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ALGAE AS NUTRITION, MEDICINE AND COSMETIC: THE FORGOTTEN HISTORY, PRESENT STATUS AND FUTURE TRENDS

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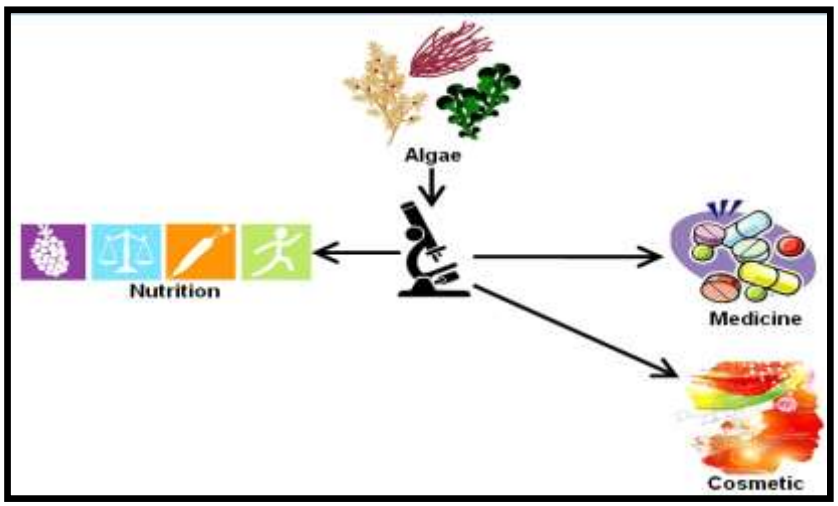
ABSTRACT

Marine algae have been known and utilized from the ancient era. It is the source of chemical compounds mainly useful as a food for their richness in protein, fatty acids, minerals and vitamins. Physiologically active compounds also have a great potential to play an important role as cosmetic, medicine and as a pharmaceutical aid. In this review, the provided information will play an important role in the medicinal and cosmeceutical production in future.

KEYWORDS: Algae, algal research, history, cosmeceutical, medicine, nutrition.



Graphical abstract

INTRODUCTION

The ocean (more than 70% of the earth) provides rich resources of large number of marine organisms having great potential for bioactive compounds that can be used as cosmeceuticals,

nutraceuticals, and pharmaceuticals [1]. Algae is a class of chlorophyll containing species ranges from 3 – 10 µm unicellular to 70 m long giant kelps [2]. Algae have adapted to extremely harsh and competitive environments by production of secondary metabolites for chemical defense and thus are able to live in wide range of ecological regions [3].

The following algae have been discussed in this review.

Bacillariophyta

1. *Nitzschia laevis* Hustedt.
2. *Phaeodactylum tricornutum* Bohlin.
3. *Pseudofallacia tenera* (Hustedt) Liu, Kociolek & Wang.

Chlorophyceae

1. *Acetabularia major* G. Martens.
2. *Avrainvillea nigricans* f. floridana D.S. Littler & Littler.
3. *Caulerpa lentillifera* J. Agardh., *C. prolifera* (Forsskal) J. V. Lamouroux., *C. taxifolia* (M.Vahl) C. Agardh., *C. stigmatophora* Butcher., *C. vulgaris* Beyerinck., *C. pyrenoidosa* H. Chick.
4. *Cladophora fascicularis* (Mertens ex C. Agardh) Kützing., *C. socialis* Kützing.
5. *Codium fragile* (Suringar) Hariot., *C. reediae* P.C. Silva., *C. tomentosum* Stackhouse.
6. *Cymopolia barbata* (Linnaeus) J. V. Lamouroux.
7. *Dunaliella tertiolecta* Butcher.
8. *Haematococcus pluvialis* Flotow.
9. *Penicillus capitatus* Lamarck.
10. *Rhipocephalus phoenix* (J.Ellis & Solander) Kützing.
11. *Tetraselmis suecica* (Kylin) Butcher.
12. *Ulva fasciata* S.F.Gray., *U. intestinalis* L., *U. lactuca* L., *U. pertusa* Kjellman.

Cyanophyceae

1. *Arthrospira platensis* Gomont.
2. *Lyngbya majuscula* Harvey ex Gomont.
3. *Spirulina platensis* (Gomont) Geitler.

Phaeophyceae

1. *Ascophyllum nodosum* (Linnaeus) Le Jolis.
2. *Bifurcaria bifurcata* R. Ross.

3. *Caulocystis cephalornithos* (Labillardière) Areschoug.
4. *Chrysophaeum taylorii* I.F. Lewis & H.F. Bryan.
5. *Cystoseira abies-marina* (S.G.Gmelin) C. Agardh., *C. indica* (Thivy & Doshi) Mairh., *C. tamariscifolia* (Hudson) Papenfuss., *C. usneoides* (Linnaeus) M. Roberts.
6. *Dictyopteris polypodioides* (A.P.De Candolle) J.V. Lamouroux., *D. polypodioides* (A.P.De Candolle) J.V. Lamouroux.
7. *Dictyota coriacea* (Holmes) I. K. Wang, Hy. S. Kim & W. J. Lee., *D. dichotoma* (Hudson) J.V. Lamouroux., *D. menstrualis* (Hoyt) Schnetter, Hörning & Weber-Peukert., *D. pfaffi* Schnetter.
8. *Ecklonia cava* Kjellman., *E. kurome* Okamura., *E. maxima* (Osbeck) Papenfuss., *E. stolonifera* Okamura.
9. *Eisenia arborea* Areschoug., *E. bicyclis* (Kjellman) Setchell.
10. *Fucus spiralis* L., *F. vesiculosus* L.
11. *Himanthalia elongata* (Linnaeus) S. F. Gray.
12. *Ishige okamurae* Yendo.
13. *Laminaria cloustonii* Edmondston., *L. digitata* (Hudson) J.V. Lamouroux., *L. hyperborea* (Gunnerus) Foslie., *L. japonica* Areschoug., *L. saccharina* (Linnaeus) J. V. Lamouroux., *L. saccharina* (Linnaeus) J. V. Lamouroux.
14. *Landsburgia quercifolia* Harvey.
15. *Lobophora variegata* (J.V.Lamouroux) Womersley ex E. C. Oliveira.
16. *Macrocystis pyrifera* (Linnaeus) C. Agardh.
17. *Nereocystis luetkeana* (K.Mertens) Postels & Ruprecht.
18. *Nizamuddinia zanardinii* (Schiffner) P. C. Silva.
19. *Notheia anomala* Harvey & J. W. Bailey.
20. *Pelvetia siliquosa* C.K.Tseng & C. F. Chang.
21. *Saccharina japonica* (Areschoug) C.E.Lane, C.Mayes, Druehl & G.W. Saunders.
22. *Sargassum bacciferum* (Turner) C. Agardh., *S. fulvellum* (Turner) C. Agardh., *S. fusiforme* (Harvey) Setchell., *S. muticum* (Yendo) Fensholt., *S. sagamianum* Yendo., *S. siliquastrum* (Mertens ex Turner) C. Agardh., *S. thunbergii* (Mertens ex Roth) Kuntze., *S. tortile* (C.Agardh) C. Agardh., *S. vulgare* C. Agardh.
23. *Stypopodium zonale* (J.V. Lamouroux) Papenfuss.
24. *Turbinaria conoides* (J. Agardh) Kutzing., *T. triquetra* (J. Agardh) Kutzing.
25. *Undaria pinnatifida* (Harvey) Suringar.

