Biopresspecting Algal Biomolecules: Extraction of Polypeptides and Polysaccharides for Cosmeceutical and Therapeutic Applications

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Abstract
The present work reports the extraction of protein-polysaccharide extracts from brown algae (A.nodosum and S.latissima) for potential food industry applications. A sequential extraction method was employed to maximize yields by incorporating ultra sound, pH adjustment, and enzymatic treatment. It is fundamentally about sidestepping the feeling of starting. Traditional extraction techniques have been replaced more often than not by sustainable techniques such as enzyme-based extraction, ultrasound-assisted extraction, microwave-assisted extraction, and supercritical fluid extraction, all of which ensure efficient extraction, maintain bioactivity, and minimize the environmental burden. This literature review presents the bio prospecting prospects of algal bio molecules, classification of algae and their bioactive compounds, sources and structural features of algal polypeptides and polysaccharides, biomass pre-treatment, and new extraction techniques. In addition, the increasing use of algal bio molecules in cosmetics and drugs is also considered in this review in the light of the challenges being faced due to large-scale production and commercialization of algal molecules.

Keywords: Algae; Bio prospecting, Polypeptides, Polysaccharides, Bio molecule extraction, Cosmeceuticals, Therapeutics, Bioactive compounds, Brown algae, green extraction technologies.

1. Introduction

The increasing need for sustainable and eco-friendly bio-resources has raised the popularity of marine and freshwater algae as potential sources of high-quality bio molecules. Algae belong to a diverse category of photo-synthesizing organisms, which include both microalgae and macro algae that thrive in different aquatic ecosystems and possess a great variety of metabolic pathways. The advantages of fast-growing rates, biomass productivity, land independence, and carbon dioxide utilization make algae very promising candidates for sustainable biotechnology (Shannon & AbuGhannam, 2019; Zerrifi et al.). The various bioactive compounds include polypeptides and polysaccharides, which have received immense interest due to their multiple properties and biological functions. The polypeptides obtained from algae through protein extraction and enzymatic hydrolysis process have exhibited various biological functions like ant oxidative, antihypertensive, antimicrobial, anti-inflammatory, and anti-cancer properties (Apone et al., 2019). Also, algal polysaccharides such as alginate, fucoidan, laminar in, carrageen an, agar, and ulvan have unique chemical and physical properties and also have functions like moisturizing, immunomodulatory, antiviral, wound healing, and drug delivery properties (Wijesekara et al., 20. Bio prospecting, which is understood to mean the search for commercially valuable compounds using biological resources, has been one of the key ways through which novel compounds from algae have been discovered for application in cosmetics, pharmaceuticals, nutraceuticals, and biomedicine. The development in marine biotechnology and analytical technologies has resulted in the identification of various bioactive compounds in algae such as proteins, peptides, polysaccharides, pigments, polyphenols, lipids, and secondary metabolites (Rajauria & AbuGhannam, 2020; Cotas et al., 2021). Bioactivities of these molecules are significantly affected by the following factors: molecular structure, level of sulfation, molecular weight, and conditions of extraction. The traditional approaches to molecule extraction, which include hot water extraction and acid/alkali-assisted extraction, consume a large amount of energy, while the integrity of molecules might be affected during this process (Fernando et al., 2019; Rajauria & Abu-Ghannam, 2020). Thus, sustainable extraction technologies are becoming popular nowadays. The cosmetics industry has increasingly utilized algae-derived molecules in their formulas due to their ability to retard aging processes, offer photo-protection, hydration, and promote regeneration of skin cells (Ariede et al., 2017; Cotas et al., 2021). At the same time, algal polypeptides and polysaccharides are used for more therapeutic purposes because of their antimicrobial, ant oxidative, immunomodulating, and anticancer properties (Wijesekara et al., 2011; Muhamad et al., 2019). Nevertheless, problems with variability, scaling, standardization, regulatory approval, and stability need to be overcome in order to allow commercial application of such products (Zerrifi et al., 2023).

2. Bio prospecting of algal biomass:

Bio prospecting is the process of exploration, identification, and exploitation of biological sources for the discovery of new chemicals that can be exploited commercially and industrially. Primary and secondary metabolites produced by marine and freshwater algae include proteins, peptides, polysaccharides, pigments, lipids, polyphenols, vitamins, and minerals. Many of these metabolites possess biological properties that are useful for pharmaceutical, cosmetics, nutraceutical, and biomedical industries (Shannon & Abu-Ghannam, 2019; Rajauria & Abu-Ghannam, 2020). With the incorporation of green extraction processes and biorefining in sustainable bioprospecting practices, the industrial prospects of algal bio molecules have been enhanced further.

