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REVIEW PAPER

TITLE

SEAWEED SELECTION: EXPLORING BEST TYPE FOR BIOPLASTIC PRODUCTION

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Abstract

Extensive research has been conducted on biodegradable materials due to the growing worldwide concern about plastic pollution and the hunt for sustainable alternatives. Because of their environmentally beneficial qualities, bioplastics made from seaweed have become one of these alternatives' most promising solutions. The unique characteristics of seaweed-derived alginate aid in the creation of biodegradable polymers with prospective uses in a range of sectors. The article looks at several types of bioplastics, such as those made of cellulose, polylactic acid, starch, and polyhydroxyalkanoates. Even though these bioplastics have made significant progress, alginate-based bioplastics highlight their enormous potential as a substitute for conventional plastics. Their adaptable qualities—such as excellent biodegradability, tunable mechanical strength, flexibility, environmental friendliness, and renewability—make them ideal for a variety of uses, including 3D printing, packaging, and agricultural applications. The performance and scalability of alginate-based bioplastics might be further improved by the current research and development in this area.

Keywords: Bioplastic, Seaweed, Environment, Biotechnology.

1. Introduction

Since their invention, plastics and polymers have been incorporated into contemporary civilization on a large scale, to the point that we are unable to conceive living without them. The global endeavor to decrease the quantity of plastic trash is based on recycling. An estimated 7.8 to 8.2 million tons of plastic waste are dumped into the ocean annually (1). The fact that plastic solid waste is not biodegradable is a mystery to landfills. When greenhouse gases, such as carbon dioxide, and other air pollutants are released into the environment, people are severely harmed. Petroleum-based plastics can be replaced with renewable and biodegradable biopolymers to lower environmental hazards. Almost all plastics made today are synthetic, and compared to naturally occurring polymers, they possess many more desired properties. Because they do not degrade biologically, environmentalists are campaigning against their usage and manufacture. In response to increased public concern about the environmental damage produced by plastic, several countries are pursuing various solid waste management programs, including the reduction of plastic waste by the manufacture of biodegradable plastic material (2). However, biowaste may be converted into biodegradable polymers employing a syntrophic population of bacteria from several sources. The environmental harm that plastic causes has come to light in recent decades because to its non-biodegradability, which makes it extremely difficult for it to break down. Our landfills, rivers, seas, beaches, and other natural areas are brimming with plastic garbage of all types, even with all of our recycling efforts. The term "Bioplastic" refers to a novel biomaterial that was created in response to this issue. Bioplastics are biodegradable because they are made from renewable resources like bacteria or plants. Researchers are experimenting with various raw materials to create bioplastics using more affordable and productive production techniques. Much research has been done on bioplastics since 1862. The development of bioplastic has incorporated a variety of researchers and raw materials (3, 4).

In this review article, we aim to explore why seaweed stands out as an optimum source for sustainable bioplastic production, with a particular aim on alginate as the superior option within seaweed-derived bioplastics. Seaweed, abundant in marine ecosystems, offers a promising alternative to traditional fossil fuel-based plastics due to its basic renewable nature, exponential growth rates, and minimal environmental footprint. Our paper seeks to explain the advantageous nature of utilizing seaweed as a raw material for the production of bioplastic, emphasizing its sustainability, biodegradability, and versatility in applications ranging from packaging to biomedical devices and much more. Furthermore, we will examine the specific properties of alginate, a prominent polysaccharide extracted from seaweed, which makes it an absolute candidate for bioplastic manufacturing. Through a comprehensive and critical inspection of existing literature and research findings, we aim to provide insights into the potential of seaweed-derived bioplastics, particularly alginate-based formulations, in addressing the pressing challenges of plastic pollution and resource depletion throughout the modern world.

2. Literature Review

- SC Shravya et al. prepared bioplstics from seaweed using a couple of chemical procedures including alkaline treatment extraction and photo bleaching extraction. The results of bio-plastic synthesis from seaweed/ starch/ cellulose and other composites showed quite the good thermal stability, water solubility to some extent, a good degradation rate (89).
- In their article, Rajendran et al. studied the methodical harvesting and processing of seaweed to maintain its quality for synthesis of bio-plastic. After drying and purification, seaweeds undergo a hot extraction process to isolate polysaccharides, followed by two clarification steps. The polysaccharides are recovered through either potassium chloride addition or precipitation in isopropyl alcohol, with subsequent drying and blending. The authors also highlighted ongoing research into seaweed-based bioplastics, emphasizing the importance of biotechnological and genetic engineering techniques in feasibility of further studies on the innovative topic of seaweed as a source of bioplastic. They foresee that advancements in the broader bio-plastics industry will ultimately benefit seaweed-based bioplastics (90).
- S. L. Hii et al. investigated the synthesis of bioplastic films from Malaysian red seaweed using two extraction methods: alkali treatment and photo bleaching. While alkali treatment produced slightly more agar, the main component extracted, both methods produced films with definitive characteristics. Alkali-extracted films indicated more air bubbles but higher thermal stability,

