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Marine Polysaccharides and their Potential in Agriculture

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REVIEW ARTICLE

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ABSTRACT

Polysaccharides are polymers composed of monosaccharides linked by glycosidic bonds and are widely found in microorganisms, animals, algae, and plants. Some species of microalgae have naturally high carbohydrate concentrations. Polysaccharides derived from algae are safe, biocompatible, biodegradable and stable. These polymeric macromolecules have different complex biochemical structures according to the type of algae and microalgae. Microalgal polysaccharides are mainly composed of pentose and hexose monosaccharide subunits with various glycosidic linkages. Microalgae polysaccharides can be structural components of the cell wall, energy reserves or protective polysaccharides. Today, the industrial use of microalgae polysaccharides is increasing. These microorganisms and the compounds extracted from them have wide rheological and biological properties that make them a suitable option for use in food and agriculture industries. Therefore, microalgal polysaccharides are suitable alternatives for wide applications and the choice of microalgal species depends on the required functional activity. This paper aims to provide an overview to identify the potential of algal polysaccharides for agricultural applications.

KEYWORDS: *Biopolymer, Microalgae polysaccharides, Macroalgal polysaccharide, Plant resistance.*

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1. BACKGROUND

There are three important families of biopolymers, which are: protein, nucleic acid and polysaccharides (Torres *et al*., 2019). Polysaccharides are the most abundant carbohydrates in nature and can be obtained from plants, animals and microbes (Altaf *et al*., 2020). Polysaccharides are macromolecules with monosaccharide units that are connected to each other through glycosidic bonds and have unique properties that distinguish them from other families of biopolymers (Seidi *et al*., 2022; Hojjati *et al*., 2022). These biological molecules are abundant in nature and can be extracted from algal (alginate), plant (pectin), microbial (dextran) and animal (chitosan) sources (Barber *et al*., 2020) Depending on the type of constituent units, polysaccharides may be homopolymers or heteropolymers, contain anionic or neutral sugars (pentose and hexose), and may also contain non-sugar compounds (Jindal and Khattar, 2018). According to different sources of biomolecules, a significant difference can be seen in their chemical nature and characteristics. These molecules consist of linear, branched, cationic, anionic and neutral polysaccharides, they are renewable, non-toxic, biodegradable and relatively cheap (Dheer *et al*., 2017). In recent years, polysaccharides have attracted the attention of researchers due to the health benefits of their respective bioactive compounds. They have shown various biological effects, including prebiotic, hepatoprotective, antidiabetic, anticoagulant, antitumor, antiviral, immunomodulatory and anti-inflammatory, hematopoietic, antioxidant, and blood lipid profile modification (Tadayoni *et al*., 2015; Sorourian *et al*., 2020). Among aquatic organisms, seaweed has long been used as a renewable food source worldwide, specially in Asian countries such as China, Japan, and Korea. The low content of saturated fats, high amounts of carbohydrates, low calories, as well as biological properties such as antioxidant, antiviral, antibacterial, and antifungal have made seaweed a suitable option for the food and pharmaceutical industry (Ghanavati *et al*., 2022). Marine organisms are rich sources of structurally diverse biologically active compounds such as: fatty acids, polysaccharides, essential minerals and vitamins, enzymes, pigments and peptides with promising cosmetic potential. Their possible exploitation in order to obtain valuable chemicals is an important scientific challenge and ethical issue, specially in the current period of strong economic, food and the environmental crises around the world. Macroalgae have a lot of biomass, most of the algae biomass that is naturally produced and harvested is decomposed on the beach and many problems are created through their waste (Massironi *et al*., 2020). Nevertheless, algae can be an ideal source of renewable biological materials. Their current use is mainly limited to food consumption, however, they are considered as a renewable and sustainable raw material of bioactive molecules such as fatty acids, proteins and specially polysaccharides. Therefore, they have good potential for use. The amount of bioactive molecules in them can reach 70% of the total dry weight (Ruocco *et al*., 2017). Most of the seaweed polysaccharides obtained from green (ulvan), brown (fucoidan and alginate) and red (carrageenan) algae are the basic structural components of the plant cell wall. These natural polymers are currently classified as dietary fibers because they cannot be digested by the human metabolism. However, dietary fibers have many beneficial effects on human health, such as reducing the risk of colon cancer, hypercholesterolemia, and diabetes (Massironi *et al*., 2020).

