

EXTRACTION OF BIOACTIVE COMPOUNDS FROM SEAWEEDS AND ITS APPLICATIONS

Abstract

The finding of metabolites and biological activity from seaweed has intensely increased over the past three decades. There are several research techniques for creating chemical compounds, but still naturally occurring bioactive molecules in nature play an important role. Scientists are searching for additional physiologically active compounds. Pharmaceutical industry and researchers are increased attention to the bioactive compounds found in seaweeds that can be used for development of drugs. Seaweeds are receiving scientific attention because of their bioactive compound and several beneficial features, including anti-viral, anti-tumour, anti-inflammatory, and. The key topics covered in this review were chemicals like metabolites, seaweed types, and their characteristics. The primary metabolite and its characteristics are highlighted. Marine seaweeds include a variety of bioactive substances that can be used for dietary, cosmetic, and therapeutic purposes to enhance health. Several compounds, including polyphenols, polysaccharides, carotenoids, and fatty acids, were shown to exhibit bioactive properties. These chemicals have been extracted using cutting-edge methods such as supercritical fluid extraction, pressurised liquid extraction, ultrasound-assisted extraction, enzyme-assisted extraction (EAE), and microwave-assisted extraction, which have an advantages over traditional methods. To produce extracts containing the desired bioactive chemicals, each method's process parameters must be tuned.

Keywords: Seaweeds, Algae, Health, Industry, Extraction.

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I. INTRODUCTION

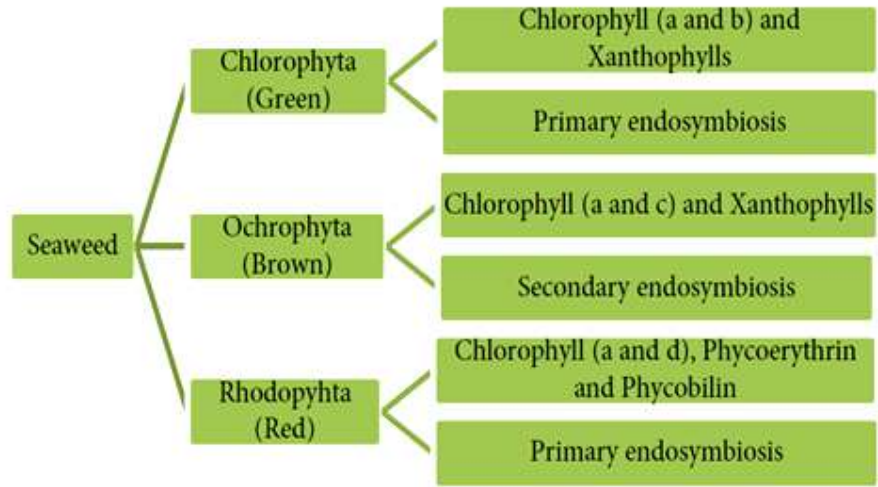
Seaweed cultivation is a type of marine sector microalgae that grew by 1.4 % globally from 34.6 MT in 2019 to 500,000 tonnes in 2020. In 2020, seaweed harvests in Southeast Asia and the Republic of Korea, which also includes China and Japan, showed significant development. Cai et al., (2021), reported that seaweeds are processed into dietary additives and supplements and are a good source of iodine, fucoidan, fucoxanthin, and phlorotannins. According to FAO2022, aquatic products made from seaweed and other algae represent for USD 1.9 billion (58%) of the total revenue from microalgae and seaweed. According to the Central Marine Fisheries Research Institute (CMFRI), 342 prospective sites are available for cultivating marine plants and algae in India and has the capacity to generate about 9.7 million tonnes of seaweed annually. ICAR-CMFRI also stated that as of 2022, the world produced 35 million tonnes of seaweed, which consists of various marine plant species and algae, and was valued at about USD 16.5 billion. Moreover, government's made an allocation of Rs. 640 crores under the Pradhan Mantri Matsya Sampada Yojana (PMMSY) for the promotion of seaweed cultivation, with a goal production of more than 11.2 lakh tonnes by 2025.

Seaweeds and microalgae are major sources of a number of important bioactive compounds with various biological roles. In addition to the pharmaceutical, cosmetic, and other food-related industries, they are widely utilised and marketed commercially in the food sector. The utilisation of bioactive compounds obtained from seaweeds in the food and pharmaceutical industries for enhancing health has the potential to increase due to the multiple biological benefits (Merilyn et al., 2022). Consumer demand for healthful and useful meals has increased in recent years as they become more aware of the connection between diet and health (Granato et al., 2020). According to their primary colours, green, brown, and red algae (Chlorophyta, Phaeophyta, and Rhodophyta, respectively are typically divided into three groups. Rhodophyta is the phylum of algae with the greatest variety and number of species. These species have large concentrations of carotenoids, including, carotene, fucoxanthin, astaxanthin, and xanthophyll, as well as additional pigments including phycoerythrin, phycocyanin, and allophycocyanin (Maria et al., 2021). Macro-algae have a variety of bioactivities due to the presence of biocompounds, including anti-aging, antioxidant, antibacterial, anti-inflammatory, anti-proliferative, and neuroprotective action (Ana-Marija et al.,2018)

II. CLASSIFICATION OF SEAWEEDS

Seaweeds are classified into main three classes based on their photosynthetic pigments i.e. brown, green, and red. According to Collins et al. (2016) and Gutierrez-Rodriguez et al. (2018) among 10,000 different types of seaweeds, there are about 2000 brown, 1500 green, and 6500 red seaweed species.