Efficient extraction procedures, such as enzyme-assisted extraction, ultrasound-assisted extraction, microwave-assisted extraction, and supercritical fluid extraction, have contributed to effective recovery and conservation of bioactive compounds without any harmful effects on the environment (Pinto et al., 2022). Algal bio prospecting, therefore, plays an important role in the production of eco-friendly products and represents an approach to moving towards the bio economy and blue biotechnology.

3. **Classification of algae and their bioactive constituents:**

Algae represent a varied polyphyletic category of photoautotroph's found in marine, fresh water, and terrestrial habitats. Algae can be grouped into microalgae and macro algae depending on their cellular structure. Microalgae consist of unicellular or colonial cells while macro algae consist of multicellular forms like seaweed. The taxonomic system usually focuses on pigmentation, storage materials, cell wall type, and morphology. Generally, there are three main classes of macro algae; these are Green algae (Chlorophyta), Brown algae (Phaeophyceae in division Ochrophyta), and Red algae (Rhodophyta). Chlorophytes mainly have chlorophyll a and b pigments and store starch as the reserve material. Phaeophytes have chlorophyll a and c along with the accessory pigment fucoxanthin which causes their brownish coloration. Rhodophytes have chlorophyll and phycobiliproteins including phycoerythrin and phycocyanin to capture light efficiently in deep aquatic regions. Examples of microalgae are diatoms (Bacillariophyta), dinoflagellates (Dinophyta), euglenoids (Euglenophyta), and cyanobacteria. Algae have emerged as sustainable producers of bioactive substances with a wide range of applications in the nutraceutical, pharmaceutical, cosmetic, and functional food industry (Lafarga & Acién-Fernández, 2025; Otero et al., 2026). The primary groups of bioactive substances produced by algae include polysaccharides, proteins, peptides, lipids, pigments, polyphenols, vitamins, minerals, and sterols (Khalid et al., 2026; Mayer et al., 2022). Examples of bioactive polysaccharides are sulphated fucoidan isolated from brown algae, carrageenans and agar extracted from red algae, and ulvans found in green algae, which are antioxidants, anticoagulants, antiviral, immunomodulators, and anticancer agents (Hakim & Patel, 2020; Lopes et al., 2024). Proteins and Algae have emerged as sustainable producers of bioactive substances with a wide range of applications in the nutraceutical, pharmaceutical, cosmetic, and functional food industry (Lafarga & Acién-Fernández, 2025; Otero et al., 2026). The primary groups of bioactive substances produced by algae include polysaccharides, proteins, peptides, lipids, pigments, polyphenols, vitamins, minerals, and sterols (Khalid et al., 2026; Mayer et al., 2022). Proteins and bioactive peptides of algae demonstrate antihypertensive, antimicrobial, and antiinflammatory activity (Mayer et al., 2022; Otero et al., 2026).

4. **Algal polypeptides: sources and structure:**

Algae have been discovered as sources of sustainable and renewable biomolecules owing to their fast growth and high productivity. Out of all the biomolecules derived from algae, algal polypeptides have become of great interest owing to their broad biological activities and uses in various nutraceutical, pharmaceutical, cosmetic, and functional food products. Algal polypeptides are small peptide chains obtained from native algal proteins by enzymatic degradation, fermentation process, chemical means, or gastrointestinal digestion. These peptides are sometimes called bioactive peptides or cryptides, which become active after the hydrolysis of the parent proteins (O'Connor et al., 2022).

4.1 Sources of algal polypeptides:

The sources of algal polypeptides include microalgae and macro algae (seaweeds). The protein content varies from species to species and based on the environmental condition and the method used to cultivate and extract them.

4.2 Microalgae

Microalgae are characterized by high protein content (ranging from 40% to 70%). Some important microalgal sources include *Chlorella vulgaris, Arthrospira platensis* (also called *Spirulina*), *Dunaliella salina, Nannochloropsis spp., Tetraselmis spp.*, and *Isochrysis galbana* (O'Connor et al., 2022). *Chlorella vulgaris* contains a high number of proteins, which act as precursors of antioxidative and anti-hypertensive polypeptides. *Spirulina* is a well-known protein source and also has phycobiliproteins that form antioxidative, immunomodulating, and antimicrobial peptides (Becker, 2013).

4.3 Structure of algal polypeptides

polypeptides usually consist of Polypeptides Structure in Algal polypeptides of 2–20 amino acids and have molecular weights less than 3 kDa, even though some peptides with higher molecular weights were identified. Biological activities of algal polypeptides are strongly related to the amino acid content, sequence, length, molecular weight, and structure. Many bioactive algal peptides contain abundant amounts of hydrophobic amino acids like leucine, valine, alanine, phenylalanine, proline, and isoleucine. The presence of aromatic amino acids, namely tyrosine, tryptophan, and phenylalanine, is very important for antioxidant properties due to electron donation and free radical scavenging abilities (O'Connor et al., 2022). Positively charged amino acids like lysine, arginine, and histidine increase the chances of interaction with the negative charges of the microbial cell membrane and have antimicrobial effects. In addition, antihypertensive peptides often contain hydrophobic amino acids in the C-terminus and have the ability to inhibit the angiotensin-converting enzyme (ACE) (Sathasivam et al., 2024). It is evident from the study on the structure-activity relationship of algal peptides that small peptides tend to have higher biological effects because of better absorption and target interactions (O'Connor et al., 2022).

