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A review on phytoconstituents of marine brown algae

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Abstract

Background: From the last few years, the development and discovery of bioactive compounds and their potential properties from marine algae have been enhanced significantly. The coastal area is a huge storehouse for propitious algae. It has been the genuine reality that the consequence of marine algae as a source of different compounds is increasing.

Main body: Numerous advanced research devices are available for the discovery of synthetic compounds but still many researchers are working on natural bioactive compounds to discover their biological properties, which are useful to society. Marine algae are taking the preponderance of consideration from investigators owing to its phenomenon of biological activity like anti-cancer, anti-viral, cholesterol-reducing, and many more. A variety of compounds are collected from algae with specific purposes as they remain in an extremely ambitious and hard state; this condition is responsible for the synthesis of very particularly effective bioactive compounds. The present article is concentrating on the brown algae of the Gujarat coast, phlorotannins, polyphenol, phytosterol from brown algae, and their various applications. The main importance has been given to the secondary metabolites and various applications of marine brown algae.

Conclusion: From this review, it can be concluded that the prominent bioactive compounds from brown algae can cure many serious diseases. Besides, the potential biological activities of a special bioactive compound may represent the interest in the industry of pharmaceuticals, cosmeceutical, and functional foods.

Keywords: Marine Brown algae, Bioactive compound, Applications

Background

Seaweeds mean the varieties of macro algae available abundantly at sea or nearby areas which can be used commercially. Macroalgae/seaweeds are categorized as green algae (Chlorophyta), brown algae (Phaeophyta), and red algae (Rhodophyta) according to their pigmentation, nutritive, and chemical composition. Brown, red algae are mainly used in human nutrition as a source of many mineral elements, vitamins, protein, amino acids, etc. Brown algae are more abundant in a shallow rocky coastal area, especially when exposed at low tide. The vegetation of the algae provides an ideal habitat, food, and shelter for various animals. They act as epiphyte fauna. The holdfast of seaweeds binds the sediments together and prevents coastal erosion [1]. These are vast and various groups of organisms that play an important role in the marine ecosystem [2]. Marine algae have always aroused great interest in Asian culture as marine food sources [3]. Seaweeds come in an incredible variety of attractive shapes, color, and size, and are found in all the ocean of the world. In India, brown algae represent 0.2%, red algae 27.0%, and the other 72.8%. About 206 algae are reported in the mangrove environment [4].

Marine algae live in a harsh condition that promotes the formation of oxidizing agents and secondary metabolites [5], and these types of compound have the responsibility for specific biological activity [6]. A variety of chemically active metabolites in their body, potentially help to protect themselves against other organisms.

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These active metabolites are also known as biogenic compounds, such as halogenated compounds, alcohols, aldehydes, and terpenoid, are produced by different species of marine micro and macro algae and have antibacterial, anti-algal, and anti-fungal properties that are effective in preventing biofouling and have other uses in therapeutics [1]. Sterols are the main nutritional component of seaweeds. Different species have different types of sterols, as green algae contain ucocholesterol, cholesterol, and ß-sitosterol while brown algae contain fucosterol, cholesterol, and brassicasterol. Red algae have desmosterol, cholesterol, sitosterol, fucosterol, and chalinasterol [7, 8]. These properties make seaweeds more potential as a functional dietary supplement or for compound extraction. Seaweed extracts are rich in natural plant growth hormone and beneficial trace mineral. In algae extract, natural growth hormones like auxin, cytokines, and gibberellins are present in large quantities [9].

Brown algae were a huge and diverse class (Pheophyceae) of golden-brown algae varying from small filamentous form to large/giant complex seaweed. The brown algae contain the fucoxanthin pigment and different pheophycean tannins that are responsible for the characteristic greenish-brown color like the name indicated. Brown algae also provide a number of active components including unique secondary metabolites such as phlorotannin and many of them have specific biological activities that offer opportunities for their economical use [10].

The major orders found worldwide are fucales, dictyotales, and laminariales, these three orders are extensively used for bioactive compounds. More than 1140 secondary metabolites have been reported in phaeophyceae [11]. The different species of dictyotales group produce a wide range of bioactive secondary metabolites with broad defensive action against herbivores in the marine environment [12]. Among the three marine algae group, brown algae have an immense source of polysaccharide namely alginate and fucoidans, which reveals good biological activities such as anti-cancer, anti-viral, anti-inflammatory, and anti-proliferative [1]. Bioactive compound fucosterol abundantly reported in brown algae and has so many biological activities such as anti-cancer [13], cholesterol-reducing [14], and anti-diabetic properties [15]. Brown algae are mainly used in different conditions such as hypothyroidism, cough, asthma, fatigue, stomach pain, hemorrhoids, and headache. It has been also used to promote weight loss and help in skincare [16]. There are various benefits of brown seaweed including reduced inflammation, blood thinning and cancer prevention [17]. Brown algae consist of a significant level of phenolic compound, a complex type of polysaccharide, extremely high biological activity, and more effective antioxidant compared to green and red algae [18]. Therefore, the objective of the present review is to focus on the distribution of brown algae along the coast of Gujarat, its bioactive compounds, and the bioactivity of isolated compound from it.