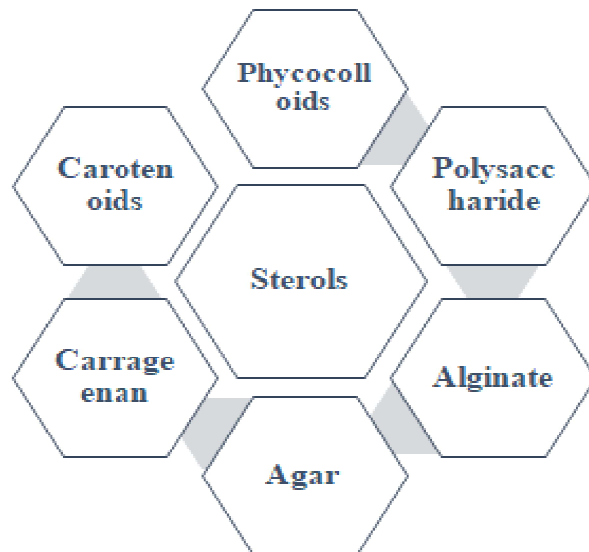
EXTRACTION OF BIOACTIVE COMPOUNDS FROM SEAWEEDS AND ITS APPLICATIONS



Pigments Present in Seaweeds (Yu et al., 2014):

Green seaweeds	α -, β -, and γ -carotene, chlorophylls a and b, siphonoxanthin, lutein, and siphonein
Brown seaweeds	Chlorophylls a, c1, and c2, β -carotene, and fucoxanthin
Red seaweeds	Chlorophyll a, r- allophycocyanin, phycocyanin, c-phycoerythrin, α - and β -carotene

