Edible Biopolymers from Marine Algae used as an Alternate Packaging material: A Review on their characteristics and properties

A.Thahira Banu, S.U.Subha Lakshmi

School of Sciences, Department of Home Science, The Gandhigram Rural Institute-(Deemed to be University), Gandhigram-624302, Dindigul, Tamilnadu, India

Corresponding author E-mail :thaaze@gmail.com

Abstract:

Food packaging is estimated to account for two-thirds of all plastic waste. As a result, it is crucial to discover alternative packaging materials that are both environmentally friendly and safe for human health. Marine algae are becoming more well-known and in demand as cutting-edge resources for producing biopolymers like proteins and polysaccharides. Because of their biocompatibility, biodegradability, and lack of toxicity, biopolymers have been suggested as potential sources for food packaging materials. Numerous research has thoroughly examined the extraction, separation, and use of marine biopolymers in the creation of sustainable packaging. Marine algae are also rich in protein and mineral content, they also have anticancer, anti-obesity, and hypolipidemic properties due to the presence of polyunsaturated conjugated fatty acids. The edible films enhance the shelf life of food by controlling moisture without changing the elements of food. The marine algae are collected either in the intertidal or subtidal areas and they will be dried for further process. The edible films are environmentally friendly. The edible film made from marine algae is a mixture of protein, polysaccharides, lipids, and resins. The factors which affect the properties of the edible film are the source of raw material, surface charge, hydrophobicity, polymer chain length, plasticizer type, proportion, and synthesis method. There are numerous research has been conducted to develop edible film using various matrix constituents. This review provides an overview of Marine algae, its process, and edible films, its characteristics, and factors affecting the film.

Keywords: Marine biopolymers, Edible film, Packaging, Characteristics, seaweed

1.Introduction:

Edible films are thin layers of edible materials made to cover a product or inserted between product parts. They prevent mass transfer to enhance the handling of the food product and increase its shelf life (of solutes, gases, and water vapour).Their primary benefit is that they can be consumed with food[1]. Edible films have the advantage of being biodegradable and environmentally beneficial, which allows for their use in place of plastic packaging and reduces the adverse effects[2].

Research has been conducted to fabricate edible film ingredients such as pectin [3], gelatin, chitosan [4], and Starch[5]. Because they are tasteless, odourless, and colourless, films made from natural biopolymer sources have excellent structural protection for food and keep the original quality.Edible packaging materials are environmentally favourable since, even if not consumed, they degrade rapidly in nature. Additionally, edible films enhance the organoleptic qualities of food and raise nutritional values when mixed with a supporting member[6].

In the 12th and 13th centuries, wax was used to create the first edible films in China, which were then placed on oranges. Yuba, a sort of edible film made from boiling soybeans, was used in Japan to improve the appearance of food preparations [7]. In the 1950s, the idea of using edible films for food in industrial applications have first occurred [8]. Edible film and coating versions of apple sugar, candy wrapped in chocolate, cheese covered in edible wax, and collagen casings for meat products have all been available for a time [9].

Without changing the essential elements of food, edible films and coatings offer a semi-permeable barrier to block the external sources of bacteria. By decreasing moisture, dissolved component migration, gas exchange, oxidative processes, and respiration rates, they increase the shelf life of food goods[10].

This article gives a general overview of how marine algae are collected, cleaned, dried, and evaluated for quality in order to determine whether they are suitable for use in edible films.The methods and tests followed for quality evaluation of edible films made from marine algae, and their characteristics are discussed. The search was restricted to literature sources in English published till 2022. Google Scholar was used to identify published references and cited articles of interest from a web of science journals. Search items that were used in the process were "Marine algae," "Film for packaging," "Marine resource Based Films," "Polysaccharide Films," "Replacement of synthetic packaging," "Environment impact of packaging," "Edible Films" etc., This review will serve as a guide for beginners in edible film doing research.

2. Marine algae:

Seaweeds, also known as marine macroalgae, are plant-like creatures that thrive in coastal environments adhering to rock or other rigid substrates. They can be produced inexpensively and easily available in the natural environment, are widely accessible, can grow in a variety of environments, and can be collected all year[11].

Seaweeds can be categorized into three classes based on their colour: red (Rhodophyta), brown (Ochrophyta), and green (Chlorophyta)[12]. Due to their high vitamin and mineral content, seaweeds are good for one's health. Seaweeds provide many nutritional benefits, including high protein and mineral content. The polyunsaturated conjugated fatty acids in seaweeds have been shown to have anticancer, anti-obesity, and hypolipidemic properties [11].

Brown Algae

Figure 1: Diagram represent the Brown algae

Red Algae

Figure 2: Diagram represent the Red algae

Green Algae

Figure 3: Diagram represent the Green algae

2.1 Collection of Marine algae:

The Seaweeds can be collected either in the intertidal area or the subtidal area. Low tide is the best time to collect seaweeds from the intertidal zone. According to tide tables, the collection can be picked up one or two hours before low tide. This will provide more time to gather and observe seaweed in its natural environment. Polyethylene bags, a knife or scalpel, labeling supplies (pencils, labels, marker pens, etc.), and seaweed must all be collected. elastic bands, Field notebook, 50-meter-long long rope, 0.25-by-1-meter quadrant, and monopan balance The sample can be obtained either through random sampling or a line transect.

Depending on the gradient and size of the intertidal zone, sample stations along the rope can be specified when using the in-line transect method of the intertidal region. If the intertidal area is small, sampling stations can be set up along the rope every 5 m, and if it is relatively large, sampling points can be set up every 10 or 20 m. A quadrant with a 0.25 m2 area is set in triplicate at the sample spots, encompassing a 5 m2 area on either side of the sampling locations. Seaweed species that are found in the area are collected. Hand removal of loosely adherent seaweed specimens from the substrate is possible. A knife or scalpel can be used to cut away substrates that are firmly bonded to the surface, such as crustose and mat-forming seaweeds. The specimens that develop close to the rocks can be taken out utilising a geologist's pick axe or other equipment of the same kind[13].

As required, samples can be chosen by the random method also. Quadrants can be used to select sampling locations throughout the region. The choice of sampling points should be made so that there is a good possibility that each species in the research area will be chosen. This sampling is typically carried out in areas with patchy distribution and extremely small intertidal expanses with steep gradients. It is also used to quantify the quality of the seaweed[13].

The rope is used to mark a transect perpendicular to the coast in the line transect method of subtidal area. The rope is fastened with nails and marked at regular intervals at a distance of between 5 and 10 metres, depending on the geography of the area. SCUBA diving is utilised for the deeper depths, whereas snorkelling is used to sample the shallow depths (0.5 to 3 metres) (3.0 to 30m deep). Seaweed is gathered at intervals of 5 to 10 metres along the transect, depending on the terrain of the area. A 1.0 m2 quadrant is employed at the designated points to gather seaweed samples. The sampling points and rope are fixed to a boat, catamaran, or canoe. Samples can be randomly chosen from the 0.5 to 3 m subtidal zone by snorkelling or SCUBA diving in deeper waters. Seaweeds found in the sampling region are collected in polyethylene bags using a similar approach to intertidal sampling by placing a 1-m2 quadrant in the sampling area[13].