Distribution of brown algae

Eighty percent of the world's plant diversity has been recorded only in the aquatic environment, including over 150,000 species of algae found in intertidal zones and tropical waters of the seas, and it is the main source of natural products [19]. There are approximately 8000 species of marine macroalgae discovered on the world's coastlines, and they can exist up to 270 m deep. A total of 25 species of green algae, 90 species of brown algae, and 350 species of red algae are found in the global coastline area which is commercially important because of their biochemical content [20]. About 1500 species of brown algae has been identified worldwide [21]. Brown algae are observed in about 6, 91, 713 places around the world (Fig. 1).

There are about 265 genera and 2040 species belong to class Phaeophyta (Fig. 2), in which 95% of those species are most widespread in cold to temperate waters. All data shown in the figure was accessed via GBIF on 21 October 2020. The GBIF (Global Biodiversity Information Facility) is an international network and research foundation supported by government authorities around the world and providing data on all types of life around the world.

The main sources of algae are found in the northwest, west-central and southwest Atlantic, and in the central-east and southwest Pacific. India, with its long coastline, has vast marine resources along many open coasts and estuarine areas. Marine benthic algae of India were first published in 1970 with 20 species [22]. Based on the reports published in different journals, [23–25] prepared the updated checklist of algae. The checklist prepared in

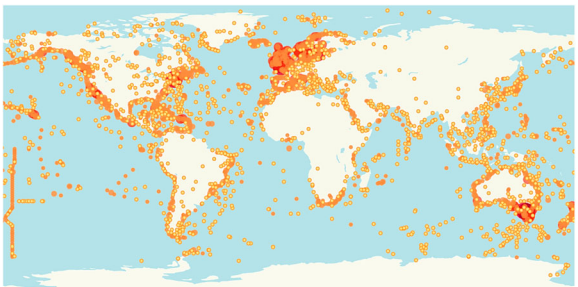

Fig. 1 A map published on GBIF, showing the worldwide occurance of brown algae. Source: GBIF (© OpenStreetMap contributors, © OpenMapTiles, GBIF) (https://www.gbif.org/occurrence/map?has_coordinate=true&has_geospatial_issue=false&taxon_key=7073593&occurrence_status=present)