III. BIOACTIVE COMPOUNDS OBTAINED FROM SEAWEEDS (MERILYN ET AL., 2022)



1. Bioactive Compounds and their Structure:

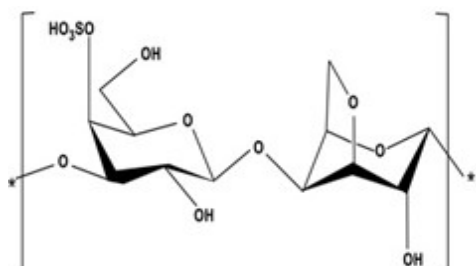


Figure 1: structure of Phycocolloids

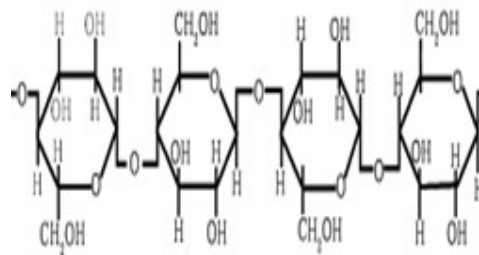


Figure 2: structure of Polysaccharide

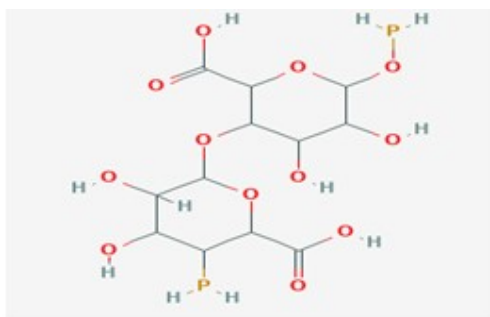


Figure 3: structure of Alginate

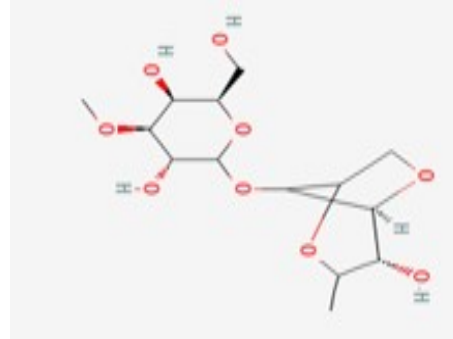


Figure 4: structure of Agar

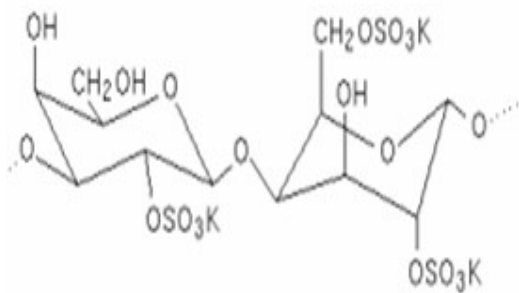


Figure 5: structure of Carrageenan

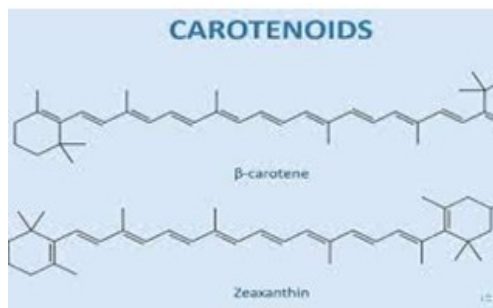


Figure 6: structure of Carotenoids

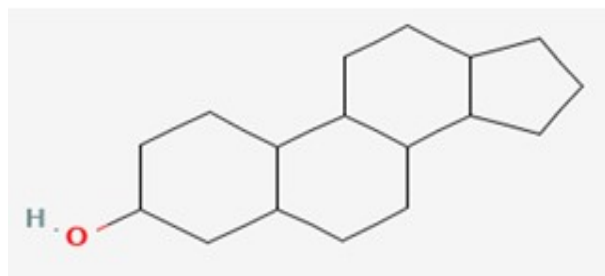


Figure 7: structure of Sterols

2. Other Bioactive Compounds and their Structure

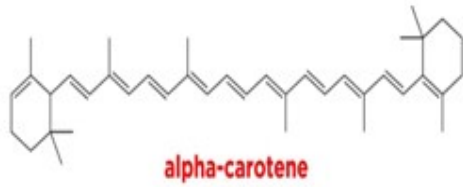


Figure 1: structure of Pigments

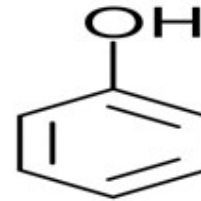


Figure 2. structure of Phenolic Compounds

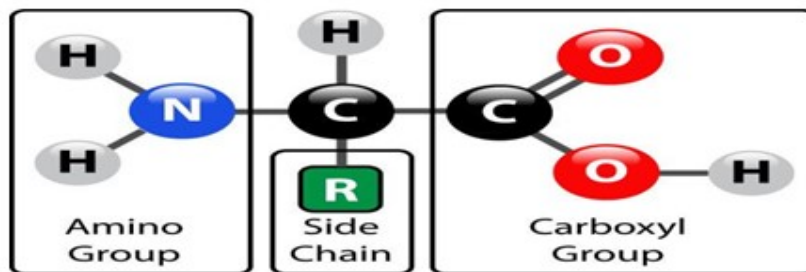


Figure 3: structure of *Proteins*

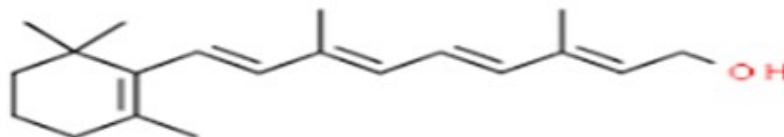


Figure 4: structure of *Vitamins*

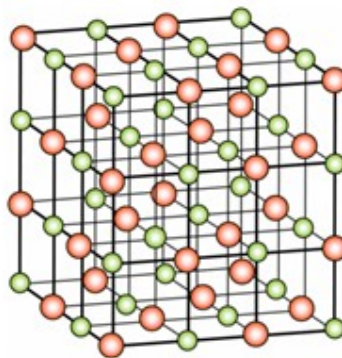


Figure 5: structure of *Minerals*

- **Phycocolloids:** Seaweed cell wall structural composition is influenced by phycocolloids. They aid in the discovery of the interaction between infections and seaweeds. Phycocolloids are polysaccharides with a high molecular weight made up of several sugar unit repetitions. Alginates, carrageenan, and agar are the three main categories of phycocolloids; their utilization in the food and cosmetic industries. (Archana et al., 2014)
- **Polysaccharides:** Polysaccharides are available in abundant quantity in marine algae, where they are largely found in the cell walls and as well as in mycopolysaccharides and storage polysaccharides. Simple sugars or monosaccharides with short chains that are joined together by glycosidic bonds are known as polysaccharides. Ulva, a kind of green seaweed, has a dry weight content of 65% polysaccharide. The amount of cellulose and hemicellulose in the relevant seaweed species ranges from 2% to 10% and 9% of dry weight, respectively. Sulphated galactans, a polymer containing sulfuric acid, are found in chlorophyceae or green algae. (Archana et al., 2014)
- **Alginate:** Brown algae is used to produce alginate, which has a substantial impact on the food and pharmaceutical industries due to its ability to chelate metal ions and produce highly viscous solutions. Additionally, it serves as a gelling agent in the textile sector, it helps to empty the digestive tract and prevents cancer. They can also absorb materials like cholesterol, which is then excreted from the colon and results in hypolipidemic and hypocholesterolemic reactions (Archana et al., 2014).
- **Agar:** Agar is a polysaccharide mixture of agarose and agar pectin that shares structural and functional characteristics with carrageenan. Sulphated polysaccharides called agar are derived from red seaweeds such *Gelidium* sp. and *Gracilaria* sp. as well as from the Phaeophyceae family. Due to its ability to gel, emulsify, and have a high viscosity, agar is mostly used in commercial and scientific settings. Agar is a general term for seaweed galactans that contain (1-4)-3, 6-anhydro-L-galactose and (1-3)-D-galactose residues and have up to 6% (w/w) of sulphate esterification. Additionally, it has been demonstrated that agar-oligosaccharide inhibits the enzyme responsible for nitric oxide generation as well as the creation of a pro-inflammatory cytokine (Archana et al., 2014).
- **Carrageenan:** It is a sulfated galactan that occurs naturally and dissolves in water. Its alternative backbone is made up of (1-4)-3, 6-anhydro-D-galactose and (1-3)-D-galactose. Carrageenan comes in a variety of forms. Lambda (carrageenan), kappa (carrageenan), and iota (carrageenan) Although reports of more carrageenan types, including ν -carrageenan and ν -carrageenan (Rhein-Knudsen et al., 2017) which ranges between 20% (w/w) and 40% (w/w), is generated by the different types of seaweeds and how they were collected. Additionally, carrageenan exhibits anti-tumor, anti-viral, anti-coagulant, and immunomodulatory properties, making it a potential pharmaceutical. (Archana et al., 2014)
- **Carotenoids:** The most prevalent pigments are carotenoids, which are present in all algae, higher plants, and photosynthetic microorganisms. They stand in for red, orange, or yellow wavelength photosynthetic pigment. Five isoprene carbon units are used to form the natural pigments known as carotenoids (Archana et al., 2014).