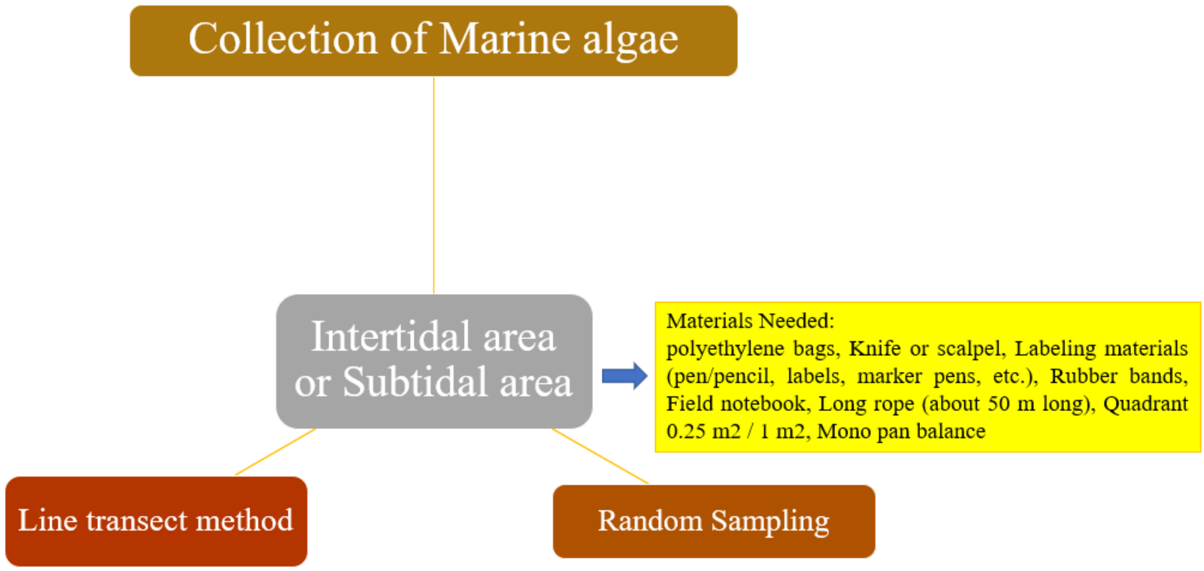

Figure 4: Diagram represents the Collection of Marine algae

2.2. Drying of marine algae:

A portion of the proteins is in the aqueous fraction attached to the seaweed. The protein in this water fraction would be lost by drippage if mechanical drying were to be used. It was anticipated that the harvested seaweed biomass had been thermally air dried to a moisture content of 22%, which is typically advised for seaweed biomass storage and consumption[14][15].

The hot ingoing air is restricted to 35 °C because of the greater risk of denaturalization and protein loss at temperatures higher than that as well as the requirement to preserve those protein in the dried seaweed. A simplified mass balance is used to measure how much water remains in the seaweed after harvest, during transport to the coast, and during nighttime storage in order to calculate the amount of energy needed for drying. The seaweed will be compacted by its own weight while shipping and a brief period of storage prior to drying. The seaweed-bound protein-containing water is preserved. However, it is believed that the water content of the biomass is lost in the process around 20% .Using SimaPro's "maize drying" procedure, the second phase determines the effects of removing the remaining water, bringing the moisture content to 22 per cent [15].

2.3. Characteristics of the Marine algae:

Films are mostly made of biopolymers, including proteins, polysaccharides, lipids, and resins.They can be used separately or in combination. The physical and chemical characteristics of the biopolymers have a considerable impact on the attributes of the finished films and coatings.Materials that create films can either be hydrophilic or hydrophobic. However, the only solvents allowed to be employed are water and ethanol to retain edibility[16].

Proteins differ from other substances that can form films primarily because of their amphiphilic makeup, conformational denaturation, and electrostatic charges. Protein conformation is influenced by a number of factors, such as charge density and the hydrophilic-hydrophobic balance. These factors will eventually have an impact on the physical and mechanical characteristics of the produced films and coatings. Although the characteristics of produced films and coatings may not be significantly affected by the electrostatic neutrality of carbohydrates, the presence of relatively high concentrations of hydroxyl groups or other hydrophilic components in the structure raises the possibility that hydrogen bonds are crucial for both film formation and characteristics. The alginate, pectin, and carboxymethyl cellulose showed various rheological properties under acidic environment than in neutral or alkaline conditions[16].

A seaweed's moisture content (H_20) should not exceed 35%, its salt content (KCl) should not exceed 28%, and its dried matter (SDM) should not exceed 34%. The colours purple, green, and white, and some salt crystals indicate high grades(Tiroba, 2013). Although the quality of the raw material and the drying circumstances were shown to have a substantial impact on the quality of dried and rehydrated items, the initial microbial load of the fresh samples was discovered to be a determining factor.It demonstrated that the microbiological quality of seaweeds is affected by the drying and handling processes, in this the substances used are pseudomonas agar base, rose- Bengal chloramphenicol agar base, violet red glucose agar base; thus, the safety assessment of the seaweed can be checked[17].

According to ISO, the moisture content can be measured by ISO 6496 method, nitrogen can be measured by ISO 5983, ether extract by ISO 6492, Ash by ISO 5984, crude fibre by ISO 6865, Starch by ISO 15914, total sugar by ISO 152, Tryphtophan by ISO 139.Non-protein N (NPN) and the N to protein (N:P) conversion coefficients KP and KA were determined. The ratio of amino acid N (AA- N; g/kg DM) to the total amount of anhydrous AAs (g/kg DM) is KP, whereas the ratio of anhydrous AAs to N is KA. To calculate real protein, the sum of anhydrous AAs (g/kg DM) was employed[18].

According to ISO, the moisture content can be measured by ISO 6496 method, nitrogen can be measured by ISO 5983, ether extract by ISO 6492, Ash by ISO 5984, crude fibre by ISO 6865, Starch by ISO 15914, total sugar by ISO 152, Tryphtophan by ISO 139.

DNA-based Quantitative Polymerase Chain Reaction, or qPCR, is used to test genomic cyanobacteria for synthesizing cyanotoxins. A gene can exist without causing the creation of cyanotoxins, but it must exist for cyanotoxins to be formed. Whether additional ELISA or other testing for algal toxins is necessary can be determined based on whether toxin-producing genes are present or absent in an algal bloom. Enzyme-linked immunosorbent assay tests, or ELISA tests, are screening assays that identify particular cyanotoxin subgroups. These toxins are detectable by ELISAs in drinking water and surface water at low concentrations.