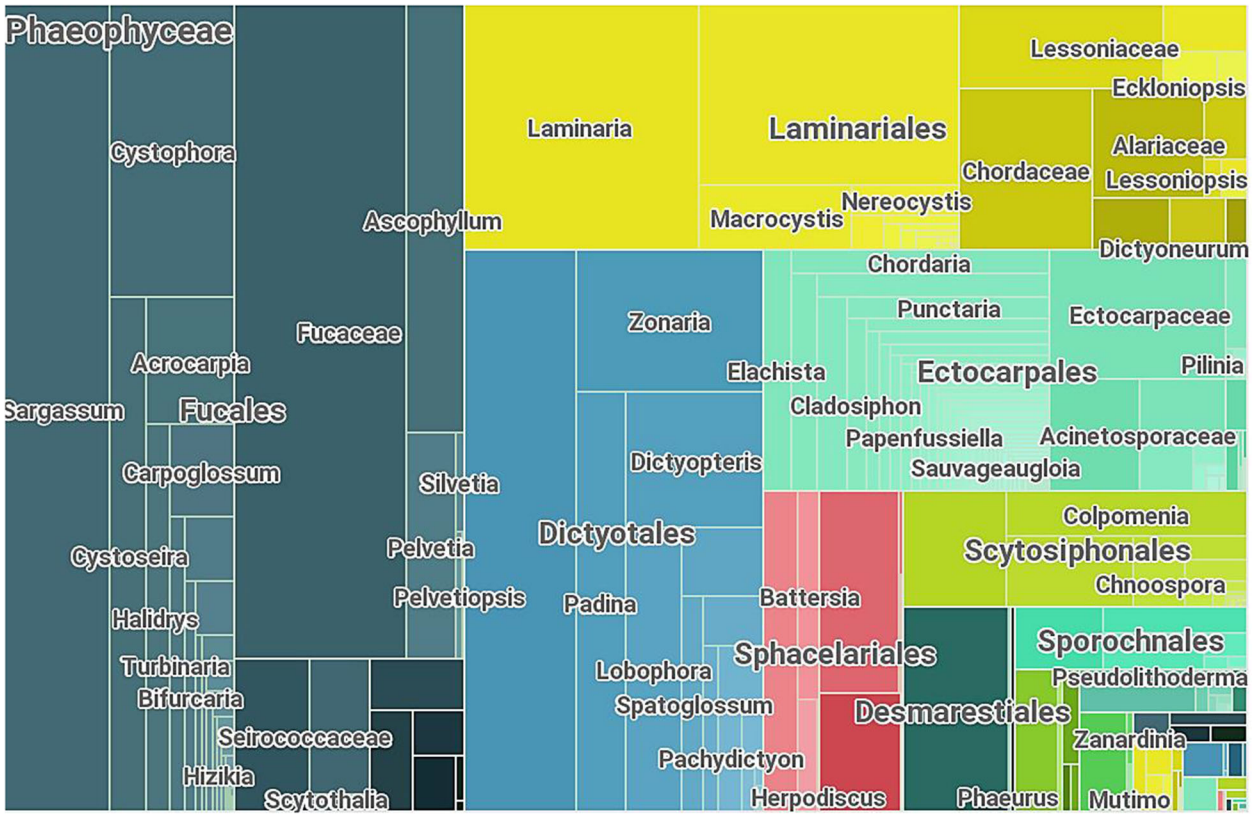

Fig. 2 Taxonomic distribution of major order and genus from phaeophyta group, record published by GBIF website. Source: GBIF (© OpenStreetMap contributors, © OpenMapTiles, GBIF) (https://www.gbif.org/occurrence/map?has_coordinate=true&has_geospatial_issue=false&taxon_key=7073593&occurrence_status=present)

2001 comprises a total of 280 species from the Gujarat coast [24]. Seaweeds on the Indian coast consist of 814 species belonging to 217 genera. Out of these species, 216 species of Chlorophyta, 191 species of Phaeophyta, 217 species of Rhodophyta, and 3 species of Xanthophyta were recorded on Indian coasts among these 202 species were found only in Gujarat [26]. The coastline of Gujarat is made up of Deccan traps and tertiary stones and in places; there are fossilized forms of milliolite with limestone [27]. A list of brown algae recorded in the coastal area of Gujarat has been described in Table 1.

Main text

Prominent secondary metabolites in brown algae

Marine algae represent a good source of secondary metabolites/specialized metabolites. These specialized metabolites play important role in defense against pathogens. Phlorotannin, phytosterol, and polyphenol are prominent secondary metabolites groups that are found in brown algae. The variety of compounds within a particular group plays a vital role in many biological activities. Some prominent secondary metabolites from brown algae are as follows.

Phlorotannins

Polyphenols of marine algae are known as phlorotannins, which are observed in seaweeds and synthesized by the acetate-malonate pathway also known as polyketide pathway produced by the polymerization of phloroglucinol. Phlorotannins are extremely hydrophilic components with a wide range of molecular sizes between 126 kDa and 650 kDa [28]. Among the green, brown, and red seaweeds, phlorotannins are normally isolated from the brown seaweed. This phytochemical has been isolated through chromatographic methods [29, 30]. In addition, for characterizing the structure of compounds, nuclear magnetic resonance spectroscopy has been used [31, 32]. It has been recorded that members of laminariaceae are a rich source of phlorotannins compare to other seaweeds [33]. Phlorotannins have different biological activities such as anti-diabetic, antioxidant, anti-proliferative, anti-HIV, and skin protection, radioprotective, and anti-allergic activities [34].

Cystophora congesta have phlorotanin likes phloroglucinol triacetate, diphlorethol pentacetate, and triphlorethol-A-heptacetate [35]. The extract of *Cystoseria* showed good antioxidant and cytotoxic results, which can suggest that it can be effectively used in the synthesis of the cytotoxic

Table 1 List of brown algae recorded at Gujarat coast [27]