- **Sterols:** Seaweed's nutritional value comes from its sterol content. Sterols predominate in plants, animals, and fungus, with "cholesterol" being the most well-known sterol found in animals. Animal cell membrane fluidity and cellular activity are both influenced by cholesterol, which also serves as a secondary messenger in embryonic signalling. Precursors to steroid hormones and fat-soluble vitamins include cholesterol. According to reports, plant sterols such -sitosterol and fucosterol cause a reduction in the amount of cholesterol present in serum in both human and animal experiments. (Archana et al., 2014)

3. Other Bioactive Compounds:

- **Pigments:** Chlorophyll, carotenoid, and phycobiliproteins, three separate types of pigments found in seaweeds, have antiangiogenic, anticancer, anti-diabetic, anti-inflammatory, antioxidant, and immunomodulatory properties. These pigments have a lot of potential as both physiologically active agents and ingredients for nutraceuticals. They are also used in food colouring. Chlorophylls are lipid-soluble, greenish pigments that play an important role in seaweed photosynthesis. These three colours exhibit various protein concentrations, spectrum characteristics, and protein shapes (Cherry et al., 2019; Aryee et al., 2018).
- **Phenolic Compounds:** Catechins, flavonoids, phenolic acids, phlorotannins, tannins, and other phenolic compounds are found in seaweed. As a result, the type and volume of phenolic chemical extraction are significantly influenced by the species of seaweed. Green and red seaweeds are rich in phenolic acids, flavonoids, and bromophenols. Montero et al., 2017; Gomez-Guzman et al., 2018 and Cotas et al., 2021 reported in their studies that the majority of the complex polymers found in brown seaweeds are phlorotannin and phloroglucinol oligomers.
- **Proteins:** Seaweed's protein content is influenced by elements such as species, seasonal cycle, and seasonal change. According to Erna (2011) and Fleurence et al. (2018), protein content was higher for red seaweeds, are 47% on dry weight basis, 35% on dry weight basis and lower in brown seaweeds i.e. 24% dry weight basis. According to Makkar et al. (2016), Nitrogen-to-protein conversion ratios are lower than 6.25, so it was suggested for feed components because the protein content of seaweeds has been more as a result of the presence of non-protein nitrogen. Gullon et al., 2020 and Furuta et al., 2016 reported that seaweeds also include limited amino acids such as aspartic acid, glycine, alanine, proline, arginine, and glutamic acid.
- **Minerals:** Cofrades et al. (2017) and Lorenzo et al. (2017), analysed in their investigation that the seaweeds have a high mineral concentration in the range between 8–40%, such as Na, K, Mg, and Fe. Calcium, the mineral with the highest visibility is most abundant in plant sources. Therefore, Circuncisao et al.(2018), minerals were considered better for promoting a healthy cardiovascular system since they have a lower Sodium/Potassium ratio than other foods included in typical Western diets. Zava ea.al (2011), suggested that consuming seaweeds can also help treat an iodine shortage due to their high iodine content.

- **Vitamins:** According to Hentati et al. (2020), seaweeds were considered as a good source of water-soluble vitamins including vitamin C, folic acid, pantothenic acid, niacin, riboflavin, and vitamin B complex (B12, B6, B3, and B2). Seaweeds are also high in fat-soluble vitamins like vitamin A, D, E, and provitamin A.

Table 1: Bioactive Compounds and their Source ((Silvia et al 2022))

Sr. no	Class of Seaweed Bioactive Compounds	Principal Source	References	Year of publication
1	Alginate	Brown seaweed (Laminaria sp., <i>Ascophyllum nodosum</i>)	Review of extractions of seaweed hydrocolloids: Properties and applications.	2018
2	Fucoidan	Brown seaweed (<i>Undaria pinnatifida</i> , Fucus sp.)	A Sulfated Polysaccharides from Brown Algae as Therapeutic Target for Cancer	2015
3	Laminarin	Brown seaweed (Laminaria sp.)	Extraction, structure and bio-functional activities of laminaria from brown algae	2015
4	Agar	Red seaweed (Gracilaria sp.)	Algal biotechnology industries and research activities in China.	2001
5	Carrageenan	Red seaweed (Gigartina sp., Chondrus sp.)	Metabolites from algae with economic impact.	2007
6	Porphyran	Red seaweed (Porphyra sp.)	Antioxidant and anti-inflammatory activities of porphyrin isolated from discolored nori (<i>Porphyra yezoensis</i>).	2015
7	Ulvan	Green seaweed (Ulva sp.)	Ulvan from <i>Ulva armoricana</i> (Chlorophyta) activates the PI3K/Akt signalling pathway via TLR4 to induce intestinal cytokine production.	2017
8	Phlorotannin	Brown seaweed (Ecklonia sp., Eisenia sp., Laminaria sp., <i>Undaria pinnatifida</i>)	Bactericidal activity of phlorotannins from the brown alga Ecklonia kurome.	2002

IV. DIFFERENT METHODS FOR EXTRACTION

- 1. Enzyme-Assisted Extraction (EAE):** The enzymatic conditions and characteristics of the enzymes are given in Table 2. One litre of the suitable buffer and one gram of seaweed powder were added to a 2 L reaction vessel. The reaction vessel was placed in a water bath that was maintained at the proper temperature for enzyme activation, and it was connected to an overhead stirrer. Once the mixture had achieved the correct temperature, 1 mL (0.1% enzyme) was added, and it was stirred in a water bath for 20 hours at 350 rpm. After incubation, the enzyme was deactivated by heating at 100 °C for 10 minutes and cooling in ice. The mixture was centrifuged at 1500g for 10 minutes to separate the supernatant. The resulting extract was freeze dried, weighed to ascertain its yield, then reconstituted in a predetermined volume of water. A water extract was also created in the same way for comparison. (Sabeena et al., 2019)

