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Medicinal prospective of seaweed resources in India: A review

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Abstract
The marine ecosystems are the integral part of biodiversity and support the wide range of marine phytodiversity, consisting of marine algae, seagrasses and mangroves. The marine macro algae are popularly known as 'seaweeds'. Presently, c.11,000 taxa of seaweeds are reported globally and c. 221 taxa have been recognized as economically important in various forms like food, fodder and in various biochemical and pharmaceutical industries. Seaweeds contain many bioactive compounds such as proteins, peptides, fatty acids, antioxidants, vitamins, minerals, Caulerpenyne, Sulfated polysachharides, domoic acid, kainik acid etc. which have high therapeutic potential in various forms, such as antimicrobial, antiviral, anticancerous, anticoagulants, anti-inflammatory etc. The present paper deals with the medicinal potentiality of 39 taxa of seaweeds, belonging to 20 taxa of Chlorophyceae, 4 taxa of Phaeophyceae and 15 taxa of Rhodophyceae.

Keywords: bioactive compounds, chlorophyceae, medicinal, phaeophycea, rhodophyceae

Introduction
Algae constitute an important component of the marine floral diversity and play a very crucial role in the aquatic food chains as primary producer. Seaweeds are the marine macro algae and exclusively found growing in the marine ecosystems on rocks, coralline beds, reefs, pebbles, shells, dead corals and also as epiphytes on other plants like seagrasses in the intertidal shallow sub-tidal and deep sea areas. It constitutes an integral part of the marine phytodiversity. Seaweeds are broadly classified into three classes *i.e.* Chlorophyceae, Phaeophyceae and Rhodophyceae, based on the presence of photosynthetic pigments, colours, and reserve food materials. As seaweeds grow in the harsh environment of marine ecosystems, they develop many protective secondary metabolites and mechanism to survive and adapt in such situation [1]. Besides, they possess many bioactive compounds such as proteins, peptides, fatty acids, antioxidants, vitamins, minerals. These bioactive compounds are endowed with a variety of therapeutic potentials. Globally, c. 72,500 taxa of algae have been estimated to be present, of which c. 45,000 taxa of algae have been reported [2]. Among these, seaweeds or marine macro algae constitute a considerable fragment of algal resources. To date c. 11,000 taxa of seaweeds have been reported which includes *c.* 7,200 taxa of Rhodophyceae, 2,000 taxa of Phaeophyceae and 1,800 taxa of Chlorophyceae [3]. The Indian coastlines, endowed with about *c.* 7500 km of length, support diverse coastal habitats and harbours 865 taxa of seaweeds, comprising 442 taxa of Rhodophyceae, 212 taxa of Chlorophyceae and 211 taxa of Phaeophyceae [4] as shown in Fig. 1 and Fig. 2.

Materials and Methods
The present review study is primarily based on the study of relevant literature on the medicinal aspects of seaweeds in India and abroad. All the relevant literature were scrutinized and the medicinal aspects of seaweeds in respect to Indian coast were analyzed.