Rhodophyceae

1. *Agardhiella tenera* (J.Agardh) F.Schmitz in Schmitz & Hauptfleisch.
2. *Alsidium helminthochorton* (Schwendimann) Kutzing.
3. *Asparagopsis taxiformis* (Delile) Trevisan.
4. *Callophycus serratus* (Harvey ex Kützing) P.C. Silva.
5. *Centroceras corallophiloides* R. E. Norris.
6. *Ceratodictyon spongiosum* Zanardini.
7. *Chondria armata* (Kützing) Okamura., *C. atropurpurea* Harvey., *C. oppositiclada* E.Y. Dawson.
8. *Chondrus crispus* Stackhouse.
9. *Delisea pulchra* (Greville) Montagne.
10. *Digenea simplex* (Wulfen) C. Agardh.
11. *Eucheuma cottonii* Weber-van Bosse., *E. denticulatum* (N. L. Burman) Collins & Harvey.
12. *Gelidium amansii* (J.V.Lamouroux) J.V. Lamouroux., *G. cartilagineum* (Linnaeus) Gaillon., *G. cartilagineum* (Linnaeus) Gaillon., *G. corneum* (Hudson) J. V. Lamouroux.
13. *Gigartina acicularis* (Roth) J.V. Lamouroux., *G. pistillata* (S. G. Gmelin) Stackhouse., *Gigartina tenella* Harvey.
14. *Gracilaria asiatica* Zhang & Xia., *G. changii* (B. M. Xia & I. A. Abbott) I. A. Abbott, J. Zhang & B.M. Xia., *G. chilensis* C. J. Bird, McLachlan & E. C. Oliveira., *G. corticata* (J. Agardh) J. Agardh., *G. gracilis* (Stackhouse) M. Steentoft, L. M. Irvine & W. F. Farnham., *G. lichenoides* (J.V. Lamouroux) Greville., *G. verrucosa* (Hudson) Papenfuss.
15. *Grateloupia carnosa* Yamada & Segawa., *Grateloupia elliptica* Holmes.
16. *Hypnea japonica* Tanaka., *H. musciformis* (Wulfen) J.V. Lamouroux., *H. nidifica* J. Agardh., *H. nidifica* J. Agardh.
17. *Jania rubens* (Linnaeus) J.V. Lamouroux.
18. *Kappaphycus alvarezii* (Doty) Doty ex P.C. Silva.
19. *Laurencia brongniartii* J. Agardh., *L. dendroidea* J. Agardh., *L. majuscula* (Harvey) A.H.S. Lucas., *L. nipponica* Yamada., *L. obtusa* (Hudson) J.V. Lamouroux., *L. okamurae* Yamada., *L. pacifica* Kylin., *L. rigida* J. Agardh., *L. similis* K. W. Nam & Y. Saito., *L. venusta* Yamada.
20. *Marginisporum aberrans* (Yendo) H. W. Johansen & Chihara.
21. *Murrayella periclados* (C.Agardh) F. Schmitz.
22. *Nothogenia fastigiata* (Bory) P.G. Parkinson.
23. *Palmaria palmata* (Linnaeus) F. Weber & D. Mohr.

24. *Peyssonnelia inamoena* Pilger.
25. *Phyllophora nervosa* (A. P. de Candolle) Greville.
26. *Plocamium cartilagineum* (Linnaeus) P.S. Dixon., *P. telfairiae* (W. J. Hooker & Harvey) Harvey ex Kützing.
27. *Polysiphonia morrowii* Harvey.
28. *Porphyra coccinea* J. Agardh ex Areschoug., *P. perforata* J. Agardh., *P. tenera* Kjellman., *P. umbilicalis* Kutzing.
29. *Porphyridium cruentum* (S. F. Gray) Nageli.
30. *Portieria hornemannii* (Lyngbye) P. C. Silva.
31. *Pyropia columbina* (Montagne) W. A. Nelson., *P. tenera* (Kjellman) N. Kikuchi, M. Miyata, M.S.Hwang & H.G. Choi.
32. *Rhodymenia palmata* (Linnaeus) Greville.
33. *Solieria filiformis* (Kutzing) P. W. Gabrielson.
34. *Sphaerococcus coronopifolius* Stackhouse.
35. *Symphyocladia latiuscula* (Harvey) Yamada.
36. *Vertebrata lanosa* (Linnaeus). A. Christensen.
37. *Vidalia obtusiloba* (Mertens ex C. Agardh) J. Agardh.

1. Historical glimpse of algae consumption

Historical approach provides basis for modern discoveries in the light of primitive and practical based conceptions. Hippocrates in his "On Ancient Medicine," stated that the great medical discovery up to his time (400 B.C.) had involved countless experiments ranging from field of kitchen and finally resulted in the baking of bread.

Algae as food

Circa 800 B.C.: An earliest record of algae has been found in the Chinese Book of Poetry, wherein pondweed and duckweed appear as edible, delicacies and worthy. **1660:** Chinese were using a white, shiny, transparent, tasteless and odorless extract of *Gracilaria lichenoides* and *Gelidium corneum* as a prime source of summer jelly, soup stock, dessert or candy. On the coast of Armorica, natives were using *Chondrus crispus* and *Laminaria saccharina* combined to make a jelly like seaweed bread "pain des algues". **1745-1884:** The Chinese were using *Porphyra tenera* as a base for soups and as a salad. Livestocks were encouraged to feed on algae washed up on the shore in the Northern British Isles and North Sea areas. In Yugoslavia seaweeds were mixed with conventional fodder for cattle. *Porphyra*

perforata was the only locally available algae used as a salad, fried in fat and taken as breakfast on the Pacific coast, from Canada to Mexico. *Rhodymenia palmata* was chewed fresh and used in dried form as a salad in Scotland, Ireland and the Northeastern United States. **1914-1917 (World war-I):** When the supply of grain became exhausted, dried seaweeds were used by French military for hungry horses for saving that crucial battle. The extract of *Chondrus crispus* was orally taken in case of throat irritation of soldiers who had been gassed. **1939-1945 (World war-II):** In Europe, particularly Ireland, Scandinavia and Scotland seaweeds were used as food. In County Clare, Ireland meal prepared by dried and desalinated sea weeds were used as stock feed for human. German occupation troops built two bakeries in Norway for making bread from dried, desalinated and ground algae. In Sweden seaweeds were used as fodder in case of scarcities. Maori soldiers serving in the Middle East were using *Pyropia columbina* to have greater thirst-quenching tendency as compare to chewing gum.[4]

Algae as medicine

First century B.C.

