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Review Article

Existence of Diverse Species of Algae, Composition and Biological Activity: A Review along India's Coastlines

Reshma Choudhury, Nityananda Sahoo*

ABSTRACT

This review discusses the most recent discoveries of various species of algae (seaweeds), their bioactive composition and the bioactive properties of algal extracts found along India's shorelines. India is the 12th position among the world's topmost mega-biodiversity countries. There are 770 species of bio-diverse marine algae, which cover 8100 kilometers of coastline in India. Gray, red and brown algae, diatoms, dinoflagellates and euglenophytes are among the marine algae found. Secondary metabolites that are structurally and biologically active can be located in abundance in seaweeds. Amino acids, fats, vitamins, carotenoids, polypeptides, polysaccharides, proteins, glycerolipids, polyunsaturated fatty acids, pigments, polyphenols, minerals and plant growth hormones are all contained in bioactive extracts. Several marine macro and micro-algae organisms contain biogenic compounds like halogenated complexes, alcoholic contents, aldehydes and some terpenes used in various activities. The extracts have several biologic effects which include antioxidant, antimicrobial, anti-inflammatory, antibiotic, antiviral, antifouling and cytotoxic activity. Seaweed species and their environment influence the composition, quantity and medicinal properties of extracts. A diverse algae biomass can be found along India's various coastlines.

Key words: Algae, Bioactive extract, Therapeutic properties, Pharmaceuticals, Indian coastline.

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INTRODUCTION

Marine life is a vibrant underwater ecosystem filled with a diverse range of plants, animals and other organisms that flourish in the ocean's salty water. Micro-organisms make up the majority of marine organisms. They generate oxygen while also storing carbon. Apart from animal life, aquatic plants, including kelp and algae, grow in the water and form the foundation of certain underwater ecosystems. Phytoplankton (cyanobacteria), seaweeds (marine algae) and sea grasses are the three forms of plants identified. An alga is a colloquial word for a wide-ranging and multiple communities of photosynthetic protesters. Green algae (8,000 species), red algae (7,000 species), brown algae (2,000 species), diatoms (1,00,000 species), dinoflagellates (2,000 species) and euglenophytes are examples of marine algae. Algae may be classified as microalgae or macroalgae based on their size. Phytoplankton is microscopic, free-floating aquatic organisms while seaweeds (algae) are macroscopic, bound and free-floating planets. In 2016, the global seaweed output of various species was estimated to be 30 million wet tons (FAO 2018). Secondary metabolites derived from algae found in seaweeds have a huge number of biological activities which includes antioxidant, antimicrobial, anti-inflammatory and antibiotic activity as well as antiviral, antifouling and cytotoxic activity. There are numerous examples of seaweed avoidance in the sense of human profit. Marine seaweeds are generally macro and microalgae creatures contain active compounds, better known as biogenic compounds, like halogenated compounds, alcoholic contents, aldehydes and terpene groups in seaweeds.

Indian seaweed varieties

Seaweeds are an essential part of marine ecosystems and serve a valuable ecosystem resource supporting the life of many marine organisms.[1] India is ranked 12th in the world for mega-biodiversity. A wide range of seaweeds can be found underneath the blue ocean water along India's 8100-kilometer-long coastline. They are found in India's coastal regions and only 770 species of seaweed have been identified in Indian marine ecosystems.[2] Some of the seaweeds are also unknown, according to the report.

Sea coastlines of India

India's total coastline is approximately 7516.6 kilometers with 6100 kilometers on the mainland and 1197 kilometers on the islands. The coastline of India stretches through 9 states like Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal and 4 union territories like Daman and Diu, Puducherry, Andaman and Nicobar and Lakshadweep[3] as in Figure 1.

The southeast coastlines of Tamil Nadu starting from Mandapam to Kanyakumari covers 21 islands situated in the Gulf of Mannar, the Gujarat coast,

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Figure 1: The coastlines of India.

Figure 2: Structure of Rhodophyta.

Lakshadweep and the Andaman-Nicobar Islands are the coastal areas in India where many species of green, brown, and red algae thrive. The other places with abundant seaweed sources on the east and west coasts are Bombay, Goa, Karwar, Ratnagiri, VarkaJa, Pulicat, Vizhinjam and Chilka.[4] About 844 different species of seaweeds have been identified to date but harvesting commercially is not yet to begin in India. Red seaweeds account for 844 species, brown seaweeds for 194 and green seaweeds for 216.[5]

Some common species of red seaweeds

Over 7,000 different species of rhodophytes are currently being studied but the taxonomy is constantly changing with new species being identified every year.[6,7] Most of these are aquatic with just around 200 freshwater species.

Some examples of different species and genera of Rhodophytes (red algae) are:

Cyanidioschyzon merolae, an ancient red alga, *Atractophora hypnoides*, *Gelidiella calcicola*, *Lemanea* (a freshwater genus), *Palmaria palmata*, dulse, *Schmitzia hiscockiana*, *Chondrus crispus*, Irish moss, *Mastocarpus stellatus*, *Vanvoorstia bennettiana* (became vanished in the early 20th century), *Acrochaetium efflorescens, Audouinella* (found in freshwater as well as marine species), *Polysiphonia ceramiaeformis* (A banded siphon seaweed), Vertebrata simulan.

