J. C. M., Miki, K. S. L., Ramos, A. S., & Teixeira-Costa, B. E. (2020). Development of biodegradable films based on purple yam starch/chitosan for food application. *Heliyon*, *6*(4), Article e03718. https://doi.org/10.1016/j.heliyon.2020.e03718.

Da Silva, M. A., Iamanaka, B. T., Taniwaki, M. H., & Kieckbusch, T. G. (2013). Evaluation of the antimicrobial potential of alginate and alginate/chitosan films containing potassium sorbate and natamycin. *Packaging Technology and Science*, *26*(8), 479-492. https://doi.org/10.1002/pts.2000.

Deepa, B., Abraham, E., Cordeiro, N., Faria, M., Primc, G., Pottathara, Y., Leskovšek, M., Gorjanc, M., Mozetiè, M., Thomas, S., & Pothan, L. A. (2020). Nanofibrils vs nanocrystals bio-nanocomposites based on sodium alginate matrix: An improved-performance study. *Heliyon*, *6*(2), Article e03266. https://doi.org/10.1016/j.heliyon.2020.e03266.

Deepa, B., Abraham, E., Pothan, L. A., Cordeiro, N., Faria, M., & Thomas, S. (2016). Biodegradable nanocomposite films based on sodium alginate and cellulose nanofibrils. *Materials*, *9*(1), Article 50. https://doi.org/10.3390/ma9010050.

De Moura, M. R., Avena Bustillos, R. J., McHugh, T. H., Krochta, J. M., & Mattoso, L. H. C. (2008). Properties of novel hydroxypropyl methylcellulose films containing chitosan nanoparticles. *Journal of Food Science*, *73*(7), N31-N37. https://doi.org/10.1111/j.1750-3841.2008.00872.x.

Di Pierro, P., Chico, B., Villalonga, R., Mariniello, L., Damiao, A. E., Masi, P., & Porta, R. (2006). Chitosan"whey protein edible films produced in the absence or presence of transglutaminase: Analysis of their mechanical and barrier properties. *Biomacromolecules*, *7*(3), 744–749. https://doi.org/10.1021/bm050661u.

Dou, L., Li, B., Zhang, K., Chu, X., & Hou, H. (2018). Physical properties and antioxidant activity of gelatin-sodium alginate edible films with tea polyphenols. *International Journal of Biological Macromolecules*, *118*, 1377-1383. https://doi.org/10.1016/j.ijbiomac.2018.06.121.

Eltabakh, M., Kassab, H., Badawy, W., Abdin, M., & Abdelhady, S. (2022). Active biocomposite sodium alginate/maltodextrin packaging films for food containing *Azolla pinnata* leaves extract as natural antioxidant. *Journal of Polymers and the Environment*, *30*, 1355-1365. https://doi.org/10.1007/s10924-021-02287-z.

Ferreira, C. O., Nunes, C. A., Delgadillo, I., & Lopes-da-Silva, J. A. (2009). Characterization of chitosan–whey protein films at acid pH. *Food Research International*, *42*(7), 807–813. https://doi.org/10.1016/j.foodres.2009.03.005.

Galus, S., & Lenart, A. (2013). Development and characterization of composite edible films based on sodium alginate and pectin. *Journal of Food Engineering*, *115*(4), 459-465. https://doi.org/10.1016/j.jfoodeng.2012.03.006.

Gao, P., Zhu, Z., & Zhang, P. (2013). Effects of chitosan–glucose complex coating on postharvest quality and shelf life of table grapes. *Carbohydrate Polymers*, *95*(1), 371-378. https://doi.org/10.1016/j.carbpol.2013.03.029.

Ghaderi, J., Hosseini, S. F., Keyvani, N., & Gómez-Guillén, M. C. (2019). Polymer blending effects on the physicochemical and structural features of the chitosan/poly (vinyl alcohol)/fish gelatin ternary biodegradable films. *Food Hydrocolloids*, *95*, 122-132. https://doi.org/10.1016/j.foodhyd.2019.04.021.

Gheorghita, R., Gutt, G., & Amariei, S., (2020). The use of edible films based on sodium alginate in meat product packaging: An eco-friendly alternative to conventional plastic materials. *Coatings*, *10*(2), Article 166. https://doi.org/10.3390/coatings10020166.