2. OBJECTIVES

This paper aims to provide an overview to identify the potential of algal polysaccharides for agricultural applications.

3 .EVIDENCE ACQUISITION

This research was conducted based on the published findings of valid scientific research.

4. RESULTS AND DISCUSSION

4.1. *Chitosan*

Chitosan is a semi-synthetic polysaccharide that is obtained through the deacetylation of chitin, the main component of the exoskeleton of crustaceans such as crabs and shrimps. This polysaccharide is a copolymer of D-glucosamine linked through a β-(1,4) bond (deacetylated unit) and N-acetyl-D-glucosamine (acetylated unit). Chitosan has been widely exploited in the field of biomedicine due to its antimicrobial activity against pathogenic bacteria (Dash *et al*., 2011). The antimicrobial activity of chitosan has made it an excellent additive for product preservation and food packaging, and it is currently used as a coating layer or nanostructure system (Shahidi *et al*., 1999). Chitosan nanoparticles are usually prepared through electrostatic interaction between amine groups of chitosan and negatively charged groups of polyanions such as tripolyphosphate.

4.2. *Alginate*

Alginate is obtained from brown algae such as: *Laminaria* spp, *Ascophyllum nodosum* and *Ecklonia maxima*. Chemically, alginate is an anionic copolymer of β-4,1-D-mannuronic acid and α-L-glucuronic acid (Massironi *et al*., 2020). Alginate has unique thickening and coating properties, so that it forms a gel in contact with water, and is therefore widely used for use in the food and pharmaceutical industries (Gheorghita Puscaselu *et al*., 2020). In the food industry, alginate macroscopic grains are produced without the need for laboratory equipment by pouring the alginate-water suspension into a solution of divalent cations (usually $CaCl_2$). However, the gelation technique allows the development of structures even at the micro/nano scale by optimizing the reaction conditions. Active agents can be easily loaded into alginate nanoparticles by adding them to the reaction mixture (Massironi *et al*., 2020).

4.3. *Sulfated polysaccharidesV*

Among seaweed polysaccharides, sulfated polysaccharides have emerged as a promising biomaterial for the preparation of edible and biocompatible micro/nanostructures (Wijesekara *et al*., 2011). The use of sulfated polysaccharides as emulsifiers has not been investigated yet due to their high hydrophilicity that disrupts their interaction with hydrophobic molecules (Massironi *et al*., 2020). However, the high content of bound proteins in their chemical structure and the presence of several hydrophobic groups can cause the formation of stable oil in aqueous emulsions. Carrageenan extracted from red algae is used as an emulsion stabilizer due to its gelling and thickening properties (Sudha *et al*., 2014). According to the studies, fucoidans obtained from brown seaweeds are compared to carrageenan, they show stronger emulsifying properties (Massironi *et al*., 2020). In addition, a new study has shown the strong antioxidant activity of fucoidan (Mak *et al*., 2013). These antioxidant properties seem to be strongly related to molecular weight, degree of sulfation and position of sulfated groups (Saravana *et al*., 2020). In addition, stronger antioxidant activities have been observed in cases with higher polyphenol and protein content in crude extracts (Hifney *et al*., 2016). Such features create new opportunities to use it to preserve bioactive molecules prone to degradation caused by oxidizing agents. Recently, ulvan, which is a sulfated heteropolysaccharide extracted from edible green algae belonging to *Ulva* spp, has shown biphilicity due to its polymer structure containing hydrophilic (hydroxyl, sulfate, and carboxyl) and hydrophobic (methyl) groups. It has been reported that it is used as an emulsifier to develop emulsions for food and cosmetic applications (Shao *et al*., 2016). Investigations have shown that the activity of ulvan surfactant as an emulsion stabilizer is increased by the high protein part and it has been reported that this surfactant is stably attached to the polysaccharide structure even after the extraction process (Chiellini *et al*., 2011). In addition, ulvan polysaccharide shows antioxidant activity similar to fucoidan, which is proportional to the sulfate content. Due to the worldwide availability of this material, sulfated polysaccharides obtained from algal biomass is one of the most important categories of renewable polymers with promising potential in several research fields (Massironi *et al*., 2020).