Romans treated their joint pain by external application of kelp poultice prepared from *Fucus vesiculosus*.[5] Roman ladies used a rouge extracted from *Fucus vesiculosus* for cosmetic purpose.[4] **3000 B.C.:** Shen Nung Pen Ts'ao Ching or The Divine Farmer's Materia Medica shared the therapeutic qualities of algae which was an outstanding contribution of Chinese scholar to algal research. It mentioned the use of marine algae to cure goiter.[6,7] **First century A.D.:** Pliny the Elder in *Naturalis Historis* recommended certain algae for gout. Dioscorides in his book *De Materia Medica* prescribed powder of *Muscus corralinus* for burns, diarrhea, heartburn, scurvy, skin rashes and abrasions.[4] Galen in *De Simplicibus* noted that the mucilaginous substance present around the thallus of algae had remarkable properties of wound dressing.[8] **Eighth century A.D.:** The ancient Polynesians made poultices from filamentous algae for bruises, cuts and inflammation. Chinese and Japanese monks recommended *Gelidium amansii* in case of fever attributed to stomach conditions. A jelly type preparation made by boiling *Gelidium amansii* and sprinkled with sugar and ginger was useful in disorders related to sun stroke. *Gracilaria lichenoides* was used against intestinal and bladder complaints because of its demulcent properties. The Materia Medica of Chinese described *Porphyra coccinea* as "*This algal plant is a sort of laver which is green in the fresh state and purple when dry. It grows on the seashore……. and the Fukienese……. Press it into cakes. It is not poisonous, but when taken in excess it*

produces colicky pains, flatulence, and eructations. It is recommended in diseases of the throat, especially goiter". **1000-1300 A.D.:** In Hawaii aqeous extracts of *Centroceras corallophiloides* and *Hypnea nidifica* was used for constipation.[4] People of coastal areas, administered fresh juice of *Fucus vesiculosus* to cure anaemia.[5] Ibn Sina /Avicenna in his famous book *Al Qanoon Fit Tibb* mentioned 23 different marine resources, including algae used as medicine.[9] **Eighteenth century A.D.:** Vermifuges prepared from *Laminaria* species were used in Europe. In 1775, the anthelmintic properties of *Alsidium helminthochorton* was discovered by Greek physician Stephanopoli. In Japan and Mediterrean area *Gelidium cartilagineum, Dictyopteris polypodioides, Laminaria saccharina* and *Chondrus crispus* were used in diarrhea and irritation of urinary tract. In surgery, stem pieces of *Laminaria cloustonii* were used because of its property to become swollen up after getting a moisture to widen fistulas and wound openings. The same stem pieces were also employed to distend the uterine neck during labor. **Nineteenth century A.D.:** In China, extract of dried red algae *Digenea simplex* was sold by Oriental apothecaries by the name of "helminol" for the treatment of ascariasis and oxyuriasis. The Indians of Alaska Sitka, devised a mechanical nostrum for earache. The tube like stalk of the *Nereocystis luetkeana* was placed in the ear and the bulb on a hot wet stone. In this way, steam was entered the auditory canal to relieve earache. South American Indians were used *Sargassum bacciferum* to cure goiter, renal disorders and externally applied in case of inflammation, sprains and rheumatism. In the U.S. the jelly extract of *Chondrus crispus* was recommended against cough, diarrhea, dysentery and gastric ulcer. In 1885, algin and alginic acid were discovered from *Laminaria digitata*, *Laminaria hyperborea* and *Macrocystis pyrifera*.[4] **Twentieth century A.D.:** In South-East Asia *Acetabularia major* was used against gall stone. *Dictyopteris polypodioides* was used against lung diseases and scrofula in Mediterranian countries. *Ulva pertusa* was used as febrifuge in China. *Laminaria saccharina* was used in Russia for chronic constipation, goiter and as a prophylactic treatment of arteriosclerosis. *Chondria sanguinea* and *Chondria vermicularis* were used as anthelmintic in Brazil. *Digenea simplex* was used as anthelmintic especially in the treatment of ascariasis. *Gelidium cartilagineum* was used in Japan for colds and scrofula. *Hypnea musciformis* was used as anthelmintic and vermifuge in Greece and Turkey. *Hypnea nidifica* was used in stomach ailments in Hawaiian Islands. *Phyllophora nervosa* found in Turkish coasts was used as hypolipidemic agent.[10] The natives of Kanembu tribe in Chad was a daily routinely dietary habit for taking 10 g (one tablespoon) of *Arthrospira platensis* (*Spirulina*) algae along with their meals to avoid them from vitamin A deficiency.[11]

2. Algae as food and in food industries

Genus *Acanthophora, Caulerpa, Codium, Enteromorpha, Eucheuma, Gracilaria, Laminaria, Laurencia, Macrocytis, Monostroma, Porphyra, Ulva* and *Undaria* constitute protein rich algae and consumed as salad, soup and curry in China, Indonesia, Japan, Korea, Malaysia, Philippines, and Thailand. In China, Japan, and Korea, species of *Ulva*, *Enteromorpha*, *Monostroma* and *Porphyra* are added in soup while *Laminaria* and *Undaria* are eaten in dried form. In Philippines, *Caulerpa lentillifera* is consumed as salad while *Codium tomentosum, Eucheuma denticulatum* and *Kappaphycus alvarezii* in the form of curry **(table-1)**. The food value of algae depends on the proteins, minerals, trace elements and vitamins. Marine algae have almost all essential amino acids required in the human food. The algal food products include jellies from *Gelidiella* and *Gracilaria*; jams from *Enteromorpha* and *Ulva*; pickle from *Acanthophora, Gracilaria*, *Hypnea* and *Laurencia* species. Agar is added in the preparation of foodstuffs such as tomato sauce, ice cream, jelly, lime jelly and marmalade.[12] *Listeria monocytogenes* is the pathogen responsible for food borne diseases contaminates a variety of processed foods and causes confusion, diarrhea, fever, stiff neck, weakness and vomiting. *Himanthalia elongata* is a healthy candidate to be use as food preservative against food borne diseases caused by *Listeria monocytogenes.* The methanolic extracts of *Himanthalia elongata* reported to inhibit *Listeria monocytogenes* more significantly than synthetic preservatives such as sodium nitrite and sodium benzoate. *Campylobacter jejuni* is frequent cause of foodborne illness in poultry based products. Campylobacteriosis causes abdominal colic, fever and diarrhea accompanied by nausea and vomiting. Carrageenan and chitosan based coating obtained from marine algae containing heat-treated oriental mustard extract significantly reduced the numbers of *Campylobacter jejuni* on vacuum-packed raw chicken breasts. *Fucus spiralis* have a significant potential to inhibit foodborne bacteria *Aeromonas hydrophila*, *Bacillus cereus*, *Bacillus subtilis*, *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas fluorescens*, *Staphylococcus aureus*, *Vibrio parahaemolyticus* and *Vibrio alginolyticus*, when compared with genera, *Ascophyllum, Bifurcaria, Gracilaria* and *Ulva*[13] Algae extracts are the ingredient of functional food due to their health promoting properties. *Arthrospira platensis* (*Spirulina*) is a good source of protein and other nutrients, and useful in hyperglycemia, hyperlipidemia, hypertension and renal failure. The extract from *Arthrospira platensis* (*Spirulina*) are added to functional foods as they have anti-inflammatory, antimicrobial, antioxidant, antitumor and antiviral properties due to the presence of carotenoids, phenolic acids, phycocyanins and ω-3 fatty acid and poly

unsaturated fatty acids. *Chlorella* species has been use as a food additive contain β-1-3glucan which has antioxidant, hypolipidemic and immunostimulant properties.[14,15]

3. Algae as nutrition

Algae are more nutritional than land based higher plants. As algae does not take considerable energy to form circulatory systems, leaves, roots, stem and reproductive organs which depleted the rich stores of phytonutrients, protein and lipids. Algae do not have these features so it does not waste energy. Genetically-modified seeds are generally used for plantation have less nutritious than their natural cousins.[11]

Polysaccharides

Microalgal genera include *Aphanizomenon*, *Arthrospira*, (*Spirulina*), *Chlorella*, *Dunaliella*, *Haematococcus*, *Odontella*, *Porphyridium*, *Scenedesmus* and *Ulva* are rich in polysaccharides.[16] Green algae (Chlorophyceae) contain sulfated galactans and sulphuric acid polysaccharide. Brown algae (Pheophyceae) have alginic acid, fucoidan and laminarin. Red algae (Rhodophyceae) possess carrageenan, floridean and porphyran. *Ulva* species contain high amount of polysaccharides i.e. 65% of dry weight.[17] Many water soluble polysaccharides such as pectins, guar gum, etc. possess hypoglycemic and hypocholesterolemic effects, whereas the water-insoluble polysaccharides like cellulose have laxative effect.[18]

Dietary fibers

Marine algae is rich source of water soluble (alginic acid, agars, furonan, laminarin and porphyran) and water insoluble fibers (cellulose, mannans and xylan) which contain some valuable nutrients and also behave as functional foods. These fibers play an active role against obesity, cholesterol and large intestine cancer.[17,19] In algae, high amount of dietary fibers (% dry weight) reported exceed those for wheat bran, ranging from 23.5 (*Codium reediae*) to 64.0 (*Gracilaria* spp).[16] *Porphyra umbilicalis* contains slightly more fiber (3.8 g/100 g) than bananas (3.1 g/100 g).[20] Table-2 contains dietary fiber contents.