Gol, N. B., Patel, P. R., & Rao, T. V. R. (2013). Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. *Postharvest Biology and Technology*, *85*, 185-195. https://doi.org/10.1016/j.postharvbio.2013.06.008.

Gómez-Estaca, J., López de Lacey, A., Gómez-Guillén, M. C., López-Caballero, M. E., & Montero, P. (2009). Antimicrobial activity of composite edible films based on fish gelatin and chitosan incorporated with clove essential oil. *Journal of Aquatic Food Product Technology*, *18*(1-2), 46-52. https://doi.org/10.1080/10498850802581252.

Hafsa, J., Smach, M. A., Khedher, M. R. B., Charfeddine, B., Limem, K., Majdoub, H., & Rouatbi, S. (2016). Physical, antioxidant and antimicrobial properties of chitosan films containing *Eucalyptus globulus* essential oil. *LWT-Food Science and Technology*, *68*, 356-364. https://doi.org/10.1016/j.lwt.2015.12.050.

Hajji, S., Chaker, A., Jridi, M., Maalej, H., Jellouli, K., Boufi, S., & Nasri, M. (2016). Structural analysis, and antioxidant and antibacterial properties of chitosan-poly (vinyl alcohol) biodegradable films. *Environmental Science and Pollution Research*, *23*(15), 15310-15320. https://doi.org/10.1007/s11356-016-6699-9.

Hambleton, A., Voilley, A., & Debeaufort, F. (2011). Transport parameters for aroma compounds through i-carrageenan and sodium alginate-based edible films. *Food Hydrocolloids*, *25*(5), 1128-1133. https://doi.org/10.1016/j.foodhyd.2010.10.010.

Han, D., Yan, L., Chen, W., & Li, W. (2011). Preparation of chitosan/graphene oxide composite film with enhanced mechanical strength in the wet state. *Carbohydrate Polymers*, *83*(2), 653-658. https://doi.org/10.1016/j.carbpol.2010.08.038.

Han, Y., Yu, M., & Wang, L. (2018). Physical and antimicrobial properties of sodium alginate/carboxymethyl cellulose films incorporated with cinnamon essential oil. *Food Packaging and Shelf Life*, *15*, 35-42. https://doi.org/10.1016/j.fpsl.2017.11.001.

Hasan, M., Gopakumar, D. A., Olaiya, N. G., Zarlaida, F., Alfian, A., Aprinasari, C., Alfatah, T., Rizal, S., & Khalil, H. P. S. A. (2020). Evaluation of the thermomechanical properties and biodegradation of brown rice starch-based chitosan biodegradable composite films. *International Journal of Biological Macromolecules*, *156*, 896-905. https://doi.org/10.1016/j.ijbiomac.2020.07.076.

Hashemi, M., Hashemi, M., Amiri, E., Hassanzadazar, H., Daneshamooz, S., & Aminzare, M. (2019). Evaluation of the synergistic antioxidant effect of resveratrol and *Zataria multiflora* boiss essential oil in sodium alginate bioactive films. *Current Pharmaceutical Biotechnology*, *20*(12), 1064-1071. https://doi.org/10.2174/1389201020666190719143910.

He, M., Zhang, B., Dou, Y., Yin, G., & Cui, Y. (2017). Blend modification of feather keratin based films using sodium alginate. *Journal of Applied Polymer Science*, *134*(15), Article 44680. https://doi.org/10.1002/app.44680.

Ho, T. C., Kim, M. H., Cho, Y. J., Park, J. S., Nam, S. Y., & Chun, B. S. (2020). Gelatin-sodium alginate based films with *Pseuderanthemum palatiferum* (Nees) Radlk. freeze-dried powder obtained by subcritical water extraction. *Food Packaging and Shelf Life*, *24*, Article 100469. https://doi.org/10.1016/j.fpsl.2020.100469.

Hou, X., Xue, Z., Xia, Y., Qin, Y., Zhang, G., Liu, H., & Li, K. (2019). Effect of SiO_2 nanoparticle on the physical and chemical properties of eco-friendly agar/sodium alginate nanocomposite film. *International Journal of Biological Macromolecules*, *125*, 1289-1298. https://doi.org/10.1016/j.ijbiomac.2018.09.109.