Sr. no.	Name of algae	Distribution
1.	*Colpomenia sinuosa* (Martens ex Roth) Derbes and solier	Okha, Shivrajpur, Veraval
2.	*Cystoseria indica* (Thivy and Doshi) Mairh	Dwarka, Okha, Porbandar Shivrajpur
3.	*Cystoseria trinoidis* (Forsskål) C. Agardh	Okha, Porbandar, Veraval
4.	*Dictyopteris delicatula* Lamouroux	Shivrajpur
5.	*Dictyopteris acrostichoides* (J. Agardh) Bornet	Okha, Shivrajpur
6.	*Dictyopteris austalis* (Sonder) Askenasy	Adri, Dwarka, Okha, Porbandar Shivrajpur, Veraval
7.	*Dictyota bartayresiana* Lamouroux	Adri
8.	*Dictyota cervicornis* Küzing	Kotada, Okha, Shivrajpur
9.	*Dictyota ciliolate* Küzing	Dwarka, Kotada, Shivrajpur
10.	*Dictyota dichotoma* (Hudson) Lamouroux	Okha, Shivrajpur, Veraval
11.	*Dictyota pinnatifida* Küzing	Kotda, Shivrajpur, Okha
12.	*Dictyota serrata* (Areschoug) Hyot	Okha
13.	*Harmophysa cuneiformis* (J. Gmelin) P. Silva	Okha, Porbandar, Shivrajpur Veraval, Vervala
14.	*Hincksia mitchelliae* (Harvey) Silva	Shivrajpur
15.	*Hydroclathrus clathratus* (C. Agardh) Howe	Dwarka, Okha, Porbandar Shivrajpur, Veraval, Vervala
16.	*Iyengaria stellata* (Børgesen) Børgesen	Dwarka, Okha, Porbandar Shivrajpur, Veraval, Vervala
17.	*Levringia boergesenii* Kylin	Adri, Okha, Veraval
18.	*Lobophora variegate* (Lamouroux) Womersley ex Oliveria	Adri, Okha, Porbandar, Shivrajpur Veraval
19.	*Padina tetrastromatica* Hauck	Okha, Porbandar, Shivrajpur
20.	*Padina boergesenii* Allender and Kraft	Okha, Porbandar, Shivrajpur
21.	*Padina boryana* Thivy	Okha, Porbandar, Shivrajpur
22.	*Rosenvingea intricate* (J. Agardh) Børgesen	Shivrajpur
23.	*Rosenvingea orientalis* J. Agardh	Okha, Shivrajpur
24.	*Sargassum cinctum* J. Agardh	Dwarka, Okha, Porbandar Shivrajpur, Veraval
25.	*Sargassum cinereum* J. Agardh	Dwarka, Okha, Porbandar Shivrajpur, Veraval
26.	*Sargassum johnstonii* Setchell and Gardner	Dwarka, Okha, Porbandar Shivrajpur, Veraval
27.	*Sargassum linearifolium* (Turner) C. Agardh	Dwarka, Okha, Porbandar Shivrajpur, Veraval
28.	*Sargassum plagiophyllum* (Martens) J. Agardh	Okha, Porbandar, Shivrajpur
29.	*Sargassum prismaticum* Chauhan	Okha, Porbandar, Shivrajpur
30.	*Sargassum swartzii* C. Agardh	Dwarka, Okha, Porbandar Shivrajpur, Veraval
31.	*Sargassum tenerrimum* J. G. Agardh	Dwarka, Okha, Porbandar Shivrajpur, Veraval, Vervala
32.	*Sargassum vulgare* C. Agardh	Okha, Porbandar, Shivrajpur Veraval
33.	*Spatoglossum asperum* J. Agardh	Adri, Okha, Porbandar, Shivrajpur Veraval
34.	*Stoechospermum marginatum* (C. Agardh) Küzing	Adri, Kotda, Okha, Porbandar, Shivrajpur, Veraval
35.	*Turbinaria ornata* (Turner) J. Agardh	Okha, Porbandar

drug [36] and have bieckol, fucophloroethol, 7-phloroeckol, and phlorofucofuroeckol compound [37]. Different species of *Ecklonia* revealed antioxidant, anti-cancer, and anti-diabetic properties due to the presence of different phlorotannin compounds like fucodiphlorethol G, phloroglucinol, eckol, dieckol, and phlorofucofuroeckol A [38–43]. Edible brown algae *Eisenia arborea* was used in folk medicine and showed anti-allergic properties owing to the phlorofucofuroeckol B compound [44]. *Himanthalia elongate* showed high anti-microbial and antioxidant activity, due to the presence of phloroglucinol [45]. *Ishige okamurae* showed the presence of diphloretohydroxycarmalol phlorotannin [46]. A list of phlorotannins in brown seaweeds has been recorded in Table 2.

Phytosterol

Sterols are found in animals as well as plants. The sterols found in plants are known as phytosterol [47]. Phytosterol is a bioactive compound in marine algae, terrestrial, and marine plants. There are about 200 types of phytosterol have been found [48]. Stigmasterol and sitosterol are two common examples of phytosterols [49]. Mostly, brown seaweeds contain fucosterol and fucosterol derivatives [7]. These bioactive compounds are important because of the many beneficial health effects associated with them. The determination of phytosterols is generally performed by mass spectrometry or flame ionization detection [50].

The phytochemical compound fucosterol was first isolated by RP-HPLC method in *Cystoseria foeniculacea* and *Dictyota ciliolate*, and the fraction of compound also analyzed by NMR technique [51]. Bioactive compound fucosterol was responsible for anti-proliferative and cytotoxic properties in *Padina sanctae-Crucis* and *Dictyota ciliolate* [52]. HPLC analysis of brown algae *Himanthalia elongate*, *Undaria pinnatifid*, and *Laminaria ochroleuca* have showed the presence of steroid compounds like fucosterol and cholesterol [7]. By performing GC-MS analysis in brown algae, *Hormophysa triquetra* and *Padina pavonica* showed the presence of important phytosterols like fucosterol, stigmasterol, campesterol, and β-sitosterol [53]. *Padina gymnospora* and *Sargassum angustifolium* has great antioxidant activity and testified that they have a good source of fucosterol, brassicasterol, cholesterol, and stigmasterol by GC-MS analysis [54]. *Sargassum asperifolium* have important phytosterol compound like fucosterol, stigmasterol, saringosterone, and saringosterol [55], which gave good biological activities to it. The amount of phytol and fucosterol was quantified in edible brown algae *Sargassum fusiforme* [56]. A list of phytosterols reported in brown seaweeds has been recorded in Table 3.

Polyphenols

Polyphenols are a group of prominent secondary metabolites, which support the plant in structural development and protect the algae from biotic and abiotic stress condition [57]. Brown algal species have unique secondary metabolites namely as polyphenols and phlorotannin compound are a class of these polyphonic compound [58], this type of compound were formed under harsh condition and able to absorb UV-radiation and repair wound [59]. Polyphenols have great biological activities; these characters make brown algae used as major ingredients for cosmeceutical and nutraceutical products [60]. Polyphenols have shown therapeutic properties such as anti-oxidative, anti-bacterial, anti-cancer, anti-allergic, anti-diabetes, anti-aging, anti-inflammatory, and anti-HIV activities [61, 62].