Proteins and amino acids

Algal protein contents differ greatly from phylum to phylum. Brown algae contain 5-16% and 10-30% of protein is reported in green and red algae. Some red seaweeds such as *Palmaria palmata* and *Porphyra tenera* contain 36% and 48% of proteins respectively, are comparable with 35% content of soybeans. The protein in *Ulva* species are in the range of 15-

20%. The free amino acids are composed of alanine, aminobutyric acid, citrulline, hydroxyl proline, ornithine and taurine. The edible algae have almost similar essential amino acid composition. Some have high level of arginine e.g. *Porphyra tenera, Ulva pertusa* and *Undaria pinnatifida*.[21] *Chlorella, Porphyra* and *Spirulina* species contain up to 70 % dry wt protein along with all of the essential amino acids that human cannot synthesize such as leucine, lysine, methionine, threonine, tryptophan, and valine compares well with egg albumin. In most analyses of used amino acid, glutamic acid, and aspartic acid represent the highest proportions of amino acids.[16]

Lipids and fatty acids

Algal lipid contents are reported as polyunsaturated fatty acids with omega 3 and omega 6 acids which are important to prevent from cardiovascular diseases, diabetes and osteoarthritis. Green algae contains alpha linolenic acid, while brown and red algae are rich in eicosapentanoic acid and docosahexanoic acid.[12] Alpha-linolenic acid, eicosapentaenoic acid and docosahexanoic acid are omega-3 fatty acids which are important for human physiology. High eicosapentaenoic acid contents are reported in *Porphyridium cruentum* (3 % dry weight), *Nitzschia laevis* (2-4% dry weight) and *Phaeodactylum tricornutum* (1-5% dry weight). Whereas high docosahexanoic acid is reported in *Crypthecodinium cohnii* (2-6% dry weight), *Thraustochytrium aureum* (6-7% dry weight), *Schizochytrium limacinum* (5-15% dry weight) and *Schizochytrium mangrovei* (12-21% dry weight).[22] Different types of sterols are reported from algae. Green algae contain cholesterol, methylene cholesterol and β-sitosterol. Desmosterol, cholesterol, sitosterol, fucosterol and chalinasterol are common in red algae. Brown algae contain high level of fucosterol. *Laminaria* and *Undaria* species contain 83-97% of fucosterol of total sterol (0.66 - 2.32 mg/g dry weight). *Palmaria* and *Porphyria* species reported to possess 87-93% desmosterol of total sterol (0.08 - 0.33 mg/g dry weight).[17]

Minerals

The mineral composition varies from phylum to phylum and other factors e.g. environmental, physiological, seasonal, and geographical variations. The macro algae have high calcium, iodine, iron, potassium, phosphorus and sodium.[12] Genus *Porphyra* contain high Fe ranges from (0.2–0.7 g/100 g). High manganese is reported from *Pseudofallacia tenera* i.e. 33.2–409 µg/g dry weight.[20] Seaweeds are a good nutritional source for iodine, particularly in foods

deficient regions. *Laminaria* and *Saccharina* species are traditionally used for thyroid goiter due to their high iodine contents.[16] Some reported minerals are mention in **table-3**.

Vitamins

The vitamins in algae vary among the algal species, environment, growing stage and season. Some red seaweed e.g. *Palmaria palmata* and *Porphyra tenera* have large quantity of vitamins A, B_1, B_2 and B_{12}.[12] β-carotene (pro-vitamin A) found in *Codium fragile* and *Gracilaria chilensis* exceed those measured in carrots. *Chlorella stigmatophora*, *Dunaliella tertiolecta*, *Isochrysis galbana and Tetraselmis suecica* are particularly rich in lipid-soluble (A and E) and B-group vitamins (including vitamins B_1, B_2, B_6 and B_{12}). Foods and vegetables are poor sources of vitamin B_{12}. Therefore, strict vegetarians are vitamin B_{12} deficient. Some vitamin B_{12} rich edible algae are one of the vegetarian alternatives in this regard. *Ulva* and *Pyropia* sp. contain considerable amounts of vitamin B_{12}.[16] *Arthrospira platensis* or *Spirulina platensis* is rich source of vitamin B_{12}. Only one g of *Spirulina* provides the daily requirements of B_{12}.[20] *Gracilaria changii*, *Himanthalia elongata* and *Porphyra umbilicalis* contain same levels of vitamin C as of tomatoes and lettuce. The vitamin-C content of brown seaweed *Eisenia arborea* (34.4 mg/ 100 g dry wt) approaches those reported for mandarin oranges.[16] The Vitamin C contents of brown and green algae ranges from 50 to 300 mg/100 g dry wt, are comparable to *Petroselinum crispum* (Mill.) Fuss. i.e. parsley.[20] Brown algae contain vitamin E higher than green and red seaweeds. *Ascophyllum* and *Fucus* sp. contain 200 - 600 mg of tocopherols / kg of dry weight.[18] *Macrocystis pyrifera* contain similar levels of α-tocopherol (vitamin E) as compare with vitamin E rich plant oils such as *Elaeis guineensis* Jacq. (palm oil), *Helianthus annuus* L. (sunflower seed oil) and *Glycine max* (L.) Merr. (soybean oil).[16]

4. Algae as medicine

Marine algae have been used in folk medicine. Algae is useful candidate to prevent diseases and also to protect most prevalent deficiency diseases such as malnutrition, nutritional anemia (iron and B12 deficiency), *xerophthalmia* (vitamin A deficiency), and endemic goiter (iodine deficiency). Algae are rich in the antioxidant vitamins C and E, in higher concentrations than land plants. Vitamin C prevents from scurvy, while vitamin E helps to manage neurological problems due to poor nerve conduction and anemia due to oxidative damage to red blood cells. Algae iron is more readily absorbed by the human body as compare with higher land plants due to its blue pigment, phycocyanin. Phycocyanin forms

soluble complexes with iron and other minerals during digestion. The presence of less fat and cholesterol, more soluble fibers per bite slows the release of blood glucose after a meal and immediately bioavailable nutrients to gain full nutrition with less food make algae to behave as good anti-obese agent. The phenolic rich extracts obtained from *Alaria, Ascophyllum, Palmaria, Ulva* species not only are natural antioxidants but also inhibit digestive enzymes and achieve anti-diabetic effects. *Laminaria* species (kelp) are brown algae contain up to 13 times more calcium than milk and powerful antioxidants that are not found in land plants: fucoxanthin and fucoidan. Kelps are macroalgae rich in vitamin B, C and K1 with high mineral contents of magnesium, potassium and iron[11]. The reported pharmacological activities of isolated algal compounds (table-4) and their pharmaceutical applications have been summarized in table-5.