4.4. *Microalgae polysaccharides*

Through photosynthesis, microalgae convert CO_2 or other inorganic (bicarbonate) or organic (industrial and domestic wastewater) carbon sources into carbohydrates, lipids, and proteins, among other bioactive metabolites (Yi *et al*., 2021; De Morais *et al*., 2020). Carbohydrates can make up 15 to 75% of dry biomass (Patel *et al*., 2023). Some species can produce large amounts of polysaccharides, while others must be exposed to cellular stress conditions to synthesize these compounds (Yi *et al*., 2021). However, stimulation of carbohydrate synthesis can reduce biomass production (Markou *et al*., 2012). Polysaccharides are polymeric carbohydrate macromolecules with complex structures that are different (structurally and biochemically) in each type of microorganism. Xylose, galactose, glucose, rhamnose and mannose are the constituent monomers of polysaccharides synthesized by microalgae (Yi *et al*., 2021; Chanda *et al*., 2019). In microalgae, polysaccharides are mainly found as structural polymers (which form part of the cell wall) or energy storage polymers for various metabolic processes, in addition to exopolysaccharides (Yi *et al*., 2021; Markou *et al*., 2012; Morais *et al*., 2022). The main advantages of using polysaccharides or any biomolecule as a source of microalgae are: production takes place throughout the year, biomass harvesting does not depend on weather conditions or season, growth is fast, and cultivation is relatively simple compared to plants. (De Carvalho Silvello *et al*., 2022; De Jesus Raposo *et al*., 2013). Microalgae can be cultivated with solar energy, waste water and exhaust gas as a source of nutrients and does not require arable land. In addition, microalgae-based carbohydrates are easily converted to sugars and require less treatment than other sources (Chen *et al*., 2013). Microalgal polysaccharides have advantages over other polysaccharide sources (land plants, crustaceans, and fungal cell walls) such as safety, stability, biocompatibility, and biodegradability (Patel *et al*., 2023; Kazachenko *et al*., 2021). The functional activity of polysaccharides depends on monosaccharides, their molecular weight and degree of sulfation. Therefore, the choice of microalgae species to be cultivated depends on the final application of the biomolecule. In addition, cultivation conditions can be adapted according to production needs (Chanda *et al*., 2019).

4.5. *Applications of polysaccharides obtained from microalgae*

Microalgae are promising alternatives to obtain polysaccharides while helping to reduce environmental pollution produced by industrial wastes (Costa *et al*., 2021). Microalgae usually grow faster than land plants and do not need fertile land for cultivation. The efficiency of microalgae for carbon fixation is 10 to 50 times that of plants. Microalgae help reduce greenhouse gases by absorbing carbon dioxide from industrial processes. They can grow in fresh water, sea salt water and sewage (Patel *et al*., 2023). Microalgae polysaccharides have rheological and biological properties for application in food and sustainable agriculture fields. In the study conducted on the functional properties of polysaccharides and ethanolic extracts of *Spirulina platensis*, it was observed that both extracts affected the probiotic growth and had high concentration phenolic compound. Also, both extracts showed significant scavenging ability against of DPPH and OH radicals (Habibi *et al*., 2024).