3. Characteristics of the edible film:

Biofilms have a variety of characteristics, including physical, optical, mechanical, morphological, thermal, antioxidant, antibacterial, and biodegradability. The thickness, solubility, water vapour permeability (WVP), water vapour transmission rate (WVTR), and moisture content of films are examples of their physical characteristics. Transparency, opacity, and levels of light transmission are optical qualities. Tensile strength and elongation are mechanical factors. Atomic Force Microscopy (AFM), Field Emission Scanning Electron Microscope (FESEM or SEM), and Fourier-transform infrared (FTIR) spectroscopy can all be used to study morphology[19]. Thermal characteristics are measured by Thermal Gravimetric Analysis (TGA) and Differential Scanning Calorimetry. Total phenolic content, DPPH, and ABTS radical scavenging activities can all be used to assess antioxidant capabilities. Inhibitory characteristics are responsible for antimicrobial properties, which can be measured by inhibitory effects against *E.coli*, *L.monocytogenes*, and *S.Typhimurium*.The most common method of determining biodegradability is a soil-burial test[19][20][21].

To test the physical and mechanical properties of packaging materials, various ASTM standards are available. For measuring the seal strength of the material the F88 / F88M – 09 method can be used, the slow rate penetration resistance of films can be tested using F1306 - 90(2008) el. The Hot Seal Strength (Hot Tack) of Thermoplastic Polymers and Blends Comprising the Sealing Surfaces of Flexible materials can be tested using F1921 / F1921M - 12e1. The Burst testing of flexible packages can be tested using F2054 / F2054M – 13 by internal air pressurization technique. The thickness of flexible material can be accessed using F2251 - 13, For testing the tensile properties of thin plastic sheet the ASTM D882 - 2012 test is used. By ASTM D1709 - 15a and using Free- Falling dart method, the impact resistance of plastic film can be calculated. The propagation tear resistance of plastic film can be tested using ASTM D1922 – 2015. For accessing the Oxidative- Induction time of polyolefins ASTM D3895 – 2014 can be used. ASTM D5748 - 95(2012) standard test method is used for measuring the protrusion puncture resistance[22].

Film thickness is used to calculate a film's mechanical properties and opacity. As the layer thickness rises, pest resistance, gas permeability, and mechanical properties all get better[19][20][21]. The Japanese Industrial Standard, with a maximum thickness of 0.25 mm, is ideal for food packaging[23].

The composition of a film affects its hygroscopicity, or moisture content. If the film is very soluble, it is suitable for covering edible products. Solubility is another factor that affects a film's biodegradability[19][20][21]. Controlling the passage of gases or moisture through or out of food is another crucial part in defining the functional properties of edible films. The term "water vapour permeability" refers to a food coating's capacity to prevent water from entering or leaving a food (WVP). According to S. Patricia Miranda (2004), it is computed by dividing permeance by thickness. The majority of goods in food packaging need to be shielded from environmental moisture. Therefore, it is crucial that they have water barrier properties[24][25].

The Water Vapour Transmission Rate (WVTR), which represents the barrier properties of the film, measures the ability of moisture to pass through the film. WVTR is influenced by the morphology or structure, degree of cross-linking, and chemical makeup of the biopolymer and additives[19][20][21].Water Vapour Transmission Rate is defined as "the steady water vapour flow in unit time through unit area of a body, normal to particular parallel surfaces, under specific conditions of temperature and humidity at each surface," per American Society for Testing and Materials nomenclature. The process for calculating the rate of water vapour transmission through flexible barrier materials is covered by this test method. The process is applicable to single- or multilayer synthetic or natural polymers as well as foils up to a thickness of 3 mm (0.1 in), including coated materials. It enables the computation of the water vapour transmission rate (WVTR), the water vapour permeability of the film, and the water vapour permeability coefficient for homogeneous materials[26].

The optical properties of edible films are used in numerous commercial applications. In some circumstances, a film should be optically transparent, whereas in others, it should be turbid or opaque. Additionally, it is essential for many applications that a film be able to selectively block specific light wavelengths, notably UV rays, from permeating underneath the food. This is because numerous dietary components, such curcumin, resveratrol, and carotenoids, can degrade chemically when subjected to UV or other forms of light[24]. A conventional edible film material's transparency can be visualized as its degree of clarity; the standard used is the clarity of aquades which has a transparency value of 0.0683 for food packaging [23].

Tensile strength and elongation are two crucial functional characteristics of edible film that are used as food packaging. In the end, interactions between molecules and within molecules among the elements of the film-forming network have an impact on the mechanical properties of films [24][27].

To calculate the film's tensile strength, divide the maximum force needed to tear it (F) by its cross-sectional area (A). The tensile strength is determined by determining the highest load at which the film ruptures. The cross-sectional area of the film is computed by dividing the width of each piece of the film by the usual thickness of the film[23].Tensile strength is calculated using the formula:

$$\text{Kuat Tarik (MPa)} = \frac{F}{A}$$

The tensile strength of the edible film is influenced by both the type of substance in the solution and the thickness of the film. The edible film is less brittle and can withstand pressure better since it has a higher tensile strength[23].

The amount of film material is quantified in percent elongation from the beginning of the film till it is pulled off. Although the percentage elongation and tensile strength are inversely related, higher percentage elongation results in lower tensile strength. The amount of elongation of the edible film might vary depending on the type of plasticizer and concentration added. An edible film is more elastic and the percentage level of elongation is more substantial due to the interaction between the molecules of carrageenan[23].

Morphology is a technique for analyzing the microstructure of films, indicating structure uniformity, layering, fissures, holes or pores, smoothness or roughness, thickness, and surface[19][20][21]. For more thorough morphological inspection and interfacial characterization, scanning electron microscopy (SEM) is typically used. At liquid nitrogen temperature, it comprises the observation of surface layers[28]. To understand the molecular interactions of the film, FT-IR analysis is performed.The molecular interactions will not be affected if there is no incorporation or addition of extracts or materials.A helpful method for determining the surface roughness of fibres is atomic force microscopy (AFM). Its benefits, including excellent resolution and non-destructivity, present a unique opportunity for repeated examinations. The films will have a flat, smooth surface free of any fissures, whereas the composite films will have various shapes, be bulged, and include particles[29].

Thermogravimetric analysis (TGA) is an experimental technique used to determine a material's thermostability and its percentage of volatile compounds by observing the mass change that occurs as a sample is heated at a steady rate. The weight is often recorded as a function of rising temperature during the measurement, typically done in air or an inert environment like helium or argon[28]. At first, the water evaporation of polymeric structures will happen, then the components present in the film will decompose, especially around 240-300^0 C for chitosan-derived films[29]. The other polysaccharide films will undergo an initial stage that is a water desorption stage around 100^0 C with 10 % loss and a decomposition stage around 100^0 C to 200^0 C. Then the trend rapidly decreases, and it leaves 23-26% mass residue at high temperature[30].

Scientists can measure the energy necessary to achieve a nearly zero temperature difference between a material and an inert reference material by using differential scanning calorimetry (DSC), which subjects two specimens to similar temperature regimes in a space that is heated or chilled at a constant rate. The fundamental idea behind this technique is that to maintain the sample and the reference at the same degree of temperature throughout a physical transformation, like a phase transition, more (or less) heat must be provided to the sample than to the reference[28].Usually, the polysaccharide films will exhibit an exothermic peak around 300^0 C and an endothermic transition around 100^0 C. Among TGA or DSC, TGA would probably be a better option if the sample produced a lot of gas when heated to the desired temperature (such as during thermal breakdown). DSC might be more appropriate if you are interested in the temperature and energy associated with an endothermic or exothermic transition[30].