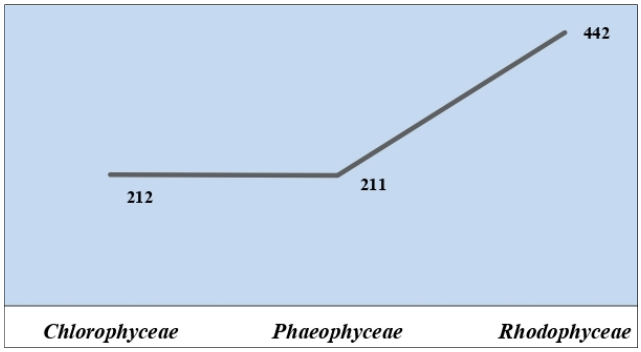


Fig 1: Graph representing diversity of seaweeds in India

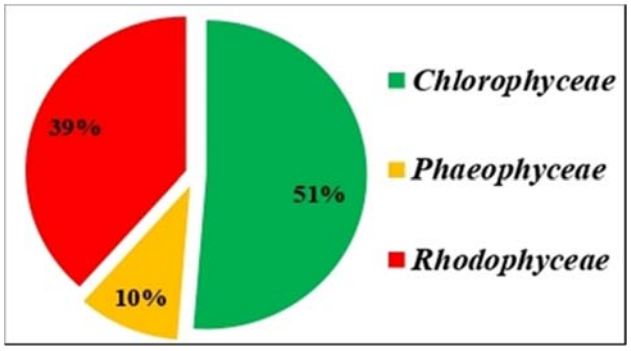


Fig 2: Pie chart showing medicinal potential of seaweeds

Results and Discussion

Glimpses of seaweeds in Indian coast

The Indian coastlines significantly support around 865 taxa of seaweeds. However, the scrutiny of literature reveals that the diversity and distribution of seaweeds along the Indian coast is not uniform throughout and shows ample variations. Among the various maritime states, Tamil Nadu exhibits the highest diversity of seaweeds with 282 species [5,6], followed by Maharashtra coast with 240 species [7], Gujarat coast with 198 species [8], Kerala with 147 taxa [9], Karnataka with 105 taxa [10], Goa with 90 taxa of seaweeds [11], Andaman & Nicobar islands with 80 species [12], Diu island with 70 species [13], Andhra Pradesh with 65 species [14], West Bengal with 14 species [15] and Odisha with 14 species [16].Besides, the coastline of India also supports around 125 taxa of seaweeds endemic to India [17]. It is also observed that in the recent years, many new records of seaweeds have been added in the list of the Indian seaweed flora by various researchers [18, 19, 20]. Therefore, the concrete number of seaweed species from the Indian coastline may increase even more, when there will be more exploration in the under explored or unexplored or remote localities of the coastlines.

Medicinal prospective of seaweeds

In the recent years, the importance of seaweeds as one of the important marine living resources has got more attention. The literature reveals that seaweeds have been used by the human beings in the forms of foods and fodders as early as 2500 years ago [21]. Worldwide, *c.* 7.5 – 8 million tons of wet seaweeds are being produced every year [22]. Globally, c. 221 taxa of seaweeds are commercially utilized in various forms, which include 145 taxa for food and 110 taxa for phycocolloid production [23, 24]. Because of the increasing demands and awareness about the economic potentiality of these promising resources in the form of food, fodder, cosmetics, fertilizers, carrageenan, agar, alginates etc. at industrial level, the cultivation of seaweeds has got momentum globally. Presently, around 42 countries in the world are actively involved in the artificial cultivation and commercial utilization of seaweed resources. Among them, China ranks first [25].

Since times immemorial, seaweeds have been an integral part of the human civilization [26, 27]. Many species of seaweeds are of high therapeutic potential and contain secondary metabolites which are of high pharmaceutical potential and used in making medicines. For instance, *Chondria armata*, a red seaweed, is known to have chemical components like Domoic acid and Kainic acid, useful in neurological treatment and also have anthelminthic and insecticidal properties [28]. Similarly, sulphated polysaccharides extracted from *Cladophora glomerata* are known to be useful in cancer treatment [28, 29]. Information on the therapeutic values of seaweed resources are usually available but sporadically and species specific. Therefore, author has attempted to review such information and present a comprehensive account on the medicinal potential of these seaweeds from the Indian coast. The study reveals that 39 taxa of seaweeds, belonging to 20 taxa of Chlorophyceae (51%), 4 taxa of Phaeophyceae (10%) and 15 taxa of Rhodophyceae (39%) have been recognized as medicinally important (Table 1, Fig. 3). Among these, 15 taxa exhibit antibacterial potentialities, 10 taxa having antioxidant activities, 6 taxa having antiviral activities, 5 taxa having anti cancerous activities, 4 taxa showing anti-inflammatory activity and 3 taxa showing anthelminthic activities. The medicinal properties of these seaweeds may be dealt under the following heads:

Antibacterial activities

Many of the bioactive compounds such as flavonoids, polyphenols, polysaccharides etc. found in seaweeds exhibit antibacterial activities. Considerable literatures are available sporadically which show the antibacterial potentiality of seaweeds. In the present study, 15 species of seaweeds like *Ulva prolifera, Chaetomorpha antennina, Chaetomorph linum, Cladophora glomerata, Bryopsis plumose, Caulerpa scalpelliformis, Dictyota bartayresiana, Stoechospermum marginatum, Grateloupia lithophila, Corallina officinalis, Hypnea valentiae, Spyridia filamentosa, Spyridia hypnoides Bostrychia tenella* have been recognized with antibacterial potentials against various bacteria and have been provided in table 1. *Hypnea valentiae* is known to have antibacterial potential against *Staphylococcus aureus, vibrio fischeri, V. alginolyticus, Pseudomonas aeruginosa* and *Micrococcus luteus* [30]. Similarly, *Cladophora glomerata* is known to possess antibacterial potential against multidrug resistant human pathogen *Acinetobacter baumannii* and various fish pathogens such as *Vibrio fischeri, V. vulnificus, V. anguillarum, V. parahaemolyticus, Escherichia coli and Bacillus cereus* [31].

Antioxidant activities

Antioxidant compounds are of high importance in the food and pharmaceutical industries. Continuous usage of synthetic antioxidants in pharmaceutical drugs sometimes causes toxicity and danger to human health [32]. In such circumstances, seaweeds serve as important and alternative natural sources for the compounds which have the capacity to inhibit the oxidation process without any side effects to health [33]. In the present study, 10 species of seaweeds like *Ulva compressa, Ulva prolifera, Ulva reticulata, Chaetomorpha*

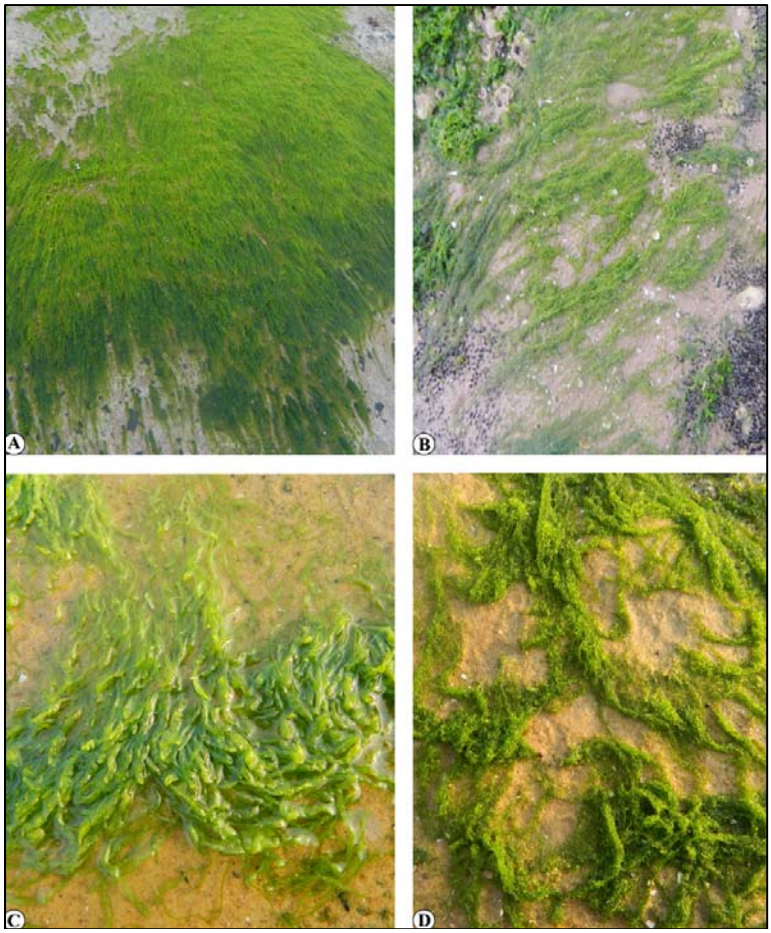


Fig 3: Seaweeds growing on various substrata at Digha coast, West Bengal: A. Luxuriant growth of *Ulva prolifera* O.F. Muell.; B. Mixed growth of *Ulva* spp. on rocky substrata; C. *Ulva compressa* L.; D. *Chaetomorpha crassa* (C. Agardh) Kuetz.