General Characteristics

Photosynthetic species such as red seaweed or Rhodophytas can absorb sunlight and turn it into energy. They have *rodoplasts* containing chlorophyll and pigments like *phycoerythrin* and *phycocyanin* that protrude from the chlorophyll. They get their distinctive red color from these pigments. They produce colloids, primarily agar-agar and carrageenan, commonly used in the manufacturing of pharmaceutical and food product.[8] The structure of Rhodophyta given below as in Figure 2.

A group of marine researchers guided by Felix Bast of the CUPB (Central University of Punjab, Bathinda) recently discovered a new rhodophyta seaweed species. They discovered native seaweed organisms along Tamil Nadu's Kanyakumari, Gujarat, and Daman Diu coasts. The two new species of algal seaweeds like *Hypnea indica* and *Hypnea bullata* were discovered in Kanyakumari as shown in Figure 3. In Sivrajpur and Somnath Pathan, the species *Hypnea indica* was recently discovered.[9]

Some common species of green algae

There are over 7,000 species of green seaweed recorded, with 800 of them being marine species. Green algae can be found mainly in tidelands and

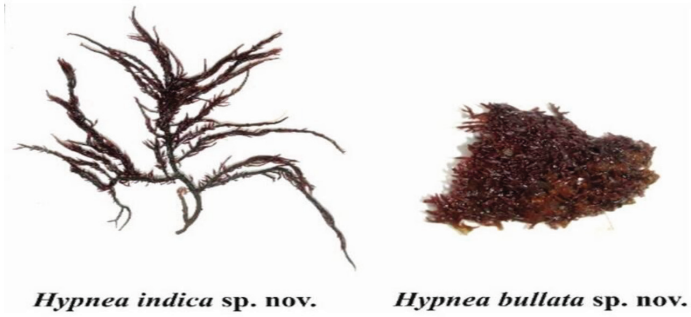

Figure 3: Structure of *Hypnea indica* and *Hypnea bullata*.

mangrove swamps. Two hundred thirteen species belonging to 43 genera have been recorded from Indian waters (Kaliaperumal and Kalimuthu, 2004), but most chlorophytes remain unidentified.[10]

Examples of some Chlorophytes of India

Some of Indian chlorophyte species are *Bryopsis pennata, Caulerpa laetevirens, Caulerpa peltata, Caulerpa racemosa Caulerpa scalpelliformis, Caulerpa serrulata, Caulerpa sertularioides, Caulerpa taxifolia, Chaetomorpha aerea, Chaetomorpha antennina, Chaetomorpha linum, Codiumdwarkense, Enteromorpha compressa, Halimeda gracilis, Halimeda macroloba, Ulva lactuca Ulva reticulate, Valoniopsis pachynema, etc.*

Importance

Green algae are the primary sources of energy-dependent active compounds, the foundation of all aquatic consumers' food chains. Green algae may be harvested and used as fertilizer in water bodies. The structures of Green algae **Chara** as shown in Figure 4 which contain calcium are eneficial in acidic soils while others are beneficial in alkaline soils.[11]

Some common brown seaweed

Brown algae are often present in marine environments, such as intertidal and sub-tidal reefs. They are essential in the marine environment because they provide basic requirements (food and shelter) for marine organisms. Two hundred eighty-nine species belonging to 37 genera have been identified in Indian waters (Kaliaperumal and Kalimuthu, 2004).[12]

Figure 4: Structure of Green algae Chara.

Figure 5: Structure of brown seaweeds.

Examples of some common brown algae

Some species of Indian *Phaeophyceae (brown algae)* are *Chnoosporaimplexa, Dictyota cervicornis, Dictyota divaricate, Hydroclathrus clathratus, Lobophora variegate, Padinate trastromatica, Rosenvinge anhatrangensis, Sargassum polycystum, Sargassum wightii, Spatoglossum asperum, Stoechospermum marginatum, Turbinaria conoides,* etc.

Importance

The extract of brown seaweeds has shown to be beneficial in preliminary studies. It appears to have these health benefits, but further research is required on hormone regulation, weight loss, diabetes, and cognitive improvement.[13] The structures of brown seaweeds are shown as in Figure 5.

BIOACTIVE COMPONENTS OF SEAWEEDS

The Biological activities of seaweeds have been discovered in a number of metabolites isolated from marine algae. Because of their possible health benefits, these bioactive compounds have gained widespread acceptance.[14] The different metabolites marine algae are shown as in Figure 6.

Polysaccharides

Brown macro algae have a complex and active cell wall that is rich in polysaccharides like alginate (in the form ofalginic acid and algin), fucoidan (in the formfucoidin and fucan), laminarin (in the formlaminaran), and cellulose.[15,16] While brown algae contain a wide variety of compounds, the majority of focus and research has been directed towards the application of algal polysaccharides, especially fucoidan,

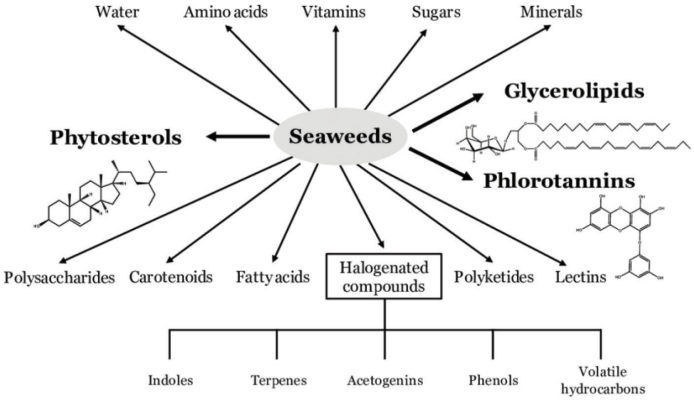

Figure 6: Metabolites marine algae.