Imran, M., Klouj, A., Revol-Junelles, A. M., & Desobry, S. (2014). Controlled release of nisin from HPMC, sodium caseinate, poly-lactic acid and chitosan for active packaging applications. *Journal of Food Engineering*, *143*, 178-185. https://doi.org/10.1016/j.jfoodeng.2014.06.040.

Justin, R., & Chen, B. (2014). Characterisation and drug release performance of biodegradable chitosan–graphene oxide nanocomposites. *Carbohydrate Polymers*, *103*, 70-80. https://doi.org/10.1016/j.carbpol.2013.12.012.

Kadam, A. A., Singh, S., & Gaikwad, K. K. (2021). Chitosan based antioxidant films incorporated with pine needles (*Cedrus deodara*) extract for active food packaging applications. *Food Control*, *124*, Article 107877. https://doi.org/10.1016/j.foodcont.2021.107877.

Kaewklin, P., Siripatrawan, U., Suwanagul, A., & Lee, Y. S. (2018). Active packaging from chitosan-titanium dioxide nanocomposite film for prolonging storage life of tomato fruit. *International Journal of Biological Macromolecules*, *112*, 523-529. https://doi.org/10.1016/j.ijbiomac.2018.01.124.

Kale, R. D., Maurya, Y., & Potdar, T. (2018). Paper-reinforced sodium alginate/carboxyl methyl cellulose-based bio-composite films. *Journal of Plastic Film & Sheeting*, *34*(2), 179-195. https://doi.org/10.1177/8756087917715675.

Kamdem, D. P., Shen, Z., Nabinejad, O., & Shu, Z. (2019). Development of biodegradable composite chitosan-based films incorporated with xylan and carvacrol for food packaging application. *Food Packaging and Shelf Life*, *21*, Article 100344. https://doi.org/10.1016/j.fpsl.2019.100344.

Khwaldia, K., Basta, A. H., Aloui, H., & El-Saied, H. (2014). Chitosan–caseinate bilayer coatings for paper packaging materials. *Carbohydrate Polymers*, *99*, 508–516. https://doi.org/10.1016/j.carbpol.2013.08.086.

Lan, W., He, L., & Liu, Y. (2018). Preparation and properties of sodium carboxymethyl cellulose/sodium alginate/chitosan composite film. *Coatings*, *8*(8), Article 291. https://doi.org/10.3390/coatings8080291.

Lei, J., Yang, L., Zhan, Y., Wang, Y., Ye, T., Li, Y., & Li, B. (2014). Plasma treated polyethylene terephthalate/polypropylene films assembled with chitosan and various preservatives for antimicrobial food packaging. *Colloids and Surfaces B: Biointerfaces*, *114*, 60-66. https://doi.org/10.1016/j.colsurfb.2013.09.052.

Li, J., Yang, J., Zhong, J., Zeng, F., Yang, L., & Qin, X. (2021). Development of sodium alginate-gelatin-graphene oxide complex film for enhancing antioxidant and ultraviolet-shielding properties. *Food Packaging and Shelf Life*, *28*, Article 100672. https://doi.org/10.1016/j.fpsl.2021.100672.

Li, K., Zhu, J., Guan, G., & Wu, H. (2019). Preparation of chitosan-sodium alginate films through layer-by-layer assembly and ferulic acid crosslinking: Film properties, characterization, and formation mechanism. *International Journal of Biological Macromolecules*, *122*, 485-492. https://doi.org/10.1016/j.ijbiomac.2018.10.188.

Liakos, I., Rizzello, L., Scurr, D. J., Pompa, P. P., Bayer, I. S., & Athanassiou, A. (2014). All-natural composite wound dressing films of essential oils encapsulated in sodium alginate with antimicrobial properties. *International Journal of Pharmaceutics*, *463*(2), 137-145. https://doi.org/10.1016/j.ijpharm.2013.10.046.

Liu, K., Lin, X., Chen, L., Huang, L., Cao, S., & Wang, H. (2013). Preparation of microfibrillated cellulose/chitosan–benzalkonium chloride biocomposite for enhancing antibacterium and strength of sodium alginate films. *Journal of Agricultural and Food Chemistry*, *61*(26), 6562-6567. https://doi.org/10.1021/jf4010065.

Liu, Z., Ge, X., Lu, Y., Dong, S., Zhao, Y., & Zeng, M. (2012). Effects of chitosan molecular weight and degree of deacetylation on the properties of gelatine-based films. *Food Hydrocolloids*, *26*(1), 311–317. https://doi.org/10.1016/j.foodhyd.2011.06.008.