Antimicrobial edible films are critical for preventing food deterioration and increasing food safety. Edible films antibacterial capabilities can be considerably enhanced by the addition of specific bioactive chemicals[24].

Antioxidants can increase the anticorrosion properties of edible coatings, limit browning processes, and reduce nutrient oxidation[31]. Particularly, the types of active components, film-forming substances, encapsulation, and food affect a film's antioxidant capabilities[24].To assess the abilities of plant constituents to scavenge free radicals, the 2,2-diphenylpicrylhydrazyl (DPPH) experiment is frequently employed in plant biochemistry. The technique is based on spectrophotometric analysis of the change in DPPH concentration brought on by the interaction with an antioxidant. For this assay, several methods have been employed under various conditions, including different reaction periods, solvents, pH levels, and various chemicals used as antioxidant standards[32]. The sample concentration needed to inhibit a radical by 50% was estimated using the IC_{50} value. The antioxidant activity of samples increases with decreasing IC_{50} values[33].

The 2,2-azinobis-(3-ethylbenzothiazoline-6-sulfonate) (ABTS•+), a green-blue stable radical cationic chromophore used in the ABTS assay (also known as the Trolox equivalent antioxidant capacity (TEAC) assay), is formed by oxidation and shows absorption maxima at 414, 645, 734, and 815 nm[34][35]. It has been suggested to combine two techniques for assessing antioxidant activity in attempt to better understand the antioxidant characteristics of the sample[36].

The Total phenolic content activity is measured by the phenolic content of the sample.The phenolic chemicals found in plants have redox characteristics that allow them to function as antioxidants. The higher the phenolic content, the more the bioactivity, and it shows excellent antibacterial and antioxidant properties[37].

The ASTM D5526 and ASTM D5511 standards are the two most widely used, reputable, and accepted techniques for evaluating biodegradability. Using ASTM D5526 method, the biodegradation of plastic materials anaerobically in landfills can be tested. The ASTM D5526 method is the more rigorous test since it lasts longer and more accurately represents circumstances in actual landfills. Using ASTM D551, the anaerobic biodegradation of plastic can be tested. A quicker test, ASTM D5511, uses simulated lab settings and based the time of long-term projected biodegradability on immediate actions. The modified ASTM G21-70 method for qualitative degradability testing can also be used to test the edible films. This process frequently uses some fungus and bacteria for testing and analysis through biodegradability scores. If the growth of the microbes is high, then the biodegradability level is high; if it is low, then the biodegradability level is low[38].

3.1 Factors affecting the edible film:

The molecular size, synthesis process, chemical structure, and aggregation between the seaweeds and plasticizers all influence the thickness of films[19][20][21]. According to studies, biopolymers absorb more water and expand at greater moisture levels, which reduces the tensile strength of sodium alginate films[39][24].

Raw material source, surface charge, hydrophobicity, polymer chain length, plasticizer type, proportion, and synthesis method all influence mechanical characteristics[19][20][21]. The type of bioactive compounds' interactions with film-forming biopolymers determines how they affect the mechanical properties of edible films[24]. The mechanical characteristics of edible films are also influenced by the particle size of the active substance and the moisture content of the atmosphere. Smaller oil droplet sizes can facilitate the formation of a continuous network within the biopolymer matrix, enhancing interactions between biopolymers and producing edible films with higher tensile strengths[40].

The hydrophilic or hydrophobic properties of the active component can also be used to enhance the WVP of edible films based on proteins or polysaccharides. The structure, concentration, reactive groups, plasticizers, and crosslinkers of active components are the main factors affecting the WVP of edible films[24][25].

The antibacterial properties of edible films are influenced by the sorts of spoilage microorganisms present, the types of film-forming materials used, and the nature of the antimicrobial agents[24]. The Incorporation of antioxidant elements will change the edible film's antioxidant capacity by altering the microstructure and mechanical features of the film, which are impacted by the qualities of the active ingredients and biopolymers[41].

3.2 Application of the edible film:

Sustainable packaging, biodegradable plastics, active packaging, edible packaging, and sachets could all be derived using marine resources. They are superior to traditional materials in every way. It improves the biodegradability of any biodegradable polymer when combined with and increases the product's long-term viability, functioning, and sensory quality[12].

Table 1: Application of the Edible film

S.No	Matrix Constituent	Application	Reference
1	Algae	Act as a Functional ingredient and increase the antioxidant, neuroprotective, antigenotoxic, and extended the shelf life	[42]
2	Essential Oil and Chitosan-based film	Alternative to chemical preservatives and shows excellent properties against microbes	[43]
3	Sodium Alginate	Microencapsulation is used to inhibit the growth of *E.coli* and *Listeria* species	[44]
4	Furcellaran	Increases the functional and physical properties	[45]
5	Sodium Alginate	Increases moisture content and antimicrobial properties	[46]
6	Carrageenan	It improves the thermal stability and water resistance	[47]
7	Agar	The tensile strength was increased and water permeability was decreased	[48]
8	K-carrageenan	Increases the properties that are suited for antimicrobial food packaging	[49]
9	K-carrageenan	Bactericidal effect on *L. monocytogenes* and the films tensile strength also increased	[50]
10	Chitosan	Increases the shelf life of the foods	[51]

11	Fish gelatin & Chitosan nanoparticles	Thermal stability is increased and can be used for dry food packaging application	[52]
12	Fish Gelatin& Fucoidan	Enhanced antioxidative properties	[21]
13	Carrageenan	Tensile strength , WVP, and elongation break are increased when the carrageenan % is increased	[53]
14	Cellulose and ulvan	The film thickness, water solubility, water vapour permeability will be increased and it decreases in oxygen permeability	[54]
15	agar–gelatin–titanium dioxide nanoparticles	Minimize photooxidation	[55]
16	Agar- Essential oil	strong antimicrobial activity against strains ofL. monocytogenes	[56]
17	Agar	Increases the shelf life	[57]
18	Chitosan	Mechanical properties of the film have increased, moisture resistance, inhibits the fungal growth on bread	[58]
19	Chitosan- tannic acid	Improves the physiochemical properties	[59]
20	Carrageenan-glycerol	Improves the barrier protection properties	[60]
21	Carrageenan-agar	It improves the water holding capacity, antimicrobial activity	[61]
22	Carrageenans and agars, phycobiliproteins	Increases the Antioxidant activity	[62]
23	Alginate and Chitosan with codium tomentosum extract	Alginate with extract reduces their solubility and VWP, Chitosan with extract increase the solubility	[63]

24	Sodium alginate	Had excellent thermal stability , lower water solubility and inhibitory effect on Alternaria	[64]
25	Chitosan and native glutinous rice starch and essential oil	Improved the physiochemical and antimicrobial properties which make them suitable for food applications	[65]
26	Coffee waste and Kappaphycus	Increased the functional properties of the film	[66]
27	Ulva, Gelatin, Beeswax	Increased antimicrobial properties and lower water sensitivity	[67]

Wang et al. investigate the advantageous algal active components and their application to meat products. Algal bioactive substances can have antioxidant, neuroprotective, and antigenotoxic effects on meat products, leading to better diets. Additionally, incorporating algal sources into meals can assist to prolong their storage life and delay bacterial destruction, making them sustainable[42].