while photo bleached films showed stronger chemical interactions and better mechanical properties. Rheological studies revealed non-Newtonian behavior in both films, with alkali-extracted films displaying fragile gel characteristics. Additionally, soil burial tests indicated higher biodegradability for alkali-extracted films, suggesting their potential as sustainable alternatives in bioplastic production (91).

- The study by MP Sudhakar et al. focused on the manufacture of bioplastic film using red seaweed (Kappaphycus alvarezii) and polyethylene glycol (PEG-3000) as a plasticizer. The process included seaweed collection, polymer extraction, bioplastic film fabrication, and characterization. Key findings include the analysis of moisture content, solubility, water uptake ratio, ATR-FTIR analysis, physical and mechanical properties, thermal analysis, and morphological analysis of the bioplastic film. The study summarized that K. alvarezii-derived bioplastic film, particularly at a concentration of 3% w/v with PEG-3000, exhibited promising properties for various applications, suggesting potential for commercial use of these bioplastic in food and non-food packaging. Additional research is recommended to assess its degradability, renewability, and edibility for broader uses and economic viability (92).
- In the study by F. Adam et al., bioplastic was synthesized by incorporating cellulose into refined carrageenan. Three different sizes of cellulose were utilized: microcrystalline cellulose (MCC), cellulose nanowhisker (CNW), and nanofibrillated cellulose (NFC). CNW was mechanically nano-grinded, while NFC was ultrasonicated to produce nanoparticles. The presence of hydroxyl groups in cellulose facilitated intermolecular interactions with carrageenan, leading to increased viscosity, shear stress, and tensile strength of the resulting Carra-CNW bioplastic. The study also observed changes in 1H-NMR spectra, indicating shifts in hydrogen bonding due to cellulose size variations. Moreover, Carra-MCC demonstrated enhanced thermal stability compared to Carra-CNW, with higher activation energy. Additionally, the bioplastic exhibited promising biodegradability and compostability, with up to 65% weight decomposition in tests. Overall, the incorporation of cellulose into carrageenan matrix presents a potential eco-friendly alternative to conventional plastics, particularly suitable for applications like food packaging, based on its mechanical strength, thermal stability, and biodegradability properties (93).
- In the research conducted by M. Ayala et al., the environmental impacts of producing a bioplastic film using seaweed as a bioresource were assessed through a comprehensive Life Cycle Assessment (LCA). The study delineated system boundaries encompassing seaweed cultivation, alginate extraction, pilot-scale

bioplastic film production, and different end-of-life pathways. Scenario modeling examined the recirculation of seaweed co-products in the film production process. Results indicated that the primary hotspot in production occurred during film fabrication, primarily due to glycerol usage. Furthermore, the choice of end-of-life pathway significantly influenced environmental impacts, with composting demonstrating a 30% reduction compared to incineration (94).

3. Bio-plastic: A Better Alternative to Plastic

One important type of biomaterials are bioplastics; biomaterials are distinct chemical compounds produced by microorganisms under a variety of environmental conditions. These polyesters are found in nature and assemble as storage granules. Their physicochemical properties are comparable to those of petrochemical plastics. (3) The content of monomers, macromolecular structure, and physical properties of these bioplastics differ according on the microbiological source. Their biodegradability and biocompatibility make them highly interesting from a biotechnological standpoint since they provide a solution to the current pollution or health issues associated with standard bioplastics (2, 5).

3.1 Types of Bioplastics

In addition to being a biodegradable bioplastic, it also tends to be made from a variety of starting materials, such as bacteria, starch, cellulose, milk (galalith), and algae, among others. These raw materials provide us even more possibilities to pick from. For example, alginate, rhodophyta, and chlorophyta may be used to make seaweed (algae) bioplastics. Furthermore, using distinct raw materials gives us unique qualities tailored to certain applications; for example, cellulose-based bioflex is best suited for producing plastic bags, while starch-based bioflex may be used to make electronic sheets and rods. On the other hand, surgical sutures and medication delivery systems employ polyhydroxyalkanoates (PHA) and polylactic acid (PLA) (6).