Lopez-Carballo, G., Higueras, L., Gavara, R., & Hernaìndez-MunÞoz, P. (2013). Silver ions release from antibacterial chitosan films containing in situ generated silver nanoparticles. *Journal of Agricultural and Food Chemistry*, *61*(1), 260-267. https://doi.org/10.1021/jf304006y.

Luo, Y., Liu, H., Yang, S., Zeng, J., & Wu, Z. (2019). Sodium alginate-based green packaging films functionalized by guava leaf extracts and their bioactivities. *Materials*, *12*(18), Article 2923. https://doi.org/10.3390/ma12182923.

Ma, W., Tang, C. H., Yang, X. Q., & Yin, S. W. (2013). Fabrication and characterization of kidney bean (*Phaseolus vulgaris L.*) protein isolate–chitosan composite films at acidic pH. *Food Hydrocolloids*, *31*(2), 237-247. https://doi.org/10.1016/j.foodhyd.2012.10.007.

Maftoonazad, N., Ramaswamy, H. S., & Marcotte, M. (2008). Shelf life extension of peaches through sodium alginate and methyl cellulose edible coatings. *International journal of Food Science & Technology*, *43*(6), 951-957. https://doi.org/10.1111/j.1365-2621.2006.01444.x.

Mahcene, Z., Khelil, A., Hasni, S., Akman, P. K., Bozkurt, F., Birech, K., Goudjil, M. B., & Tornuk, F. (2020). Development and characterization of sodium alginate based active edible films incorporated with essential oils of some medicinal plants. *International Journal of Biological Macromolecules*, *145*, 124-132. https://doi.org/10.1016/j.ijbiomac.2019.12.093.

Noshirvani, N., Ghanbarzadeh, B., Mokarram, R. R., & Hashemi, M. (2017). Novel active packaging based on carboxymethyl cellulose-chitosan-ZnO NPs nanocomposite for increasing the shelf life of bread. *Food Packaging and Shelf Life*, *11*, 106-114. https://doi.org/10.1016/j.fpsl.2017.01.010.

Ojagh, S. M., Rezaei, M., Razavi, S. H., & Hosseini, S. M. H. (2010). Development and evaluation of a novel biodegradable film made from chitosan and cinnamon essential oil with low affinity toward water. *Food Chemistry*, *122*(1), 161-166. https://doi.org/10.1016/j.foodchem.2010.02.033.

Porta, R., Mariniello, L., Di Pierro, P., Sorrentino, A., & Giosafatto, C. V. L. (2011). Transglutaminase crosslinked pectin-and chitosan-based edible films: A review. *Critical Reviews in Food Science and Nutrition*, *51*(3), 223-238. https://doi.org/10.1080/10408390903548891.

Poverenov, E., Danino, S., Horev, B., Granit, R., Vinokur, Y., & Rodov, V. (2014). Layer-by-layer electrostatic deposition of edible coating on fresh cut melon model: Anticipated and unexpected effects of alginate–chitosan combination. *Food and Bioprocess Technology*, *7*(5), 1424-1432. https://doi.org/10.1007/s11947-013-1134

Prabhu, S., Bubbly, S. G., & Gudennavar, S. B. (2021). Sodium alginate/bismuth (III) oxide composites for ã ray shielding applications. *Journal of Applied Polymer Science*, *138*(19), Article 50369. https://doi.org/10.1002/app.50369.

Priyadarshi, R., Sauraj, Kumar, B., Deeba, F., Kulshreshtha, A., & Negi, Y. S. (2018). Chitosan films incorporated with Apricot (*Prunus armeniaca*) kernel essential oil as active food packaging material. *Food Hydrocolloids*, *85*, 158-166. https://doi.org/10.1016/j.foodhyd.2018.07.003.

Qiu, Z. Z., & Chin, K. B. (2020). Physicochemical properties and shelf-life of low-fat pork sausages wrapped with active film manufactured by sodium alginate and cherry tomato powder. *Asian-Australasian Journal of Animal Sciences*, *33*(9), 1470-1476. https://doi.org/10.5713/ajas.20.0132.