5. Algae as Cosmeceuticals

Marine algae have a demanding potential for cosmeceuticals. Their medicinally active compounds have the ability to kill bacteria and fungi that destroy the skin flora and therefore act as preservative. Algal compounds having antioxidant properties help to protect from skin aging, sun-related skin damage and other photoaging problems such as melanoma, cutaneous inflammation and skin cancer. Skin naturally possesses antioxidants to prevent cell destabilization. However, the UV exposure generates reactive oxygen species which in turn cause free radical cell damage, cell death via apoptotic or necrotic processes. These effects are clearly noticeable by the presence of skin dryness, wrinkles and mottled pigmentation. Tyrosinase enzyme catalyzes melanin synthesis to promote skin melanisation and tanning. Algal compounds act as tyrosinase inhibitors are the potential candidates for skin whitening. *Arthrospira platensis* extract can repair the symptoms of skin aging, provides a tightening effect, and inhibits stria formation; while *Chlorella vulgaris* an extract is reported to stimulates collagen synthesis in the skin, helps in tissue regeneration and reduce wrinkle formation. Algae derived polysaccharides takes part in skin hydration and their moisturizing effect protects skin from dryness. Thus helping to maintain skin appearance, elasticity and strengthening to provide barrier against harmful environmental factors. The polysaccharides from *Saccharina japonica* can absorb and retain moisture more than hydroxyl acid, the commonly used skin moisturizer in clinical practice. Therefore, algal polysaccharides may be used in cosmetics as an additive. Agar and alginic acids are good hydrocolloids and emollient and used as cosmeceutical aid.[23]

6. Algae in different industries

Agar, algin and carrageenan are obtained from algae. Agar is obtained from red algae such as *Gracilaria, Gelidiella, Gelidium,* and *Pterocladia* ; carrageenan from *Eucheuma, Gigartina* and *Hypnea* and algin from brown algae like *Ascophyllum, Cystoseira, Lallinaria, Macrocystis, Sargassum,* and *Turbinaria.* Agar is used as a substrate for bacteriologic culture and tissue culture eukaryotic cell in research and medical facilities. Alginates obtained from the cell wall of brown algae are used in food and pharmaceutical industries in the form of stabilizers for suspension and emulsions. Xanthophyll has a large application in the coloration of cosmetic and drugs. Phycobillins specially blue phycobilin from *Arthrospira* are water soluble pigments used as colorants for cosmetic and food products [12]. These seaweeds are used as thickening, gelling and stabilizing agents in dairy, food, confectionary, pharmaceutical, textiles, paint, paper and varnish industries etc. Some other chemicals such as iodine, mannitol, laminarin, fucoldin are also obtained from marine algae. Carrageenans are not only used in the food but also in textile, cosmetics and medicines.[24]

CONCLUSION

This review has focused on compound related nutritional, medicinal and cosmeceutical effects which will help to spark interest to take forward research work pertaining to the secondary metabolites in algae and their utility.

Table 1: Examples of some edible algae.[21]

Brown algae (Phaeophyta)	
Genus	**Common Name**
Alaria	Kelp and bladder locks.
Ascophyllum	Egg wrack.
Fucus	Bladder wrack and rockweed.
Himanthalia / Bifurcaria	Sea spaghetti and fucales.
Hizikia	Hijiki.
Laminaria	Kelp and kombu.
Saccharing	Sugar wrack.
Sargassum	Mojaban and Indian brown seaweed.
Undaria	Wakame.
Red algae (Rhodophyta)	
Asparagopsis	Limukohu.
Chondrus	Irish moss.
Mastocarpus / Gigartina	Stackhouse and guiry.
Porphyra	Nori, haidai , and kim.
Rhodymenia / Palmaria	Dulse
Green algae (Chlorophyta)	
Ulvaria / Enteromorpha	Leaver, sea lettuce and sea grass.

Table 2: Dietary fiber contents of some algae.[21]

Algae	Dietary fiber (% dry weight)		
	Soluble	Insoluble	Total
Phaeophyceae			
Himanthalia elongata	25.70	7.00	32.70
Sargassum fusiforme syn. *Hizikia fusiforme*	32.90	16.30	49.20
Laminaria digitata	32.50	4.60	38.00
Undaria pinnatifida	30.00	5.30	35.30
Chlorophyceae			
Ulva lactuca	21.40	16.70	38.00
Rhodophyceae			
Pyropia tenera	18.00	6.90	34.80

Table: 3 Reported Minerals in some edible algae.[21]

Minerals	Mineral contents in algae (mg/100 g dry matter)			
	Palmaria palmata	***Undaria pinnatifida***	***Laminaria* species**	***Ulva* species**
Calcium	360-1200	1100-3000	500-3000	860-560
Iodine	10-100	25	200-1000	2 - 25
Iron	15-140	8	4-80	6-100
Magnesium	170-500	1000-3000	500-2000	2000-5200
Phosphorus	360	200-600	150-800	90-270
Potassium	7000-9000	5500-6300	1300-10600	730-1030
Sodium	1700-2500	1600-4000	900-6000	900-5900

Table: 4 Pharmacological activity of secondary metabolites from algae.

Algae	Chemical compounds	Mechanism	Activity
Agardhiella tenera	Galactan sulphate	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[25]
		Active against Herpes simplex virus type-1 and 2	Anti-herpes[25]
Ascophyllum nodosum	Laminarin	Active against *Escherichia coli, Listeria monocytogenes, Salmonella typhimurium.* and *Staphylococcus aureus*	Antibacterial[13]
	Sulphated fucan	-------	Anticoagulant[26]
Asparagopsis taxiformis	Pentabromopropen-2-yl acetate and pentabromopropen-2-yl dibromoacetate	Aldose reductase inhibitor	Antidiabetic[27]
Avrainvillea nigricans	Glycoglycerolipids, nigricanosides-A and B	Antimitotic	Anticancer[28]
	Hydroxyisoavrainvilleol	Protein tyrosine phosphatase-1B inhibitor	Antidiabetic[28]
Bifurcaria bifurcata	Eleganolone	Active against *Trypanosoma cruzi*	Trypanocidal[29]

