MARINE ALGAE: A SOURCE OF PROFOUND POTENTIAL FOR HUMAN WELFARE

Review Article

[1]Shambhu Chaudhary, [2]Ashwini S, [3]Sumitra Poudel
[1]Department of Pharmacology,
[1]Karnataka College of Pharmacy, Bangalore-560064, India

Abstract : Marine organisms are potentially prolific sources of highly bioactive secondary metabolites that might represent useful leads in the development of new pharmaceutical agents. Organisms such as algae, molluscs, sponges, corals, and tunicates have evolved to survive the high concentrations of infectious and surface-fouling bacteria that are indigenous to ocean waters. Algae, the chlorophyll containing organisms, are known to have more than 20,000 species. Algae can be classified into 2 main groups, first one is the microalgae which includes blue green algae, dinoflagellates, bacillariophyta (diatoms), etc. and second one is macroalgae (seaweeds) which includes green, brown and red algae. Both macroalgae and microalgae contain pharmacologically active compounds such as phlorotannins, fatty acids, polysaccharides, peptides, and terpenes which combat bacterial invasion. To survive in a competitive environment, marine algae have developed defense strategies that result in a significant level of structural-chemical diversity, from different metabolic pathways. Hence, such organisms provide novel biologically active substances and essential compounds for human nutrition. The present paper reviews the significance of the marine alga in various aspects for the human welfare.

Keywords **– Marine alga, macroalgae, microalgae, seaweeds.**

INTRODUCTION

The search for bioactive compounds from marine organisms in recent decades has produced an abundance of extracts with pharmaceutical and industrial applications. In 2013 alone, over one thousand pharmacologically active compounds of marine origin were characterized worldwide, with potential efficacy against cancer, viruses, bacteria, fungi, hypertension, high cholesterol and other diseases.[1] During the last four decades, numerous novel compounds have been isolated from marine organisms and many of these substances have been demonstrated to possess interesting biological activities.[2]

Algae, the chlorophyll containing organisms, is known to have more than 20,000 species.[3] These are composed of one cell or grouped together in colonies or as organisms with many cells, sometimes collaborating together as simple tissues. They vary greatly in size – unicellular of 3-10 µm to giant kelps up

to 70 m long and growing at up to 50 cm per day. Algae can be classified into 2 main groups, first one is the microalgae which includes blue green algae, dinoflagellates, bacillariophyta (diatoms), etc. and second one is macroalgae (seaweeds) which includes green algae (Chlorophyta), brown algae (Phaeophyta) and red algae (Rhodophyta).[2] The species of algae find its applications in food, dairy, pharmaceutical, cosmetic, and industry. Algae can also be used in the preparation of biodiesel, bioethanol, biobutanol and hydrogen gases.[4] Seaweeds are measured as a source of bioactive compounds and a prodigious variety of secondary metabolites categorized by a broad spectrum of biological and pharmacological activities.[5]

Micro and macroalgae, such as diatoms and seaweeds, have developed indigenous systems to combat pathogenic bacteria and other microbes, ubiquitous to the ocean environment.[1] To survive in a competitive environment, marine algae have developed defense strategies that result in a significant level of structural-chemical diversity, from different metabolic pathways. They provide novel biologically active substances and essential compounds for human nutrition which include fatty acids, sterols, carotenoids, phycocolloids, lectins, mycosporine like amino acids (MAAs) and halogenated compounds which possess various pharmacological properties (antioxidant, antitumour, antiviral, antimicrobial, anticoagulant, etc.).[6] This review focuses on various pharmacological, cosmeceutical, environmental & industrial potential of marine alga which is of much importance to the humans.

APPLICATIONS

1.ANTIOXIDANT ACTIVITY

Free radicals are highly reactive molecules with an unpaired electron and are produced by radiation or as byproducts of metabolic processes. They initiate chain reactions which lead to disintegration of cell membranes and cell compounds, including lipids, proteins and nucleic acids, Antioxidant compounds scavenge free radicals such as peroxide, hydroperoxide or lipid peroxyl and reduce the level of oxidative stress and slow/prevent the development of complications associated with oxidative stress-related diseases.[7]

It is found that, several algal species have prevented oxidative damage by scavenging free radicals and active oxygen and hence able to prevent the occurrence of cancer cell formation.[8] The most powerful water soluble antioxidants found in algae are polyphenols, phycobiliproteins and vitamins.[9] The brown alga *Ecklonia stolonifera* collected from S. Korea yielded a new phlorotannin, eckstonolol which possessed a potent DEPP radical scavenging activity.[10] The known plastoquinones were isolated from brown alga *S. micracanthum*. They displayed significant antioxidant activity and were potentely active against human cytomegalo virus (HCMV) *in vitro*.[11]

The known compound taondiol, isoepitaondiol, stypoldione and sargaol isolated from brown alga *Taonia atomaria* exhibited free radical scavenging activity (DPPH and chemiluminescence tests).[12] Cyclohexanone isolated from the red alga *Symphocladia latiuscula* has a free radical scavenger activity.[13] The bromophenols isolated from the red alga *Polysiphonia urceolata* were potent DPPH radical scavengers.[14] *Gelidiella acerosa* is used as a valuable antioxidant for treating ROS mediated diseases.[5] Antioxidant activity was also reported from *Sargassum siliquastrum, Rhodomela confervoides, Symphocladia latiuscula, Sargassum micracanthum, Kappaphycus alvarezzi, Gelidiella acerosa, Fucus vesiculosus, Ishige okamurae, Undaria pinnafida, Sargassum pallidum, Enteromorpha compresssa,* etc.[15]

2. ANTI-INFLAMMATORY ACTIVITY

Inflammation is defined as the local response of living mammalian tissues to injury due to any agent.[16] Inflammation can result to genetic defects and immunoregualtion and mechanism defects can lead to tissue damage.[17] Due to several side effects of anti-inflammatory drugs and resistance of pathogens to the drug, safe biological sources are now been considered.[18] Previous studies report the presence of anti-inflammatory compounds in seaweeds.[2]

An anti-inflammatory 3-0-β-D-glucopyranosy-lstigmasta-5,25-diene have been isolated by Awad in 2000 from the green alga *Ulva laetuea*.[19] Two new anti-inflammatory macrolides, lopophorins A and B have been isolated from the fermented broths of a marine bacterium isolated from the surface of the Caribbean brown alga *Lobophora variegata*. They are potent inhibitors of tropical PMA-induced edema in the mouse ear assay when administered either topically or i.p.[20] (Z)-Sargaquinone, the more saturated analogue and the known sargaquinone were isolated form the brown alga *Taonia atomaria* and were anti-inflammatory agents by inhibition of leukotriene biosynthesis.[21] Chemical investigation of the marine red alga *Ceratodictyon spongiosum* containing the symbiotic sponge *Sigmadocia symbiotica* collected from Indonesia, afforded two isomers, cis-Ceratospongamide and trans-Ceratospongamide. The trans isomer exhibits potent inhibition to sPLA2 expression in a cell based model for anti-inflammation (ED50 32nM) whereas the cis form was inactive.[22]

The anti-inflammatory bromophenolic metaboliotes named vidalols A and B were isolated from the Caribbean red alga *Vidalia obtusaloba* that acts through the inhibition of phospholipase enzyme.[23] The anti-inflammatory effect of *Sagarssum hemiphyllum* against Phorbol 12-myristate 13-acetate (PMA) and A23187-induced IL-8 and on TNF-A secretion from human mast cells (HMC-1), *Galaxaura marginata* against croton oil induced ear mouse ear edema, erythema and blood flow, *Sargassum micracanthum* against LPS induced RAW 264.7 macrophage, *Petalonia binghamiae* against ethyl acetate LPS induced RAW 264.7 macrophges, *Sargassum swartzii* and *Ulva reticulata* against Carrageenan induced hind paw edema in rats and peritonitis for acute and chronic inflammatory models has been reported.[15]

3. ANTICANCER ACTIVITY

One of the most important treatments currently available for cancer and other diseases is chemotherapy which has limited effectiveness due to some serious life-threatening side effects (like fatigue, irritation of oesophagus that can cause difficuty in swallowing and inflammation of lungs). It may also cause vomiting, neutropenia, anemia, another infectious complications and development of drug resistance cancerous cells.[24] The side effects of the anticancer drugs not only prevent effective chemotherapy, but also compromise the quality of life of the patients.[25] One effective solution of the problem mentioned above can be using natural products like algae as anticancer agents.[26] Different types of macro and micro marine algal extracts have been experimentally proved to reduce or to destroy the effectiveness of cancer.