Table 1: List of the seaweeds with medicinal potential, occurring in the Indian coast

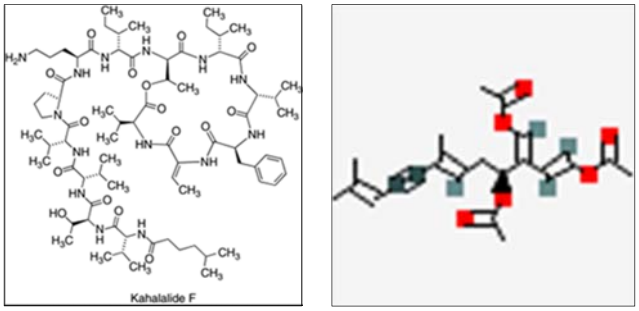
Sl. No.	Name of the taxa	Medicinal potential of seaweeds	References
Class: Chlorophyceae			
1.	FAMILY: ULVACEAE *Ulva compressa* L.	Medicinal (Antioxidant Activity)	[43]
2.	*Ulva conglobata* Kjellm.	Medicinal (Anti-inflammatory)	[45]
3.	*Ulva prolifera* O.F. Muell.	Medicinal (Antioxidant, antibacterial and immunomodulatory activities)	[46]
4.	*Ulva fasciata* Delile	Medicinal (Antiviral, Cytotoxic activity)	[47,47,48]
5.	*Ulva lactuca* L.	Medicinal (Anti-inflammatory)	[45,47]
6.	*Ulva reticulata* Forssk.	Medicinal (Anti-protozoal, Antioxidant activities)	[43, 44, 45, 46, 50, 51]
7.	*Ulva rigida* C.Agardh	Medicinal (Anti-inflammatory, Cytotoxic activity, Antiviral)	[43, 44, 47, 52]
8.	FAMILY: ACROSIPHONIACEAE *Acrosiphonia orientalis* (J. Agardh) P.C.Silva	Medicinal (Antiviral, Vibriocidal properties)	[46, 53]
9.	FAMILY: CLADOPHORACEAE *Chaetomorpha antennina* (Bory) Kuetz.	Medicinal (Antibacterial, antioxidant, antiplasmodial)	[8, 54, 55, 56]
10.	*Chaetomorpha crassa* (C. Agardh) Kuetz.	Medicinal (Antioxidant properties)	[57]
11.	*Chaetomorph linum* (O.F. Muell.) Kuetz.	Medicinal (Antibacterial activity)	[58]
12.	*Cladophora albida* (Nees) Kuetz.	Medicinal (Anticancerous activity)	[59]
13.	*Cladophora glomerata* (L.) Kuetz.	Medicinal (Antibacterial, antifungal, Antioxidant, Anti-ulcer, hypotensive and analgesic activities)	[29, 34]
14.	FAMILY: BRYOPSIDACEAE *Bryopsis pennata* J.V. Lamour.	Medicinal (Kahalalide F, as antiviral, antimicrobial and anti-cancerous activity)	[34, 61]
15.	*Bryopsis plumosa* (Huds.) C. Agardh	Medicinal (Antibacterial activity)	[34, 62]
16.	FAMILY: CAULERPACEAE *Caulerpa scalpelliformis* (R. Br. ex Turner) C. Agardh	Medicinal (Antibacterial activity)	[63]
17.	*Caulerpa taxifolia* (Vahl) C. Agardh	Medicinal (*Caulerpenyne*- - a sesquiterpene as Antitumerous potential)	[28, 35, 36]
18.	FAMILY: Codiaceae *Codium dwarkense* Boergesen	Medicinal (Anticoagulant property)	[64, 65]