5. **Algal polysaccharide sources and structure:**

Algal polysaccharides are natural high-molecular-weight carbohydrates that are produced by marine and freshwater algae. They are among the important compounds of the cell wall and extracellular matrix of algae where they provide structure, protection, and energy storage roles. Due to biocompatibility, biodegradability, low toxicity, and biological activities, algal polysaccharides have been used in pharmaceuticals, nutraceuticals, cosmetics, foods, and biomedical products (Holdt & Kraan, 2011). The chemical diversity of algal polysaccharides is due to differences in the composition of monosaccharides, glycosidic bonds, molecular weight, sulfation, and branched structures. They possess different physicochemical properties based on their algal origin (Usov, 2011).

5.1 Sources of algal polysaccharides

Algal polysaccharides are primarily derived from three major groups

5.2 Macro algae

- Brown algae (Phaeophyceae).
- Red algae (Rhodophyceae).
- Green algae (Chlorophyceae).

5.3 Brown Algae (Phaeophyceae)

Brown algae are known to contain high amounts of structural and storage polysaccharides, especially alginate, fucoidan, and laminarin(figure.1). Some of the commonly occurring genera of brown algae are *Laminaria, Saccharina, Fucus, Sargassum, Ascophyllum,* and *Undaria*. Alginate makes up to 40% of the dry weight of brown algae and is a main cell wall polysaccharide, while fucoidan is found mostly in the intercellular matrix and cell walls. Laminarin acts as a storage glucan in the cytoplasm (Deniaud-Bouët et al., 2017).