4.6. *Sustainable agriculture*

Agricultural chemicals such as pesticides and fertilizers contain toxic elements and pollute food, soil and water. These pollutions can cause numerous environmental consequences on global biodiversity. Agricultural systems that aim to replace synthetic materials such as chemical fertilizers prevent environmental damage and contribute to sustainable agriculture. Due to the increasing demand to reduce the use of chemical compounds in agriculture, polysaccharides and oligosaccharides are considered as suitable alternatives due to their biological properties. In this regard, compounds of biological origin such as biofertilizers, biostimulants and biopesticides are important (Costa *et al*., 2019; Renuka *et al*., 2018). Microalgae play various roles in agriculture. One of the activities of microalgae in agriculture is its ability to improve plant and soil properties and reduce the environmental effects produced by chemical fertilizers (Alvarez *et al*., 2021; Stirk and Van Staden, 2020). Polysaccharides from microalgae are potential biostimulants of plants to protect against biotic and abiotic stresses (Rachidi *et al*., 2020). Enrichment of soil and plants through microalgae is related to the release of bioactive substances (vitamins, amino acids, polypeptides, antibacterial or antifungal substances, phytohormones and polysaccharides) (Alvarez *et al*., 2021; Stirk and Van Staden, 2020). The release of polysaccharide materials has been reported to be effective for increasing the rate of germination and biomass accumulation in vascular plants. Exopolysaccharides of cyanobacteria and microalgae can maintain soil moisture through water retention. Studies have shown the potential of these molecules to stimulate different metabolic pathways in plants, helping their growth and development. In the study conducted on the crude extract of polysaccharides from three leafy microalgae of *Solanum lycopersicum,* it was observed that the use of 1 mg.ml^{-1} of polysaccharide from *Arthrospira platensis, Dunaliella salina* and *Porphorydium* sp in tomato plants significantly increased the number of nodes, dry weight of aerial organs and length of stems. 75, 46.6 and 25.26% improved compared to the control. In addition, treatment with crude polysaccharides increased the concentration of carote\noids, chlorophyll and proteins (Rachidi *et al*., 2020). Another study reported that exopolysaccharides extracted from *Phaeodactylum tricornutum* and *Dunaliella salina* stimulate pepper germination under salt stress conditions. In addition, the exopolysaccharides obtained from *Dunaliella salina* showed the potential to stimulate the germination, growth and tolerance of tomato and wheat plants under salt stress. Some polysaccharides may have antifungal activity and act as a biopesticide in plant products (Righini *et al*., 2019). Microalgal polysaccharides, such as alginate, lead to plant resistance by increasing the activity of several defense-related enzymes. Sodium alginate can be used to improve seed germination, increase stem length, root growth and resistance to plant pathogens. In laboratory studies, polysaccharide extracts obtained from *Anabaena* sp and *Ecklonia* sp. It inhibited the growth of *Botrytis cinerea* colonies. Polysaccharides from *Anabaena* sp., *Ecklonia* sp., and *Jania* sp., reduced the fungal infection level in strawberry fruits, indicating that they can be good crop protection compounds when used in preharvest treatment (Rachidi *et al*., 2020). The presented studies show the high potential of microalgae polysaccharides in agriculture. Polysaccharides help plant growth and protect plant products from pollutants. Therefore, these compounds have a high potential to be used as alternatives to chemical fertilizers and pesticides for sustainable agriculture.

4.7. *Challenges and opportunities*

Microalgae polysaccharides are used in several fields, including human and animal nutrition and agriculture. These macromolecules have been studied and identified for several decades. However, compared to other microorganisms such as bacteria, algae, and macroalgae, its commercial application is limited due to less biomass production (Delattre *et al*., 2016). Studies involving different strategies have been conducted to increase the production of polysaccharides by microalgae (Sasaki *et al*., 2020; Medina-Cabrera *et al*., 2020). However, the production process has challenges that prevent the stability of producing exopolysaccharides for commercial application. The main limitations of these microorganisms are the high operational costs of production related to the culture medium, CO_2 addition, electrical energy consumption and biomass recycling steps (Delattre *et al*., 2016; Colusse *et al*., 2022). New alternatives can reduce nutrient costs of the culture medium, such as using wastewater as a source of nutrients in microalgae culture (Kumar *et al*., 2020; Song *et al*., 2020). In this sense, strategies aimed at increasing the biomass yield of microalgae cultures can balance the costs related to the recovery phase. In addition, it is interesting to investigate microalgae strains that provide higher yields of polysaccharides. The nature of the macromolecules produced must also be known. The use of nanotechnology processes to develop polysaccharide-based products can also impact the food, health, and beauty markets (Morais *et al*., 2022). Considering the above, more research on microalgae cultivation should be done to improve the production of polysaccharides and make this process more economically viable. Therefore, new approaches are very important for the development of this process, such as optimizing the culture conditions/design of photobioreactors and replacing culture media with domestic or industrial wastewater (Colusse *et al*., 2022).

5. CONCLUSION

Microalgae are novel and alternative sources to obtain stable and functional polysaccharides. These microorganisms have a photosynthetic nature and the ability to use industrial waste as nutrients. The properties responsible for the physiological effects and/or biological functions of microalgae polysaccharides are due to the diversity of structures and biochemical compositions of these molecules. The potential applications of microalgae-based polysaccharides in food, packaging and agriculture are significant. So new production strategies and conditions must be developed to increase cell growth rates, biomass production, and polysaccharide yields. Also biotechnological steps for the production of these compounds should be optimized for large-scale production and expand market competition. Therefore, the use of microalgae as a source of functional and stable polysaccharides in the agricultural applications can improve global food security and reduce environmental problems caused by the expansion of agricultural production.

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