The dietary intake of seaweed has been implicated as a potential protective agent in the aetiology of breast cancer.[27] The brown algae *Fucus* sp. has shown activity against both colorectal and breast cancers. An anticancer effect of different seaweeds on human colon and breast cancers has been well documented by Ghislain et al.[28] In ancient times, Chinese used *Laminaria* sp. in the treatment of cancer and it has also been recorded in ancient ayurvedic texts.[29] Cryptophycin from *Nostoc* species acts as a microtubule depolymerizing agent. The compounds and its analogues are very effective against solid tumours.[30] Isorawsonol has been isolated from the tropical green alga *Arrainvills rawsonii* which shows anticancer and immunosuppressive properties by inhibiting IMPDH.[31] The novel compounds cytochalasans, penochalasins A,B,C and chaetoglobosin O were isolated from a strain of *Penicillium* species. They exhibited potent cytotoxic activity against cultured P388 cells.[32]

The cyclic depsipeptide Kahalalide F isolated from the green alga *Bryopsis* sp. was introduced into Phase I trials as a lead compound against prostate cancer.[33] A linear cytotoxic diterpene bifurcadiol was isolated from the brown alga *Bifurcaria bifurcarta* by Guardia et. al which exhibit cytotoxicity against human tumour cell lines (A-549, SK-OV-3, SKL-2, XF 498 and HCT).[34] Leptosins have been isolated from the mycelium of a strain of *Leptsphaeria* species attached to marine alga *Sargassum tortile* which showed potent cytotoxicity against cultured P388 cells.[35] Four diterpene with xenicane and norxenicane have been isolated from species of *Dityota dichotoma* from Okinawa Island which showed anti-tumour activity.[36] Stypolactone, a diterpenoid of mixed biogenesis has been isolated from the brown alga *Stypopdium zonale* and showed weak cytotoxic activity *in vitro* against the A-549 and H-116 cell lines.[37] Sterols B isolated from *Stypopdium caryophyllum* exhibited cytotoxic activity against several cultured cancer cell lines.[38]

Brown alga *Perithalia capillaris* yielded new bis-prenylated quinones which are inhibitors of superoxide production in human neutrophils *in vitro* and of proliferation of HL-60 cells.[39] Halmon is a polyhalogenated monoterpene isolated from the red alga *Poriteirra hornemanii* & is considered as a novel *in vitro* antitumour

agent.[40] The Laurinterol was isolated from *Laurecia okamurai* which is used in the prevention and inhibiton of melanoma. It can effectively inhibit the growth of melanoma cells by inducing apoptosis therein without adverse effect as in synthetic medicines.[41] Furoplocamioid, perfuroplocamioid, pirene and tetrachlorinated cyclohexane from the red alga *Plocumium cartilagineum* exhibited selective cytotoxicity against human tumour cell lines with pirene showing a specific and irreversible effect on SW480 cells.[42]

4. ANTIBACTERIAL ACTIVITY

Bacterial resistance towards antibiotics has been the main factor responsible for the increase of morbidity, mortality and health care costs of bacterial infections. The defense mechanism against antibiotics is widely present in bacteria (e.g.: *Pseudomonas, Klebsiella, Enterobacter, Acinetobacter, Salmonella, Staphylococcus, Enterococcus and Streptococcus*) and became a worldwide concern. So there is rising interest of researchers for natural products for the discovery of new antimicrobial and antioxidant agents in the last three decades. Secondary metabolites with antibacterial activity are widely produced by cyanobacteria.[43]

Wei et al.[44] reported that low molecular weight phlorotannins extracted from *Sargassum thunbergii* damaged the cell membrane and cell wall of *Vibrio parahaemolyticus*, causing cytoplasm leakage and deconstruction of membrane permeability. The study suggested that low molecular weight phlorotannins from algae could potentially be used in food safety control and aquacultural drugs. Lee et al.[45] tested a range of solvent extracts from the brown seaweed, Arame *(Eisenia bicyclis)* against antibiotic resistant *Propionibacterium*-related acne. A phlorofucofuroeckol compound (phlorotannin with an alcohol substituent) exhibited the most potent antibacterial activity with an MIC of 32 μg/mL, while also significantly reversing the resistance of *Propionibacterium* to erythromycin and lincomycin.

Cermák et al.[46] reported the antibacterial long-chain fatty acids in the green microalga *Planktochlorella nurekis* to be significant inhibitors of *Campylobacter jejuni, Escherichia coli, Salmonella enterica* var. *Enteritidis, Salmonella enterica* var. *Infantis, Arcobacter butzleri,* and *Lactobacillus johnsonii* using a suspension concentration range of 0.75–6 mg/mL. Polysaccharides, such as fucoidan and laminarin, have been successfully used in drug delivery as oral antibiotics to inhibit the growth of *Staphylococcus aureus* and *Escherichia coli;* and to prevent the adhesion of *Helicobacter pylori* biofilms in gastric mucosa. Kadam et al. reported a significant inhibition of *Staphylococcus aureus, Listeria monocytogenes, Escherichia coli* and *Salmonella typhimurium* growth with ultrasound assisted extraction of laminarin from the Irish brown seaweeds *Ascophyllum nodosum* and *Laminaria hyperborea* using 0.1M hydrochloric acid.[47] Abou Zeid et al.[48] demonstrated that hot and cold water-extracted polysaccharides from the red seaweed *Pterocladia capillacea* and brown seaweed *Dictyopteris membranacea* inhibit the growth of Gram-positive *Bacillus*

cereus and *Staphylococcus aureus*, and Gram-negative *Pseudomonas fluorescens* and *Escherichia coli* in disc diffusion assays.

Holanda et al.[49] evaluated the inhibitory effect of lectin extracts from the red alga *Solieria filiformis* against Gram-negative and Gram-positive pathogenic bacteria. At a concentration of 1000 µg/mL, the extract inhibited growth of the Gram-negative species *Pseudomonas aeruginosa, Enterobacter aerogenes, Serratia marcescens, Salmonella typhi, Klebsiella pneumoniae,* and *Proteus species*. Lane et al.[50] extracted bromophycolides (diterpene-benzoate macrolides) from the Fijian red alga *Callophycus serratus* with water, methanol, and dichloromethane. Extracts significantly inhibited MRSA and vancomycin-resistant *Enterococcus faecium*, with maximal inhibitory concentration (IC50) values of 1.4 µM and 5.8 µM respectively.