Ramachandraiah, K., Gnoc, N. T. B., & Chin, K. B. (2017). Biosynthesis of silver nanoparticles from persimmon byproducts and incorporation in biodegradable sodium alginate thin film. *Journal of Food Science*, *82*(10), 2329-2336. https://doi.org/10.1111/1750-3841.13865.

Ramakrishnan, R. K., Wacławek, S., Černík, M., & Padil, V. V. T. (2021). Biomacromolecule assembly based on gum kondagogu-sodium alginate composites and their expediency in flexible packaging films. *International Journal of Biological Macromolecules*, *177*, 526-534. https://doi.org/10.1016/j.ijbiomac.2021.02.156.

Rambabu, K., Bharath, G., Banat, F., Show, P. L., & Cocoletzi, H. H. (2019). Mango leaf extract incorporated chitosan antioxidant film for active food packaging. *International Journal of Biological Macromolecules*, *126*, 1234-1243. https://doi.org/10.1016/j.ijbiomac.2018.12.196.

Reesha, K. V., Panda, S. K., Bindu, J., & Varghese, T. O. (2015). Development and characterization of an LDPE/chitosan composite antimicrobial film for chilled fish storage. *International Journal of Biological Macromolecules*, *79*, 934-942. https://doi.org/10.1016/j.ijbiomac.2015.06.016.

Remya, S., Mohan, C. O., Bindu, J., Sivaraman, G. K., Venkateshwarlu, G., & Ravishankar, C. N. (2016). Effect of chitosan based active packaging film on the keeping quality of chilled stored barracuda fish. *Journal of Food Science and Technology*, *53*(1), 685-693. https://doi.org/10.1007/s13197-015-2018-6.

Ren, L., Yan, X., Zhou, J., Tong, J., & Su, X. (2017). Influence of chitosan concentration on mechanical and barrier properties of corn starch/chitosan films. *International Journal of Biological Macromolecules*, *105*, 1636-1643. https://doi.org/10.1016/j.ijbiomac.2017.02.008.

Russo, R., Malinconico, M., Petti, L., & Romano, G. (2005). Physical behavior of biodegradable alginate–poly (vinyl alcohol) blend films. *Journal of Polymer Science Part B: Polymer Physics*, *43*(10), 1205-1213. https://doi.org/10.1002/polb.20413.

Sachan, N. K., Pushkar, S., Jha, A., & Bhattcharya, A. (2009). Sodium alginate: the wonder polymer for controlled drug delivery. *Journal of Pharmacy Research*, *2*(8), 1191-1199.

Salama, H. E., Aziz, M. S. A., & Alsehli, M. (2019). Carboxymethyl cellulose/sodium alginate/chitosan biguanidine hydrochloride ternary system for edible coatings. *International Journal of Biological Macromolecules*, *139*, 614-620. https://doi.org/10.1016/j.ijbiomac.2019.08.008.

Salmanian, H., Khodaiyan, F., & Hosseini, S.S. (2019). Biodegradable kefiran-chitosan-nanocellulose blend film: Production and physical, barrier, mechanical, thermal and structural properties. *Journal of Food and Bioprocess Engineering*, *2*(2), 101-106.

Sánchez-González, L., González-Martínez, C., Chiralt, A., & Cháfer, M. (2010). Physical and antimicrobial properties of chitosan–tea tree essential oil composite films. *Journal of Food Engineering*, *98*(4), 443-452. https://doi.org/10.1016/j.jfoodeng.2010.01.026.

Santos, L. G., Silva, G. F. A., Gomes, B. M., & Martins, V. G. (2021). A novel sodium alginate active films functionalized with purple onion peel extract (*Allium cepa*). *Biocatalysis and Agricultural Biotechnology*, *35*, Article 102096. https://doi.org/10.1016/j.bcab.2021.102096.

Sarwar, M. S., Ghaffar, A., & Huang, Q. (2021). Development and characterization of sodium alginate/poly (sodium 4-styrenesulfonate) composite films for release behavior of ciprofloxacin hydrogen chloride monohydrate. *Polymers and Polymer Composites*, *29*(9), S143-S153. https://doi.org/10.1177/0967391121990278.

Sarwar, M. S., Ghaffar, A., Huang, Q., Zafar, M. S., Usman, M., & Latif, M. (2020). Controlled-release behavior of ciprofloxacin from a biocompatible polymeric system based on sodium alginate/poly (ethylene glycol) mono methyl ether. *International Journal of Biological Macromolecules*, *165*, 1047-1054. https://doi.org/10.1016/j.ijbiomac.2020.09.196.