3.1.1 Starch-Based Bioplastic

The use of starch-based biopolymers is growing in popularity because of their low cost, biodegradability, renewable nature, and wide availability. Furthermore, starch is thought to be a viable raw material for the synthesis of biopolymers. Starch-based polymers made up the second-highest portion of all bioplastics produced, behind polylactic acid (7). Its composition consists of two different types of polymers: branching amylopectin and linear amylose (8). The chemical makeup and granule and glucan structural properties of starches derived from different sources vary because of variables related to nutrition, environment, and heredity that plants are exposed to during their growth. To prevent water absorption, phosphorylated residue, lipids, and lengthy lateral chains of amylopectin interact inside starch amylose granules. On the other hand, a high concentration of amylopectin, particularly in short lateral chains, permits hydration through less restrictive hydrogen bonding, leading to a gel that can undergo retrogradation if held for extended periods of time. The surface pores and channels on smaller starch granules enhance water absorption, yet their greater superficial area permits quick hydration. Thus, the starch granules' ability to expand, their viscosity, and their gelatinization are all increased by the greater hydration rate. Amylopectin has an expanded structure that stabilizes the stiffness and flexibility, whereas sugar amylose provides the adaptibility that's a key component in bioplastics (9). Because starch is so inexpensive, it is one of the most promising biopolymers for making edible films (9).

A multitude of distinct types of bioplastics with a range of distinct physical and chemical properties may be created by combining or using different types of natural starches, both alone and in combination, with and without the inclusion of different plasticizers and types and quantities of natural fillers (10, 11). These variations will enable the bioplastics to be utilized in a range of applications. Since every bioplastic generated was environmentally benign and biodegradable, it served as a useful replacement for plastic and effectively reduced the issue of plastic pollution (12).

3.1.2 Poly Lactic Acid -Based Bioplastic

Polylactic acid, also referred to as polylactide or PLA, is a commercially available biodegradable thermoplastic based on lactic acid. PLA is a thermoplastic made of lactic acid and lactide which is aliphatic, non-cyclic, and aromatic. It is created by polymerizing sugars that are produced from a variety of agricultural biomass sources (13). Developed for biodegradable packaging materials, polylactides break down in industrial composting systems in three weeks. It is the first synthetic polymer made from sustainable materials (14). Additionally, polylactic acid demonstrates some positive attributes, such as ease of synthesis, biocompatibility, biodegradability, non-toxicity, and superior thermal stability. Greenhouse gas emissions are decreased when polylactic acid biodegrades as it releases water, CO2, and organic matter that has broken down and is useful to green plants (15). Additionally, no hazardous products are created when oxygen is introduced to polylactic acid. The greenhouse gas emissions of polylactic acid are comparatively lower than those of other artificial polymers (16).

In manufacturing processes that need a physiological reuse of post-process material, such as thermoforming, where large volumes of waste material are naturally generated during the trimming phase, PLA and the majority of bioplastics present significant challenges. This is due to PLA's high propensity to deteriorate, which makes it more difficult to recover the material known as "post-process" material (i.e., process waste).

According to the mechanical study, when PLA increases, the elongation at break for PLA is reduced. It confirms that the administration of PLA may reduce elongation at break and increase tensile strength. PLA's mechanical characteristics include brittleness and a high stretchibility of 55.4 MPa (17), which may be used to improve the elasticity of bioplastic composites. This is consistent with other research showing that PLA has lower bending capabilities than starch-based bioplastics due to the presence of amylose/amylopectin linkages in the former, which provide flexural qualities. The flexibility of bioplastics could be increased due to glycerol in starch-based bioplastics. Meanwhile, PLA has a very low elongation at break since PLA has strong bonds between lactic acid monomers, which lack the flexibility of starch and increase PLA's rigidity (18). Increasing the concentration of PLA can reduce the density of the bioplastic composite, making it lighter, which is advantageous for bioplastic. As a green food packaging material, PLA is gaining traction after it was discovered that, in many cases, it performed better than synthetic plastic materials. PLA is available in several forms such as films, paper and paper board coatings, thermoformed cups and trays, and containers. Its shortcomings include low heat stability and flammability, however. If PLA-lignin biocomposites are to eventually fully replace traditional petroleum-based polymers, they must be developed with better thermal and fire-retardant qualities.