5. ANTIFUNGAL ACTIVITY

Fungi, as a major disease causing agent, were realized after 1980, especially among the immunocompromised and other serious diseases.[51] There are limitations with regards to antifungal drugs because of their price and side effects.[52] So, the researchers are exploring biodiversity for search of new lead compounds with minimum or no toxicity. In this regard the marine algae came out to be a novel organism.[53]

Cyclic depsipeptide Lyngbyabellin B was isolated from *L. majuscula* which show toxicity against brine shrimp and fungus *Candida albicans*.[54] Studies done by Vijayakumar Madhumathi et. al. also revealed antifungal activity of various strains of cyanobacteria. It was found that acetone extract of *Phormidium corium*, methanol extract of *Lyngbya martensiana* and diethyl ether extract of *Microcystis aeruginosa* have antifungal activity. In addition, *Oscillatoria latevirens, Chrococcus minor* and *Microcystitis aeroginosa* were also found to have antifungal activity on *Candida albicans*.[55] Other authors also reported that methanolic crude extract of *Aphanothece bullosacrude* was found more potent antifungal in comparision to *Lyngbya aestuarii*.[56]

6. ANTIVIRAL ACTIVITY

Vaccines are very successful in controlling many viral diseases, yet some diseases are not controlled by vaccination. Some synthetic antiviral compounds developed for treatment of active herpetic infections, were not effective for the treatment of latent infections.[57] It reported on severe side effects and development of some resistant mutations of this virus, especially during long term medication with antiviral drugs.[58] All

marine algae seem to have antiviral sulfated polysaccharides. Carrageenans, fucoidans and sulfated rhamnogalactans have substantial antiviral activity against enveloped viruses, such as herpes and HIV. These compounds obstruct the entry of viruses into cells, although other algal fractions have virucidal and enzyme inhibitory activities, or can slow down syncytium formation.[59]

Halitunal isolated from the marine alga *Halimeda tuna* shows antiviral activity against murine coronavirus A 59 *in vitro*.[60] In 1992, Garg et. al isolated the antiviral derivative, sphingosin which demonstrated antiviral activity *in vivo* protection against Semeliki forest virus (SFV). This compound was isolated from Indian green alga *Ulva fasciata*.[61] The dollabelladiene derivatives isolated from the brown alga *Dictyota pfaffi* showed strong anti-HSV-1 activity *in vitro* but little inhibiton of HIV-1 reverse transcriptase.[62] The diterpenes from the brown alga *D. mentrualis* exhibited antiretroviral activity *in vitro*.[63] The phlorotannin derivatives 8,8'-bieckol and 8,4''-bieckol from the brown alga *Ecklonia cava*, are inhibitors of HIV-1 reverse transcriptase (RT) and protease. Both compounds inhibited the RT more potently than the protease and the inhibitor activity of 8,8'-bieckol against HIV-1 was comparable to that of a reference compound Nevirapine.[64]

The sulfoquinovosyldiacylglycerol has been isolated from the marine red algae *Gigartina tenella* as a potent inhibitor of eukaryotic DNA and HIV-1 reverse transcriptase type-1.[65] The sulfoquinovosyldiacylglycerol was also isolated from the marine brown alga *Ishige okamurai* which displayed selective antiviral activity against *Herpes simplex* virus 2 (HSV-2).[66] Venustatriol , thyrsiferol and thyrsiferyl 23-acetate were isolated from the red alga *Laurencia venusta* and all displayed significant antiviral activity against *Vesicular stomatitis* virus (VSV) and *Herpes simples* virus type 1 (HSV-1).[67] The sesquiterpene hydroquinone peyssonol A and B have been isolated from the active anti-HIV RTs extracts red sea alga *Peyssonnelia species* for anti HIV RTs activities (reverse transcriptases of human immunodeficiency virus).[68]

7. ANTIDIABETIC ACTIVITY

Diabetes mellitus is one of the common metabolic disorders with micro-and macrovascular complications that results in significant morbidity and mortality. It is considered as one of the five leading causes of death in the world. In modern medicine no satisfactory effective therapy is still available to cure diabetes mellitus. Hence, there is increasing demand by patients to use natural products with antidiabetic activity due to side effects associated with the use of insulin and oral hypoglycemic agents.[69] The marine algae could be of better use in this case.

Aqueous extract of *Ulva fasciata* has shown a good remarkable difference while treated against diabetic rats as compared to other standard medicine. Abirami, 2013 experimented over a 28 day of oral treatment against

infected rats and found a significant decrease in blood glucose and glycosylated hemoglobin while pretreatment with aqueous extract of *Ulva fasciata*.[70] *In vivo* testing fucosterol which was isolated from the brown alga *Pelvetia siliquosa* demonstrated that it is the main antidiabetic principle from *Pelvetia siliquosa*.[71] Hydroxyisoavrainvilleol was originally isolated from the tropical green alga *Avrainvillea nigrican* but now has been isolated from red alga *Polysiphonia urceolata* as a protein tyrosine phosphatase 1B inhibitor which is useful as an antidiabetic agent.[72] A vanillic acid biphenyl derivative and the sulfate adduct were isolated from the Australian green alga *Cladophora socialis* as a protein tyrosine phosphatase 1B inhibitors.[73] The bromophenols isolated from the red alga *Symphocladia latiuscula* have significant aldose reductase inhibitory activity.[74]

8. INSECTICIDAL ACTIVITY

Chemical pesticides play a significant role in increasing the agricultural production and also in the protection of crops from damage caused by insect pests. But only 0.1% of the agrochemical used in crop protection reach the target pests and the remaining 99.9% enter into the environment causing severe adverse effects on human beings, domestic animals and wild animals. Botanical insecticides are ecofriendly and environmentally safer alternative methods for crop protection. Marine algae have been shown to have insecticidal activities.[75]

The insecticidal and acaricidal polyhalogentaed monoterpenes have been isolated from Chilean specimens of the red alga *Plocamium catilagineum*. The insecticidal activity of these compounds proved to be effective against the Aster leafhopper.[76] Laurepinacine and isolaurepinnacin are acetylinic sesquiterpene ethers isolated from the red alga *Laurancia pinnata* that demonstrated insecticidal activity.[77] (Z)-Laureatin, (Z)-isolaureatin and deoxyprepacifenol are other related compounds from the red alga *Laurencia nipponica*. They show strong insecticidal activity against the mosquito larvae *Culex pipens pallens*.[78] Telfairine is another related monoterpene reported from the red alga *Plocamium telfairia*, with strong insecticidal activity against the mosquito larvae *Culex pipens pallens*.[79]

The new insecticidal amino acids namely, isodominic acid A, isodomic acid B and isodomic acid C were isolated from the red alga *Chondria arnata.* They show significant insecticidal activity when they are injected subcutaneously into the abdomen of American cockroach.[80] *Laurencia obtuse*, collected from off Symi Island in the Greece, Aegean Sea was the source of C_{15} acetogenins 13-epilaurencienyne (3Z), 13-epinnatifidenyne (3E) and two diaceto-xypentadec-3-en-1-yne derivatives. The first two compounds exhibited strong toxicity against ants with considerable knockdown effect from the first day, while latter two compounds exhibited gradual toxicity that was escalated at the fourth day with >70% mortality.[81]

9. IN COSMETICS

Algotherapy is a science in which, seaweed extracts are used in health or beauty treatments. Seaweed baths were a widespread feature of seaside resorts at the end of the 19th and beginning of 20th century in several southern and western locations and considered as a treatment for arthritis, rheumatism and other aches and pains. A number of compounds extracted from seaweeds are thought to be of value in various cosmetic applications and some are now becoming commercially important.[82]

Chlorella and *Arthrospira (Spirulina)* are used in skin care, sun protection and hair care products.[83] There is a vast possibility that discovery of new metabolites from micro algae is very likely. There is therefore also potential for the discovery and production of high value compounds. As it is rich in vitamins and minerals, algae conditions and hydrates the skin while it nourishes, rejuvenates, detoxifies and replenishes minerals. In cosmetics, algae act as thickening agents, water-binding agents, and antioxidants.[84]

Novel marine terpenoids show great promise as a source for new antioxidant agents in cosmetic preparations,[85] due to their good penetration-enhancing abilities, low systemic toxicity and low irritation. Fucosterol is a steroidal terpenoid extracted from Phaeophyta marine algae *(Ecklonia stolonifera, Pelvetia siliquosa, Sargassum carpophyllum).*[86] This compound shows strong antioxidant activity by increasing the concentration of antioxidant enzymes Superoxide Dismutase (SOD), catalase and glutathione peroxidase (GSH-px), enzymes that are involved in the fine control of cellular H_2O_2 concentration. Fucosterol can help in cellular defense mechanisms by preventing cell membrane oxidation as it has an important role in scavenging hydrogen peroxide and restoring SOD activity.[87]