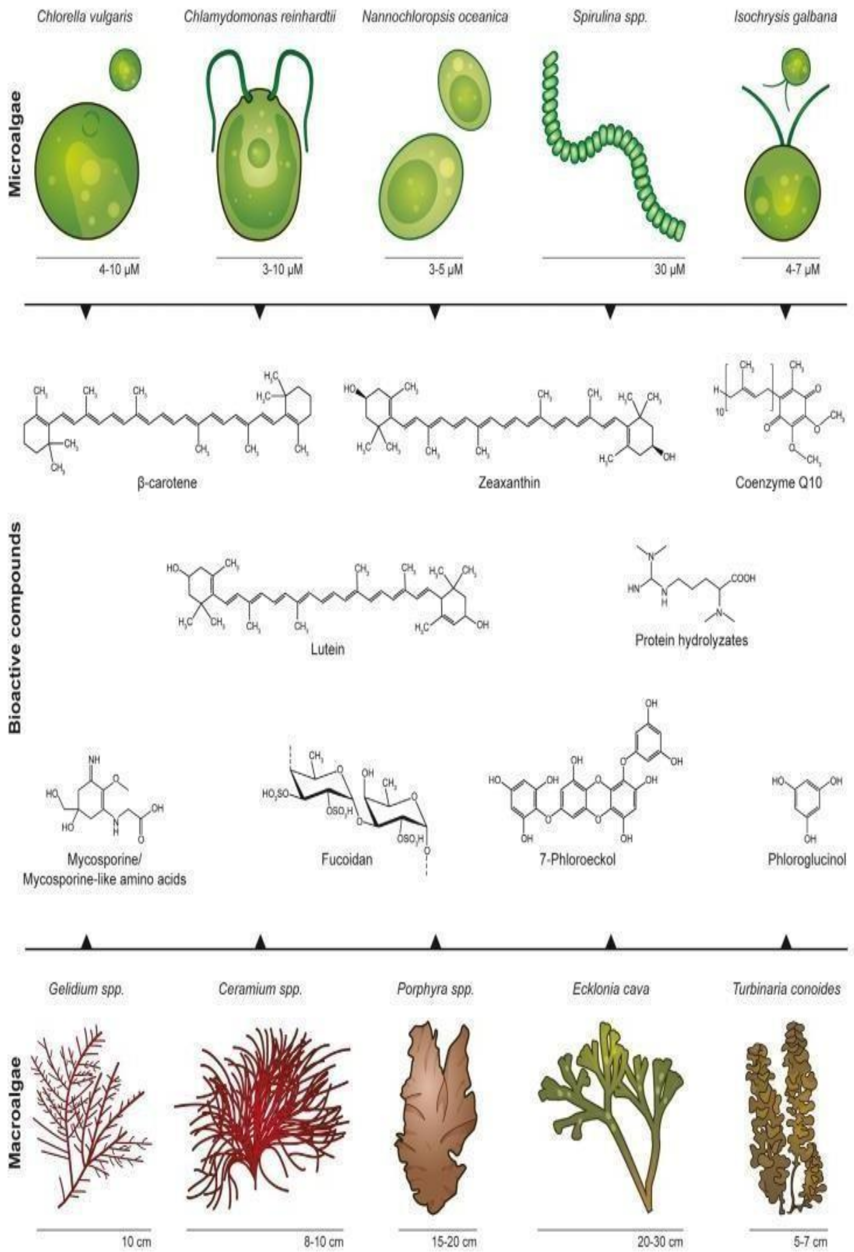

Figure 1. Bioactive ingredients in microalgae and macroalgae (Aslam*etal*.,2021)

5.4 Red Algae (Rhodophyta)

Sulfated galactans such as agar and carrageenan make red algae their main production products.

Some of the main sources of agar and carrageenan are *Gelidium, Gracilaria, Chondrus crispus, Kappaphycus alvarezii*, and *Eucheuma denticulatum*. Agar is mostly used as a gel-forming product in microbiology and food industry applications, while carrageenan is a popular stabilizer, thickener.

5.5 Green Algae (Chlorophyta)

Green algae are known to have certain sulfated heteropolysaccharides, particularly ulvan, which is isolated from species belonging to the genera *Ulva* and *Enteromorpha*. Other types of polysaccharides found in green algae are cellulose, xyloglucan, and rhamnan. Ulvan has gained much interest due to its degradability and biocompatibility (Kidgell et al.,) (table.1).

Table 1. Classification of algae, their major bioactive constituents, and industrial applications.

Algal group	Major pigments	Representative genera	Major bioactive compounds	Key applications
Green algae (chlorophyta)	Chlorophyll a, chlorophyll b.	*Ulva, enteromorpha, chlorella*	Ulvan, proteins, bioactive peptides, chlorophylls, vitamins.	Nutraceuticals, cosmetics, wound healing, functional foods.
Brown algae (phaeophyceae)	Chlorophyll a, chlorophyll fucoxanthin	*Ascophyllum, saccharina, laminaria, sargassum*	Alginate, fucoidan, laminarian, polyphenols, phlorotannins.	Drug delivery, anti-aging products, functional foods, pharmaceuticals.
Red algae (rhodophyta)	Chlorophylla, phyoerythrin, phycoerythrin, phycocyanin	*Grailaria, gelidium, porphyra, kappaphycus*	Agar, carrageenan, porphyran, phycobiliproteins,m, pigments	Food stabilizers, pharmaceuticals, cosmetics, biomedical materials
Diatoms	Fucoxanthin,	Phaeodactylum,	Eicosapentaenoic	Nutraceuticals,
(bacillariophyta)	chlorophyll a, chlorophyll c	thalassiosira	acid (EPA), polysaccharides, carotenoids, pigments	biofuels, aquaculture feed, pharmaceuticals
cyanobacteria	Phycocyanin, chlorophyll a	Arthrospira (spirulina), nostoc	Proteins, bioactive peptides, phycobiliproteins, exopolysaccharides	Functional foods, therapeutics, dietary supplements, cosmetics

5.6 Microalgae

There are some kinds of microalgae that synthesize extracellular polysaccharides with special biological activities. Among them are the genera *Chlorella, Porphyridium, Dunaliella,* and *Arthrospira (Spirulina),* which are well-known producers of sulfated exopolysaccharides (Raposo et al., 2013). Polysaccharides from microalgae display a wide range of biological activities like antiviral activity, antioxidative properties.

6. Structure of algal polysaccharides

6.1 Alginate

Alginate is an anionic polysaccharide, which consists of linear chains containing β-D-mannuronic acid (M) and α-L-guluronic acid (G) units connected by β-(1→4) glycosidic bonds. The monomers are arranged in blocks of homopolymers M, G, and MG (Draget et al., 2005).The amount and arrangement of mannuronic and guluronic acid residues have a profound effect on the physical and chemical properties of alginate such as gel strength, viscosity, and cation binding affinity (Draget et al., 2005).

6.2 Fucoidan

Fucoidan is a sulfated heteropolysaccharide characterized by the predominance of L-fucose residues and sulfate ester groups. Small quantities of galactose, xylose, mannose, and glucuronic acid residues can be present in some algae species (Li et al., 2008). Fucoidan molecules usually consist of α-(1→3)-linked L-fucopyranose residues or alternately linked residues α-(1→3) and α-(1→4) with varying degrees of sulfation (Li et al., 2008).