Callophycus serratus	Bromophycolides- A and B	Cytotoxic for human cancer cell lines	Anticancer[28]
		Active against *Enterococcus faecium*	Antibacterial[13]
Caulerpa prolifera	Caulerpynyne	Lipoxygenase and Phospholipase-A_2 inhibitor	Anti-inflammatory[27, 30]
Caulerpa taxifolia	Caulerpals-A and B	Tyrosine kinase inhibitor	Anticancer[28]
	Caulerpenyne	Pancreatic lipase inhibitor	Anti-obesity[27]
		Decrease bee sting inflammation	Anti-inflammatory[25]
Caulocystis cephalornithos	6-n-tridecylsalicylic acid	-------	Anti-inflammatory[25]
Ceratodictyon spongiosum	*cis*, *cis*-Ceratospongamide	Phospholipase-A_2 inhibitor	Anti-inflammatory[28]
Chlorella pyrenoidosa	Chlon-A and Respondin (acidic polysaccharide)	--------	Anticancer and immunostimulatory[16]
Chondria oppositiclada	Cycloeudesmol	Active against *Staphylococcus aureus* and *Candida albicans.*	Antibacterial[28]
Chondria armata	Isodomic acid-A, B and C	Active against *Periplaneta americana* (American cockroach)	Insecticidal[28]
Chondria atropurpurea	Chondriamide-A	Active against Herpes simplex virus type-2	Anti-herpes[30]
		Cytotoxic against human nasopharyngeal and colorectal cancer cell lines	Anticancer[30]
	Chondriamide-C	Active against *Nippostrongylus brasiliensis* (gastrointestinal roundworm that infects rats)	Anthelmintic[28]
Cladophora fascicularis	2-(2′,4′-dibromophenoxy)-4,6-dibromoanisol	Active against *Bacillus subtilis, Escherichia coli* and *Staphylococcus aureus*	Antibacterial[28]
Cladophora socialis	Vanillic acid biphenyl derivative	Protein tyrosine phosphatase-1B inhibitor	Antidiabetic[28]
Chrysophaeum taylorii	Chrysophaentins	Active against *Enterococcus faecium* and *Staphylococcus aureus*	Antibacterial[13]
Cymopolia barbata	Cymopol and cyclocymopol	Phospholipase-A_2 inhibitor	Anti-inflammatory[27]
Cystoseira abies-marina	Meronorsesquiterpenoids cystoazorone- A and B, meroditerpenoids cystoazorol-A	Cytotoxic for human cancer cell lines	Anticancer[29]
Cystoseira indica	Sulphated fucan	Active against herpes virus type 1 and 2	Anti-herpes[26]
Cystoseira tamariscifolia	Methoxybifurcarenone	Active against *Agrobacterium tumefaciens* and	Antibacterial[28]

		Escherichia coli.	
Cystoseira usneoides	Meroditerpenoids cystodione A–F	Free radical scavenging activity (ABTS assay)	Antioxidant[29]
	Usneoidone-E and Z	Active against cancer cell lines	Anticancer[30]
Delisea pulchra	Halogenated furanone or fimbrolide	Active against *Pseudomonas aeruginosa*	Antibacterial[13]
Dictyota coriacea	1,9-dihydroxycrenulide and epiloliolide	Tyrosinase inhibitor	Antimelanogenic[29]
Dictyota dichotoma	Dictyol-J diterpenes, dietactonesanadaol and perhydroazulenediterpenes,	Active against *Heterosigma akashiwo, Karenia mikimotoi* and *Alexandrium catenella.*	Algicidal[28]
Dictyota pfaffi	10-acetoxy-8,18-hydroxy-2,6-dolabelladiene	Herpes simplex virus type-1 inhibitor	Anti-herpes[27]
	(6R)-6-hydroxydichotoma-3,14-diene-1,17-dial and 8,10,18-trihydroxy-2,6-dolabelladiene	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
	Dolabelladienetriol	Active against *Leishmania amazonensis*	Anti-leismanial[31]
Dictyota menstrualis	(6*R*)-6-hydroxy dichototomo 3,14-diene-1,17-dial	HIV integrase inhibitor	Anti-AIDs [28]
		HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
Digenea simplex	Kainic acid	----------	Anti-helmintic[31]
Ecklonia cava	Dieckol	----------	Hepatoprotective [27]
		Pancreatic lipase inhibitor	Anti-obesity[27]
		Tyrosinase inhibitor	Antimelanogenic[27]
		α-amylase and α-glucosidase inhibitor	Antidiabetic[27]
		Matrix metalloproteinase inhibitor in human dermal fibroblast cell	Against photo aging of skin[32]
	Eckol	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
	6,6′-bieckol	Inhibitory effect on histamine release	Antiallergic[32]
		α-amylase and α-glucosidase inhibitor	Antidiabetic[27]
		HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
	Fucodiphlorethol-G	Free radical scavenger (DPPH assay)	Antioxidant[28]
		α-amylase and α-glucosidase inhibitor	Antidiabetic[27]
	8,4”-bieckol and 8,8’-bieckol	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[28]
	Dieckol, phlorofucofuroeckol A, eckol, eckstolonol and	Angiotensin converting enzyme inhibitor	Antihypertensive[27]

	triphlorethol		
Ecklonia kurome	Eckol and phlorofucofuroeckol-A	α 2-plasmin inhibitor	Anticoagulant[27]
	Sulphated fucan	-------	Anticoagulant[26]
	Dieckol	Inhibitory effect on hyaluronidase	Antiallergic[32]
Ecklonia maxima	Eckol and phloroglucinol	α-glucosidase inhibitor	Antidiabetic[27]
Ecklonia stolonifera	Phlorofucofuroeckol-A	Tyrosinase inhibitor	Antimelanogenic[27]
	Dieckol and eckol	Matrix metalloproteinase inhibitor	Against photo aging of skin[32]
	Eckstolonol and phlorotannin,	DEPP radical-scavenging activity	Antioxidant[28]
	Eckol, phlorofucofuroeckol-A and dieckol	Angiotensin-converting enzyme inhibitor	Antihypertensive[28]
	Dieckol, eckstolonol, eckol and phlorofucofuroeckol-A	----------	Hepatoprotective[28]
	Dieckol, eckol, phloroglucinol, dioxinodehydroeckol, phlorofucofuroeckol-A, and 7-phloroeckol.	α-glucosidase and protein tyrosine phosphatase 1B inhibitor	Antidiabetic[27]
	Dioxinodehydroeckol, triphloroethol-B, 2-phloroeckol	Aldose reductase inhibitor	
	Dieckol, eckol, eckstolonol, fucosterol, 24-hydroperoxy 24-vinylcholesterol, 2-phloroeckol, phlorofucofuroeckol A, phloroglucinol, 7-phloroeckol and triphlorethol.	Acetyl cholinesterase inhibitor	Against alzheimer and dementia[27]
Eisenia arborea	8,8′-bieckol	Inhibits histamine release	Antiallergic[32]
	Phlorofucofuroeckol-B	Inhibitorys Ig-E overexpression	
	Communesins-A and B	Cytotoxic	Anticancer[28]
Eisenia bicyclis	Phlorofucofuroeckol-A	Active against *Staphylococcus aureus*	Antibacterial[13]
		Inhibitory effect on hyaluronidase	Antiallergic[32]
	Pyropheophytin-A	Free radical scavenging activity (ferric thiocyanate assay and thiobarbituric acid method)	Antioxidant[33]
	Fucoxanthin	Aldose reductase and protein tyrosine phosphatase-1B inhibitor	Antidiabetic[27]
	Dioxinodehydroeckol and fucofuroeckol	α-glucosidase inhibitor	
	Fucofuroeckol and 7-phloroeckol	Pancreatic lipase inhibitor	Anti-obesity[27]