Carotenoids are a diverse class of naturally occurring tetraterpenoid molecules that are synthesized by plants, bacteria, fungi and algae. They have been found to have a defensive role in the protection of cells and tissues from oxidative stress.[88] Some carotenoids function as direct quenchers of reactive oxygen species.[89] Studies involving hairless mice given topical applications of d-α-tocopherol showed a decrease in edema, erythema and skin sensitivity, whereas pre-treatment with 5% tocopherol before UVB exposure demonstrated a 75% decrease in the severity of skin wrinkling and a significant decrease in the formation of skin tumours. Vitamin C should be included in formulations containing vitamin E, not only for its contributing effect but also to stabilise vitamin E within the formulation against UVA irradiation.[90]

10. BIOREMEDIATION

In this present scenario industrial revolution has harmed our environment to much extent. Effluents released have contaminated water bodies and causing several serious health problems. Water bodies receiving the effluent show high BOD, COD and chloride levels that are well above the stipulated concentrations prescribed by the Indian Standard Institute (ISI). So there is a need to remove all these pollutants from our water bodies. There are several approaches for remediating pollutants, among those is "Bioremediation". Bioremediation is gaining importance as a less expensive alternative to physical and chemical means of decomposing organic pollutants.[91]

Both marine and freshwater species of cyanobacteria have been found to be useful in bioremediation. Blue green algae have been shown to be highly effective as accumulators and degraders of different kinds of environmental pollutants, including pesticides, crude oil, naphthalene, phenanthrene, phenol and catechol, and xenobiotics.[92] Worldwide, cyanobacteria have been used efficiently as a low-cost method for remediating dairy wastewater by converting the dissolved nutrients into biomass.[93] The studies conducted by various researcher show biodegradation and biosorption capacity of some potential cyanobacterial species: *Oscillatoria* sp., *Synechococcus* sp., *Nodularia* sp., *Nostoc* sp. and *Cyanothece* sp. dominated the effluents. Some author also reported natural ability of two filamentous cyanobacteria *Anabaena* sp. and *N. ellipsosporum* degrade a highly chlorinated aliphatic pesticide, lindane (g-hexachlorocyclohexane) and this ability can be enhanced by genetic engineering.[94]

Algal biomass is an inexpensive biomaterial for removal of toxic heavy metals. The use of micro algae for removal of heavy metals from waste water have huge application.[95] Blue green algae could serve as effective biosorbant for removing heavy metals from contaminated waters.[96] Chromium is a heavy metal and its toxicity can cause serious carcinogenic, genotoxic and immunotoxic effects in humans and animals. Conventional methods used for the removal of hexavalent Cr use chemical procedures, which are expensive and lack specificity. So an alternative method was proposed by Kannan V et al. for the removal of chromium present in tannery effluent. Filamentous Cyanobacteria *Anabaena flos-aquae* was found to grow in effluent at various dilutions.[97]

Heavy metal nickel (Ni) released into the environment over a long period of time through various anthropogenic activities like burning of fossil fuels and residual oils, coal mine spoils, sewage sludge, production of Ni-Cd batteries exhibit toxic effect on biota.[98] Remediation of nickel (Ni) by *Anabaena doliolum* has been suggested by M.K. Shukla et al.[99] In several other studies it was found that cultures of *Oscillatoria* sp. BDU 30501, *Aphanocapsa* sp. BDU 16 and a halophilic bacterium *Halobacterium* US 101 were used to treat a factory effluent and resulted in reduction of calcium and chloride to levels that did not inhibit survival and multiplication of fish.[100] Further in an study conducted by Slotton et al.[101] it was found

that *Spirulina platensis*, a cyanobacterium contained detectable levels of mercury and lead when grown under contaminated conditions implying that this cyanobacterium was taking up the toxic metal ions from its environment.

11. FOOD SUPPLEMENT

Seaweeds are used in many maritime countries, particularly in Asia, Japan, Korea and China as a source of food, industrial applications and for fertilizer. Some seaweed has an excellent dietary content, mainly protein, some carbohydrate, vitamins A, B, B_2 and C & besides these, a lot of trace elements and minerals, the most prominent of which is iodine. An additional advantage is that it is low in calories and very suitable for vegetarians of all kinds.[102] Omega-3 fatty acid extracted from algae are used as economical food supplement.[103]

Some red algae, brown algae and green algae, are eaten by humans. Approximately 500 species are eaten by humans, and some 160 are commercially important. The red alga *Porphyra* is the most important commercial food alga.[104] *Palmaria palmata*, another red alga, is eaten in the North Atlantic region.[105] *Laminaria* species (brown algae) is eaten with meat or fish and in soups. The green algae *Monostroma* and *Ulva* look like lettuce leaves (their common name is sea lettuce), and they are eaten as salads or in soups, relishes, and meat or fish dishes.[106] Seaweeds like *Ulva* sp., *Enteromorpha* sp., *Caulerpa* sp., *Codium* sp., *Monostroma* sp., *Sargassum* sp., *Hydroclathrus* sp., *Laminaria* sp., *Undaria* sp., *Macrocystis* sp., *Porphyra* sp., *Gracilaria* sp., *Eucheuma* sp., *Laurencia* sp. and *Acanthophora* sp. are used in the preparation of soup, salad and curry. Some of the seaweeds are also taken in dried form.[102]

12. FOOD ADDITIVES

The cell walls of many types of seaweed contain phycocolloids that have received increasing use in prepared foods. The three major phycocolloids are alginates, agars, and carrageenans.

i) Alginates, or alginic acids, are commercially extracted from brown seaweeds, especially the kelp *Macrocystis*, *Laminaria*, and *Ascophyllum*. Alginates are used in ice creams to limit ice crystal formation, thereby producing a smooth texture, and are also used as emulsifiers and thickeners in syrups and as fillers in candy bars and salad dressings.[107]

ii) Agars are extracted primarily from species of the red alga *Gelidium*, but they are also obtained from other red algae, especially *Gracilaria, Pterocladia, Acanthopeltis,* and *Ahnfeltia*. Agars are used in instant pie fillings, canned meats or fish, and bakery icings. Agar is also used as a clarifying agent in beer and wine.[108]

iii) Carrageenan, from the Irish word "carraigin" (meaning Irish moss), are extracted from various red algae: *Eucheuma* in the Philippines, *Chondrus crispus* in the United States and the Canadian Maritime Provinces, and *Iridaea* in Chile. Carrageenans are used as thickening and stabilizing agents in dairy products, imitation creams, puddings, syrups, and canned pet foods.[109]

13. BIOFUEL

Biodiesel can be produced from algae oils from both macroalgae and microalgae.[110] Lipids, carotenoids, pigments, vitamins and aromatic compounds are found in cyanobacteria. Lipids (accumulated in the thylakoid membranes) are associated with high levels of photosynthesis and rapid growth rate and are of particular interest, since they can be used as lipid feedstock for biodiesel production.[111] Microalgae accumulate large amounts of lipids as reserve material, but only in conditions of stress and slow growth.[112] The cyanobacteria have a natural advantage to produce lipids in high-speed growth. The presence of double bonds in the fatty acids (FAs) from cyanobacterial lipids is related to their morphological complexity.[113] *Synechococcus* sp. PCC7942, *M. aeruginosa* NPCD-1 and *Trichormus* sp. CENA77 had the best set of properties to be used as a feedstock source in the synthesis of biodiesel. They showed appropriate values of biomass and lipid productivity, as well as FA profiles similar to the oil seeds already used successfully in the synthesis of biodiesel.[114]