In order to enhance the antibacterial and antioxidant properties of food products, Arfat Anis conducted research on the use of essential oils and edible films and coatings made of chitosan as alternatives to chemical preservatives. The oxidative degradation of the food products is also delayed, where it shows good barrier properties against oxygen and water vapour too. The films are suggested for use in the packaging of agricultural items, meat, and fish items because the combination increases the shelf life of food[43].

Bustos C et al., studied the edible antimicrobial films based on microencapsulation of the lemongrass oil. They can be used to maintain the natural sensorial properties of fruit, fish, meat, and cheese foods. They observed that the controlled release of lemon grass and films were able to inhibit the growth of *E. coli* and *L. monocytogenes*[44].

Researchers examined the films formed of furcellaran, gelatin hydrolysate, and rosemary extract for their active and intelligent properties. And it showed that it increases tensile strength, thickness, and good antioxidant properties, and it can be used as packaging material[45].

Antibacterial films were made with a matrix of sodium alginate and carboxymethyl cellulose, a plasticizer of glycerin, and a cross-linking agent of $CaCl_2$, as well as the natural antibacterial ingredient pyrogallic acid. It demonstrates that it increases oxygen permeability, water vapour permeability, and moisture content while being effective towards *Staphylococcus aureus* and *E. coli*[46].

A layered agar/-carrageenan/clay bio-nanocomposite film showed increased tensile strength, enhanced water vapour permeability, water uptake ratio, and water solubility, according to Shahbazi. The developed composite also showed increased thermal resilience and water resistance[47].

Rhim et al. (2011) observed an increase in tensile strength and swelling ratio in a film combining agar and nano-clay for biodegradable food packaging. Water vapour permeability, the contact angle of water, and water solubility are all decreased[48].

Shojaee-Aliabadi, Mohammadifar, and colleagues (2014) developed a K-CG, montmorillonite, and Z*ataria multiflora* boiss essential oil that inhibited *S. aureus, B. cereus, E. coli*, *S. typhimurium*, and *P. aeruginosa*. In addition, the film's elongation at break, moisture content, water solubility, water vapour permeability, and tensile strength was increased and can be used for food packaging[49].

Carrageenan, locust bean gum and modified nano-clay were combined and found to have a bactericidal effect on *L. monocytogenes*. The tensile strength and elongation at break have increased , there was a delay in thermal deterioration[50].

The films show that optimal moisture absorption, solvent resistance, and the interactions among them increase the barrier and mechanical properties, and it is best suited for Packing materials for thbAfood[51].

The integration of the nanoparticles into the film matrix has improved the thermal resistance of the film and reduced the contact angles, resulting in a more hydrophobic surface. It is ideal for applications involving the packing of dry foods[52].

Inferred from hydrogen atom donation and free radical inhibition is that the composite gelatin-fucoidan film demonstrated anti-oxidative capabilities. The composite film also has barrier qualities against light, UV, and water vapour, making it suitable for use in foods with a medium level of moisture. It also had high tensile strength and elastic modulus[21].

The films are developed by the extraction of carrageenan from seaweed. As the carrageenan content rises, the cast films mechanical and water vapour permeability also rise[53].

The elements are extracted out of *U.Lactuca*. The findings demonstrated that adding various ulvan concentrations increased the thickness, Water vapour permeability, and Water solubility while decreasing the Oxygen permeability of the composite films. Additionally, the composite films had improved UV and visible light barrier characteristics. Additionally, the kind of food simulant had a significant impact on the film's high antioxidant qualities. According to the findings, the film had thermal, barrier, and antioxidant capabilities, supporting its use in food application[54].

The application of a high concentration of TiO_2 (particularly 2 per cent) significantly reduced the transmission of UV light through the bilayer films, according to light transmittance measurements, which suggests a considerable potential to prevent photooxidation[55].

The films are developed with the use of agar, nisin, cinnamon essential oil, and ZnO particles, and the films are used to cover the minced fish, it shows strong antimicrobial activity against the *L.monocytogene*[56].

Agar is used to create the films, which are then utilised to cover meat items and test the food's storage life. And it demonstrates that it lengthens food's storability[57].

Using apricot kernel essential oil improved the chitosan film's ability to package food. Additionally, it was discovered that the films were essentially effective at preventing fungal development on bread, extending its shelf life. Due to the improvement in the hydrophobic phase in the polymer, the inclusion also improved the film's ability to resist moisture and act as a water vapour barrier[58].

Tannic acid improved the surface characteristics, heat resistance, barrier properties of bio - based films made of chitosan, gelatin, and methylcellulose. The gelatin film's tensile strength had been raised by tannic acid. Tannic acid has the potential to function as an antibacterial agent, according to antimicrobial research, which also found that the biopolymer's inhibitory zone against *Staphylococcus aureus* and *E.coli* . Also, the films effectively kept grapes and cherry tomatoes when compared to control films that had low weight loss and browning index values[59].

The films are developed with the use of carrageenan and glycerol, which increases the barrier protection properties and aroma properties of the encapsulated aroma compound[60].

Agar, carrageenan, and konjac glucomannan were combined to create films, which were then examined for their mechanical and barrier qualities. Fresh spinach is covered with the films, which demonstrate their great water-holding capacity, antibacterial activity, and antifogging properties[61].

The films are developed from the phycolloids and phycobiliproteins from seaweed *Porphyra columbina,* and it shows better antioxidant activity[62].

A wider range of uses in the food sector as well as the use of the material in goods with higher moisture levels are now possible due to the ability of C. tomentosum SE to reduce the solubility and Water Vapour permeability of the polysaccharide films. However, chitosan films containing C. tomentosum SE were simpler to make because of an increase in solubility. They displayed increased flexibility and resistance to mechanical forces, which suggests that they could be used as a film in products with more flexible qualities[63].

The edible film was prepared by layer-by-layer self-assembly technology using Sodium alginate (SA) and "-polylysine ("-PL) as polyanion and polycation. It prolonged the shelflife of a blueberry by inhibiting the the growth of the mold[64].

The study developed an edible composite film using chitosan and Native glutinous rice starch based composite edible films with different essential oil incorporation. Among the essential added edible films, the garlic and galangal films showed inhibitory activity against various microorganisms. The films physiochemical and antimicrobial properties have been improved and is suitable for food applications[65].

The films are made by red seaweed and coffee powder using solvent casting technique. The hydrophobic properties was enhanced with the incorporation of coffee filler and the tensile properties, functional properties of the film was also improved [66].

The antimicrobial film was developed by incorporation of ulva into gelatin and beeswax. The mechanical, thermal, microstructural properties was increased. The water sensitivity is reduced with the addition of beeswax [67].

The edible films are sustainable and biodegradable as it made up of natural resources and takes lesser time to degrade. Numerous studies have recently focused on the usefulness of edible materials as an enhancement to packaged foods.