alginate, and Sugars are stoked by red algae as floridean starch, a strongly branched amylopectin without amylose that is assembled surface of the plastid located in cytosol of cell.[17] In different types of ulvans, four types of different monosaccharide's are rhamnose (Rha), xylose (Xyl), iduronic acid (IdoA) and glucuronic acid (GlcA) have been identified along with sulfate groups. Ulvans have also been reported to contain many disaccharide fragments. All four forms of monosaccharide's can be located in the backbone, but only glucuronic acids were identified as side chains of polysaccharides, according to Synytsya *et al.*[18]

Carotenoids

Carotenoids, also known as tetra terpenoids are organic pigments formed by plants, algae, bacteria, and fungi in the colours yellow, orange and red. Fucoxanthin, along with chlorophylls a, b, and c-carotene, is an orange-coloured pigment found in *Chromophyta* (Heterokontophyta or Ochrophyta), which includes brown seaweeds (*Phaeophyceae*) and diatoms (*Bacillariophyta*).[19,20] **α-carotene and its derivatives** as well as **γ**-carotene and lutein with a ring, are found in red algae.[21,22] Seybold and Egle discovered that brown algae differ from green algae, red algae and land plants in that they contain more carotene than non-carotene carotenoids (xanthophylls) than fucoxanthin.[23] Fucoxanthin, zeaxanthin, -carotene, violaxanthin, echinenone, carotenoid, and chlorophyll have been identified as the primary colorful pigments of *H. elongate.*[24,25]

Fatty acids

The dry weight of lipids in seaweed can reach 2%. PUFAs account for up to 50% of lipid content, with omega-3 and omega-6, commonly contained in fish oil, accounting for most of it. Omega-6 content in red algae was observed higher than omega-3 content.[26-28] A closer examination of the data showed that the amount of Eicosapentanoic acid (EPA) and docosahexaenoic acid (DHA) in all seaweeds was consistently poor, accounting for only 3%–4% of total FAs. Linolenic acid (18:3) was the most abundant polyunsaturated fatty acid (PUFA) in *R. riparium* and *C. Linum*. The seaweed species *U. Prolifera* has higher linoleic acid (18:2) content than other species in the genus. *C. linum*, seaweed having a high quantity of 18:1, while *U. Lactuca* and *U. intestinalis* having a lower quantity of this FA. The big SFAs were myristic acid (14:0) and palmiticacid (16:0). Eicosapentaenoic acids (EPA, 20:5) are abundant in some marine macroalgal organisms, such as *Palmaria palmate*, while docosahexaenoic acid (DHA) is also present in *Sargassum natans*. EPA and DHA, in particular, are critical for neurological development and cardiovascular disease prevention.[29,30]

Proteins (polypeptides)

Seaweeds are the storehouse of protein, containing up to 47 percent by dry weight when harvested and processed in the right place and at the right time.[15] Tryptophan and methionine, on the other hand, are often restricting amino acids in particular seaweed. The most common amino acids like leucine and isoleucine are found in red algae, while the brown algae contain lack amount of amino acids like methionine, cysteine, and lysine.[31,27] Various heating, baking, and mixing methods were used in a series of experiments to alter or combine algal content with known food products. Algae have been tried in bread and noodle preparations.[32] *In vitro* bio-accessibility of the seaweed species *P. tenera, U. pinnatifida,* and *Ulva pertusa* were 78 percent, 87 percent and 95 percent, respectively, as a percentage of casein bio-accessibility (100 percent).[3] *U. Lactuca* has an *in vitro* absorption rate is 85.7 percent 1.9 percent, whereas Hypneacharoides and *Hypnea japonica*, both red seaweeds, have high absorptive rate is 88.7 percent 0.7 percent and 88.9 percent 1.4 percent, respectively.[33]

Lectins

Lectins are a form of protein that can attach to carbohydrates or compounds reversibly containing them. Algae also have been identified for use in biomedical applications (Singh *et al*., 2015). Agglutinins were located in the *Rhodophyceae, Chlorophyceae, Cyanophyceae,* and *Phaeophyceae* families of alga. A lectin from *Griffithsia* sp. (GRFT) has been extensively studied among red marine algae (Mori *et al*. 2005).[34]

Phytosterols

Phytosterols, which include both sterols and stanols, are a type of sterol compound that is structurally and functionally similar to cholesterol. Physiologically, they help plant cells perform essential functions, including interstitial tissue fluid and conduction of signals (Piironen *et al*., 2000).[35] The chemotaxonomic biomarker Phytosterols can be used to classify in to three major groups of algae: Green algae (*Chlorophyceae*), Redalgae (*Rhodophyceae*) and Brown algae (*Phaeophyceae*) (Chapman 1957; Bouzidi *et al*. 2008). In brown and green algae, the main compounds are C29 sterols, specifically fucosterol and isofucosterol.[36] The hydrocarbons and sterols contained in unsaponifiable fractions of S. chordalis and *U. armoricana*were investigated by using Gas chromatography with mass spectrometry (GC-MS) for the analysis.[37]