In a study it was found that *Chlorella protothecoides,* and *Cladophora fracta* can be used for biodiesel production.[110] The microalgal biodiesel can be used in place of traditional diesel fuel, it can reduce carbon dioxide upto 78%.[115] Algal biodiesel is easy in transportation, it's use can reduce green house gas emission up to 40%. Through a review it has been concluded that algal biodiesel has the potential to replace petroleum biodiesel fuel.[116]

14. BIOFERTILISER

Biofertilizer has gained much importance in recent years and play vital role in maintaining long term soil fertility and sustainability by fixing atmospheric dinitrogen (N=N), mobilizing fixed macro and micro nutrients or convert insoluble phosphorus in the soil into forms available to plants, thereby increases their efficiency and availability. It has been observed that by applying biofertilizers, crop production can be enhanced by 20-30% if are used properly.[92] The microorganisms (*Azotobacter*, Blue green algae, *Rhizobium*, *Azospirillum*) in biofertilizer are the major component promoting the adequate supply of nutrients to the host

plants and ensuring their proper development and regulation in their physiology. Biofertilizer can also protect plants from soil borne diseases to a certain degree. Cyanobacteria play an important role to retain soil fertility by consequently increasing the yield by converting atmospheric nitrogen into an available form of ammonium. Dominant nitrogen-fixer blue-green algae are *Anabaena, Nostoc, Aulosira, Calothrix, Plectonema* etc.[117] The activities of algae include:

(1) Increase in soil pores with having filamentous structure and production of adhesive substances.
(2) Excretion of growth promoting substances such as hormones (auxin, gibberellin), vitamins, amino acids.[118]
(3) Increase in water holding capacity through their jelly structure.
(4) Increase in soil biomass after their death and decomposition.[119]

Seaweeds have been used as agricultural fertilizers for centuries in many parts of the world.[120] In common; seaweed has sufficient amount of micronutrients, growth promoting hormones, potassium, nitrogen and humic acids. Presence of such materials in seaweed makes them as excellent fertilizer. Species of *Laminaria, Ascophyllum, Sargassum* are used as an organic manure and are biodegradable, non-toxic, non-polluting and non-hazardous to human, animals and birds. Besides this, it increases the soil fertility and has good moisture holding capacity.[121]

15. INDUSTRIAL USES

Koch (1882), formally announced the use of agar, extracted from seaweeds, as a new solid medium for microorganisms following his experiments on *Mycobacterium tuberculosis*. It is still the medium of choice for general microbial growth and identification.[122] Major seaweeds genera which are being involved for the production of agar includes; *Ahnfeltiopsis, Gelidium, Gelidiella, Gracilaria, Pterocladiella and Pterocladia.*

Agar has been produced by most of the countries including Argentina, Canada, Chile, China, France, India, Indonesia, Japan, Madagascar, Mexico, Morocco, Namibia, New Zealand, Peru, Portugal, Russia, South Africa, Spain, Thailand, and the USA. No modern microbiological laboratory in the world can survive without agar, and no reasonable alternative has been found even in with today's technological advances.[123] The highest quality of agar and its derivative called agarose comes from red algae belonging to family *Gelidiaceae* while other lower-quality agars are mainly found in other families, particularly the *Gracilariaceae*.[124] Agarose, because of its higher degree of purity and consistency, is being used increasingly by scientists for critical cultures and gel documentation studies.[125]

CONCLUSION

This review article involved a thorough study of the marine alga from different literatures across the globe. The marine environment is a home to an immense taxonomic diversity that has remained relatively unexplored in drug discovery. The marine alga are chief resources of essential vitamins, trace elements, proteins, lipids, polysaccharides, enzymes and minerals. Medicinal plants and seaweeds available in the marine environment is the ideal place for the discovery of novel molecules with various biological activities such as antibacterial, anticancer, antifungal, antidiarrhoeal, analgesics, antidiabetic, anti-inflammatory and antioxidant activities, etc. as demonstrated by a number of studies. These herbal plants and their products can be used to cure different diseases as it has no side effect as compared to allopathic drugs.

Most of the work has been done on marine alga with special reference to its nutritive value, medicinal property, pharmaceutical, pharmacological and industrial uses. Nowadays, algae has been exploited as a source of bioremediation and biofuel. The algae can be used to solve the problems of food crisis and malnutrition. But regular uptake of seaweed may not be safe as it could be contaminated by heavy metals. The cultivation of algae population with so many benefits needs to be promoted and improved using modern techniques since it acts as an ideal and cost effective substitute. This is an attempt to provide information in the field of science and awareness for a common man about such a great noble resource. The main objective of writing this review is to provide information related to uses and applications of the marine alga in the past, present as well as in the future scenario.

ACKNOWLEDGMENT

I would like to acknowledge the almighty God for guiding me throughout my life journey and my parents and my guide for their kind support and encouragement.

CONFLICT OF INTEREST

Declared none

REFERENCES

1. Shannon E, Ghannam NA. 2016. Antibacterial derivatives of marine alga: an overview of pharmacological mechanisms and applications. Mar Drugs, 14(81):1-23.
2. Gamal AA. 2010. Biological importance of marine algae. Saudi Pharm J,18:1-25.
3. Kharkwal H, Joshi DD, Panthari P, Pant MK, Kharkwal AC. 2012. Algae as future drugs. Asian J Pharm Clin Res, 5(4):1-4.
4. Pooja S. 2014. Algae used as medicine and food-a short review. J Pharm Sci & Res, 6(1):33-5.
5. Sharma N, Tyagi N, Kumar SS. 2017. *Gelidiella acerosa*: A précis. Int Res J Pharm, 8(4):20-3.

6. Cardozo KH, Guaratini T, Barros MP, Falcao VR, Tonon AP, Lopes NP, et al. 2007. Metabolites from algae with economical impact. Comparative Biochemistry and Physiology, Part C 146, 60-78.
7. Wu XJ, Hansen C. 2008. Antioxidant capacity, phenolic content, polysaccharide content of *Lentinus edodes* grown in Whey permeate-based submerged culture. J Food Sci, 73:M1-M8.
8. Richardson JS. 1993. Free radicals in the genesis of Alzheimers disease. Annals of the New York Academy of Sciences, 695:73-6.
9. Plaza M, Cifuentes A, Ibanez E. 2008. In the search of new functional food ingredients from algae. Trends in Food Science & Technology, 19(1):31-9.
10. Kang HS, Chang HY, Jung JH, Son BW, Choi JS. 2003. A new phlorotannin from the brown alga *Ecklonia stolonifera*. Chem Pharm Bull, 51:1012-4.
11. Iwashima M, Mori J, Ting X, Matsunaga T, Hayashi K, Shinoda D, et al. 2005. Antioxidant and antiviral activities of plastoquinones from the brown alga *Sargassum micracanthum*, and a new chromene derivative converted from the plastoquinones. Biol Pharm Bull, 28:374-7.
12. Nahas R, Abatis D, Anagnostopoulou MA, Kefalas P, Vagias C, Roussins V. 2007. Radical scavenging activity of Aegean Sea marine alga. Food Chem, 102:577-81.
13. Choi JS, Park HJ, Jung HA, Chung HY, Jung JH, Choi WC. 2000. A cyclohexanonyl bromophenol from the red alga *Symphocladia latiuscula.* J Nat Prod, 63:1705-6.
14. Li K, Li XM, Ji NY, Wang BG. 2007. Natural bromophenols from the marine red alga *Polysiphonia urceolata* (Rhodomelaceae): structural elucidation and DPPH radical-scavenging activity. Bioorg Med Chem, 15:6627-31.
15. Mariya V, Ravindran VS. 2013. Biomedical and pharmacological significance of marine macro algae-review. Ind J Geo Mar Sci, 42(5):527-37.
16. Mohan H. 2010. Textbook of Pathology. 6th ed. New Delhi: Jaypee Brothers, 130 p.
17. Jones MR, Quinton LJ, Simms BT, Lupa MM, Kogan MS, Mizgerd JP. 2006. Roles of interleukin-6 in activation of STAT proteins and recruitment of neutrophils during *Escherichia coli* pneumonia. J Infect Dis, 193:360-9.
18. Kaboli PJ, Doebbeling BN, Saag KG, Rosenthal GE. 2001. Use of complementary and alternative medicine by older patients with arthritis; a population based study. Arthritis Rheum, 45:398-403.
19. Awad NE. 2000. Biologically active steroid from the green alga *Ulva lactuea*. Phytother Res, 14:641-3.
20. Jiang ZD, Jensen PR, Fenical W. 1999. Lobophorins A and B, new anti-inflammatory macrolides produced by a tropical marine bacterium. Bio Med Chem Lett, 9:2003-6.
21. Tziveleka LA, Abatis D, Paulus K, Bauer R, Vigias C, Roussis V. 2005. Marine polyprenylated hydroquinones, quinones and chromenols with inhibitory effects on leukotriene formation. Chem Biol, 2:901-9.