Table 2: Optimum conditions and characteristics of enzymes used
(Source: Habeebullah et al 2020)

Enzyme	Optimum conditions		Buffer used	Characteristics
Carbohydrases	Temperature	pH		
Viscozyme L	50 °C	4.5	0.1 M acetate buffer	A multi-enzyme complex (containing arabinase, cellulase, β -glucanase, hemicellulase, and xylanase)
AMG 300 L	60 °C	4.5	0.1 M acetate buffer	Exo-1,4- α -D-glucosidase
Celluclast 1.5 L FG	50 °C	4.5	0.1 M acetate buffer	Cellulase
Termamyl 120 L	60 °C	6	0.1 M phosphate buffer	A heat-stable α -amylase
Ultraflo L	40 °C	6	0.1 M phosphate buffer	A heat-stable multi- β -glucosidase
Flavourzyme 500MG	50 °C	7	0.1 M phosphate buffer	Containing both endoprotease and exopeptidase
Alcalase 2.4 L FG	50 °C	8	0.1 M phosphate buffer	Endopeptidase
Neutrase 0.8 L	50 °C	8	0.1 M phosphate buffer	Metalloendoprotease

- 2. Microwave-Assisted Extraction (MAE):** Using a Microwave reactor Monowave 450 with an auto-sampler Mas 24 (Anton Paar, Austria), Microwave Assisted Extraction (MAE) was carried out to recover highly valuable compounds from milled algae with an average particle size of 200 μ m. Purified water, dried milled algae, and a solid liquid ratio of 1:30 (w:w) were placed in the microwave vials. Initial studies were carried out to choose the operating parameters while taking into account the findings of past seaweed-related research. The first set of samples were heated for a microwave time (t_{MAE}) of 3

min at a wide range of temperatures: 70, 90, 130, 150, 170, 190 °C and the second set of samples were heated for t_{MAE} of 6 min at the same temperatures. Following that, both were cooled to a temperature of 55 °C. The liquid fraction was then separated from the solid fraction using a vacuum filter. The samples were kept in the freezer until further usage.

A volume of the liquid fraction created by MAE was precipitated using a volume of ethanol (96%, Sigma-Aldrich, USA). Filtering was performed if necessary to separate the precipitate. After that, a 40 °C oven was used to dry the recovered biopolymer. The dried carrageenan was weighed in order to determine the yield (g hybrid carrageenan/g dried alga powder) (Elise et al., 2020)

- 3. Ultrasound-Assisted Extraction (UAE) (Wizi et al. 2022):** A universal disintegrator was used to clean, oven dry, and pulverise seaweed-wakame (*Undaria pinnatifida*) samples. Algae samples were extracted using an ultrasonic device (Ningbo Licheng co. Ltd., China) using a 25kHz ultrasound frequency. For the extraction, a solvent mixture of 70% ethanol and 30% water (v/v) was used, which promotes good recovery. The algae sample was cleaned, dried in the oven, and pulverised with a universal disintegrator (Yongshi Jiupin Company, China). To achieve the best extraction conditions, algae powder was added to the solvent and chemicals were leached at several temperatures (45°C, 55°C, and 65°C) and periods (20 and 30 min) using ultrasonic power of 70% and 30%, respectively. For each extraction condition in UAE, temperature, ultrasonic power treatment, and time were set. Each extraction condition was repeated three times, and the temperature of the mixture was measured using a thermometer. The input power was supposed to be turned into heat and diffused in the medium during the UAM extraction. The liquor extract was centrifuged for 5 minutes at 3000 rpm in a countertop high-speed Bioridge (TG16-WS) centrifuge. The residue was re-extracted to ensure that all soluble bioactive compounds were recovered. The concentrated extracts were dried using a freeze dryer.

The yield for each form was calculated using the equation below

$$\text{Yield\%} = (\text{Mass of extract} / \text{Mass of sample used}) \times 100$$

- 4. Supercritical Fluid Extraction (SFE):** A CO₂ flow rate of 2 ml/min was employed with 0.5 g of dried algal biomass for each extraction. Each extraction took two hours to complete in triplicate. Three variables influence the extraction conditions: temperature (40–60 °C), pressure (100–300 bar), and the amount of ethanol used as a co-solvent (0–15%). Following extraction, the obtained extracts were put into vials, and the extraction yield was determined by vacuum-evaporating the remaining ethanol. The dried extracts were then diluted with ethanol to concentrations ranging from 10 to 20 mg/ml and kept at 20 °C until analysis while being shielded from light. (Joanna et al., 2016)
- 5. Pressurized Liquid Extraction (PLE):** Once the procedure is complete, an extract is pushed out using a pump. an extraction cell, which is the actual location of the extraction. In order to maintain consistent extraction conditions, it must be designed for high pressures and have at least two on/off valves. The extraction cell is placed in an oven so that it can be heated to the desired temperature of 200 °C. The PLE instrument may have heating coils for the purpose of heating the solvent during dynamic extractions. Additionally, it may incorporate a nitrogen circuit, which aids in exhausting all of the

solvent from the lines following extraction. It must be remembered that corrosive-resistant materials must be utilised due to the typical operating pressures and temperatures (Ballesteros et al., 2020)