3.1.3. PHAs-Based Bioplastic

PHAs are biodegradable biopolymers that are produced by a variety of microalgae (19, 20). With a melting point of around 180 celsius, polyhydroxyalkanoates (PHAs) are biodegradable, thermoplastic, biocompatible, and thermal stable. Natural processes use bacterial fermentation of feedstocks taken from plants to generate these polymers. PHAs are produced for carbon storage by a variety of prokaryotic microorganisms in settings with inadequate nutrients (21). PHAs, also known as hydroxy alkanoic acids, are polymers of three hydroxy acids formed when One monomer's carboxylate group forms an ester link with the subsequent monomer's hydroxyl group (22). PHAs are able to have several monomer units. The carbon source that the organism has access to and the substrate specificity of the PHA synthase enzyme in the host organism—which polymerizes hydroxyacyl-CoA units to polymer—determine the ultimate composition of the po lymer chain. Special pathways must be designed to convert the existing metabolites into monomers that may be synthesized by PHA synthase (23). Acetyl coenzyme A is the primary metabolite used to synthesise PHB. It undergoes three straightforward enzyme-catalysed stages to transform into a polymer. The reason PHB has drawn the greatest interest as a target molecule for plant production is due to its relatively easy biosynthesis. Due to its extreme hardness and brittleness, PHB has certain limits as a plastic (24, 25). This is similar to the most popular biodegradable plastic available today, polylactic acid (PLA), which is created by chemically polymerizing lactic acid that is obtained through fermentation. PHAs are competitive substitutes for petro-chemical polymers in the expanding global bioplastic industry because of their similar physical characteristics (26). PHAs have not been used extensively in bioplastics; this might be because of their expensive manufacturing and recovery costs. Researchers are looking for less expensive (27) feedstocks to take the role of PHA. Because the biodegradation processes of PHAs and starch are similar, over 90% of the microorganisms that break down PHAs also break down starch (28).

3.1.4 Cellulose-Based Bioplastic

To make cellulose, variety of biomass may be utilised such as wood, grass, marine creatures (tunicates), algae, fungus, invertebrates, bacteria, and seed or bast fibres (29). Not only can higher plants synthesise cellulose, but also acetic acid bacteria (30). Like starch, cellulose is made up of linear chains joined by glycosidic linkages that span from a few hundred to over ten thousand units of glucose. Despite sharing the same monomer unit, the orientation of their polymeric chains is different in starch and cellulose (31). Since cellulose is naturally hydrophilic and very water-absorbing, it has a good chance of replacing conventional plastics. Additionally, it has a limited barrier capacity against gases and water, and because it is insoluble in most solvents and infusible, processing it is difficult. Usually, cellulose is chemically modified to circumvent this. Indeed, cellulose may be chemically functionalized in a wide variety of ways, including etherification, esterification, silylation, amination, and more. Biopolymers derived from cellulose have garnered interest lately because of their strength, stiffness, extended durability, and biodegradability (32). Cellulose-based reinforced composites are not only inexpensive, low-density, and non-abrasive, but they are also non-abrasive. Bioplastics made of cellulose break down quickly because they have weak hydrogen bonds and far-off molecules. On the other hand, cellulose-based bioplastics have weaker hydrogen bonds, which results in a decrease in their mechanical qualities, including flexibility and strength (33). Since cellulose is crystalline and hydrophilic by nature, with poor mechanical qualities in its unprocessed state, it is exceedingly challenging to employ in packaging. Consequently, in order to create cellophane with superior mechanical properties, it needs to be treated with substances like as NaOH, H2SO4, CS2, etc (34, 35). Derivatization of cellulose from the solvated state by hydroxyl group esterification or etherification can result in the production of cellulose derivatives. Films and edible coatings are made from derivatives of cellulose: cellulose hydroxypropyl, methyl cellulose, carboxymethyl cellulose, or hydroxypropyl methyl cellulose (36–38). Incorporating hydrophobic substances, such as fatty acids, into the cellulose ether matrix to form a composite film is one method of boosting the moisture barrier (39).

The ability of seaweed to be chemically modified into the building blocks needed to make plastic, as well as the fact that converting it into industrial materials is a great idea in and of itself due to its inherent properties, have prompted many researchers to focus on bioplastics made from seaweed. In addition to being extremely common and found practically anywhere there is a coastline, seaweed also grows profusely without the fresh water, fresh land, pesticides, and fertilisers that modern agriculture firms rely so heavily on (40). As a result, we are talking about the many kinds of seaweed that may be used to make bioplastics.