Phlorotannins

Phlorotannins are a special group of polymeric phloroglucinol (1, 3, 5-trihydroxybenzene) complexes were found in marine brown algae. Phlorotannins are a group of heterogeneous polymeric compounds composed of phloroglucinols units with different polymerization rate. Phlorotannins are divided into four subclasses depending on the linkage mode: those with ether linkages (fuhalols and phlorethols), those with phenyl linkages (fucols), those with both ether and phenyl linkages (fucophlorethols), and those with a dibenzodioxin linkage (eckols).[38] A Polyphenolic complex like phlorotannins, bromophenols, flavonoids, phenolic terpenegroups, andmycosporine (amino acids) are abundant in seaweeds. The main polyphenolic class in brown seaweeds is phlorotannins, which are only present in marine brown seaweeds. The phenolic compounds likeBromophenols, flavonoids, phenolic acids, phenolic terpenoids, and mycosporine-like amino acids, otherwise found in green and red seaweeds in huge amount.[39, 40]

Glycerolipids

Monogalactosyldiacylglycerides (MDGs), digalactosyldiacylglycerides (DGDGs), and sulfoquinovosyl diacyl glycerides (SDGs) are the three significant glycolipids produced by seaweeds.[41,42] Antiviral, anticancer, anti-herbivory, antibacterial, and antimicroalgal activities have been identified for macroalgal lipids. The red alga (Gracilaria Vermiculophylla) is a fantastic source of prostaglandins like PGE2 and PGE2. These algal prostaglandins are derived from glyceroglycolipids and phospholipid substrates of the algal extract.[43] Prostaglandins are commonly used in the pharmaceutical sector due to their cytotoxic and platelet aggregation inhibition activity. The number of total lipids (TL) and the composition of fatty acids were highly influenced by different sampling technique.

The amounts of TL and PUFAs in temperate seaweeds were higher than in tropical seaweeds. The main PUFAs accumulated in temperate seaweeds, including eicosapentaenoic acid and stearidonic acid found in *Ochrophyta,* linolenic acid and SDA foundin *Chlorophyta*, and EPA in *Rhodophyta.*[44]

Amino acids

The red, brown, and green seaweeds collected from the sub-Antarctic regions of Magallanes, where proteins, amino acid profile, and AA score total were found. The quality of protein, essential AA, non-essential AA, and EAA/NEAA ratio differed significantly due to genera and seaweed colour. Brown seaweed has serves less protein than a red or green seaweed.[45] Protein content in red seaweeds ranges from 10 to 30 percent dry weight, 5 to 15 percent dry weight in brown seaweeds, and 3 to 47 percent dry weight in green seaweeds.[46] The ratio of EAA to non-EAA in seaweeds was nearly 0.41–0.5, and the ratio of EAA to total amino acids was nearly 0.41–0.5. Many of the seaweeds tested had high levels of EAA, including leucine, isoleucine, and lysine. Amino acids like Histidine, aspartic acid, glutamic acid, serine, proline, glycine, and alanine, all were found relatively high in non-EAAs. *U. fasciata* has a total amino acid content of 444.5 to 647.5 mg/g protein, while *E. flexuosa* has relatively low in total amino acid content.[47]

Vitamins

Vitamins like vitamin A (carotenoids), Vitamin C, Vitamin D, Vitamin E, and B Vitamins, are abundant in seaweed. Seaweed, like kale and other leafy greens, contain Vitamin K, which is important for blood clotting. Microalgae vitamin composition can be equally impressive as sea plants. *Tetraselmis suecica*, *Isochrysis galbana*, *Dunaliella tertiolecta*, and *Chlorella stigmatophora* were found to be especially rich in lipid-soluble (A and E) and B-group vitamins [including vitamins B^1, B^2 (riboflavin), B^6 (pyridoxal), and B^{12} by Fabregas and Herrero (1990). Algal foods can provide a wealth of these crucial micronutrients.[48] Rupérez (2002) found that some seaweed has contained ten to hundred times more minerals and vitamins per unit dry mass than terrestrial plants or animal-derived foods. Vitamins A, D, E, K, C, B^1, B^2, B^9, B^{12}, as well as essential minerals calcium, iron, iodine, magnesium, phosphorus, potassium, zinc, copper, manganese, selenium, and fluoride are among them (Misurcova 2011; Qin 2018). The amount of content differs according to the species. For example, total tocopherol (Vitamin E) content in five brown, eight red, and eight green seaweeds from northern European waters ranged from 1.6 to 122 mg kg^1 in brown, 10–26 mg kg1 in red, and 8.8–12.0 mg kg^1 in green species (dry mass, DW).[49]

Sugars

The neutral sugars like glucose, xylose, mannose, arabinose and galactose and the deoxy sugars like fucose rhamnose, the sugar alcohol (menthol) and uronic acids like mannuronic acid, guluronic acid, glucuronic acid and galacturonic acid are found as carbohydrate present in seaweed. Carbohydrate found in *Ulva pertusa* (green seaweed), *Laminaria japonica* (brown seaweed) and *Gelidium amansii* (red seaweed) by using sulfuric acid and hot-compress method into a variety of sugars. Sugars like Galactose (49.32 wt.%) and glucose (12.62 wt.%) has been extracted

from dried seaweeds of *U. pertusa*, while rhamnose (37.89 wt.%) and glucose (16.14 wt.%) were extracted from dried algae *G. amansii*. Mannitol and dried algae *L. japonica* (31.53 wt %).[50]