22. Tan LT, Williamson RT, Gerwick WH, Watts KH, McGough K, Jacobs R. 2000. *Cis*, *cis* and *trans*, *trans*-ceratospongamide, new bioactive cyclic heptapeptides from the Indonesian red alga *Ceratodictyon spongiosum* and symbiotic sponge *Sigmadocia symbiotica.* J Org Chem, 65:419-25.
23. Weimer DE, Idler DD, Fenical W. 1991. Vidalols A and B, new anti-inflammatory bromophenols from the Caribbean marine red alga *Vidalia obtusaloba*. Experientia, 47:851-3.
24. Mishima T, Murata J, Toyoshima M, et al. 1998. Inhibition of tumor invasion and metastasis by calcium spirulan (Ca-SP), a novel sulfated polysaccharide derived from a blue-green alga, *Spirulina platensis*. Clin Exp Metastasis, 16(6):541–50.
25. Chen T, Wong YS. 2008. *In vitro* antioxidant and antiproliferative activities of selenium-containing phycocyanin from selenium-enriched *Spirulina platensis*. J Agric Food Chem, 25(12):4352–8.
26. Henry JB. 1996. Clinical diagnosis and management by laboratory methods. Philadelphia: W.B Saunders Co.
27. Teas J. 1981. The consumption of seaweed as a protective factor in the aetiology of breast cancer. Med Hypothesis, 7:601-3.
28. Ghislain M, Kwak DH, Brice WO, Maranguy CA, Sylvatrie DB, Lee DH, et al. 2014. Anticancer effects of different seaweeds on human colon and breast cancers. Mar Drugs, 12:4898-911.
29. Loeser AA. 1956. Hormones and breast cancer. Letters to the editor, Lancet ii, 961 p.
30. Smith CD, Zhang X, Moobery SL, Patterson GM, Moore RE. 1994. Cryptophycin, a new microtubule depolymerizing agent from Cyanobacteria. Cancer Res, 54:3779-84.
31. Chen IL, Gerwick WH, Schatzman R, Laney M. 1994. Isorawsonol and related IMO dehydrogenase inhibitors from the tropical alga *Avrainvillea rawsoni*. J Nat Prod, 57:947-52.
32. Iwamoto C, Yamada T, Ito Y, Minoura K, Numata A. 2001. Cytotoxic cytochalasans from a *Penicillium* species separated from a marine alga. Tetrahedron, 57:2904-97.
33. Hamann MT, Scheuer PJ. Kahalide F. 1993. A bioactive depsipeptide from the sacoglossan mollusk *Elysia rufescens* and the green alga *Bryopsis* sp. J Am Chem Soc, 115:5825-6.
34. Guardia SD, Valls R, Mesguiche V, Brunei JM, Gulioli G. 1999. Enantioselective synthesis of (-)-bifuracadiol: a natural antitumour marine product. Tetrahedron Lett, 40:8359-60.
35. Takahashi C, Numata A, Ito Y, Matsumura E, Araki H, Iwaki H, et al. 1994a. Leptosins, antitumour metabolites of a fungus isolated from a marine alga. J Chem Soc Perkin Trans, 113:1859.
36. Sheu JH, Wang GH, Sung PJ, Duh CY. 1999. New cytotoxic oxygenated fucosterols from the brown alga *Turbinaria conoides*. J Nat Prod, 62:224-7.
37. Dorta E, Cueto M, Diaz-Marrero AR, Darias J. 2002a. Stypolactone an interesting diterpenoid from the brown alga *Stypopodium zonale.* Tetrahedron Lett, 65:9043-6.
38. Tang HF, Yi YH, Yao XS, Xu QZ, Zhang SY, Lin HW. 2002a. Bioactive steroids from the brown alga *Sargassum carpophyllum*. J Asian Nat Prod Res, 4:95-101.

39. Blackman AJ, Dragar C, Wells RJ. 1979. A new phenol from the brown alga *Perithalia caudate* containing a "reverse" isoprene unit at the 4-position. J Aust J Chem, 32:2783-6.
40. Fuller RW, Cardellina JH, Kato Y, Brinen LS, Clardy J, Sander KM, et al. 1992. A pentahalogenated monoterpene from the red alga *Poritieria hornemannii* produced a novel cytotoxicity profile against a diverse panel of human tumour cell. J Med Chem, 35:3007-11.
41. Moon-Moo K, Sang Hoon L, Se-Kwon K. 2009. Patent from PCT Int. Appl., WO 2009048195 A1 20090416. Language: English, Database: CAPLUS.
42. De Ines C, Argandona VH, Rivirosa J, San-Martin A, Diaz-Marrero AR, Cueto M, et al. 2004. Cytotoxic activity of halogenated monoterpenes from *Plocamium cartilagineum*. Z Naturforsch C Biosci, 59:339-4.
43. Burja AM, Banaigs B, Abou-Mansour E, Burgess JG, Wright PC. 2001. Marine cyanobacteria- a prolific source of natural products. Tetrahedron, 57:9347-77.
44. Wei Y, Liu Q, Xu C, Yu J, Zhao L, Guo Q. 2015. Damage to the membrane permeability and cell death of *Vibrio parahaemolyticus* caused by phlorotannins with low molecular weight from *Sargassum thunbergii*. J Aquat Food Prod Technol, 25:37-44.
45. Lee JH, Eom SH, Lee EH, Jung YJ, Kim HJ, Jo MR, et al. 2014. *In vitro* antibacterial and synergistic effect of phlorotannins isolated from edible brown seaweed *Eisenia bicyclis* against acne-related bacteria. Algae, 29:47–55.
46. Cermák L, Pražáková Š, Marounek M, Skrˇivan M, Skrˇivanová E. 2015. Effect of green alga *Planktochlorella nurekis* on selected bacteria revealed antibacterial activity *in vitro*. Czech J Anim Sci, 60:427–35.
47. Kadam S.U, O'Donnell CP, Rai DK, Hossain MB, Burgess CM, Walsh D, et al. 2015. Laminarin from Irish brown seaweeds *Ascophyllum nodosum* and *Laminaria hyperborea:* Ultrasound assisted extraction, characterization and bioactivity. Mar Drugs, 13:4270–80.
48. Abou Zeid AH, Aboutabl EA, Sleem AA, El-Rafie HM. 2014. Water soluble polysaccharides extracted from *Pterocladia capillacea* and *Dictyopteris membranacea* and their biological activities. Carbohydr Polym, 113:62–6.
49. Holanda ML, Melo VM, Silva LM, Amorim RC, Pereira MG, Benevides NM. 2005. Differential activity of a lectin from *Solieria filiformis* against human pathogenic bacteria. Braz J Med Bio. Res, 38:1769–73.
50. Lane AL, Stout EP, Lin AS, Prudhomme J, le Roch K, Fairchild CR, et al. 2009. Antimalarial bromophycolides J-Q from the Fijian red alga *Callophycus serratus*. J Org Chem, 74:2736–42.
51. Jaki B, Orjala J, and Sticher O. 1999. A novel extracellular diterpenoid with antibacterial activity from the cyanobacterium *Nostoc.* Comm J Nat Prod, 62:502–3.