3.1.5 Seaweed Based Bioplastics

Seaweeds are macro-algae that usually live attached to rocks or other substrates in coastal areas. When compared to other feedstocks, they provide a number of advantages as raw materials. For instance, lowering the environmental GHG proportion and planting plentiful and high-yielding plants in saltwater as opposed to land. Additionally, some seaweeds can be used in the food packaging industry since they are edible. They have a high biomass and many polysaccharides. They can exhibit good tensile strength, making them suitable for various applications and because seaweeds can form films, they hold promise for the production of bioplastics. Seaweed films have several uses, such as an edible cup, pot, wrapper, interleaf, and sachet or pouch.

3.1.5.1 No competition with food resources:

Unlike other bio-based plastics that rely on agricultural crops (e.g., corn or sugarcane), seaweed cultivation doesn’t compete with land resources for food production, addressing the food vs. fuel debate. Seaweed farms provide habitats for marine species, leading to increased biodiversity, and can also improve water quality by absorbing excess nutrients, which can combat eutrophication.

3.1.5.2 Reduce carbon footprint:

In particular, seaweed may provide a multitude of ecological advantages, including the removal of pollutants from the coast, providing home for other aquatic animals, and functioning as a carbon skin by absorbing a sizable quantity of carbon dioxide from the aquatic ecosystem throughout its development period. The total carbon footprint of bioplastics made from these seaweeds may be less than that of plastics made from petroleum (41).

3.1.5.3 Biodegradability:

Using seaweeds as a raw material for plastic production decreases the dependency on non-renewable fossil fuels, which are the primary source for conventional plastics. It's because they have better biodegradability profiles compared to petroleum-derived plastics, meaning they can decompose naturally over time and reduce persistent plastic pollution in the environment. Thus, substituting a significant amount of plastics derived from fossil fuels with biobased alternatives might aid in accomplishing both UN Development Goals and EU climate protection objectives (42).

3.1.5.4 Unemployment solving:

The numerous coastal people benefit from their increasing output since it create job opportunities and the commercialization of seaweed bioplastic allowed for employment, hence this is a good opportunity for solving the problem of unemployment.

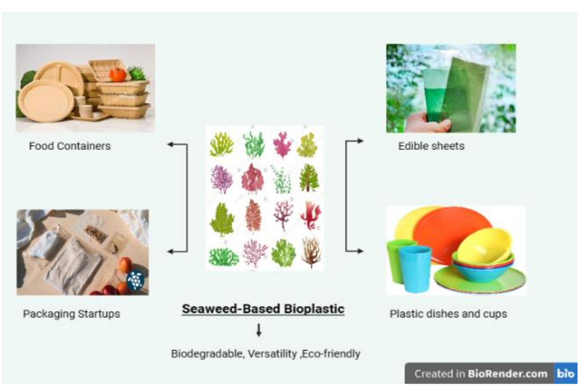

Figure 1: Bioplastic Products From seaweed

3.1.5.5 Blending:

Blending bioplastics derived from seaweed refers to the process of combining seaweed-based bioplastics with other biopolymers or additives to enhance or modify their characteristics. bioplastic have previously been produced using this processing method from gluten (7), soy protein and meat industry, blood plasma among other ingredients. The primary objective of blending is to overcome limitations of the individual seaweed-based bioplastics. To tailor the properties of the bioplastic to suit specific applications and improve processability, mechanical strength, thermal stability, and other functional attributes. Some of the common seaweed-based bioplastics are alginate which is extracted from brown seaweeds, it forms flexible and water-soluble films. Secondly agar sourced from red seaweeds, it provides rigidity and forms thermo-reversible gels. Third is Carrageenan also extracted from red seaweeds, it has varying gel strengths based on its type (iota, kappa, or lambda). Blending helped achieve a balance of strength and flexibility. Blending agar (rigid) with alginate (flexible) can yield a bioplastic with intermediate mechanical properties. Blending might improve resistance to gases, moisture, or UV light, crucial for packaging applications. Some seaweed bioplastics have low melting points. Blending with polymers like PLA can enhance thermal resistance. While seaweed bioplastics are often biodegradable, blending can be used to adjust the rate of decomposition to suit specific applications (7). Bioplastics are melted and mixed together, often using twin-screw extruders. Bioplastics are dissolved in a common solvent, mixed, and then the solvent is removed, leaving a blended film.