Şen, F., Uzunsoy, Ý., Baştürk, E., & Kahraman, M. V. (2017). Antimicrobial agent-free hybrid cationic starch/sodium alginate polyelectrolyte films for food packaging materials. *Carbohydrate Polymers*, *170*, 264-270. https://doi.org/10.1016/j.carbpol.2017.04.079.

Shen, Z., & Kamdem, D. P. (2015). Development and characterization of biodegradable chitosan films containing two essential oils. *International Journal of Biological Macromolecules*, *74*, 289-296. https://doi.org/10.1016/j.ijbiomac.2014.11.046.

Siddaramaiah, Swamy, T. M. M., Ramaraj, B., & Lee, J. H. (2008). Sodium alginate and its blends with starch: thermal and morphological properties. *Journal of Applied Polymer Science*, *109*(6), 4075-4081. https://doi.org/10.1002/app.28625.

Siripatrawan, U., & Kaewklin, P. (2018). Fabrication and characterization of chitosan-titanium dioxide nanocomposite film as ethylene scavenging and antimicrobial active food packaging. *Food Hydrocolloids*, *84*, 125-134. https://doi.org/10.1016/j.foodhyd.2018.04.049.

Solak, A. O., & Dyankova, S. M. (2014). Composite Films from sodium alginate and high methoxyl pectin-physicochemical properties and biodegradation in soil. *Ecologia Balkanica*, *6*(2), 25-34.

Sun, X., Sui, S., Ference, C., Zhang, Y., Sun, S., Zhou, N., Zhu, W., & Zhou, K. (2014). Antimicrobial and mechanical properties of â-cyclodextrin inclusion with essential oils in chitosan films. *Journal of Agricultural and Food Chemistry*, *62*(35), 8914-8918. https://doi.org/10.1021/jf5027873.

Tan, Y. M., Lim, S. H., Tay, B. Y., Lee, M. W., & Thian, E. S. (2015). Functional chitosan-based grapefruit seed extract composite films for applications in food packaging technology. *Materials Research Bulletin*, *69*, 142-146. https://doi.org/10.1016/j.materresbull.2014.11.041.

Tharanathan, R. N. (2003). Biodegradable films and composite coatings: past, present and future. *Trends in Food Science & Technology*, *14*(3), 71-78. https://doi.org/10.1016/S0924-2244(02)00280-7.

Thivya, P., Bhosale, Y. K., Anandakumar, S., Hema, V., & Sinija, V. R. (2021). Development of active packaging film from sodium alginate/carboxymethyl cellulose containing shallot waste extracts for anti-browning of fresh-cut produce. *International Journal of Biological Macromolecules*, *188*, 790-799. https://doi.org/10.1016/j.ijbiomac.2021.08.039.

Tripathi, S., Mehrotra, G. K., & Dutta, P. K. (2011). Chitosan–silver oxide nanocomposite film: Preparation and antimicrobial activity. *Bulletin of Materials Science*, *34*(1), 29-35. https://doi.org/10.1007/s12034-011-0032-5.

Uriarte-Montoya, M. H., Arias-Moscoso, J. L., Plascencia-Jatomea, M., Santacruz-Ortega, H., Rouzaud-Sández, O., Cardenas-Lopez, J. L., Marquez-Rios, E., & Ezquerra-Brauer, J. M. (2010). Jumbo squid (*Dosidicus gigas*) mantle collagen: Extraction, characterization, and potential application in the preparation of chitosan–collagen biofilms. *Bioresource Technology*, *101*(11), 4212–4219. https://doi.org/10.1016/j.biortech.2010.01.008.

Vroman, I., & Tighzert, L. (2009). Biodegradable Polymers. *Materials*, *2*(2), 307–344. https://doi.org/10.3390/ma2020307.

Wang, H., Gong, X., Miao, Y., Guo, X., Liu, C., Fan, Y. Y., Zhang, J., Niu, B., & Li, W. (2019). Preparation and characterization of multilayer films composed of chitosan, sodium alginate and carboxymethyl chitosan-ZnO nanoparticles. *Food Chemistry*, *283*, 397-403. https://doi.org/10.1016/j.foodchem.2019.01.022.