Different brown algae showed immense in vitro antioxidant activity and quantified the polyphenolic compound using the HPLC method [63]. It has been reported that *Fucus* species have gallic acid, protocatechuic acid, genistic, vanillic acid, and caffeic acid; *Sargassum multicum* have a good source of gallic acid, protocatechuic acid, genistic, vanillic acid, caffeic acid, and syringic; *Saccharina latissima* have gallic acid, protocatechuic acid, genistic, vanillic acid, and *Laminaria*

Table 2 List of phlorotannins reported in brown algae

Sr. no.	Name of brown algae	Name of phlorotannins	References
1.	*Cystophora congesta*	Phloroglucinol triacetate, diphlorethol pentacetate, triphlorethol-A-heptacetate	[35]
2.	*Cystoseria mudicaulis*	Bieckol, fucophloroethol, 7-phloroeckol, and phlorofucofuroeckol	[37]
3.	*Cystoseria tamariscifolia*	Bieckol, fucophloroethol, 7-phloroeckol and phlorofucofuroeckol	
4.	*Ecklonia bicyclis*	Phloroglucinol, eckol	[38, 39]
5.	*Ecklonia cava*	Fucodiphlorethol G, phloroglucinol, eckol, dieckol	[38, 40, 41]
6.	*Ecklonia kurome*	Phloroglucinol	[38]
7.	*Ecklonia stolonifera*	Eckol, dieckol, phlorofucofuroeckol A	[42, 43]
8.	*Eisenia arborea*	Phlorofucofuroeckol B	[44]
9.	*Himanthalia elongata*	Phloroglucinol	[45]
10.	*Ishige okamurae*	Diphloretohydroxycarmalol	[46]

Table 3 List of phytosterols reported in brown algae

Sr. no.	Name of brown algae	Name of phytosterol	References
1.	*Cystoseria foeniculacea*	Fucosterol	[51]
2.	*Dictyota ciliolate*	Fucosterol	[52]
3.	*Himanthalia elongate*	Fucosterol	[7]
4.	*Hormophysa triquetra*	Fucosterol, stigmasterol, campesterol	[53]
5.	*Laminaria ochroleuca*	Fucosterol, cholesterol	[7]
6.	*Padina gymnospora*	Fucosterol, brassicasterol, cholesterol, stigmasterol	[54]
7.	*Padina pavonica*	Fucosterol, β-sitosterol, campesterol	[53]
8.	*Padina sanctae-crucis*	Fucosterol	[52]
9.	*Pelvetia spliquosa*	Fucosterol	[51]
10.	*Sargassum angustifolium*	Fucosterol	[54]
11.	*Sargassum asperifolium*	Fucosterol, stigmasterol, saringosterone, saringosterol	[55]
12.	*Sargassum fusiforme*	Phytol, fucosterol	[56]
13.	*Undaria pinnatifida*	Fucosterol, cholesterol	[7]

digitata showed the presence of gallic acid, protocatechuic acid, genistic, vanillic acid, and caffeic acid. These phenolic compounds are responsible for the great antioxidant activity of algae [63]. Brown algae *Himanthalia* elongate confirmed the natural antioxidant compound like gallic acid, chlorogenic acid, caffeic acid, ferulic acid, and quercetin [45]. It has been testified that *Padina boergesenii* have important phenolic compound such as gallic acid, caffeic acid, rutin, quercetin, and ferulic acid which can be used as cancer chemopreventive agent [64]. HPLC profiling of *Padina pavonica* confirmed the presence of polyphenol compounds like kaempferol, tannic acid, caffeic acid, quercetin, and epigallocatechin, and FTIR analysis confirmed the presence of various groups like phenol, alkanes, alcohol, and aromatic compounds [65]. Different species of *Sargassum* have shown the major polyphenolic compound like gallic acid and P-hydroxybenzoic acid, the presence of this compound was confirmed by RP-HPLC method [66]. A list of polyphenols reported in brown seaweeds has been recorded in Table 4.

Biological importance of the isolated compound from the brown algae

Diterpen bifurcadiol 76 has been isolated from *Bifurcaria bifurcate*; this diterpens shows cytotoxic activity against human tumor cell line; metaterpenoids from *Sargassum tortile* showed cytotoxic activity [67].