3.1.5.6 Packaging:

Some seaweed bioplastics demonstrate good barrier properties against gases like oxygen and carbon dioxide, making them potentially suitable for food packaging applications. Given their marine origin, seaweed-derived bioplastics might be expected to resist water absorption (7). However, some can still be hydrophilic (water-attracting) to a degree, which can affect their mechanical properties and applications.

4. Types of Seaweed Bioplastic

Fucoid, ulvo and agarose. Hydrocolloids generated from algae are widely employed as biopolymers in the production of bioplastics, including carrageenan, agar, and alginate (43). Based on the pigments and colours, they are separated into three primary groupings (43).

- Green algae (Chlorophyta) - *Cordium fragile*
- Brown algae (Pheophyta) - *Macrocystis integrifolia*
- Red algae (Rhodophyta) – *Porphyra*

4.1 Brown seaweeds (phaeophyta)

Brown algae, which is the most prevalent type of seaweed, is a member of the phylum Phaeophyta, or "dusky plants". Thus, research was done on producing bioplastics from the inherent polysaccharides of Sargassum sp., a type of brown seaweed found in Sabah. Along the rugged Sabah coast, one may regularly witness these species drifting together or apart. Because alginate is readily accessible as a feedstock and is one of its active components that is necessary for the synthesis of bioplastics, it was selected (44, 45). A brown seaweed called Sargassum sp. was removed from Sepanggar Bay in Sabah, Malaysia, and cleaned to remove impurities. After that, it was dried outside before being dried again at 70 °C in the lab oven. The seaweeds were dried, then ground into a fine powder and stored in airtight jars for future use (46, 47). Phaeophyceae are characterized by fucoxanthin, a particular pigment whose structure changes according on the species (48). Fucoxanthins have anti-obesity, antioxidant, and antitumoral properties (49).

Alginate is primarily employed as a food additive, although laminaran and fucoidan are primarily interested in brown algae due to their possible biological activity. Fucoidan and laminarin, for example can compose of 20% to 50% of the dry weight of algae (50). Fucoidans can account for as much as 25–30% of the total weight in dried form of seaweed, based on the type and time of year (51). Finding out the fucoidan structure in brown seaweed is important since the biological activities of SPs are greatly influenced by the role and amount of groups of sulphate. Among the methods for ascertaining the positions of sulphate are infrared spectroscopy, de-sulfation, sulphate stability esters to alkali and analysis of methylation (52).

4.1.1 Alginate

Alginate is polysaccharide that is made of alginic acid and its salts and derivatives. Anionic linear polysaccharides known as alginates makeup as much as 40% of the dry weight of brown seaweed and have shown to create edible films. The polysaccharide known as alginate is derived from alginic acid and its salts and derivatives. Up to 40% of the dry weight of brown seaweed is composed of anionic linear polysaccharides called alginates, which have been reported to have the capacity to form edible films. They are composed of alginic acid polymers with 1,4 linkages between the -D and -L mannuronic acid (M) monomer units (53). Because the mechanical and physiochemical characteritic of gel formed from alginate rely on the length of the structure, the M/G ratio and the guluronic acid concentration leads to a gel with better gelling qualities and a more elastic gel. Conversely, robust, brittle gels with remarkable heat stability are produced by low M/G ratios; nevertheless, they also show synergy throughout freeze-thaw process (54). Because alginate is a common ingredient in food goods and pharmaceuticals because of its strong stablizing and thickening qualities. Owing to alginates' potent hydrophilicity, adding additional elements to the matrix is essential to enhancing its resistance to water contact. In addition, ions have an impact on alginates' solubility and the type of cation- cation connection in alginates dictates how effectively it gels (55). The aliginate gel becomes more resilient and durable when calcium is added, which could be a promising advance for the creation of biodegradable materials with antibacterial properties and non toxic packaging. The forms and compositions of laminarans vary depending on the species of algae.

4.2 Rhodophyta

Marine red algae generate a wide variety of secondary metabolites, including sesquiterpenes, diterpenes, triterpenes, and many more having antifungal, antibacterial, and anticancer effects (56). Carrageenans are a form of SP that are only found in red algae (57). The building block of their structures are called SPs, or galactan and they can gel in milk or water solutions. the pharmaceuticals, cosmetics and culinary industries are the main industries that use these phycocolloids. Since investigations on carrageenans revealed that they have immune-stimulating, antioxidant, anticoagulant, antitumoral, and antiviral properties, red algae extracts are used in commerce (58). The families Thichocarpaceae and phillophoraceae are widely distributed in the far eastern waters (59).