	Dieckol, phlorofucofuroeckol A and 8, 8-Bieckol	Phospholipase-A2 inhibitor	Anti-inflammatory[27]
Eucheuma cottonii	Xylomannan, galactan sulfate and κ-,λ-carrageenan	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[34]
Fucus vesiculosus	Alginate, fucoidan and laminaran	Free radical scavenging activity (DPPH assay)	Antioxidant[23]
	Fucoidan	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[34]
Gigartina acicularis	Xylomannan, galactan sulfate and κ-,λ-carrageenan	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[34]
Gigartina pistillata			
Gigartina tenella	Sulfoquinovosyldiacylglycerol		
Gracilaria asiatica	Prostaglandin-E_2	-------	Antihypertensive[30]
Grateloupia carnosa	Carnosadine	-------	Anti-inflammatory[30]
Gracilaria corticata	Agaroids	Inhibition of initial herpes type-1 and 2 viral attachment to host cell	Anti-herpes[17]
Gracilaria chilensis	Agar	Emollient and thickening agent	Controls emollience and viscosity in cosmetics[23]
Gracilaria gracilis			
Gracilaria lichenoides	Prostaglandin-E_2	-------	Antihypertensive[30]
Gracilaria verrucosa			
Grateloupia elliptica	2,4,6-tribromophenol and 2,4- dibromophenol	α-glucosidase inhibitor	Antidiabetic[27]
Haematococcus pluvialis	Astaxanthin	Inhibit melanin synthesis	Antimelanogenic [23]
		Tyrosinase inhibitor	Antimelanogenic[23]
Himanthalia elongata	Fucoxanthin	Active against *Listeria monocytogenes*	Antibacterial[13]
Hypnea japonica	HypninA-D (lectin)	Haemagglutination	Use in assays for blood type[30]
Ishige okamurae	Diphloethohydroxycarmalol	Tyrosinase inhibitor	Antimelanogenic[27]
		α-amylase and α-glucosidase inhibitor	Antidiabetic[27]
		HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
	Sulfoquinovosyldiacylglycerol	Active against Herpes simplex virus type- 2	Anti-herpes[28]
	6,6′-bieckol, phloroglucinol, Diphloethohydroxycarmalol	Acetyl and butyl cholinesterase inhibitor	Against Alzheimer and dementia[27]
	7-methoxy-9-methylhexadeca-4,8-dienoic acid	Phospholipase-A_2 inhibitor	Anti-inflammatory[27]
Jania rubens	Deoxyparguerol and isoparguerol	Active against *Allolobophora caliginosa* (earthworm)	Anthelmintic[28]
Laminaria hyperborea	Laminarin	Active against *Escherichia coli, Listeria monocytogenes, Salmonella typhimurium* and *Staphylococcus aureus*	Antibacterial[13]

Laminaria japonica	Fucoxanthin	Tyrosinase inihibitor	Antimelanogenic[29]
		Inhibit oxidative stress caused by UV radiation	Antioxidant[23]
	Butyl-isobutylphthalate	α-glucosidase inhibitor	Antidiabetic[27]
	Pheophorbide-A and pheophytin-A	Aldose reductase inhibitor	
	Sulfated polymannuroguluronate	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
Landsburgia quercifolia	Deoxylapachol	Antileukemic activity	Anticancer[28]
Laurencia dendroidea	Elatol	Active against *Leishmania amazonensis*	Anti-leismanial[31]
		Active against *Trypanosoma cruzi*	Trypanocidal[31]
Laurencia majuscula	Elatol	Active against *Staphylococcus epidermidis, Klebsiella pneumoniae* and *Salmonella* sp.	Antibacterial[12]
	Iso-obtusol	Active against *Klebsiella pneumoniae* and *Salmonella* sp.	
Laurencia okamurae	Laurinterol	Growth inhibition of melanoma cells	Anticancer[28]
Laurencia pacifica		Active against *Staphylococcus aureus*	Antibacterial[23]
Laurencia rigida	Deschloroelatol, elatol, luzonenone, luzofuran and 15-hydroxypalisadin	Active against *Bacillus megaterium*	Antibacterial[32]
Laurencia similis	3′,5′,6′,6-tetrabromo-2,4-dimethyldiphenyl ether and 2′,5′,6′,5,6-pentabromo3′,4′,3,4-tetramethoxybenzo-phenone	Protein tyrosine phosphatase-1B inhibitor	Antidiabetic[27]
Laurencia nipponica	(Z)-Laureatin, (Z)-isolaureatin and deoxyprepacifenol	Active against *Culex pipiens pallens* mosquito larvae	Insecticidal[28]
Laurencia obtusa	Fucoxanthin	Active against *Listeria monocytogenes*	Antibacterial[13]
	Iso-obtusol	Activity against *Klebsiella pneumonia*	Antibacterial[28]
	Neorogioldiol-B, prevezol-B and thysiferyl 23-acetate	Cytotoxic for human cancer cell lines	Anticancer[28]
	Snyderol sesquiterpene	Active against *Plasmodium falciparum*	Antimalarial[28]
Laurencia venusta	Thyrsiferol, thyrsiferyl 23-acetate and venustatriol	Active against Herpes simplex virus type-1	Anti-herpes[28]
Laurencia brongniartii	Polybrominated indoles	Active against *Bacillus subtilis*	Antibacterial[28]
		Active against *Saccharomyces cerevisiae*	Antifungal[28]
Lobophora variegata	Lobophorolide	Active against *Candida albicans*	

Lyngbya majuscula	Curacin-A	Antimitotic	Anticancer[28]
	γ - lactone malyngolide	Active against *Mycobacterium smegmatis* and *Streptococcus pyogenes*	Antibacterial[28]
Marginisporum aberrans	Hydroxybenzaldhyde, dichloro-acetamide, and 3,5-dinitriguaiacol	Active against *Bacillus subtilis*	Antibacterial[28]
Murrayella periclados	12-(S)-hydroxyeicosapentaenoic acid	Platelet aggregation inhibitor	Anticoagulant[28]
Nizamuddinia zanardinii	(24R)-hydroperoxy-24-vinylcholesterol	Cytotoxic for human cancer cell lines	Anticancer[29]
Notheia anomala	*Cis* dihydroxyte-trahydrofuran derivatives	Larval stage inhibition of *Haemonchus contortus* and *Trichostrongylus colubriformis* (Gastrointestinal nematode parasitic for domesticated and wild herbivorous animals)	Larvicidal[28]
Nothogenia fastigiata	Xylomannan sulphate	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[25]
		Active against Herpes simplex virus type-1 and 2	Anti-herpes[25]
Penicillus capitatus	Capisterones-A and B	Active against *Lindra thallasiae*	Antifungal[28]
Pelvetia siliquosa	Fucosterol	Inhibits glycogenolysis and lowers blood glucose level	Antidiabetic[28]
Peyssonnelia inamoena	Peyssonol-A and B	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[34]
Polysiphonia morrowii	3-bromo-4,5-dihydroxybenzyl alcohol and 3-bromo-4,5-dihydroxybenzyl methyl ether	α-glucosidase inhibitor	Antidiabetic[27]
Porphyra umbilicalis	Mycosporine-like amino acids	Absorb UV light	May act as sunscreen[23]
Portieria hornemannii	Halmon (polyhalogenatedmonoterpene)	Cytotoxic for human cancer cell lines	Anticancer[28]
Plocamium cartilagineum	Furoplocamioid-C, perfuroplocamioid, pirene and tetrachlorinated cyclohexane		
Plocamium telfairiae	Telfairine	Active against the mosquito larvae *Culex pipiens pallens*	Insecticidal[28]
Rhipocephalus phoenix	Rhiphocephalin	Phospholipase-A_2 inhibitor	Anti-inflammatory[30]
Sargassum fulvellum	Fucoxanthin	Inhibit oxidative stress caused by UV radiation.	Antioxidant[23]
Sargassum fusiforme	Cyclopentaneacetic acid and 10,13-octadeadienoic acid	Active against *Staphylococcus aureus* and *Klebsiella pneumonia*	Antibacterial[13]