Table 4 List of Polyphenols reported in brown algae

Sr. no.	Name of brown algae	Name of polyphenols	References
1.	*Dictyota dichotoma*	Gallic acid, protocatechuic acid, genistic, vanillic acid	[63]
2.	*Fucus distichus*	Gallic acid, protocatechuic acid, genistic, caffeic acid	
3.	*Fucus serratus*	Gallic acid, protocatechuic acid, genistic, vanillic acid, caffeic acid	
4.	*Fucus spiralis*	Gallic acid, protocatechuic acid, genistic, vanillic acid, caffeic acid	
5.	*Fucus vesiculosus*	Gallic acid, protocatechuic acid, genistic, vanillic acid, caffeic acid	
6.	*Himanthalia elongate*	Gallic acid, chlorogenic acid, caffeic acid, ferulic acid, quercetin	[45]
7.	*Laminaria digitata*	Gallic acid, protocatechuic acid, genistic, vanillic acid, caffeic acid	[63]
8.	*Padina boergesenii*	Gallic acid, caffic acid, rutin, quercetin, ferulic acid	[64]
9.	*Padina pavonica*	Kaempferol, tannic acid, caffeic acid, quercetin, epigallocatechin	[65]
10.	*Saccharina latissima*	Gallic acid, protocatechuic acid, genistic, vanillic acid	[63]
11.	*Sargassum cinereum*	Gallic acid, P-hydroxybenzoic acid	[66]
12.	*Sargassum ilicifolium*	P-hydroxybenzoic acid	[66]
13.	*Sargassum multicum*	Gallic acid, protocatechuic acid, genistic, vanillic acid, caffeic acid, syringic	[63]
14.	*Sargassum swartzii*	Gallic acid	[66]
15.	*Sargassum tenerrimum*	Gallic acid, P-hydroxybenzoic acid	[66]

Table 5 List of biological activity of isolated compound from brown algae

Sr. no.	Name of brown algae	Isolated compound	Biological importance	Reference
1.	*Bifurcaria bifurcata*	Bifurcadiol 76	Cytotoxic activity	[67]
2.	*Sargassum tortile*	Meroterpenoids, Sargol, Sargol-I And Sargol-LI		
3.	*Notheia anomala*	Tetrahydrofuran	Nematocidal activity	[68]
4.	*Cystoseira tamariscifolia*	Meroditerpenoid	Anti-fungal activity against pathogenic fungi; anti-bacterial activity	[69]
5.	*Lobophora variegata*	Lopophorins A 142 And B 143	Anti-inflammatory activity	[67]
6.	*Dictyota dichotoma*	Dictyol J 146, Diterpenes, Dictyolactone	Algicidal activity	
7.	*Ecklonia stolonifera*	Phloroglucinol, Eckstolonol, Eckol, Phlorofucofuroeckol A	Hepatoprotective agents	[70]
8.	*Dictyota pfaffi*	Dollabelladiene	Anti-viral activity.	[67]
9.	*Sargassum thunbergii*	Tetraprenyltoluquinols, Thunbergols	Free radical scavenger and antioxidant activities.	
10.	*Ecklonia cava*	Fucodiphlorethol G 192		
11.	*Taonia atomaria*	Taondiol, isoepitaondiol, stypodiol, stypoldione, sargaol		
12.	*Pelvetia siliquosa*	Fucosterol	Anti-diabetic priciciple from *Pelvetia siliquosa*	[71]
13.	*Dilophus okamurae*	Dictyterepenoids A 194 and B 195	Anti-feedent activity against young abalone	[72]
14.	*Eisenia arborea*	Phlorofucofuroeckol-B	Anti-allergy activity	[73]
15.	*Ecklonia stolonifera*	Eckol, phlorofucofuroeckol A, dieckol	Anti-hypertensive activity	[74]

Tetrahydrofuran from *Notheia anomala* inhibit the larval developments of parasitic nematodes [68]. *Cystoseira tamariscifolia* have metaterpenoid-methoxybifurcarenone 138 which possesses anti-fungal and anti-bacterial activity [69]. Lopophorins from *Lobophora variegate* showed anti-inflammatory activity. Diterpens-Dictyol J 146, Dictyolactone, and Sanadaol were isolated from *Dictyota dichotoma*; these compounds have algicidal activity [67]. Phloroglucinol and its derivatives from *Ecklonia stolonifera* act as hepatoprotective agents [70]. Isolated compound Dollabelladiene derivative 147 from *Dictyota pfaffi* showed in vitro anti-HSV-1 activity. Bioactive compounds like tetraprenyltoluquinols, thunbergols, fucodiphlorethol G 192, taondiol, isoepitaondiol, stypodiol, stypoldione, and sargaol which has been isolated from *Sargassum thunbergii*, *Ecklonia cava*, and *Taonia atomaria* posseses high free radical scavenger and antioxidant activities due to its bioactive compound [67]. Brown alga *Pelvetia siliquosa* showed anti-diabitic activity due to phytosterol like fucosterol [71]. Diterpenoids from *Dilophus okamurae* displayed anti-feedent activity [72]. Phlorofucofuroeckol-B has been isolated from *Eisenia arborea* which showed anti-allergic properties [73]. Different types of phlorotannin isolated from *Ecklonia stolonifera* have anti-hypertensive activity (inhibitory activity against angiotensin-converting enzyme) [74] Table 5.