4.2.1 Carregeenan

The linear polymer known as carrageenan is mostly present in red algae and is made up of galactose units that alternate between being sulfated and non-sulfated, connected by 1,3-glycosidic and 1,4-galactose links (60). Depending on where the sulphate group is linked to the galactose unit, carrageenans may be divided into many varieties (carrageenan, v-carrageenan, -carrageenan and carrageenan). Since carrageenans are mostly of hybrid origin, various bound sulphate groups exhibit distinct properties. Commercial carrageenans are widely found in water gels,paints, ice cream and medications. Based on the number of sulphated group attached to the galactose unit, they are often divide into three structural kinds; the characteristic if carregeenan are dictated by the quantity, chemical position and arragement of these groups.

To assess these substances as possible raw materials for the development of bioplastics, researchers have examined the corporeal and biological carrageenan characteristics that are extracted from Eucheuma cottonii, a red seaweed. Eucheuma cottonii provided the semi-refined carrageenan flour, whereas refined carrageenan flour was bought. Compared to bioplastic made with refined carrageenans, bioplastic made with extracted carrageenans exhibited stronger antibacterial activity. Furthermore, bioplastic derived from refined carrageenans has a greater heat resilience. Hanry and Surugau (43) studied the biofilms made from entire Kappaphycus sp. seaweed and pure κ-carrageenan. This study compared the characteristics of the two biofilms to see if it would be possible to forego the extraction of carrageenan.

According to their findings, biofilms made from the whole algae exhibited less brittleness; but, because there was less carrageenan present, the binding intermolecular forces exhibited a weaker nature. For example, single use powder container, fast food, candy, or daily-use medications like tablets or pills that don't need strong mechanical qualities and are simple to open are the greatest uses for this kind of bioplastic. A further study on κ-carrageenan from Kappaphycus alvarezii by Sudhakar et al. (61) showed that the bioplastic films had high mechanical, thermal, and physical strength, indicating that more findings will be helpful to create biodegradable films derived from Kappaphycus spp.

4.2.2 Agar

Chemically speaking, the primary ager's structure is described by a low ester sulphate concentration and repeating units of 3,6-anhydro-L-galactose, albiet with the few changes.The two types of polysaccharide that make up the strucutre of agar are agarose, aneutral polysaccharide and agropectin, an overstimulated term for the charged polymer. Agar's ability to gel is due to agarose, which also has good film qualities and is highly beneficial in skin care, herbal remedies, and medicinal uses (6). Because agar and carrageenan can be used as thickening agents, emulsifiers, and stabilizers, they are commonly used within the industrial food processing business. Both are already present in meal based on gel items, including baked goods, jams, jellies, and desserts. Agar gels are often clear and tight, but the addition of sugars makes them stronger. Low hydro-scopicity of agar is advantageous in the packaging industry. Additionally, agar films mix easily with different bioactive chemicals or plasticizers to create soft, elastic gel despite being biologically inert with bioactivity power (62).

In order to determine its biochemical qualities as a basic material used to make bioplastic, agar from Gracilaria salicornia was isolated. Agar extraction techniques were investigated, and several biofilms were created to assess their characteristics. The biofilm from agar that was extracted through phtobleaching (PB) had better tensile strength and % elongation than the agar biofilm produced by extraction of alkali (AE), whereas the AE agar film had higher thermal stability, according to the results. Furthermore, in the soil burial test, the AE agar film dissolved entirely in 30 days (63). Agar derived from Gracilaria salicornia is therefore intriguing for potential uses in bioplastic film applications in the future.

4.3 Chlorophyta

Because of the presence of carotenoids (-carotene and xanthophylls) and chlorophylls (a and b), chlorophyta display their characteristic green colour. because antioxidant activity is present in seaweed pigments. They play an essential role in shielding seaweeds from the damaging effects of radiation (64). The bulk of PUFAs in Chlorophyta, which are C16 and C18 in nature, are composed of linoleic acid. Moreover, green algae have far higher concentrations of palmitic (16:3n3 and 16:4n-3) PUFAs than do red and brown algae. The sugars that comprise the cell walls of SPs are rich in chlorophyta (65). The greatest PUFA concentration was found in Ulva linza, green seaweed, which has the ability to suppress inflammatory responses.