6.3 Laminarin

Laminarin is a storage polysaccharide from brown algae that is predominantly made up of β-(1→3)- D-glucan chains with β-(1→6) side branches. This polysaccharide contains 20–30 units of glucose and can be found either as G-type or M-type laminarin based on the terminal residue (Rioux et al., 2007). Low molecular mass along with a branched nature is responsible for high solubility and activity of laminarin.

6.4 Carrageenan

Carrageenan refers to a family of linear sulfated galactans produced by red algae. Carrageenan contains alternating units of β-D-galactose and α-D-galactose or 3,6-anhydro-α-D-galactose linked through β(1→4) and α-(1→3) glycosidic bonds (Campo et al., 2009). There are three types of carrageenans: κ-carrageenan – one sulfate group in each disaccharide repeat unit; ι-carrageenan – two sulfate groups in each disaccharide repeat unit; and λ-carrageenan – three sulfate groups in each disaccharide repeat unit.).

6.5 Agar

It is mostly derived from Gelidium and Gracilaria species and is made up of two fractions, namely agarose and agaropectin. Agarose is the neutral fraction while agaropectin is the heterogenic sulfated fraction (Usov, 2011).The agarose backbone is made up of alternate β-D-galactose and 3,6-anhydroαL-galactose units which are joined together via β-(1→4) and α-(1→3) glycosidic linkages.

6.6 Porphyran

Porphyran is a sulfated galactan which is isolated from Porphyra species. Chemically, porphyran is made up of repeating units of β-D-galactose and α-L-galactose-6-sulfate (Usov,2011).

6.7 Ulvan

Ulvan is the most abundant sulfated polysaccharide found in green algae of the genus Ulva. Ulvan is primarily made up of sulfated rhamnose, glucuronic acid, iduronic acid, and xylose (Lahaye & Robic, 2007).The repeating structural units of ulvan consist of ulvanobiuronic acid type A and type B, where rhamnose-3-sulfate is bound to either glucuronic acid or iduronic acid. The ulvan has a highly branched structure, hence the varied biological activities that it possesses (Lahaye & Robic, 2007).

7. Pretreatment of algal biomass for molecule recovery

7.1 Biomass harvesting and dewatering

Harvesting and dewatering are initial pretreatment stages, which greatly affect the effectiveness of further processing. Due to the fact that biomass concentration in algae cultures is typically quite low, considerable amounts of energy are spent on separation of biomass from the growth medium. Harvesting methods include centrifugation, flocculation, filtration, flotation, and settling. The choice of harvesting procedure depends on the type of algae, size of cells, biomass concentration, and final products desired (Barros et al., 2015). Dewatering helps to decrease the amount of water and energy consumption in further drying and extraction stages.

7.2 Drying method

Drying can be used to increase the stability of biomass as well as make it easy to store. Traditional techniques of drying include sun drying, oven drying, spray drying, drum drying, and freeze-drying. Of all the techniques mentioned above, the best technique when dealing with temperature sensitive biomolecules like pigments, proteins, and polyunsaturated fatty acids is the technique of freezedrying, which is expensive. The cheap alternatives are oven drying and spray drying, but they may lead to the destruction of sensitive molecules by heat (Vandamme et al., 2013).

7.3 Mechanical pretreatment methods

Mechanical methods include the physical breaking of algal cells and enhanced access to internal metabolites.

7.4 Bead Milling

The bead mill process includes the contact of biological material with beads due to high-speed agitating conditions. The method is popular among robust species of microalgae because no chemicals are required (Lee et al., 2017).

7.5 High Pressure Homogenization

In high pressure homogenization, an algal suspension is forced through a valve under high pressure, resulting in cavitation and turbulence that break the cell wall (Kim et al., 2013).

7.6 Ultrasonication

The ultrasonic process makes use of high-frequency sound waves to produce bubbles of cavitation that burst near the surface of the cells to facilitate cellular destruction (Chew et al., 2017).

7.7 Pretreatment Using Microwaves

The microwave treatment causes a fast heating effect of the water molecules inside the cells to create an internal pressure, causing cell destruction (Postma et al., 2015).

7.8 Chemical Pretreatment Techniques

Chemical pretreatment involves changing or dissolving cell wall components to help in extracting biomolecules.

7.9 Acid Pretreatment
Diluted acids like hydrochloric acid and sulfuric acid degrade polysaccharides and break down cell walls. Acid pretreatment is especially useful in extracting carbohydrates, though it can lead to degradation of sensitive molecules if strong methods are used (Kim et al., 2013).

7.10 Alkaline Pretreatment
Alkaline pretreatment, using sodium hydroxide, breaks down ester linkages and dissolves polysaccharides in the cell wall, making protein and carbohydrate extraction easier (Lee et al., 2017).