19.	*Codium tomentosum* Stack.	Medicinal (Anticoagulant property)	[65]
20.	*Codium decorticatum* (Woodw.) M.Howe	Medicinal (Antioxidant property)	[8, 66]
Class: Phaeophyceae			
21.	Family: Dictyotaceae *Dictyota bartayresiana* J.V. Lamour.	Medicinal (Antibacterial, cytotoxic and larvicidal activities)	[67, 68, 69, 70]
22.	*Dictyota dichotoma var. intricata* (C. Agard) Grev. [*D. dichotoma* var. *implexa* (Desf.) S. Gray]	Medicinal (Antiviral, cytotoxic activities)	[68, 71]
23.	*Stoechospermum marginatum* (C.Agardh) Kuetz.	Medicinal (Antibacterial activity)	[72]
24.	*Sargassum ilicifolium* (Turner) J. Agardh	Medicinal (Immuno-modulatory activities)	[73]
Class: Rhodophyceae			
25.	Family: Bangiaceae *Porphyra crispata* Kjellm.	Medicinal (Anticancerous activity)	[74, 75]
26.	Family: Halymeniaceae *Grateloupia lithophila* Boergesen	Medicinal (Antibacterial activity)	[76]
27.	FAMILY: CORALLINACEAE *Amphiroa anceps* (Lam.) Desce.	Medicinal (Antibacterial activity)	[77]
28.	*Corallina officinalis* L.	Medicinal (Antibacterial activity)	[78]
29.	*Jania rubens* (L.) J.V. Lamour.	Medicinal (Antioxidant activity)	[79]
30.	Family: Hypneaceae *Hypnea musciformis* (Wulf.) J.V. Lamour.	Medicinal (Antioxidant, Anti-inflammatory activities)	[23, 41, 43, 79]
31.	*Hypnea spinella* (C.Agardh) Kuetz.	Medicinal (Antiviral activity)	[81]
32.	*Hypnea valentiae* (Turner) Montagne	Medicinal (Antibacterial, antioxidant activities)	[23, 43, 79]
33.	Family: Ceramiaceae *Centroceras clavulatum* (C. Agardh) Mont.	Medicinal (Dominic and Kainik acid, anthelminthic and insecticidal activities)	[28]
34.	*Spyridia filamentosa* (Wulfen) Harv.	Medicinal (Antibacterial activity)	[82]
35.	*Spyridia hypnoides* (Bory) Papenf.	Medicinal (Antibacterial activity)	[82]
36.	FAMILY: RHODOMELACEAE *Chondria armata* (Kuetz.) Okamura	Medicinal (Dominic and Kainik acid, Anti cancerous activity)	[28]
37.	*Digenea simplex* (Wulfen) C. Agardh	Medicinal (Anthelminthic activity)	[8]
38.	*Bostrychia tenella* (J.V. Lamour.) J. Agardh	Medicinal (Antibacterial and antifungal activities)	[83]
39.	*Palisada perforata* (Bory) K.W.Nam [*Laurencia papillosa* (C. Agardh) Grev.]	Medicinal (Dominic and Kainik acid, Anti cancerous activity)	[28]

antennina, Chaetomorpha crassa, Cladophora glomerata, Codium decorticatum, Jania rubens, Hypnea musciformis, Hypnea valentiae have been recognized with antioxidant potentials.

Anti-cancerous activities

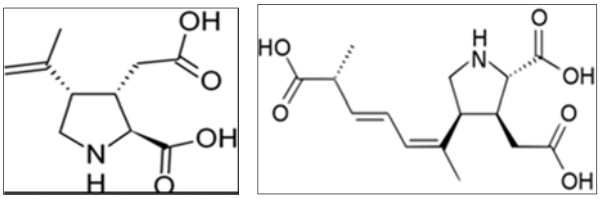
Seaweeds are the natural sources of many of the bioactive compounds which are known to have immunopharmacological and oncotherapeutical applications.