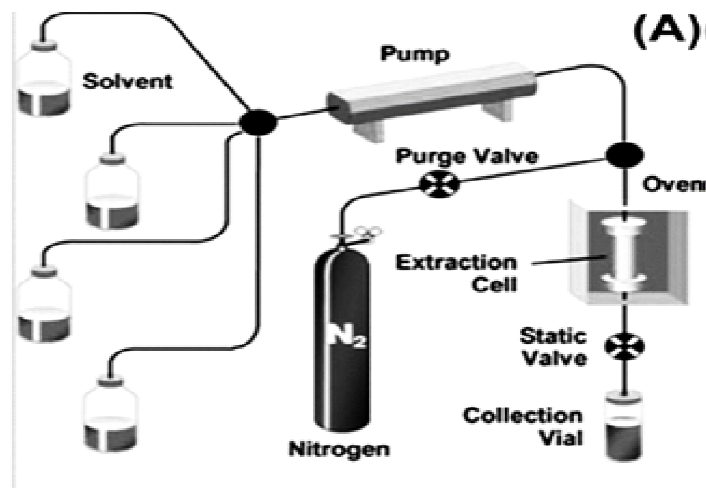
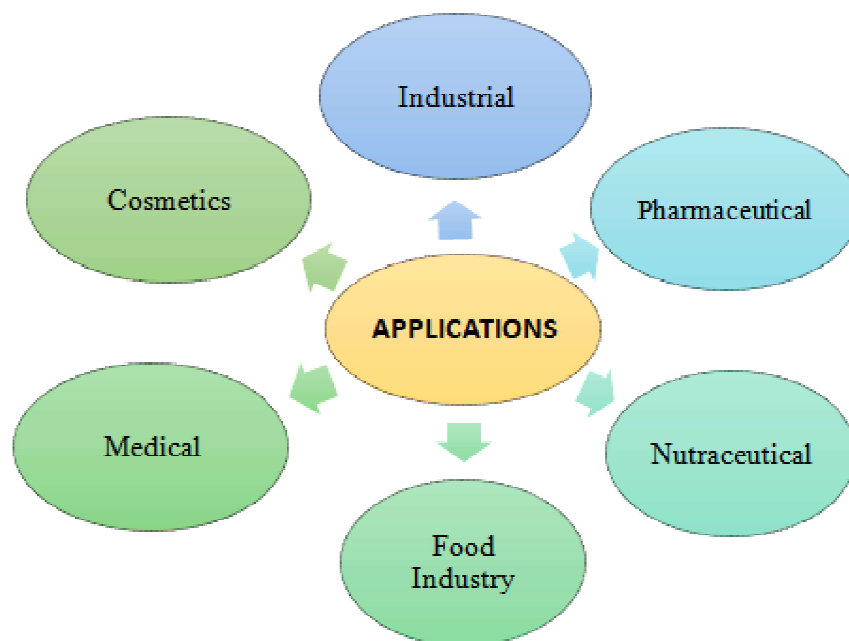


Table 3: Methods and procedures for Seaweed extraction (Source: Admassu et al. (2018), Kadam et al. (2015) and Praveen et al. (2019))

Extraction Method	Procedure (Principle)	Bioactive Components
Enzyme-Assisted Extraction (EAE)	Incorporating food-grade enzymes such as <i>cellulase</i> , <i>α-amylase</i> , <i>pepsin</i> and <i>alcalase</i> , into seaweeds for the degradation of glycosidic bonds and other internal bonds	Fucoanthin, Lipids, Phlorotannins and Phenolic compounds
Microwave-Assisted Extraction (MAE)	It was the most researched extraction technique which uses microwave energy to heat solvent-containing samples. Dielectric and total volumetric heating by microwaves of 2.45 GHz	Sulfated polysaccharides, such as fucoidan, ulvan and rhamnan sulfate.
Ultrasound-Assisted Extraction (UAE)	Ultrasonic radiation pressure was used to generate intense mixing and agitation, which promotes extraction.	Polyphenols, fucose, uronic acid Laminarin, phycobiliary proteins, taurine and antioxidants
Ultrasound-Assisted Extraction (UAE)	Ultrasonic radiation pressure was used to generate intense mixing and agitation, which promotes Extraction.	Polyphenols, fucose, uronic acid Laminarin, phycobiliary proteins, taurine and antioxidants
Supercritical Fluid Extraction (SFE) Pressurized	The supercritical fluid's temperature and pressure are both greater than the critical point.	Fatty acids (ω -3), Carotenoids, Fucoanthin, Fluorotannins, Volatile compounds, Polyphenols, Cytokinins, Auxins, Microelements, and macro elements

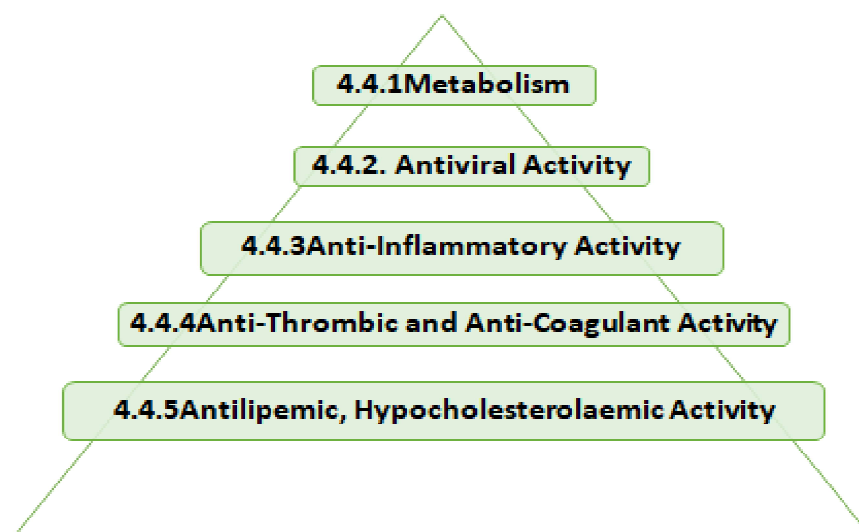
V. APPLICATIONS OF BIOACTIVE COMPOUNDS FROM SEAWEEDS