Minerals

Edible seaweeds are valued for their mineral content, which includes minerals like sodium, magnesium, phosphorous, potassium, iodine, iron, and zinc.[51] The mineral content present in seaweeds is usually high (8–40%). Seaweeds contain all of the necessary minerals and trace elements needed for human nutrition (Mabeau and Fleurence, 1993; Ortega-Calvo, Mazuelos, Hermosn, and Saiz-Jimenez, 1993).[52]

Polyketides

The polyketides, which have relatively large rings of oxygen and carbons, are secondary microbial metabolites that belong to a large category of clinically meaningful natural products with antibacterial, anticancer, or auxiliary physiologically significant bioactivities. Antibiotics such as erythromycin, tetracycline, and tylosin are polyketides. For example, polyketide compounds, including rhizoxin and bryostatins, were appearing to strengthen symbiotic relationships (Partida -Martinez and Hertweck 2005). Bioactive polyketides, fatty acids, bacteriocins, and other unusual compounds of potential clinical significance were all generated by marine *Bacillus spp.*[53]

Halogenated compounds

The halogenated compounds are generally secondary metabolites because of the abundance of chloride and bromide ions present in seawater. Bromide is commonly used by algae for organ halogen processing, even though chlorine is found in higher concentrations in seawater than bromine. Peptides, polyketides, indoles, terpenes, acetogenins, and phenols are among the peptides, polyketides, indoles, terpenes, acetogenins, and phenols contained in marine halogenated compounds.[54] Several compounds have been discovered in marine microalgae, mostly found in red and brown algae, with less green alga.[55] The halogenated compounds primarily produced by red algae, among all marine microalgae. *Laurencia*is a prolific genus found primarily in equatorial, subequatorial and temperate coastal regions.[56,57] Elatol, halogenated sesquiterpene alcohol present in many *Laurencia* species and well known for its strong antibacterial activity, earliest it was isolated in *Laurencia microcladia*, which was collected on the coast of Southern Brazil.[58] *Laurencia saitoi*, which had previously produced very few halogenated compounds, was discovered to produce four new halogenated sesquiterpenes: 10-Bromo-3-chloro-2,7-epoxychamigr-9-en8-ol, 2,10-dibromochamigra-2,7-dien-9-ol, (9S)-2-Bromo-3-chloro-6,9-epoxybisabola-7,10-diene,[59] and (9R)-2-Bromo-3-chloro-6,9-epoxybisabola-7(14),10-d Phloroglucinol and its derivatives are basically plant-based substances. Phloroglucinols (mono-, di-, tri-, tetra-, and oligomeric) and phlorotannins (mono-, di-, tri-, tetra-, and oligomeric) are easily separated by Singh and Bharate.[60] The Laminariales Eisenia Arborea has been found to contain iodophloroglucinol and bromophloroglucinol.[61] Shibata *et al*. discovered that Laminariales Eisenia bicycles and Eckloniakurome release monomeric bromophenols (2,4-dibromophenol, 2,4,6-tribromophenol, and dibromo-iodophenol) in the surrounding medium while retaining oligomers and polymers in their tissues.[62]

Therapeutic effect of bioactive components of seaweeds

The red, green, and brown seaweeds have been deliberated for its therapeutic properties for health care and disease control management, such as anticancer, antioxidant, antidiabetic, antihypertensive, antihyperlipidemic, anticoagulant, antiobesity, anti-inflammatory, immunomodulatory, neuroprotective, antiestrogenic, thyroid-stimulating, antibacterial, antiviral, antifungal, and tissue healing properties.[63] According to the several studies, that shows various therapeutic effects of different algal species against non-communicable diseases such as viral infections, inflammations, obesity, diabetes, and hypertension etc.[64]

Anti-microbial activity

Antibiotic prone and resistant micro-organisms were used to evaluate plant extracts and phytoconstituents for its antimicrobial activity.[65] The antimicrobial activity of methanol, dichloromethane, and hexane extracts of five lyophilized brown algae was investigated *in vitro*.[66] Gas chromatography-mass spectrometry (GC–MS) was used to classify the algal extracts of *S. fusiform* and *S. vulgare*. Antimicrobial compounds such as phenolic groups, terpenes groups, indole groups, fatty acids, and volatile halogenated hydro carbonic groups have been reported.[67] Since they are not explicitly involved in primary processes like photosynthesis, cell division, or algae reproduction, phenolic compounds are classified as secondary metabolites. Changes in microbial cell permeability cause the antimicrobial effect, loss of internal interference with membrane function, loss of cellular integrity, and ultimate cell death.[68] Phlorotannins are potent antioxidants that were shown to have excellent bactericidal activity against bacteria found in food.[69] The extracts *Enteromorphalinza* showed antimicrobial activity against *P. gingivalis* and *P. intermedia* and found no side effects at a modest dose. Unsaturated fatty acids like stearidonic acid (SA), and gamma-linolenic acid were the most active compounds collected by Sephadex LH-20 gel and reverse-phase HPLC, according to Park *et al*. (GLA). Their MIC values for *P. Gingivalis* and *P. intermedia* were 39.06 g/mL and 9.76 g/mL, respectively.[70]