4. Conclusion:

Marine resources are a great source of good quality proteins, lipids and other nutrients as well as antibacterial agents. Their incorporation into the food gives additional health benefits. This review also discusses new developments in the use of marine resources in the food packaging industry in considering the potential negative effects of synthetic packaging on the environment and public health. However, any negative consequences must also be examined. It can be a promising raw material for food packaging material as it has numerous beneficial properties.

Reference:

[1]. Bizymis, A. P., & Tzia, C. (2021). Edible films and coatings: properties for the selection of the components, evolution through composites and nanomaterials, and safety issues. *Critical Reviews in Food Science and Nutrition*, *0*(0), 1–16. https://doi.org/10.1080/10408398.2021.1934652

[2]. Davoodi, M. N., Milani, J. M., & Farahmandfar, R. (2021). Preparation and characterization of a novel biodegradable film based on sulfated polysaccharide extracted from seaweed Ulva intestinalis. *Food Science and Nutrition*, *9*(8), 4108–4116. https://doi.org/10.1002/fsn3.2370

[3]. Pereira, D. G. M., Vieira, J. M., Vicente, A. A., & Cruz, R. M. S. (2021). Development and characterization of pectin films with salicornia ramosissima: Biodegradation in soil and seawater. *Polymers*, *13*(16).https://doi.org/10.3390/polym13162632

[4]. Nataraj, D., Sakkara, S., Meghwal, M., & Reddy, N. (2018). Crosslinked chitosan films with controllable properties for commercial applications. *International Journal of Biological Macromolecules*, *120*, 1256–1264. https://doi.org/10.1016/j.ijbiomac.2018.08.187

[5]. Alimi, B. A., Workneh, T. S., & Femi, F. A. (2021). Fabrication and characterization of edible films from acha (Digitalia exilis) and iburu (Digitalia iburua) starches. *CYTA - Journal of Food*, *19*(1), 493–500. https://doi.org/10.1080/19476337.2021.1917667

[6]. Okcu, Z., Yavuz, Y., & Kerse, S. (2018). Edible Film and Coating Applications in Fruits and Vegetables. *Alinteri Journal of Agriculture Sciences*, *33*, 221–226. https://doi.org/10.28955/alinterizbd.368362

[7]. Tural, S., F.T. Sarıcaoğlu and S. Turhan, 2017. Edible film and coatings: Production, application methods, functions and uses in muscular foods. *Academic Food*, 15(1): 84-94.

[8]. Tavassoli-Kafrani, E., H. Shekarchizadeh and M. Masoudpour-Behabadi, 2016. Development of edible films and coatings from alginates and carrageenans. *Carbohydrate Polymers*, 137: 360-374. https://doi.org/10.1016/j.carbpol.2015.10.074

[9]. OguzhanYıldız, P. and F. Yangilar, 2016. The use of edible films and coatings in food industry: Compilation. *Bitlis Eren University Journal of Science and Technology*, 5(1): 27-35.

[10]. Artiga-Artigas, M., Acevedo-Fani, A., & Martín-Belloso, O. (2017). Improving the shelf life of low-fat cut cheese using nanoemulsion-based edible coatings containing oregano essential oil and mandarin fiber. *Food Control*, *76*, 1–12. https://doi.org/10.1016/j.foodcont.2017.01.00

[11]. Abdul Khalil, H. P. S., Tye, Y. Y., Saurabh, C. K., Leh, C. P., Lai, T. K., Chong, E. W. N., Nurul Fazita, M. R., Hafiidz, J. M., Banerjee, A., & Syakir, M. I. (2017). Biodegradable polymer films from seaweed polysaccharides: A review on cellulose as a reinforcement material. *Express Polymer Letters*, *11*(4), 244–265. https://doi.org/10.3144/expresspolymlett.2017.26

[12]. Carina, D., Sharma, S., Jaiswal, A. K., & Jaiswal, S. (2021). Seaweeds polysaccharides in active food packaging: A review of recent progress. *Trends in Food Science and Technology*, *110*(February), 559–572. https://doi.org/10.1016/j.tifs.2021.02.022

[13]. Dhargalkar, V. K., & Kavlekar, D. (2004). Seaweeds – A field Manual - National Institute of Oceanography. *National Institute of Oceanography*, 36.

[14]. Philippsen, A., Wild, P., & Rowe, A. (2014). Energy input, carbon intensity and cost for ethanol produced from farmed seaweed. *Renewable and Sustainable Energy Reviews*, *38*, 609–623. https://doi.org/10.1016/j.rser.2014.06.010

[15]. Van oirschot, R., Thomas, J. B. E., Gröndahl, F., Fortuin, K. P. J., Brandenburg, W., & Potting, J. (2017). Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. *Algal Research*, *27*(September), 43–54. https://doi.org/10.1016/j.algal.2017.07.025

[16]. Hun, J. H., & Cennadios, A. (2005). Edible Films and Coatings: a review. *Innovations in Food Packaging*, 239–262.

[17]. Lytou, A. E., Schoina, E., Liu, Y., Michalek, K., Stanley, M. S., Panagou, E. Z., & Nychas, G. J. E. (2021). Quality and safety assessment of edible seaweeds alaria esculenta and saccharina latissima cultivated in scotland. *Foods*, *10*(9). https://doi.org/10.3390/foods10092210

[18]. Bikker, P., Stokvis, L., van Krimpen, M. M., van Wikselaar, P. G., & Cone, J. W. (2020). Evaluation of seaweeds from marine waters in Northwestern Europe for application in animal nutrition. *Animal Feed Science and Technology*, *263*(November 2019), 114460. https://doi.org/10.1016/j.anifeedsci.2020.114460

[19]. Lim, C., Yusoff, S., Ng, C. G., Lim, P. E., & Ching, Y. C. (2021). Bioplastic made from seaweed polysaccharides with green production methods. *Journal of Environmental Chemical Engineering*, *9*(5). https://doi.org/10.1016/j.jece.2021.105895

[20]. Guidara, M., Yaich, H., Benelhadj, S., Adjouman, Y. D., Richel, A., Blecker, C., Sindic, M., Boufi, S., Attia, H., & Garna, H. (2020). Smart ulvan films responsive to stimuli of plasticizer and extraction condition in physico-chemical, optical, barrier and mechanical properties. *International Journal of Biological Macromolecules*, *150*, 714–726. https://doi.org/10.1016/j.ijbiomac.2020.02.111

[21]. Govindaswamy, R., Robinson, J. S., Geevaretnam, J., & Pandurangan, P. (2018). Physico-functional and Anti-oxidative Properties of Carp Swim from brown seaweed

fucoidan based edible films.pdf. *Journal of Packaging Technology and Research*, *2*, 77–89.

[22]. AGMPM. (2010). *List of fatigue standards and fracture standards developed by ASTM*. 9–11. https://www.pac.gr/bcm/uploads/astm.pdf

[23]. Ramadhani, F. S., Rostini, I., Anna, Z., & Rochima, E. (2019). Characterization of Edible Film from Seaweed Flour (Eucheuma cottonii Weber-van Bosse , 1913) with Different Types of Plasticizer. *Intenasional Scientific Journal*, *133*(July), 23–33.