It has been recorded that, compared to green and red algae, brown algae have shown higher anti-microbial activity against different aquaculture pathogens [75]. A variety of bioactive compounds are synthesized by marine algae, subjected to tolerate environmental changes such as radiation, stress, water pressure, and high temperature [76]. Brown algae contained polysaccharides such as laminarin, alginic acid fucoidan, and sargassan [76], and this type of algal polysaccharides showed anti-cancer activity [77]. Phlorotanins are a type of tannin, belongs to the group of polyphenolic compounds, which has usually found in brown algae. These polyphenols inhibit colon cancer cells [78]. Terpenes are also recorded in brown algae. In terpenes, halogenated monoterpenes are important in different biological activities. Isolated halogenated monoterpenes showed important anti-proliferative activity [79] (Fig. 3).

It has been testified that brown seaweeds are a good source of sterols like fucosterol and desmosterol, and it has been recorded that this type of sterols decreases the level of cholesterol, free triglyceride in the liver [80]. Phloroglucinol is polyphenolic compound, which showed different biological activity such as anti-oxidant, anti-diabetic, anti-inflammatory, anti-allergic, and anti-HIV [81–86]. The phlorotannins (phloroglucinol, eckol and diekol) from brown algae *E. cava* have been used in cosmeceuticals products [80]. Edible brown algae *Eisenia arborea* have phlorofucofuroeckol-B, shown strong antioxidant activity, it suggests a potential use in anti-allergic drug preparations [44]. The sulfated polysaccharides from *Padina tetrastomatica* have been used in

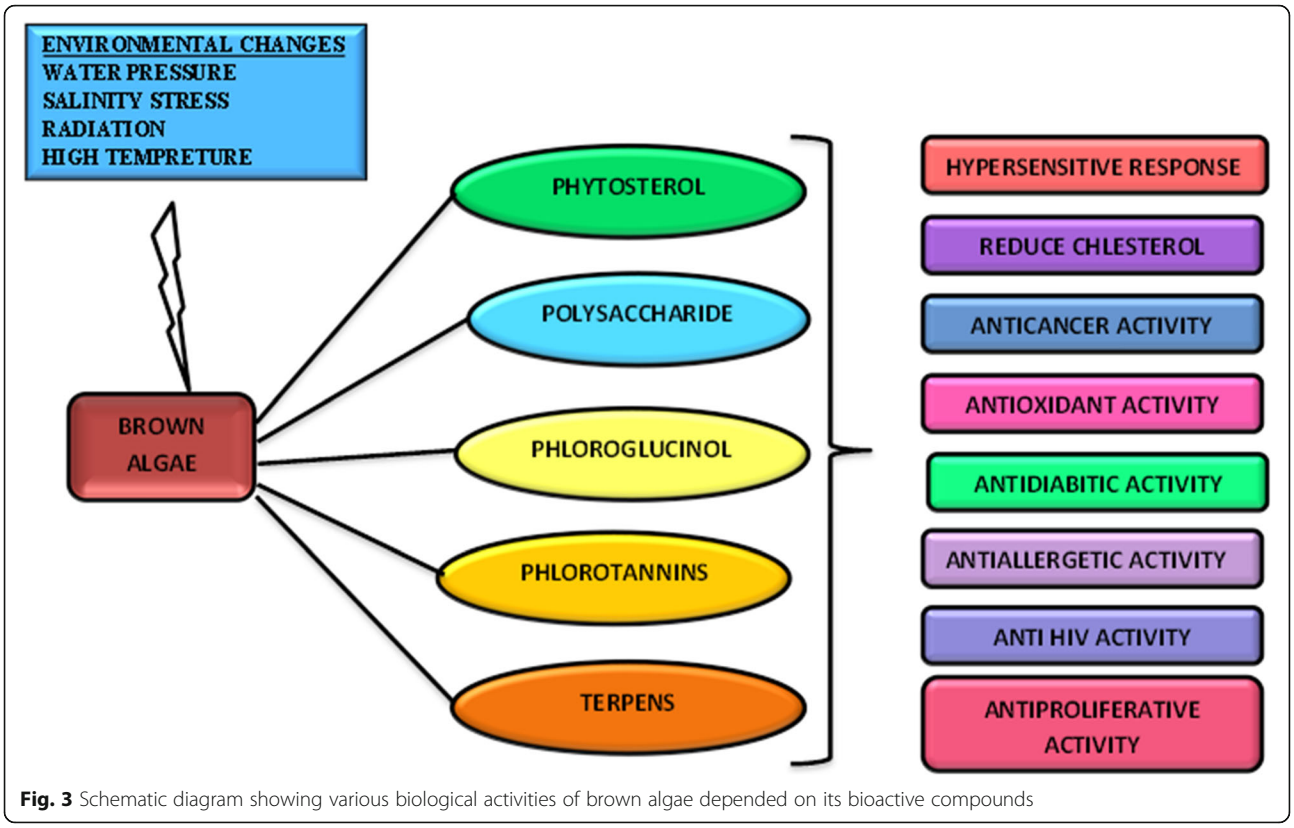

Fig. 3 Schematic diagram showing various biological activities of brown algae depended on its bioactive compounds