Wang, Z., Hu, S., & Wang, H. (2017). Scale-up preparation and characterization of collagen/sodium alginate blend films. *Journal of Food Quality*, *2017*(1), Article 4954259. https://doi.org/10.1155/2017/4954259.

Xiao, C., Liu, H., Lu, Y., & Zhang, L. (2001). Blend films from sodium alginate and gelatin solutions. *Journal of Macromolecular Science*, *38*, 317-328. https://doi.org/10.1081/MA-100103352.

Xiao, W., Xu, J., Liu, X., Hu, Q., & Huang, J. (2013). Antibacterial hybrid materials fabricated by nanocoating of microfibril bundles of cellulose substance with titania/chitosan/silver-nanoparticle composite films. *Journal of Materials Chemistry B*, *1*(28), 3477-3485. https://doi.org/10.1039/C3TB20303D.

Yan, Q., Zhang, J., Dong, H., Hou, H., & Guo, P. (2013). Properties and antimicrobial activities of starch–sodium alginate composite films incorporated with sodium dehydroacetate or rosemary extract. *Journal of Applied Polymer Science*, *127*(3), 1951-1958. https://doi.org/10.1002/app.37570.

Yang, L., Yang, J., Qin, X., Kan, J., Zeng, F., & Zhong, J. (2020). Ternary composite films with simultaneously enhanced strength and ductility: Effects of sodium alginate-gelatin weight ratio and graphene oxide content. *International Journal of Biological Macromolecules*, *156*, 494-503. https://doi.org/10.1016/j.ijbiomac.2020.04.057.

Yong, H., Wang, X., Bai, R., Miao, Z., Zhang, X., & Liu, J. (2019). Development of antioxidant and intelligent pH-sensing packaging films by incorporating purple-fleshed sweet potato extract into chitosan matrix. *Food Hydrocolloids*, *90*, 216-224. https://doi.org/10.1016/j.foodhyd.2018.12.015.

Youssef, A. M., Abou-Yousef, H., El-Sayed, S. M., & Kamel, S. (2015). Mechanical and antibacterial properties of novel high performance chitosan/nanocomposite films. *International Journal of Biological Macromolecules*, *76*, 25-32. https://doi.org/10.1016/j.ijbiomac.2015.02.016.

Youssef, A. M., El-Sayed, S. M., El-Sayed, H. S., Salama, H. H., & Dufresne, A. (2016). Enhancement of Egyptian soft white cheese shelf life using a novel chitosan/carboxymethyl cellulose/zinc oxide bionanocomposite film. *Carbohydrate Polymers*, *151*, 9-19. https://doi.org/10.1016/j.carbpol.2016.05.023.

Yu, Z., Li, B., Chu, J., & Zhang, P. (2018). Silica in situ enhanced PVA/chitosan biodegradable films for food packages. *Carbohydrate Polymers*, *184*, 214-220. https://doi.org/10.1016/j.carbpol.2017.12.043.

Yuceer, M., & Caner, C. (2014). Antimicrobial lysozyme–chitosan coatings affect functional properties and shelf life of chicken eggs during storage. *Journal of the Science of Food and Agriculture*, *94*(1), 153-162. https://doi.org/10.1002/jsfa.6322.

Zhang, W., Li, X., & Jiang, W. (2020). Development of antioxidant chitosan film with banana peels extract and its application as coating in maintaining the storage quality of apple. *International Journal of Biological Macromolecules*, *154*, 1205-1214. https://doi.org/10.1016/j.ijbiomac.2019.10.275.

Zhang, X., Lian, H., Shi, J., Meng, W., & Peng, Y. (2020). Plant extracts such as pine nut shell, peanut shell and jujube leaf improved the antioxidant ability and gas permeability of chitosan films. *International Journal of Biological Macromolecules*, *148*, 1242-1250. https://doi.org/10.1016/j.ijbiomac.2019.11.108.

Zhuang, C., Jiang, Y., Zhong, Y., Zhao, Y., Deng, Y., Yue, J., Wang, D., Jiao, S., Gao, H., Chen, H., & Mu, H. (2018). Development and characterization of nano-bilayer films composed of polyvinyl alcohol, chitosan and alginate. *Food Control*, *86*, 191-199. https://doi.org/10.1016/j.foodcont.2017.11.024.