7.11 Solvent Pretreatment
Polar and non-polar organic solvents such as ethanol, methanol, hexane, and acetone are employed in breaking down cell membranes and separating target molecules from cells. The solvent type used in pretreatment is based on the polarity and stability of the biomolecules of interest (Chew et al., 2017).

7.12 Ionic Liquids and Deep Eutectic Solvents
Ionic liquids and deep eutectic solvents are environmentally friendly solvents that have shown great success in breaking down algal biomass.

8. Cosmetics application of algal biomolecules
Algal bioactive molecules have been found to be quite useful natural ingredients for cosmetic and cosmeceutical products owing to the range of biological activity, biocompatibility, biodegradability, and sustainability associated with their production process. Macroalgae and microalgae represent a great source of polysaccharides, proteins, peptides, lipids, pigments, polyphenols, vitamins, minerals, and sterols possessing a broad spectrum of functions useful for the development of skin and hair care formulations. Sulfated polysaccharides, including fucoidan, carrageenan, alginate, and ulvan, have become popular moisturizers, thickeners, film formers, and anti-aging agents thanks to their properties allowing increasing skin hydration, improving skin elasticity, stimulating collagen synthesis, and decreasing water loss through epidermis. Algal proteins and bioactive peptides possess antioxidant, anti-inflammatory, and collagen stimulating properties that aid in skin regeneration and wrinkles. (table. 2).

Furthermore, the lipids found in algae are full of polyunsaturated fatty acids, which help protect the integrity of the skin barrier, thereby improving hydration. Other algal components, such as astaxanthin, fucoxanthin, beta-carotene, chlorophylls, and phycobiliproteins are effective antioxidants and photoprotectants against the damage caused by ultraviolet radiation (Pimentel et al., 2018). Therefore, the phenolic compounds are used in acne treatment and skin whitening products (Shannon & AbuGhannam, 2019). Due to the multifunctional nature of the algal biomolecules, they are being increasingly used in many cosmetic products like moisturizers, anti-aging creams, sunscreens, face masks, shampoos, conditioners, and color cosmetics. Recent developments in sustainable cultivation techniques, green extraction processes, and nanotechnology can further increase the stability and bioavailability of the algal cosmetic ingredients (figure. 2).

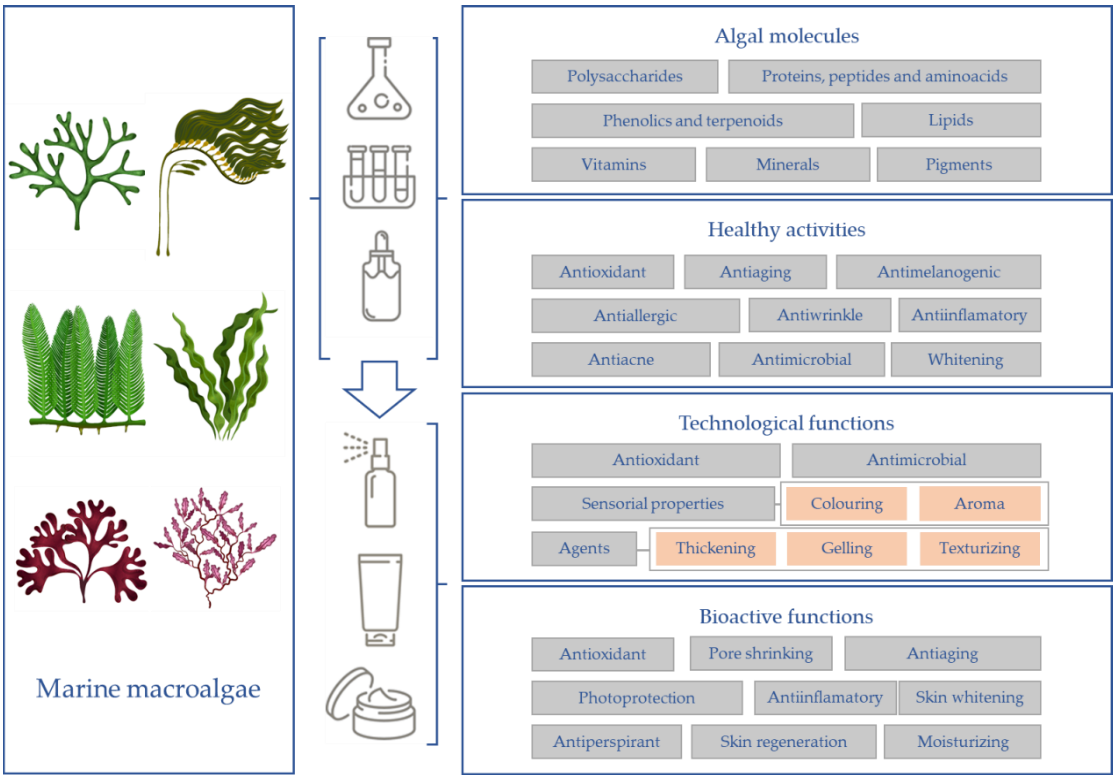

Figure 2. cosmeceutical potential of algal components.