Anti-viral activity

The antiviral activities against various viruses, seaweed polysaccharides have become a high source of potential antiviral drugs. Furthermore, unique marine polysaccharides from seaweeds have been shown to have antiviral mechanisms and medical applications. Antiviral activity was recently recorded in a significant fraction (17 of 62 species examined) of extracts extracted from seaweeds collected in different regions of British Columbia, Canada (Kim *et al*., 1997). Antiviral activity has previously been observed in a wide range of algae from various marine habitats, including California (Ehresmann *et al*., 1977), the United Kingdom (Blunden *et al*., 1981), the Mediterranean (Ballesteros *et al*., 1992), India (Premnathan *et al*., 1992), and Japan (Premnathan *et al*., 1992). (Hayashi *et al*., 1996). The detection of the active compounds, nevertheless, was seldom attempted. Sulfated polysaccharides are well-known algae components, and because some of them were revealed their antiviral activity, it has been suggested that they are to blame for the observed activities (Baba *et al*., 1988).[71] Carrageenan's were shown the anti-tumor and antiviral properties in human health studies.[72] According to new research on biocide properties, carrageenan gels from *Chondrus crispus* can prevent the spread transmitted diseases like HIV and other STD viruses, including gonorrhea, genital warts, and the herpes simplex virus.[73] Several polysaccharides and diterpenes have recently been identified as having a potent inhibitory effect against Herpes simplex virus type 1(HSV-1) (after screening assays of antiviral activity of several extracts. The herpes virus is an old virus that causes a variety of infections.[74,75] *Acanthophora specifira*, has antiviral properties.[76] The mechanism action of anti-viral activity of Algae are shown in Figure 7.

Anti-cancer activity

The anticancer ability of seaweeds extracts and extracted compounds from marine algae has been studied so far, and it is interesting. Compounds like terpenes, polysaccharides, and polyphenols are the most biogenic essential compounds because they have anticancer properties.

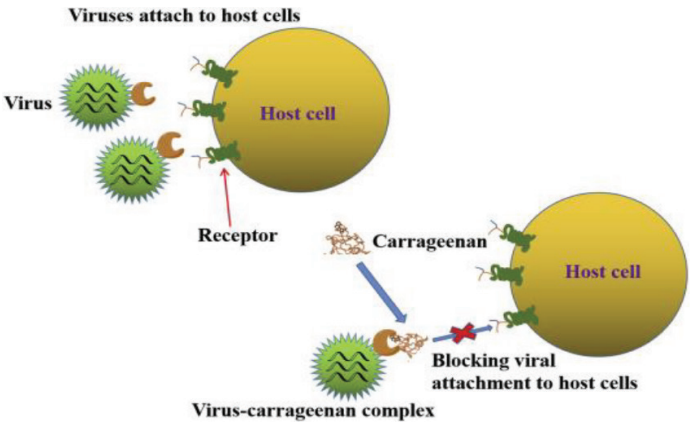

Figure 7: Antiviral activity of Algae.

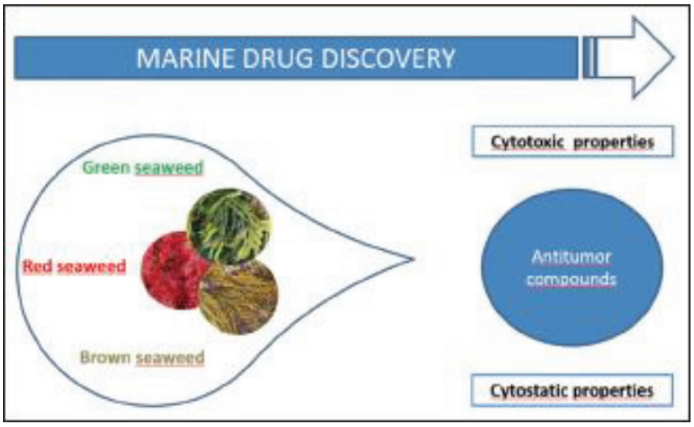

Figure 8: Anticancer activity of marine algae.

The anticancer properties of algal polysaccharides have been studied extensively. Gracilariopsis and lemaneiformis isolates, which contain 3, 6-anhydro-L-galactose, and D-galactose.[77] *Ulva lactuca*, also known as sea lettuce, is a widely spread green alga whose polysaccharides showed anticancer properties in various types of cells. Polysaccharides derived from *U. lactuca*, for example, showed anti-breast cancer activity both *in vitro* and *in vivo* evaluation. Polysaccharides from this seaweed showed chemopreventive effect. Treatment with these compounds for ten weeks prevented breast tissue alterations and cancer-causing wounds in a rat DMBA-induced in breast cancer model.[78]

As compared to the anticancer medication like cisplatin, halogenated monoterpenes isolated from the red seaweeds *Plocamium cornutum* and *Plocamium suhrii* show a significant anti-proliferative activity.[79] More research on other carcinoma cell lines and *in vivo* antitumor evaluation could be beneficial for *Sargassum oligocystum*. It is possibly a new avenue for antitumor medication as a new marine resource, demonstrating that marine algae could be possible candidate sources for antitumor drugs.[80] The Anti-cancer activities of marine algae are shown in Figure 8.