- 1. Industrial Purpose:** Brown edible seaweeds serve as the only food supply for the development of lactic acid bacteria. Three types of edible Irish brown seaweed, *Himantalia elongata*, *Laminaria digitata*, and *Laminaria saccharina*, were utilised to research the growth kinetics of lactic acid bacteria (LAB; *Lactobacillus plantarum*). The results of this study suggest that LAB-based seaweed fermentation has potential, as does the potential for the production of a wide range of functional foods. (Gupta et al., 2011). Seaweed polysaccharides with low molecular weight as prebiotics. Bifidobacterial populations significantly increased in *Gelidium* seaweed. The possibility of prebiotics is increased by seaweeds' creation of agar and alginate. Seaweed and pure glucose were fermented to provide similar amounts of butanol (Innocenzo et al., 2012).
- 2. Pharmaceutical:** According to the research done in 2022 by Lomartire et al., the biological components of marine seaweed species were evaluated using both in vitro and in vivo testing in order to examine their modes of action and use them as prospective treatments. Over time, there has been substantial progress in the study of marine medicine. Marine pharmacology, a unique discipline of pharmacy that combines multiple academic fields and calls for a broad knowledge base, is being created on the basis of this foundation. It is crucial to establish whether there is a chance that seaweed contains bioactive components before beginning pharmacological research. It is possible to have a specific range of the substances found in seaweeds that can be accurately recognized and evaluated through parameter standardization and quality control. The validity, quality, and effectiveness of biological chemicals will be ensured through such study. Pharmacognostic analysis examples are provided for *Ulva lactuca*, *Sargassum cinereum*, and *Chaetomorpha antennina*.

3. Nutraceutical: Several studies examined the effects of seaweed addition on the nutritional, sensory, and textural properties of fish products. Recently, the sensory quality and lipid oxidation of enriched fish cakes were assessed after they had been supplemented with high quality lipids (long chain n-3 LCPUFAs) and seaweed extracts as natural antioxidants. (Dellarosa, Laghi, Martinsdóttir, Jónsdóttir, & Sveinsdóttir, 2015). It was found that the quality of the products or lipid oxidation was unaffected by the addition of seaweed extracts in aqueous and ethanol. Additionally, none of the samples had an unpleasant flavour, and rotten odour and flavour received poor ratings.

4. Medical:



Therapeutic Properties of Seaweed-Derived Compounds:

- **Metabolism:** In recent years, a variety of novel diabetic medications have emerged, including insulin mimickers and oral hypoglycemic agents. Type-2 diabetes, which reverses glucose metabolism enzymes, has been demonstrated to be safe and efficient against bioactive substances from seaweed. Alkaloids, flavonoids, carotenoids, polyphenols, and phlorotannins were among the seaweed bioactive that were proven to have a hypoglycemic effect. Fucoxanthin dramatically increases insulin sensitivity and lowers blood glucose levels in diabetic rats, according to Maeda et al findings. There have been numerous reports of fucoidan from the brown algae *Fucus vesiculosus* and *Ascophyllum nodosum* lowering blood glucose levels in an animal model. This study showed that fucoidan, which has a low molecular weight, stimulates the development of beta cells while limiting glucagon output from alpha cells in the reversal of blood sugar. (Abirami et al., 2019)
- **Antiviral Activity:** Some sulphated polysaccharides from red algae have reportedly been shown to exhibit antiviral effect against viruses that cause human infection. The two most well-known species are *Aghardhiella tenera* and *Nothogenia fastigiata*. Galactan sulphate (from *Aghardhiella tenera*) and xylomannan sulphate (from *Nothogenia fastigiata*) are investigated for antiviral action against the most contagious viruses, including the human immunodeficiency virus or HIV, the herpes

simplex viruses types 1, 2, and the respiratory syncytial virus. These seaweeds contain a polysaccharide that becomes active when it binds to the cell's surface during the first stage of RNA replication. (Archana et al., 2014)