Kahalalide F ***Caulerpenyne* ($C_{21}H_{26}O_6$)**

Fig 4: A. Chemical structure of *Kahalalide F* – extracted [Science Direct ®] and B. Chemical structure of *Caulerpenyne* [39] ($C_{21}H_{26}O_6$) extracted from *Caulerpa taxifolia* [NCBI, 2020)]

The sulphated polysaccharides extracted from *Cladophora glomerata* are reported to suppress cancer cell proliferation [29]. *Bryopsis plumosa* has a unique bioactive compound called *Kahalalide F*, (Fig. 4, A) which is very much effective in treatment of AIDS cases and also in lung cancer [28, 34]. Similarly, *Caulerpenyne* - a sesquiterpene, (Fig. 4, B) extracted from *Caulerpa taxifolia* has been reported very active against pancreatic lipase and exhibits anticancerous, antitumour and antiproliferative properties [35, 36]. Therefore, it has significant therapeutic values in the treatment of pancreatic cancer.



Kainic acid **Domoic acid**

Fig 5: Chemical structure of Kainic acid and Domoic acid extracted from red seaweeds [NCBI, 2020)]

The red seaweeds like *Centroceras clavulatum, Chondria armata, Palisada perforata (Laurencia papillosa)* are known to have chemical compounds like *Domoic acid* and *Kainic acid* which has been used by the Japanese as an anthelmintic agent for centuries [28, 37, 38]. Domoic acid [(2S,3S,4S)-3-(Carboxymethyl)-4-[(1Z,3E,5R)-6-hydroxy-1,5-dimethyl-6-oxo-hexa-1,3-dienyl]pyrrolidine-2-carboxylic acid] and Kainic acid [(2S,3S,4S)-3 (Carboxymethyl)-4-prop-1-en-2-ylpyrrolidine-2-carboxylic acid] (Fig. 5) are potential neuroexcitatory amino acid against that acts by activating receptors for glutamate, the principal excitatory neurotransmitter in the central nervous system. Therefore, seaweeds serve as important natural sources of compounds, known to have high significant therapeutic values in health systems.

Antiviral activities

Many species of seaweeds like *Ulva fasciata, Ulva rigida, Acrosiphonia orientalis, Bryopsis pennata, Dictyota bartayresii, Dictyota dichotoma* var. *intricata and Hypnea spinella* have active biochemical which exhibits antiviral

potentiality. *Pachydictyols* (8ß-Hydroxypachydictyol A) - a diterpene, extracted from *Dictyota bartayresii* is known to have cytotoxicity and antiviral activities, which is of significant therapeutic potential [40].

Anti-inflammatory activities

There are considerable references which show the anti-inflammatory potential of seaweeds. *Ulva conglobata*, *Ulva lactuca*, *Ulva rigida*, *Hypnea musciformis* etc. have been reported as having bioactive compounds which have anti-inflammatory activities. *Sulphated polysaccharide* (PLS), a secondary metabolite, extracted from *Hypnea musciformis* has significant therapeutic potential against TNBS-induced intestinal damages in rats and have been useful in treatment of inflammatory bowel in human beings [41]. Similarly, the biochemical extracts from *Ulva lactuca* were tested against the mosquito larvae in *Culex pipiens*, Cotton leafworm *Spodoptera littoralis*, phytopathogenic fungi *Aspergillus niger*, *Penicillium digitatum* and *Rhizoctonia solani*. Therefore, this species can be taken into consideration for its insecticidal and fungicidal properties [42].

Conclusion

This review article highlights the importance of seaweeds as resources and its economic and pharmaceutical potential. The Indian coastlines exhibit significant diversity of more than 865 taxa of seaweeds. In the present scenario, the commercial cultivation and sustainable utilization of seaweeds at industrial scale has got momentum in many parts of the world. Seaweeds are the source of several bioactive compounds which have high therapeutic potential in various forms, such as antimicrobial, antiviral, anticancerous, anticoagulants, anti-inflammatory. Therefore, the medicinal prospective of these promising natural resources in Indian scenario need more research for its better understanding and sustainable utilization.

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