Anti- allergic activity

A common anti-allergic drug, DSCG, was effectively used as anti-allergic activity. Natural polyphenols from land-based materials, such as TP (Li *et al*., 2008) and EGCG (Maeda and Tachibana, 2012) were shown to have anti-allergic properties. They extracted polyphenol from seaweeds, a marine source, with hyaluronidase inhibition activity.[81] The ethanolic extract of two Pakistani and three Chinese brown seaweeds were showed an inhibitory effect on hyaluronidase activity were tested and compared. Positive effects included the anti-allergic medication DSCG and the natural polyphenol catechin. DSCG has previously been shown to be an efficient hyaluronidase inhibitor (Kakegawa *et al*., 1985). The seaweed extraction method was first developed for total crude Phlorotannins yield.[82]

Anti- fouling activity

Bio-fouling means the growth of micro-fouling agents (bacteria's and Protista's) and macro-fouling agents (invertebrates and alga's) organisms on submerged surfaces. As a result, new non-toxic antifouling technologies are critical. *Enteromorpha prolifera* tissue development, spore settlement, zygote formation, and germling were all inhibited by the methanolic extract of *Ishigesi nicola*. In laboratory studies, it also caused the mussel foot to have a solid repulsive behaviour and was a potent inhibitor of larval mussel settlement.[83] When natural concentrations of organic extracts from the red algae *Bryothamnion seaforthii* and *Jania Rubens* were compared to the monitor, it was found that natural concentrations of the organic extracts from the red algae *Bryothamnion seaforthii* and *Jania Rubens* exhibited extreme antifouling activity. As shown by *Perna Perna* juvenile mussels' lower byssal attachment, such findings indicate that these algae have a chemical defensive mechanism against epibionts. Even though it has antifouling chemical defenses active against *P. Perna*, *B. seaforthiithalli* show epibiosis, which may be due to the peculiar action of chemical defenses concerning target organisms, i.e., a narrow spectrum antifouling activity.[84,85]

Anti-fungal activity

By using the disk diffusion process, the antifungal effect of *Ulva lactuca* L. extracted a protein and that was determined against various pathogenic fungi like *Alternaria solani, Aspergillus niger, Aspergillus flavus, Aspergillus clavatus* and *Fusarium oxysporum*. The ethanolic extract of *S. robusta* displayed activity against fruit spoiling fungi in all five fractions. The amount of activity found in seaweed fractions ranged from minor in ethanol to primary in aqueous fractions. It has been reported that with a 20 mg/ml concentration, aqueous fraction inhibited 99 percent of *A. niger* development.[86,87] By using the cup plate process, different extracts of eight seaweed species were screened for antifungal activity against two strains, *A. niger* and *P. jenthinellum*.

Algicidal activity

Harmful algal blooms (HAB), also known as red tide phytoplankton, have been identified worldwide, posing a threat to public health and the fishing industry. A water-soluble and methanol-soluble fractional were isolated from each seaweed to confirm the presence of red tide algicidal substances in seaweed tissues. Only the extract from *Corallina pilulifera* showed growth inhibition of less than 0.5 percent of the reference culture level when methanol extracts from 28 seaweeds were applied to *C. polykrikoides* cultures at a concentration of 50 g mL1. It has been reported that at a concentration of 100 g mL1, extracts from *Endarachnebinghamiae, Ishigefoliacea*, and *Ulva pertusa* inhibited development. Only the water extracts of *C. pilulifera* inhibited by the development of *C. polykrikoides* cultures.[88,89] Kakisawa *et al*. (1988) were the first to investigate the allelochemicals of macroalgae to microalgae, finding that the algicidal material octadeca-6, 9,12,15-tetraenoic acid (ODTA) collected from the brown alga *Cladosiphon okamuranus* was toxic to 21 phytoplankton species.[90]

Anti-malarial activity

The anti-plasmodial *in vitro* assay revealed that all seaweed extracts showed dose-dependent inhibition parasitemia, with *Chaetomorpha*

antennina [(26.3-74.14) g/mL] showing the lowest level of inhibitory (IC_{50}) concentration, followed by *Enteromorpha compressa* [(55.92-7.26) g/mL], and positive controls such as chloroquine and artemether showing the IC_{50} value with the (19.10-5.93). Seaweed extracts were tested *in vitro* against *Plasmodium falciparum* (*P. falciparum*) acquired from the Jawaharlal Nehru Centre for Advanced Scientific Research, (Indian Institute of Science), Bangalore.[91] By using the chloroquine and pyrimethamine-resistant K1 strain with the standard drug chloroquine, *in vitro* activity was shown against erythrocytic stages of *P. falciparum* and was calculated using a modified [3 H]- hypoxanthine incorporation assay (Matile and Pink, 1990).[92]

Anti-cholesterol activity

Fucoxanthin, carotenoid found in seaweed, has anti-obesity properties and was shown to minimize body weight and white adipose tissue, including perirenal and epididymal abdominal adipose tissue.[93] Fucoxanthin increases the appearance of uncoupling protein (1) in side white adipose tissue, which helps to minimize fat mass. Fucoxanthin was induced on the brown seaweed like *S. polycystum* in this sample, which may explain why the HCF-fed rats gained the least weight.[94] The effects of seaweed, *I. stellata, C. racemosa, C. sinuosa, S. robusta,* and *S. asperum* on the lipid profile in standard, triton-induced, and high fat diet-induced hyperlipidemia, 5 rats were studied using pharmacological screening. As with other natural hypocholesterolemic agents, most of the seaweed tested showed promising results in lowering serum cholesterol, triglyceride, and LDL-cholesterol levels accompanied by a rise in HDL-cholesterol.[95]