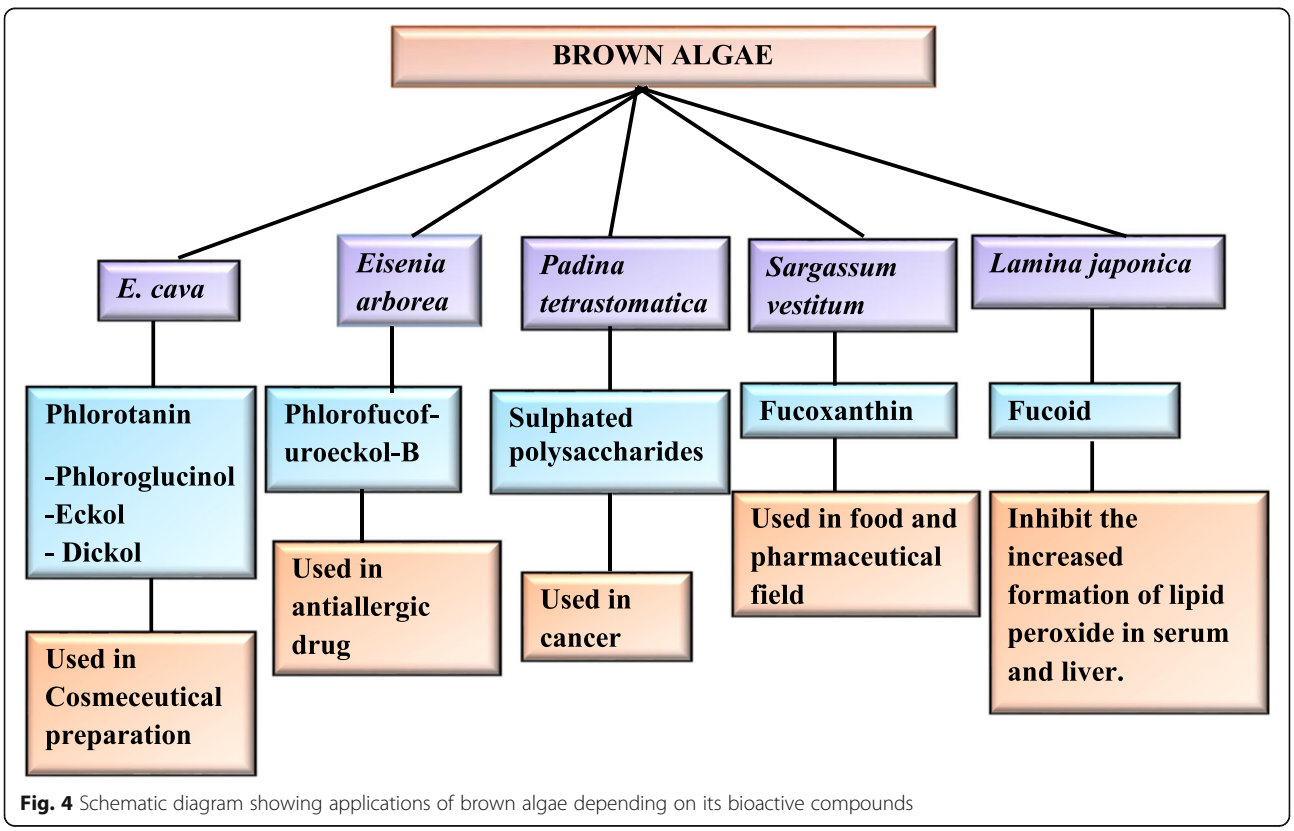

Fig. 4 Schematic diagram showing applications of brown algae depending on its bioactive compounds

cancer treatment because it showed strong antioxidant and anti-mitotic activity [87]. A brown algae *Sargassum vestitum* has active compound fucoxanthin which showed antioxidant activity, it suggests possible use in the food and pharmaceutical field [5]. Fucoid component from *Dictyota merttensi*, *Spatoglossum schroederi*, and *Fucus vesiculosus* which contain the inflammation response for their anti-inflammation activity [88]. *Lamina japonica* has strong antioxidant activity due to the fucoid component in it which inhibits the increased formation of lipid peroxide in serum and liver [89] (Fig. 4). Brown algae *Chnoospora minima* displayed significant antiproliferative activity on cancer cell lines due to the bioactive fraction [90].

Conclusion

The review work on the phytoconstituents of brown algae makes it clear that this large group of marine algae is not only used to obtain food, fodder but is an enormous source of several secondary metabolites. This review paper holds studies of the bioactive compound of brown algae, which has many more functional properties compared to red and green algae because phaeophyta group are main representative of polysaccharide and fucoidans which are responsible for prominent biological activity. It has been noted that the types and proportions of phytoconstituents vary from species to species and depend on environmental factors. The multiple mechanisms of action promote the formation of complex bioactive compounds from brown algae, which directly enhanced their biological activity, and such activities promote many drug industries for drug production. Thus, systematic work on this group of marine algae will be helpful in the formulation of new drugs that can be used for curing several fatal diseases of a human being.

Abbreviations

UV: Ultraviolet; KDa: Kilodaltons; HIV: Human immunodeficiency virus; GC-MS: Gas chromatography–mass spectrometry; RP-HPLC: Reverse phase high-performance liquid chromatography; NMR: Nuclear magnetic resonance

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