52. Bui TN, Jansen R, Pham TL, Mundt S. 2007. Carbamidocyclophanes A-E, chlorinated paracyclophanes with cytotoxic and antibiotic activity from the vietnamese cyanobacterium *Nostoc* sp. J Nat Prod, 70:499–503.
53. Pfaller MA, Diekema DJ. 2007. Epidemiology of invasive candidiasis: a persistent public health problem (Review). Clin Microbiol, 20:133-63.
54. Pfaller MA, Diekema DJ, Gibbs DL, Newell VA, Ellis D, Tullio V, et al. 2010. Results from the ARTEMIS DISK global antifungal surveillance study, 1997 to 2007: a 10.5-year analysis of susceptibilities of *Candida* species to fluconazole and voriconazole as determined by CLSI standardized disk diffusion testing. J Clin Microbiol, 6:1366-77.
55. Moore RE, Patterson GML, Carmichael WW. 1988. New pharmaceuticals from cultures blue-green algae in biomedical importance of marine organisms ed. Fauntin D.G.. Memoires Californian Academy of Science, San Francisco: Californian Academy of Science, 13:143–50.
56. Milligan KE, Marquez BL, Williamson RT, Gerwick WH. 2000. Lyngbyabellin B, a toxic and antifungal secondary metabolite from the marine cyanobacterium *Lyngbya majuscule*. J Nat Prod, 63:1440-3.
57. Naesens L, De-Clercq E. 2001. Recent developments in herpes virus therapy. Herpes, 8:12-6.
58. Serkedjieva J. 2004. Antiviral activity of the red marine algae *Ceramium rubrum*. Phytother Res, 18:480-3.
59. Philpott J, Montse B. 2006. Seaweed: Nature's secret for a long and healthy life? The Nutrition Practitioner, 1-21.
60. Koehn FE, Gunasekera SP, Niel DN, Cross SS. 1991. Halitunal, an unusual diterpene aldehyde from the marine alga *Halimeda tuna*. Tetrahedron Lett, 32:169-72.
61. Garg HS, Sharma M, Bhakuni DS, Pramanik BN, Bose AK. 1992. An antiviral sphingosine derivative from the green alga *Ulva fasciata*. Tetrahedron Lett, 33:1641-4.
62. Barbosa JP, Pereira RC, Abrantes JL, dos Sanros CC, Rebello MA, Frugulhetti CP, et al. 2004. *In vitro* antiviral diterpenes from the Brazilian brown alga *Dictyota pfaffii*. Planta Med, 70:856-60.
63. Pereira HS, Leao-Ferreira LR, Moussatche N, Teixeira VL, Cavalcanti DN, Costa LJ, et al. 2004. Antiviral activity of diterpenes isolated from the Brazilian marine alga *Dictyota menstrualis* against human immunodeficiency virus type 1 (HIV-1). Antiviral Res, 64:69-76.
64. Fukuyama Y, Kodaama M, Miura I, Kinzyo Z, Mori H, Nakayama Y, et al. 1989. Anti-plasmin inhibitor V: structures of novel dimeric eckols isolated from the brown alga *Ecklonia kurome* Okamura. Chem Pharm Bull, 37:2438-40.
65. Ohata K, Mizushina Y, Hirata N, Sugawara F, Mutsukage A, Yoshida S, et al. 1998. Sulphoquinovosyldiacylglycerol, KM043 a new potent inhibitor of eukaryotic DNA polymerases and HIV-reverse transcriptase type from a marine red alga *Gigartina tenella*. Chem Pharm Bull, 46:684-6.

66. Wang H, Li YL, Shen WZ, Rui W, Ma XJ, Cen YZ. 2007. Antiviral activity of a sulfoquinovosyldiacylglycerol (SQDG) compound isolated from the green alga *Caulerpa racemosa*. Bot Marina, 50:185-90.
67. Sakemi S, Higa T, Jefford CW, Bernardinelli G. 1986. Venustatriol: a new antiviral triterpene tetracyclic ether from *Laurencia venusta*. Tetrahedron Lett, 27:4287-90.
68. Talpir R, Rudi A, Kashman Y, Loya Y, Hizi A. 1994. Three new sesquiterpene hydroquinoes from marine origin. Tetrahedron, 50:4179-84.
69. Mohammed FA, Syed MK, Syed SG, Syeda SM, Shaik RA, Shaik MA, et al. 2010. Antidiabetic activity of *Vinca rosea* extracts in alloxan-induced diabetic rats. Intl J of Endocrin, 1-6.
70. Abirami RG, Kowsalya S. 2013. Antidiabetic activity of *Ulva fasciata* and its impact on carbohydrate enzymes in alloxan induced diabetes in rats. Int J Res Phytochem Pharmacol, 3:136-41.
71. Lee YS, Shin KH, Kim BK, Lee S. 2004. Anti-diabetic activities of fucosterol from *Pelvetia siliquosa.* Arch Pharmacol Res, 27:1120-2.
72. Liu Q, Xu H, Zhang T, Fan X, Han I. 2006. Huaxue Tongbao. Mar Nat Prod, 25:35-94.
73. Feng Y, Carroll AR, Addepalli R, Fechner GA, Avery VM, Quinn RJ. 2007. Vanillic acid derivatives from the green alga *Cladophora socialis* as potent protein tyrosine phosphatase 1B inhibitors. J Nat Prod, 70:1790-2.
74. Wang W, Okada Y, Shi H, Wang Y, Okuyama T. 2005. Tasipeptins A and B: structures and aldose reductase inhibitory effects of bromophenols from the red alga *Symphocladia latiuscula.* J Nat Prod, 68:620-2.
75. Asaraja A, Sahayaraj K. 2013. Screening of insecticidal activity of brown macroalgal extracts against *Dysdercus cingulatus* (Fab.) (Hemiptera: Pyrrhocoridae). J Bio Pest, 6(2):193-203.
76. San-Martin A, Negrete R, Rovirosa J. 1991. Insecticide and agaricide activities of polyhalogenated monoterpenes from Chilean *Plocamium cartilagineum.* Phytochemistry, 30:2165-9.
77. Fukuzawa Y, Kodamma M, Miura I, Kinzyo Z, Mori H, Nakayama Y, et al. 1989. Anti-plasmin inhibitor V: structures of novel dimeric eckols isolated from the brown alga *Ecklonia kurome* Okamura. Chem Pharm Bull, 37:2438-40.
78. Watanabe K, Umbeda K, Miyakado M. 1989. Isolation and identification of three insecticidal principles from the red alga *Laurencia nipponica* Yamada. Agric Biol Chem, 53:2513-5.
79. Watanabe K, Miyakado M, Ohno N, Okada A, Yanagi K, Moriguchi KA, et al. 1988. A polyhalogenated insecticidal monoterpene from the red alga *Plocamium telfairiae.* Phytochemistry, 28:77-8.
80. Maeda M, Kodama T, Tanaka T, Toshizumi H, Takemoto T, Nomoto K, et al. 1986. Structures of isodomic acids A, B and C novel insecticidal amino acids from the red alga *Chonria armata*. Chem Pharm Bull, 34:4892-5.