Anti-diabetic activity

The α-glucosidase activity inhibition of the unpurified aqueous extracts of *H. macroloba, T. conoides, P. sulcata,* and *S. binderi* were involved in initial screening glucosidase inhibitory activity. This aqueous extracts from four of the six seaweed species studied which yielded promising results. *In vitro*, *H. macroloba* extracts inhibited -glucosidase activity with the highest percentage inhibition (70.58 percent inhibition at 40.22 mg mL1). *T. conoides, P. sulcata,* and *S. binderi* all had inhibitory activity against glucosidase, with *T. conoides* having the highest inhibition at 67.38 percent, *P. sulcata* at 41.10 percent, and *S. binderi* at 24.18 percent.[96] According to several studies, seaweeds have been linked to anti-diabetic behaviour (Kim *et al*., 2012), (Jensen *et al*., 2013), (Akbarzadeh *et al*., 2018), (Unnikrishnan and Jayasri, 2018). As per report the anti-diabetic effect of the six studied organisms was determined by inhibiting -glucosidase in the presence of acarbose as a positive control. *H. cuneiformis* has been found to be the most effective species in inhibiting glucosidase.[97,98]

Anti-obesity activity

Fucoxanthin has a broad range of bioactivities that could benefit human health. Murine studies that showed initiation of uncoupling protein-1 inside abdominal white adipose tissue mitochondria, leading to fatty acid oxidation and heat output,[99] As per report from apart from using the entire seaweed, several experiments by using *in vitro* and *in vivo* method have shown that seaweed extracts have anti-obesity properties. For example, Kang *et al*. (2016) investigated the anti-obesity activity of ethanolic extracts from Jeju Island seaweeds.[100] The different extract from the red seaweed *Plocamium telfairiae* has been found to high potent inhibitory effect, particularly in lowering the expression of adipogenic-specific proteins such as peroxisome proliferator-activated receptor (PPAR-), cytosine-cytosine-adenosine-adenosine-thymidine (CCAAT)/enhancer-binding protein (C/EBP), In another study, mice fed a high-fat diet lost weight after being given extracts from the edible red seaweed *Gelidium amansii*.[101]

Anti- inflammatory activity

The anti-inflammatory activity has been showed carrageenan-induced test for peritonitis test is a well-studied model for acute peritoneal inflammation research. A synergistic interaction mediates carrageenan's action on peritonitis between prostanoids, leukotriene B4, and other chemotactic agents such as IL-8 and C5a, which shows vasodilation plasmatic exudation and the recruitment of leukocytes, primarily neutrophils.[102] The bisindole alkaloid was isolated from the lipid extract of *Caulerpa racemosa*. The writhing and hot plate experiments, formalin-induced pain, capsaicin-induced ear edema, and carrageenan-induced peritonitis were all used as pharmacological assays.[103] Some of varieties in quality and quantity of the Mediterranean Tunisian coast flora, which includes many marine species and seaweeds, the majority of them have yet to be studied for pharmacological and biological activities.[104]

Antioxidant activity

Carotenoids form seaweeds are the natural pigments used as antioxidant components that decrease the occurrence of many diseases, particularly those mediated by light.[105] Anti-carcinogens were found in a wide variety of antioxidants.[106] Yuan and Walsh discovered that extracts from various marine algae have antioxidant and anti-proliferative properties on human cervical adenocarcinoma cells. As a result, there should be a strong connection between phenolic compound content and antioxidant and anticancer activity.[107,108]

Photoproctecter

In a zebra fish model, the photoprotective effect of EMC was investigated *in vivo* method. Intracellular ROS generation, NO development, cell death, and lipid peroxidation were all significantly induced by UVB irradiation. Nevertheless, in UVB-irradiated zebrafish, EMC significantly reduced intracellular ROS, decreased cell death, suppressed NO production, and attenuated lipid peroxidation. Every effect was dose-dependent. These findings suggest that EMC has a robust photoprotective effect in human epidermic and dermic cells *in vitro* and *in vivo* in the zebra fish model. In conclusion, the above findings show that EMC has antioxidant, antimelanogenesis, and photoprotective properties. In the cosmeceutical industry, it may be a possible candidate for skincare products.

Wound healing

Results of *in vitro* antioxidant properties of CBL suggested that CBL improved cell viability against oxidation-induced cell death contributing to a fast healing.

CONCLUSION

A diverse range of seaweeds can be found along India's entire coastline. It has been discovered that different species of algae have different chemical compositions and bioactivity. There is still large biomass of the seaweeds, which requires special attention for their scientific studies. In this review article, we have tried to systematically collect the overwhelming array of knowledge for the benefit of the readers. Finally, it can be concluded that a diverse range of seaweeds can be found along India's entire coastline. There is still significant biomass of seaweeds that needs special attention to conduct scientific research. We have attempted to systematically compile a vast array of knowledge to benefit the readers in this review.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

CUPB: Central University of Punjab, Bathinda; **EPA:** Eicosapentanoic acid; **DHA:** Docosahexaenoic acid; **PUFA:** Polyunsaturated fatty acid; **GC-MS:** Gas chromatography with mass spectrometry; **MDGs:** Monogalactosyldiacylglycerides; **DGDGs:** Digalactosyldiacylglycerides; **SDGs:** Sulfoquinovosyldiacylglycerides; **AA:** Amino acids

EAA: Essential amino acids; **NEAA:** Non-essential amino acids; **DSCG:** DiploMe SupeRieur De Comptabilite Et De Gastion; **EGCG:** PIgallocatechin gallate; **HAB:** Harmful algal blooms; **PPAR:** Peroxisome proliferator activated receptor; **CCAAT:** Cytosine-cytosine-adenosine-adenosine-thymidine; **EBP:** Enhancer binding protein.

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