[24]. Chen, W., Ma, S., Wang, Q., McClements, D. J., Liu, X., Ngai, T., & Liu, F. (2021). Fortification of edible films with bioactive agents: a review of their formation, properties, and application in food preservation. *Critical Reviews in Food Science and Nutrition*.

[25]. Benbettaïeb, N., Karbowiak, T., & Debeaufort, F. (2019). Bioactive edible films for food applications:Influence of the bioactive compounds on film structure and properties. *Critical Reviews in Food Science and Nutrition*, *59*(7), 1137–1153. https://doi.org/10.1080/10408398.2017.1393384

[26]. S. Patricia Miranda, O. G.-S. (2004). Water Vapour Permeability and mechanical properties of chitosan composite films. *Journal of chilean chemical society*, 173-178.

[27]. Basiak, E., Lenart, A., & Debeaufort, F. (2017). Effect of starch type on the physico-chemical properties of edible films. *International Journal of Biological Macromolecules*, *98*, 348–356. https://doi.org/10.1016/j.ijbiomac.2017.01.122

[28]. Rajisha, K. R., Deepa, B., Pothan, L. A., & Thomas, S. (2011). Thermomechanical and spectroscopic characterization of natural fibre composites. *Interface Engineering of Natural Fibre Composites for Maximum Performance*, 241–274. https://doi.org/10.1533/9780857092281.2.241

[29]. Kaya, M., Khadem, S., Cakmak, Y. S., Mujtaba, M., Ilk, S., Akyuz, L., Salaberria, A. M., Labidi, J., Abdulqadir, A. H., & Deligöz, E. (2018). Antioxidative and antimicrobial edible chitosan films blended with stem, leaf and seed extracts of Pistacia terebinthus for active food packaging. *RSC Advances*, *8*(8), 3941–3950. https://doi.org/10.1039/c7ra12070b

[30]. Jamaludin, J., Adam, F., Rasid, R. A., & Hassan, Z. (2017). Thermal studies on Arabic gum - carrageenan polysaccharides film. *Chemical Engineering Research Bulletin*, *19*(September), 80. https://doi.org/10.3329/cerb.v19i0.33800

[31]. Bonilla, J., Talón, E., Atarés, L., Vargas, M., & Chiralt, A. (2013). Effect of the incorporation of antioxidants on physicochemical and antioxidant properties of wheat starch-chitosan films. *Journal of Food Engineering*, *118*(3), 271–278. https://doi.org/10.1016/j.jfoodeng.2013.04.008

[32]. Pyrzynska, K., & Pękal, A. (2013). Application of free radical diphenylpicrylhydrazyl (DPPH) to estimate the antioxidant capacity of food samples. *Analytical Methods*, *5*(17), 4288–4295. https://doi.org/10.1039/c3ay40367j

[33]. Jadid, N., Hidayati, D., Hartanti, S. R., Arraniry, B. A., Rachman, R. Y., & Wikanta, W. (2017). Antioxidant activities of different solvent extracts of Piper retrofractum Vahl. using DPPH assay. *AIP Conference Proceedings*, *1854*(June 2017). https://doi.org/10.1063/1.4985410

[34]. Opitz, S. E. W., Smrke, S., Goodman, B. A., & Yeretzian, C. (2014). Methodology for the Measurement of Antioxidant Capacity of Coffee: A Validated Platform Composed of Three Complementary Antioxidant Assays. In *Processing and Impact on Antioxidants in Beverages*. Elsevier. https://doi.org/10.1016/B978-0-12-404738-9.00026-X

[35]. Prior, R., Xianli, W., & Schaich, K. (2005). Standardized Methods for the Determination of Antioxidant Capacity and Phenolics in Foods and Dietary Supplements. *Journal of Agricultural and Food Chemistry*, *53*(6), 4290–4302.

[36]. López-Mata, M. A., Ruiz-Cruz, S., Silva-Beltrán, N. P., Ornelas-Paz, J. D. J., Ocaño-Higuera, V. M., Rodríguez-Félix, F., Cira-Chávez, L. A., Del-Toro-Sánchez, C. L., & Shirai, K. (2015).

[37]. Razali, N. S. M., Wenyin, B., Arjunan, R. D., Hashim, H., & Abdullah, A. (2019). Total phenolic content and antioxidant activities of date fruit extracts. *Malaysian Applied Biology*, *48*(2), 103–108.

[38]. Nissa, R. C., Fikriyyah, A. K., Abdullah, A. H. D., & Pudjiraharti, S. (2019). Preliminary study of biodegradability of starch-based bioplastics using ASTM G21-70, dip-hanging, and Soil Burial Test methods. *IOP Conference Series: Earth and Environmental Science*, *277*(1). https://doi.org/10.1088/1755-1315/277/1/012007

[39]. Liang, J., Yan, H., Zhang, J., Dai, W., Gao, X., Zhou, Y., Wan, X., & Puligundla, P. (2017). Preparation and characterization of antioxidant edible chitosan films incorporated with epigallocatechin gallate nanocapsules. *Carbohydrate Polymers*, *171*, 300–306. https://doi.org/10.1016/j.carbpol.2017.04.081

[40]. Xu, T., Gao, C. C., Feng, X., Yang, Y., Shen, X., & Tang, X. (2019). Structure, physical and antioxidant properties of chitosan-gum arabic edible films incorporated with cinnamon essential oil. *International Journal of Biological Macromolecules*, *134*, 230–236. https://doi.org/10.1016/j.ijbiomac.2019.04.189

[41]. De'Nobili, M. D., Pérez, C. D., Navarro, D. A., Stortz, C. A., & Rojas, A. M. (2013). Hydrolytic Stability of l-(+)-Ascorbic Acid in Low Methoxyl Pectin Films with Potential Antioxidant Activity at Food Interfaces. *Food and Bioprocess Technology*, *6*(1), 186–197. https://doi.org/10.1007/s11947-011-0684-6

[42]. Wang, M., Zhou, J., Tavares, J., Pinto, C. A., Saraiva, J. A., Prieto, M. A., Cao, H., Xiao, J., Simal-Gandara, J., & Barba, F. J. (2022). Applications of algae to obtain healthier meat products: A critical review on nutrients, acceptability and quality. *Critical Reviews in Food Science and Nutrition*, 1–18. https://doi.org/10.1080/10408398.2022.2054939

[43]. Anis, A. (2022). Essential oils and chitosan based polymeric edible films and coatings as alternative to chemical preservatives. *Polymer-Plastics Technology and Materials*, *00*(00), 1–23. https://doi.org/10.1080/25740881.2022.2039187

[44]. Bustos C, R. O., Alberti R, F. V., & Matiacevich, S. B. (2016). Edible antimicrobial films based on microencapsulated lemongrass oil. *Journal of Food Science and Technology*, *53*(1), 832–839. https://doi.org/10.1007/s13197-015-2027-5

[45]. Jancikova, S., Jamróz, E., Kulawik, P., Tkaczewska, J., & Dordevic, D. (2019). Furcellaran/gelatin hydrolysate/rosemary extract composite films as active and intelligent packaging materials. *International Journal of Biological Macromolecules*, *131*, 19–28. https://doi.org/10.1016/j.ijbiomac.2019.03.050