Table 2: Algae species and their skin benefits (macroalgae,microalgae)

No.	Name of Algae	Types	Activity
1	S.japonica,Chondruscrispus, And Codiumtomentosum	Ma	Moisturizingagent
2	Chlorellavulgaris and Spirulina maxima	Ma	Antioxidants
3	SeaPalm (Postelsia palmaeformis)	-	Skin softening, anti-wrinkle, nourish moisturizing, anti-inflammatory
4	Chlorella vulgaris	Mi	de-pigmentation,anti-aging, moisturizing and thickening agent
5	T. decurrens	Ma	Antioxidantactivity
6	Chondriabaileyana	Mi	Antioxidantactivity
7	Chaelocerossp.,Monodussp., Thalassiosira sp., and Chlorococcum sp.	Mi	anti-aging
8	Ulvalactuca	Ma	Moisturizingandanti-inflammatoryagent
9	HizikiaFusiforme	Ma	Whiteningagent
10	Fucusvesiculosus	Ma	Skinsoftnessandelasticity
11	Nostocsphaericum	Mi	Antioxidant:radicalscavenging,UVprotectiv
12	Eckloniakurome, Iseniabicyclis,Ecklonia stolonifera,Hizikia fusiformis,andEckloniacava	Ma	Antioxidant
13	Tetraselmissuecica	-	Protectiveactivity
14	Laminariajaponica	Ma	SkinMoisturizingeffect
15	Ascophyllumnodusum	Ma	SmoothingagentandAnti-ageing
16	TetraselmissIsochyrsis	Mi	AntirritantandAnti-Oxidant
17	Spirulinaplatensis	Mi	AntioxidantsMoisturizingagent
18	Postelsiapalmaeformis	Mi	Anti-oxidantandAnti-inflammatoryagents
19	Mastocarpusstellatus	Mi	Stabilizingagent
20	Poryphyratenera	Ma	PhotoProtectionactivity
21	Cylindrothecaclosterium	Mi	Antioxidant
22	Padinacrassa	Ma	Antioxidant
23	Cystoseiranodicaulis	Ma	Anti-melanogenic(whitening)

9. Therapeutic applications of algal biomolecules

Increasingly, the algae are being acknowledged as important sources of chemically diverse bioactive molecules with great medicinal value. Macro-algae and microalgae contain various biomolecules like polysaccharides, proteins, peptides, lipids, pigments, polyphenols, sterols, vitamins, and minerals, all having various pharmacological activities. The unique chemical composition of the biomolecules produced by algae and their biocompatibility, biodegradability, and low toxicity has increased the interest in their use for the pharmaceutical and biomedical purpose (Holdt & Kraan, 2011). Among the algal biomolecules, the sulfated polysaccharides fucoidan, carrageenan, alginate, laminarin, and ulvan have been found to possess antioxidants, anticoagulants, antiviral, immunomodulating, antiinflammatory, and anticancer activities. The fucoidan extracted from brown algae is known to possess ant proliferative activity and to promote apoptosis, modulate immune system and to block viral binding and replication (Li et al., 2008). Similarly, carrageenan and ulvan have shown antiviral activities against various enveloped viruses by blocking the viral entry process (Cunha & Grenha, 2016).More and more attention has been paid to algae as sources of biologically active compounds of high medicinal significance. Different kinds of biomolecules such as polysaccharides, proteins, peptides, lipids, pigments, polyphenols, sterols, vitamins, and minerals are present in macroalgae and microalgae, and all these biomolecules have different biological properties. Unique chemical structure of the biomolecules synthesized by the algae, and biocompatibility, biodegradability, and nontoxicity of them have made people more interested in their utilization for pharmaceutical purposes (Holdt & Kraan, 2011).Among the biomolecules of algae, sulfated polysaccharides such as fucoidan, carrageenan, alginate, laminarin, and ulvan have been proved to have antioxidant, anticoagulant, antiviral, immunomodulating, anti-inflammatory, and anticancer properties. Fucoidan, isolated from brown algae, has been found to possess antiproliferative effect and stimulate apoptosis, modulate immune response, and inhibit virus binding and replication (Li et al., 2008). In the same way, carrageenan and ulvan have been proved to be antiviral in regard to various enveloped viruses, inhibiting their entry into host cells (Cunha & Grenha, 2016). Pigments in photosynthesis include carotenoids, chlorophyll, and phycobiliproteins, which have strong antioxidant and photoprotective activity. Some examples of carotenoids include astaxanthin, fucoxanthin, and β-carotene that have anticancer, anti-obesity, neuroprotective, and anti-inflammatory action, while phycocyanin in cyanobacteria has immune-modulating and hepatoprotective activity (Shannon & Abu-Ghannam, 2019).Moreover, algae contain polyphenols, specifically phlorotannins found in brown algae, that can act as antimicrobial, antioxidant, anti-inflammatory, antidiabetic, neuroprotective, and anticancer agents, among others, by influencing various cellular signaling pathways and preventing oxidative stress (Fernando et al., 2016). Apart from their medicinal uses, algal molecules are being extensively used in drug delivery systems, tissue engineering, wound healing, and regenerative medicine. Alginate and carrageenan, which are among the polysaccharides, are widely used as biomaterials for the production of hydrogels and microencapsulation of drugs due to their high biocompatibility and gelation properties (Pereira, 2018).Although these products have high medical potential, some obstacles associated with the issues of large-scale production, standardization, bioavailability, and clinical trials still stand as major hurdles in the way of marketing of algal molecules as pharmaceuticals. Future work should be done to overcome these problems through efficient cultivation methods, sustainable extraction procedures, and clinical trials.