81. Ilopulou D, Vagias C, Harvala C, Roussis V. 2002. C_{15} acetogenins from the red alga *Laurencia obtuse*. Phytochemistry, 59:111-6.
82. Michanek G. 1981. Getting seaweed to where it's needed. Ceres, 14:41-4.
83. Spolaore P, Joannis-Cassan C, Duran E, Isambert A. 2006. Commercial applications of microalgae. J Biosci Bioeng, 101:87-96.
84. Anonymous. 2002. J Agric Food Chem, 840–5.
85. Paduch R, Kandefer-SzerszeÅ M, Trytek M, Fiedurek J. 2007. Terpenes: substances useful in human healthcare. Arch Immunol Ther Exp (Warsz), 55:315-27.
86. Jung HA, Hyun SK, Kim HR, Choi JS. 2006. Angiotensin-converting enzyme I inhibitory activity of phlorotannins from *Ecklonia stolonifera*. Fisheries Sci, 72:1292-9.
87. Lee S, Lee YS, Jung SH, Kang SS, Shin KH. 2003. Anti-oxidant activities of fucosterol from the marine algae *Pelvetia siliquosa*. Arch Pharm Res, 26:719-22.
88. Stahl W, Sies H. 2003. Antioxidant activity of carotenoids. Mol Aspects Med, 24: 345-51.
89. Edge R, McGarvey DJ, Truscott TG. 1997. The carotenoids as antioxidants-a review. J Photoch Photobio B, 41:189-200.
90. Kullavanijaya P, Lim HW. 2005. Photoprotection. J Am Acad Dermatol, 52:937-58.
91. Patel A, Mishra S, Ghosh PK. 2009. Defence in the globally significant N2-fixing marine cyanobacterium *Trichodesmium*. Environ Microbiol, 11:1897-908.
92. Ananya, Kamal A, Ahmad IZ. 2014. Cyanobacteria "the blue green algae" and its novel applications: a brief review. Intl J Innov Appl Sci, 7(1):251-61.
93. Shashirekha S, Uma L, Subramanian G. 1997. Phenol degradation by the marine cyanobacterium *Phormidium valderianum* BDU-30501. J Ind Microbiol Biotechnol, 19:130–3.
94. Khalil Z. 1997. Toxicological response of a cyanobacterium *Phormidium fragile* to mercury. Water Air Soil Poll, 98:179-85.
95. Perales-Vela HV, Pena-Castro JM, Canizares-Villanueva RO. 2006. Heavy metal detoxification in eukaryotic microalgae. Chemosphere, 64:1-10.
96. Narro ML, Cerniglia CE, Baalen CV, Gibson DT. 1992. Metabolism of phenanthrene by the marine cyanobacterium *Agmenellum quadriplicatum* PR-6. Appl Environ Microbiol, 58:1351–9.
97. Imai R, Nagata Y, Fukuda M, Takagi M, Yano K. 1991. Molecular cloning of a *Pseudomonas paucimobilis* gene encoding a 17-kilodalton polypeptide that eliminates HCl molecules from g-hexachlorocyclohexane. J Bacteriol, 173:6811–9.
98. Tu CM. 1976. Utilization and degradation of lindane by soil microorganisms. Arch Microbiol, 108:259–63.
99. Yule WN, Chiba M, Morley HV. 1967. Fate of insecticide residues. Decomposition of lindane in soil. J Agric Food Chem, 15:1000–4.

100. Kannan V, Vijayasanthi M, Rajmohan N. 2011. Bioremediation of tannery effluents by filamentous cyanobacteria *Anabaena Flos-Aquae*. West: Hydrol Curr Res, 2:5.

101. Welch RM. 1995. Micronutrient nutrition plant rev. Plant Sci, 14:49-82.

102. Kolanjinathan K, Ganesh P, Saranraj P. 2014. Pharmacological importance of seaweeds: a review. World J Fish Mar Sci, 6:1-15.

103. Belarbi EH, Molina E, Chisti Y. 2000. A process for high yield and scaleable recovery of high purity eicosapentaenoic acid esters from microalgae and fish oil. Process Biochemistry, 35:951-69.

104. Khan SI, Satam SB. 2003. Seaweed mariculture: scope and potential in India. Agriculture Asia, 8(4):26-29.

105. Ginneken VJ, Helsper JP, Visser WD, Keulen HV, Brandenburg WA. 2011. Polyunsaturated fatty acids in various macroalgal species from North Atlantic and tropical seas. BioMed Central, 10:104.

106. Fitton JH. 2003. Brown marine algae. Alternative and Complementary Therapies, 29-33.

107. Fenoradosoa TA, Ali G, Delattre C, Laroche C, Petit E, Wadouachi A, et al. 2010. Extraction and characterization of an alginate from the brown seaweed *Sargassum turbinarioides* Grunow. J App Phycol, 22:131-7.

108. Fredericq S, Hommersand MH, Freshwater DW. 1996. The molecular systematics of some agar and carrageenan-containing marine red algae based on rbcL sequence analysis. Hydrobiologia, 326:125-35.

109. Bixler HJ, Porse H. 2010. A decade of change in the seaweed hydrocolloids industry. J Appl Phycol, DOI 10.1007/s10811-010-9529-3.

110. Demirbas A. 2008. Production of biodiesel from algae oils. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 31(2):163-8.

111. GardeaTorresdeya JL, Arenasb JL, Franciscob NM, Tiemanna KJ. 2013. Ability of immobilized cyanobacteria to remove metal ions from solution and demonstration of the presence of metallothionein genes in various strains. J Hazard Subs Res, 1:1123-79.

112. Burja AM, Banaigs B, Abou-Mansour E, Burgess JG, Wright PC. 2001. Marine cyanobacteria: a prolific source of natural products. Tetrahedron Lett, 57:9347-77.

113. Karatay SE, Donmez G. 2011. Microbial oil production from thermophile cyanobacteria for biodiesel production. Appl Energ, 88:3632–5.

114. Costa JA and Morais MG. 2011. The role of biochemical engineering in the production of biofuels from microalgae. Bioresour Technol, 102:2–9.

115. Timothy P, Durrett CB, Ohlrogge J. 2008. Plant triacylglycerols as feedstocks for the production of biofuels. The Plant J, 593-607.

116. Bajhaiya AK, Mandotra SK, Suseela MR, Toppo K, Ranade S. 2010. Algal biodiesel: the next generation biofuel for India. Asian J Exp Biol Sci, 1(4):728-39.

117. Taher H, Al-Zuhair S, Al-Marzouqi AH, Haik Y, Farid MM. 2011. A review of enzymatic transesterification of microalgal oil-based biodiesel using supercritical technology. Enzyme Res, 468292; DOI:10.4061/2011/468292.

118. Rittmann BE. 2008. Opportunities for renewable bioenergy using microorganisms. Biotechnol Bioeng, 2:203–12.

119. Balasubramanian L, Subramanian G, Nazeer TT, Simpson HS, Rahuman ST, Raju P.2012. Cyanobacteria cultivation in industrial wastewaters and biodiesel production from their biomass: A review. Biotechnol Appl Biochem, 59:220–5.

120. Thirumaran G, Arumugam M, Arumugan R, Anantharaman P. 2009. Effect of seaweed liquid fertilizer on growth and pigment concentration of *Abelmoschus esculentus* (I) medikus. Am J Agric Econ, 2(2):57-66.

121. Dhargalkar VK, Neelam Pereira. 2005. Seaweed: promising plant of the millennium. Sci Culture, 71:60-6.

122. Koch R. 1882. Die Aetiologic der Tuberculose. Berl. Klin. Wchnschr., xix: 221-230. In milestones in microbiology: 1556 to 1940 translated and edited by Thomas D. Brock, (ASM Press. 1998), p.109.

123. Pati MP, Sharma SD, Nayak L, Panda CR. 2016. Uses of seaweed and its application to human welfare: A review. Int J Pharm Pharm Sci, 8(10):12-20.

124. Subbaramaiah. 2004. Seaweed resources and distribution in India. National Symposium and Exposition-Souvenir, p. 64.

125. FMC Bioproducts. 1988b. The Agarose Monograph in FMC Bioproducts Source Book, FMC Corp., Rockland, Maine, 95-101.