[46]. Han, Y., & Wang, L. (2017). Sodium alginate/carboxymethyl cellulose films containing pyrogallic acid: physical and antibacterial properties. *Journal of the Science of Food and Agriculture*, *97*(4), 1295–1301. https://doi.org/10.1002/jsfa.7863

[47]. Shahbazi, M., Rajabzadeh, G., Ettelaie, R., & Rafe, A. (2016). Kinetic study of κ-carrageenan degradation and its impact on mechanical and structural properties of chitosan/κ-carrageenan film. *Carbohydrate Polymers*, *142*, 167–176. https://doi.org/10.1016/j.carbpol.2016.01.037

[48]. Rhim, J. W. (2011). Effect of clay contents on mechanical and water vapor barrier properties of agar-based nanocomposite films. *Carbohydrate Polymers*, *86*(2), 691–699. https://doi.org/10.1016/j.carbpol.2011.05.010

[49]. Shojaee-Aliabadi, S., Mohammadifar, M. A., Hosseini, H., Mohammadi, A., Ghasemlou, M., Hosseini, S. M., Haghshenas, M., & Khaksar, R. (2014). Characterization of nanobiocomposite kappa-carrageenan film with Zataria multiflora essential oil and nanoclay. *International Journal of Biological Macromolecules*, *69*, 282–289. https://doi.org/10.1016/j.ijbiomac.2014.05.015

[50]. Martins, J. T., Bourbon, A. I., Pinheiro, A. C., Souza, B. W. S., Cerqueira, M. A., & Vicente, A. A. (2013). Biocomposite Films Based on κ-Carrageenan/Locust Bean Gum Blends and Clays: Physical and Antimicrobial Properties. In *Food and Bioprocess Technology* (Vol. 6, Issue 8, pp. 2081–2092). https://doi.org/10.1007/s11947-012-0851-4

[51]. Mohammadi sadati, S. M., Shahgholian-Ghahfarrokhi, N., Shahrousvand, E., Mohammadi-Rovshandeh, J., & Shahrousvand, M. (2021). Edible chitosan/cellulose nanofiber nanocomposite films for potential use as food packaging. *Materials Technology*, 1–13. https://doi.org/10.1080/10667857.2021.1934367

[52]. Hosseini, S. F., Rezaei, M., Zandi, M., & Farahmandghavi, F. (2015). Nanoparticles-Loaded Fish Gelatin based Edible Films. *Journal of Food Process Engineering*, 1–9. https://doi.org/10.1111/jfpe.12246

[53]. Abdou, E. S., & Sorour, M. A. (2014). Preparation and characterization of starch / carrageenan edible films. *International Food Research Journal*, *21*(1), 189–193.

[54]. Gomaa, M., Al, A. A., Awatief, B., & Mahmoud, F. H. (2022). Utilization of cellulose and ulvan from the green seaweed Ulva lactuca in the development of composite edible films with natural antioxidant properties. *Journal of Applied Phycology*. https://doi.org/10.1007/s10811-022-02786-z

[55]. Vejdan, A., Ojagh, S. M., & Abdollahi, M. (2017). Effect of gelatin/agar bilayer film incorporated with TiO2 nanoparticles as a UV absorbent on fish oil photooxidation. *International Journal of Food Science and Technology*, *52*(8), 1862–1868. https://doi.org/10.1111/ijfs.13461

[56]. Abdollahzadeh, E., Mahmoodzadeh Hosseini, H., & Imani Fooladi, A. A. (2018). Antibacterial activity of agar-based films containing nisin, cinnamon EO, and ZnO nanoparticles. *Journal of Food Safety*, *38*(3), 1–10. https://doi.org/10.1111/jfs.12440

[57]. Cutter, C. N. (2006). Opportunities for bio-based packaging technologies to improve the quality and safety of fresh and further processed muscle foods. *Meat Science*, *74*(1), 131–142. https://doi.org/10.1016/j.meatsci.2006.04.023

[58]. 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

[59]. Halim, A. L. A., Kamari, A., & Phillip, E. (2018). Chitosan, gelatin and methylcellulose films incorporated with tannic acid for food packaging. *International Journal of Biological Macromolecules*, *120*, 1119–1126. https://doi.org/10.1016/j.ijbiomac.2018.08.169

[60]. Hambleton, A., Fabra, M. J., Debeaufort, F., Dury-Brun, C., & Voilley, A. (2009). Interface and aroma barrier properties of iota-carrageenan emulsion-based films used for encapsulation of active food compounds. *Journal of Food Engineering*, *93*(1), 80–88. https://doi.org/10.1016/j.jfoodeng.2009.01.001

[61]. Rhim, J. W., & Wang, L. F. (2013). Mechanical and water barrier properties of agar/κ-carrageenan/konjac glucomannan ternary blend biohydrogel films. *Carbohydrate Polymers*, *96*(1), 71–81. https://doi.org/10.1016/j.carbpol.2013.03.083

[62]. Cian, R. E., Salgado, P. R., Drago, S. R., González, R. J., & Mauri, A. N. (2014). Development of naturally activated edible films with antioxidant properties prepared from red seaweed Porphyra columbina biopolymers. *Food Chemistry*, *146*, 6–14. https://doi.org/10.1016/j.foodchem.2013.08.133

[63]. Augusto, A., Dias, J. R., Campos, M. J., Alves, N. M., Pedrosa, R., & Silva, S. F. J. (2018). Influence of codium tomentosum extract in the properties of alginate and chitosan edible films. *Foods*, *7*(4), 1–13. https://doi.org/10.3390/foods7040053

[64]. Bao, R., He, X., Liu, Y., Meng, Y., & Chen, J. (2023). Preparation, Characterization, and Application of Sodium Alginate/ ε -Polylysine Layer-by-Layer Self-Assembled Edible Film. *Coatings*, *13*, 1–16.

[65]. Venkatachalam, K., Rakkapao, N., & Lekjing, S. (2023). Physicochemical and Antimicrobial Characterization of Chitosan and Native Glutinous Rice Starch-Based Composite Edible Films: Influence of Different Essential Oils Incorporation. *Membranes 2023, Vol. 13, Page 161*, *13*(2), 161. https://www.mdpi.com/2077-0375/13/2/161

[66]. Rizal, S., Abdul Khalil, H. P. S., Hamid, S. A., Ikramullah, I., Kurniawan, R., Hazwan, C. M., Muksin, U., Aprilia, S., & Alfatah, T. (2023). Coffee Waste Macro-Particle Enhancement in Biopolymer Materials for Edible Packaging. *Polymers*, *15*(2). https://doi.org/10.3390/polym15020365

[67]. Kazemi, M., Jahanbin, K., Ojagh, S. M., & Abdollahi, M. (2023). Development of antimicrobial gelatin-ulvan-beeswax composite films: Optimization of formulation using mixture design methodology. *International Journal of Biological Macromolecules*, *231*(January), 123384. https://doi.org/10.1016/j.ijbiomac.2023.123384