Sargassum muticum	Fucoxanthin	Aldose reductase and Protein tyrosine phosphatase-1B inhibitor	Antidiabetic[25]
Sargassum sagamianu	Sargaquinoic acid, sargachromenol, monooxofarnesylacetone and dihydromonofarnesylacetone	Acetyl cholinesterase inhibitor	Against Alzheimer and dementia[27]
Sargassum siliquastrum	Sargahydroquinoic acid and sargaquinoic acids	Antiplatelet aggregation	Antithrombotic[29]
Sargassum tortile	Meroterpenoids, sargol, sargol-I, sargol-II	Cytotoxic for human cancer cell lines	Anticancer[28]
Sargassum thunbergii	Sargothunbergol-A , tetraprenyltoluquinols, thunbergols-A and B	Free radical scavenging activity (DPPH assay)	Antioxidant[28]
Sargassum vulgare	Sulfoquinovosyldiacylglycerols	Active against Herpes simplex virus type-1 and 2	Anti-herpes[29]
		--------	Anticoagulant, anti-inflammatory, antioxidant and antithrombotic [35]
	Cyclopentaneacetic acid and 10,13-octadeadienoic acid	Active against *Staphylococcus aureus* and *Klebsiella pneumonia*	Antibacterial[13]
Solieria filiformis	Lectins	Active against *Enterobacter aerogenes*, *Klebsiella pneumonia*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Serratia marcescens*	
Sphaerococcus coronopifolius	Sphaerane bromoditerpenes and 12S-hydroxybromosphaerodiol.	Active against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*	
		Active against *Candida albicans*	Antifungal[13]
Spirulina platensis	C-phycocyanin	Inhibit the production of pro-inflammatory cytokines	Anti-inflammatory[36]
Stypopodium zonale	Stypoldione	Antimitotic	Anticancer[37]
Symphyocladia latiuscula	2,3,6-tribromo-4,5-dihydroxybenzyl alcohol (Bromophenol)	Aldose reductase inhibitor	Antidiabetic[27]
		Free radical scavenging activity (DPPH assay)	Antioxidant[29]
		α-glucosidase inhibitor	Antidiabetic[27]
Turbinaria conoides	Alginate, fucoidan and laminaran	Free radical scavenging activity (DPPH assay)	Antioxidant[23]
Turbinaria triquetra	Fucoxanthin	Active against *Listeria monocytogenes*	Antibacterial[13]
Ulva fasciata	Sphingosin	Active against Semliki forest virus	Antiviral[28]
Ulva intestinalis	Penostatins-A, B, C, D and	Cytotoxic for human cancer cell	Anticancer[28]

	E	lines	
Ulva lactuca	Fucoxanthin	Active against *Listeria monocytogenes*	Antibacterial[13]
Undaria pinnatifida		Aldose reductase and Protein tyrosine phosphatase-1B inhibitor	Antidiabetic[27]
		Inhibit oxidative stress caused by UV radiation.	Antioxidant[23]
	Polymannuronic acid	-------	Hypolipidemic[25]
Vertebrata lanosa	Bromophenols	Free radical scavenging activity (DPPH assay)	Antioxidant[29]
Vidalia obtusiloba	Vidalols-A and B	Phospholipase-A_2 inhibitor	Anti-inflammatory[27]

Table: 5 Common therapeutically active compounds in algae with their therapeutic effects.

Chemical compounds with sources	Mechanism	Activity
Dieckol from *Ecklonia cava, E. kurome, E. stolonifera* and *Eisenia bicyclis*	Angiotensin-converting enzyme inhibitor	Antihypertensive[28] [27]
	α-amylase, α-glucosidase and protein tyrosine phosphatase 1B inhibitor	Antidiabetic[27]
	Pancreatic lipase inhibitor	Anti-obesity[27]
	Acetyl cholinesterase inhibitor	Against alzheimer and dementia[27]
	Inhibitory effect on hyaluronidase	Antiallergic[32]
	Phospholipase-A2 inhibitor	Anti-inflammatory[27]
	Tyrosinase inhibitor	Antimelanogenic[27]
	Matrix metalloproteinase inhibitor in human dermal fibroblast cell	Against photo aging of skin[32]
Eckol from *Ecklonia cava, E. kurome, E. maxima, E. stolonifera*	Angiotensin-converting enzyme inhibitor	Antihypertensive[28]
	α-glucosidase and protein tyrosine phosphatase 1B inhibitor	Antidiabetic[27]
	α 2-plasmin inhibitor	Anticoagulant[27]
	Acetyl cholinesterase inhibitor	Against alzheimer and dementia[27]
	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
	Matrix metalloproteinase inhibitor	Against photo aging of skin[32]
Eckstolonol from *Ecklonia cava* and *E. stolonifera*	Angiotensin converting enzyme inhibitor	Antihypertensive[27]
	DEPP radical-scavenging activity	Antioxidant[28]

	Acetyl cholinesterase inhibitor	Against alzheimer and dementia[27]
Fucoidan from *Fucus vesiculosus* and *Turbinaria conoides*	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[34]
	Free radical scavenging activity (DPPH assay)	Antioxidant[23]
6,6′-bieckol from *Ecklonia cava* and *Ishige okamurae*	Inhibitory effect on histamine release	Antiallergic[32]
	α-amylase and α-glucosidase inhibitor	Antidiabetic[27]
	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[27]
	Acetyl and butyl cholinesterase inhibitor	Against Alzheimer and dementia[27]
8,8′-bieckol from *Eisenia arborea, E. bicyclis* and *Ecklonia cava*	Inhibitory effect on histamine release	Antiallergic[32]
	Phospholipase-A2 inhibitor	Anti-inflammatory[27]
	HIV-1 reverse transcriptase inhibitor	Anti-AIDs[28]
Fucoxanthin from *Eisenia bicyclis, Himanthalia elongata, Laminaria japonica, L. obtuse, Sargassum fulvellum, Turbinaria triquetra, Ulva lactuca* and *Undaria pinnatifida*	Aldose reductase and protein tyrosine phosphatase-1B inhibitor	Antidiabetic[27]
	Active against *Listeria monocytogenes*	Antibacterial[13]
	Inhibit oxidative stress caused by UV radiation	Antioxidant[23]
	Tyrosinase inihibitor	Antimelanogenic[29]
Laminarin from *Ascophyllum nodosum* and *Laminaria hyperborea*	Active against *Escherichia coli, Listeria monocytogenes, Salmonella typhimurium* and *Staphylococcus aureus.*	Antibacterial[13]

Table 6: Use of algae in Pharmaceutical formulations [24]

Gum	Source	Pharmaceutical application
Red Algae, Rhodophyceae		
Agar	*Ahnfeltia plicata, Eucheuma cottonii, E. edule, E. muricatum* and *E. spinosum.*	Emulsifying agent, gelling agent and suspending agent, in suppositories, surgical lubricant, tablet disintegrates, medium for bacterial culture.
	Gelidium amansii, G.cartilagineum and *G. latifolium.*	
	Pterocladia densa and *P. lucida.*	
Carragennan	*Chondrus cryspus* and *C. ocellatus.*	Gelling agent, stabilizer in suspensions and emulsions.
	Eucheuma cottonii, E. edule, E. muricatum and *E. spinosum,*	
	Gigartina acicularis, G. mamillosa, G. pistillata, G. radula and *G. stellata*	
Brown algae, Phaeophyceae		
Alginate	*Fucus serratus* and *F. spiralis.*	Suspending agent, stabilizer,

	Macrocytis pyrifera and *M. integrifolia.*	gelation for dental films, sustained release agent, tablet coating.
	Laminaria digitata, L. cloustoni and *L. saccharina.*	

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