4.3.1 Ulvan

The most important SP found inside the cell walls of green seaweed is ulvan. This material, together with fucoidan and carrageenan, is widely used in many different sectors, including the cosmetic formulation industry for the creation of emulsifiers, moisturizers, thickening agents, and hair conditioners (66, 67). Nine to thirty-six percent of the dry weight of ulvan biomass is usually present (68). This SP has sulphated rhamnose, glucuronic acid, iduronic acid, and xylose in addition to uronic acid linked to a sulphated neutral sugar in a repeating disaccharide structure. Ulvan may find application in a range of fields, such as medicine, agriculture, and the development of substitute biomaterials, due to its antioxidant qualities (67).

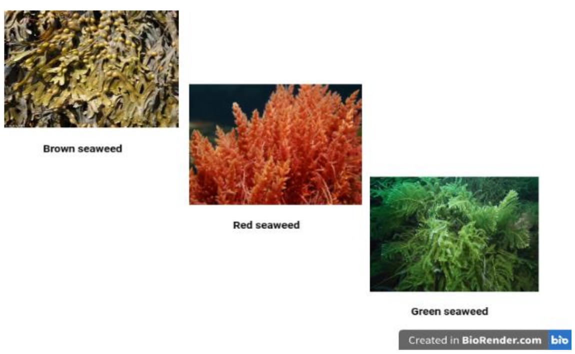

Figure 2: Three Types of Seaweed

Table 01: Seaweed Hydrocolloids

Seaweed hydrocolloids	**Properties**	**Applications**	
Carrageenan	Gelling Agent Thickening Agent Stabilizer Water-binding Capacity	Stabilizer and thickener in dairy products Enhances water retention Improves the texture and shelf life of bakery items Emulsifier and stabilizer in cosmetic	(67)
Agar	Gel Formation at Low Temperatures Thermoreversible Gelation	Culture medium in laboratories Gelling agent in confectionery	(69, 70)
	Clarity and Transparency	Biotechnolgy	
Alginate	Gel Formation in the Presence of Calcium Ions Viscosity and Thickening **Film forming capacity** Compatibility with a	Thickening and gelling agent For Encapsulation of drugs Printing and dyeing agent	(71, 72)
Ulvan	Antioxidant Activity Antimicrobial Properties Immunomodulatory Effects	Food Industry Biomaterial for tissue engineering Potential use in wastewater treatment	(73)

5. Future Perspective

Working with waste Sargassum natans to create an alginate biofilm demonstrates how alginate composite films were found to have better optimal parameters, higher water vapor permeability, and comparable material properties when compared to commercial high-density polyethylene, polyethylene tetra-phthalate, and polylactic acid. Additionally, their findings demonstrate that the alginate component does not transfer contaminants and breaks down in simulated compost after 14 days, indicating that it is a safe alternative for food packing in low-humidity situations (74).

However, the applications of films made of alginate and other biopolymers including agar, starch, chitin and chitosin are restricted because of their high water solubility and adequate mechanical qualities. These days, alginate hydrogels are widely used in commerce, although their mechanical properties are not very good, especially when water is used for their hydration (75–77). The electrical and thermal condutivity of these are extremely low, very weak cell binding activity, and no antibacterial activity—all of which are essential for a number of cuttingedge applications, such as tissue engineering. Therefore, there is even more room for application for this biopolymer in the fields of biological functionality both in vitro and in vivo, mechanical performance, electrical or thermal behavior, water sorption and diffusion,antibacterial activity and porosivity are critical to the biomedical industry and other sectors (78–86). If these undesirable traits are improved, then this can happen. Therefore, improving the alginate's chemical, physical and biological characteristics in conjunction with other materials has been the aim of a great deal of research (87, 88).

6. Conclusion

Seaweed has been ingested by humans for thousands of years, but only recently have we been able to completely understand the potential and mechanisms of action of the bioactive chemicals obtained from seaweed (1). Alginate has been determined to be the best method after a thorough investigation of several seaweed varieties in the context of bioplastic synthesis. It was investigated by a thorough analysis of the many characteristics of different seaweeds, carefully considering elements like biodegradability, mechanical strength, and application. All the data points to alginate's superiority since it combines a special set of favorable properties for the development of bioplastics. Because of its natural biocompatibility, availability, and adaptability, alginate is a perfect biomaterial for creating bioplastics that are both ecologically benign and sustainable. This finding highlights the potential of alginate to further ecologically friendly bioplastic solutions and opens the door for further advancements in eco-friendly materials research.

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