- **Anti-Inflammatory Activity:** The 20-carbon polyunsaturated fatty acids such as eicosapentaenoic and docosahexanoic referred to as PUFAS, are abundant in macroalgae, particularly red seaweeds. The two primary metabolites of the oxidative metabolism of C20 PUFAS by seaweeds are prostaglandin and gracilariales. There are two main alternate methods for producing prostaglandins: the first technique employs lipoxygenase, which also acts as archidonic acid in mammalian cells, and the second approach uses fatty acid cyclooxygenase (Archana et al., 2014)
 - **Anti-Thrombic and Anti-Coagulant Activity:** Fucoidan have anti-thrombotic and anti-coagulant properties that are heparin-like in both vivo and in vitro. These characteristics are mediated by blood coagulation inhibitors such anti-thrombin III and heparin cofactor II. Direct interaction between fucan and thrombin produces anti-coagulant activity, which typically rises with sulphation levels. *Ascophyllum nodosum* and *Fucus vesiculosus* both generate sulphated fucan, which has been patented as an anticoagulant (Archana et al., 2014)
 - **Antilipemic, Hypocholesterolaemic Activity:** There are numerous severe illnesses nowadays that are bad for society, including cardiovascular disease, which is mostly brought on by excessive blood pressure and plasma cholesterol levels. Some macroalgae, including alginate, funoran, fucoidan, laminaran, porphyran, and ulvan, have been found to cause hypocholesterolemic and hypolipidemic reactions as a result of decreased gut absorption of cholesterol. This is caused by a hypoglycemic reaction and an increase in faecal cholesterol. (Archana et al., 2014)
5. **Food Industry:** In Hawaii, red macroalgae (*Gracilaria* spp.) are consumed fresh. Commonly marketed species include *G. coronopifolia*, *G. parvispora*, *G. salicornia*, and *G. tikvahiae*, however their postharvest life is only around four days (Paul and Chen, 2008). The anti-oxidant and antibacterial phytochemicals found in seaweeds are abundant. Minerals and fibres help to improve the mineral content while lowering the salt concentration. (Innocenzo et al., 2012)
6. **Cosmetics:**
- **Tyrosinase Inhibition Activity of Seaweed:** Tyrosinase is an essential enzyme that helps to catalyze the synthesis of melanin, the pigment that gives skin its color. The hyperpigmentation in the skin was due abnormal development of melanin pigments. Skin pigmentation is brought on by aberrant melanin synthesis brought on by excessive UV exposure. Natural tyrosinase inhibitors are in high demand as safe and effective skin-whitening agents. Seaweed-based skin-whitening chemicals may therefore be helpful for the cosmetics business. *Ishige okamurae* Yendo, *Endarachne binghamiae*, and other seaweed extracts showed tyrosinase inhibitory activity when tested by researchers. (Jesumani et al., 2019)

- **Hyaluronidase:** Controlling moisture is essential for skincare since it improves skin's condition and texture, making it look younger and healthier. Extracts from a variety of sources, including *Durvillea antarctica* (Chamisso), *Cladosiphon okamuranus* Tokida, *Undaria pinnatifida* (Harvey), *Polysiphonia lanosa* (Linnaeus), and *A. nodosum* (Linnaeus) Le Jolis. It moisturizes skin and guards against dryness, as shown by Tandy. Polysaccharides can be employed as humectants and moisturisers in the cosmetics industry due to their excellent water-holding capacity. It has been established that *Laminaria japonica* Areschoug polysaccharides provide hyaluronic acid with excellent hydration and moisturising characteristics. (Jesumani et al., 2019)

Table 4: Main biological properties and industrial applications of seaweed's bioactive compounds (Source: Silvia et al 2022)

Bioactive Compounds	Applications	Principal Source
Alginate	used in food preparation and pharmaceutical products as a thickening and stabilizing agent	Brown seaweed (<i>Laminaria</i> sp., <i>Ascophyllum nodosum</i>)
Fucoidan	Anticoagulant, antiviral, antiproliferative, antibacterial, and antidiabetic properties	Brown seaweed (<i>Undaria pinnatifida</i> , <i>Fucus</i> sp.)
Laminarin	Used in food industry and biomedicine because of its nutraceutical properties such as immunostimulatory, antitumour and antioxidant activity	Brown seaweed (<i>Laminaria</i> sp.)
Agar	Used in food products and pharmaceutical field as jellifiers, stabilisers, thickeners and emulsifiers	Red seaweed (<i>Gracilaria</i> sp.)
Carrageenan		Red seaweed (<i>Gigartina</i> sp., <i>Chondrus</i> sp.)
Porphyran	Anti-inflammatory, antioxidant, antihyperlipidemic and anticancer activities	Red seaweed (<i>Porphyra</i> sp.)
Ulvan	Immunostimulatory, antitumoural, antiviral activities	Green seaweed (<i>Ulva</i> sp.)
Phlorotannin	antimicrobial, antioxidant, antiviral, anticancer, anti-inflammatory, antidiabetic properties	Brown seaweed (<i>Ecklonia</i> sp., <i>Eisenia</i> sp., <i>Laminaria</i> sp., <i>Undaria pinnatifida</i>)

VI. CONCLUSION

Seaweeds are rich in bioactive substances with a wide range of biological applications, including pigments, phenolic compounds, lipids, vitamins, proteins, minerals, polysaccharides, and polyunsaturated fatty acids, seaweeds are the most economically valuable biological resource. Seaweeds are most commonly used in the food, pharmaceutical, cosmetic, and other industries. Commercially, they are provided as fresh and extracts. Despite

the fact that seaweeds are mostly safe and healthful, there are still certain hazards associated with them, including exposure to heavy metals, arsenic, and excessive iodine concentrations. Due to the epidemiological study's ongoing inconclusiveness, there is still a paucity of information on this method. Further green extraction methods were used to separate the bioactive components, and the extract's purity was verified by chromatographic analysis. Marine medicines seek to reduce side effects brought on by synthetic substances and produce innovative treatments with natural-source ingredients. Only less than 50% of the world's population now has access to essential medicines due to the high cost of prescription drugs and the low purchasing power of the populous in regions like Africa and Asia. Despite the enormous number of studies on the constituents and extracts of seaweeds, further investigation is required to uncover unique molecules for usage in diverse biotechnological applications, improving human health both directly and indirectly.

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