10. Future persectives and research opportunities

Growing global interest in developing sustainable and multifunctional bioactive substances makes algae an interesting source material for creating advanced cosmeceuticals and therapeutics. While considerable advances have already been made in the extraction and characterization of peptides and polysaccharides of algae, there is a number of obstacles that need to be solved in order to enable the wide commercialization of these molecules.Future research needs to concentrate on the search for new algal sources among the yet untapped marine and freshwater species, especially those growing in extreme conditions. Such algae may synthesize new types of biomolecules with unusual structures and better activities. Omics technologies like genomics, transcriptomics, proteomics, metabolomics, and glycomics together with bioinformatics and artificial intelligence will help to find and characterize new bioactives and their mechanisms of action. It is important that optimization and standardization of culture conditions are undertaken in order to avoid biomass composition fluctuations owing to seasonality, geographical position, and environmental issues. The creation of new controlled culture methods such as photobioreactors and integrated aquaculture could contribute to increasing the output of biomass and ensuring biomolecule consistency. There are significant challenges associated with sustainable and economically viable extraction techniques. Future studies need to be focused on combining environmentally friendly techniques such as enzyme-assisted extraction, ultrasonic-assisted extraction, microwave-assisted extraction, pulsed electric field technology, supercritical fluid extraction, and deep eutectic solvents. This information will be helpful in creating a special molecule that would demonstrate the required biological activity and improved cosmeceutical properties. Although the in vitro studies revealed interesting results, more in vivo researches are needed to study the safety and efficacy of the algal compounds

11. Conclusion

The process of bioprospecting of algal biomolecules has proved to be an interesting approach in the field of discovery and utilization of valuable molecules that can find application in cosmeceutics and therapeutics. Macro and micro-algae constitute rich sources of structurally diverse peptides and polysaccharides possessing numerous biological activities, which include antioxidant, antimicrobial, anti-inflammatory, antihypertensive, antiviral, immunomodulatory, wound healing and anticancer properties. Algal biomolecules with their distinctive features, like molecular weight, amino acid sequence, monosaccharide content, branching and sulfation patterns, possess certain functional and bioactive properties.Recent innovations in pretreatment and extraction processes, like ultrasonicassisted, enzymatic-assisted, microwave-assisted and other green extraction technologies have helped improve the efficiency of bioactive compound extraction and their conservation. Extraction processes that include a combination of physical, chemical and enzymatic procedures have shown much promise in achieving the co-extraction of peptides and polysaccharides from algal biomass. The rising interest in natural, sustainable, and multi-purpose substances has resulted in the increased use of algal biomolecules in cosmetics and therapeutics. The use of algal polysaccharides like alginate, fucoidan, carrageenan, laminarin, agar, and ulvan is associated with the enhancement of hydration, protection from sunburns, anti-aging effect, and wound healing, while algal polypeptides possess antioxidant, collagenogenic, antimicrobial, and antihypertensive effects. It becomes evident that algae can be considered promising sources for future cosmeceuticals and pharmaceuticals. However, there are a number of issues which have to be addressed in the future: biomass variability, seasonal variations, scalability of cultivation systems, standardization of extraction process, regulatory approval procedure, and lack of clinical evidence of biological activity. Future investigations should concentrate on the optimization of cultivation parameters, development of costefficient and ecofriendly extraction methods, structure-activity relationship, and in vivo and clinical trials. In general, the combination of modern bio prospecting strategies, sustainable processing techniques, and bio refinery concepts would be important in terms of tapping into the full potential of algal polypeptides and polysaccharides. It is believed that such measures would have an impact on the further development of the blue bio economy and would be used to produce novel eco-friendly cosmeceutical/therapeutic products.

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