International Journal of Pharmacy and Pharmaceutical Sciences

ISSN- 0975-1491 Vol 8, Issue 10, 2016

Review Article

USES OF SEAWEED AND ITS APPLICATION TO HUMAN WELFARE: A REVIEW

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Received: 11 May 2016 Revised and Accepted: 12 Aug 2016

ABSTRACT

Seaweed research has been carried out for more than seven decades by many research workers. Research has been done separately in different aspects accordingly to our need. The main objective of the present review is to gather information relating to nutritional, pharmacological, clinical, biochemical, industrial uses and its application to human welfare. Seaweeds have a high concentration of essential vitamins, trace elements, proteins, lipids, polysaccharides, enzymes, and minerals as compared to terrestrial foodstuffs. These plants have been a source of food, fodder, medicine, cosmetics, energy, fertilizer and are used for industrial production of agar and alginate. Their recent utilization increases in poultry due to their nutritive value. In the present scenario, it is being used for wastewater treatment such as treatment of wastewater to reduce nitrogen and phosphorus containing compounds. This review work is an attempt to highlights all the relevant application and uses of seaweeds and its products. Finally, this paper would be helpful to a common man to know and aware about such a great living resources which is present in and around us.

Keywords: Seaweeds, Application, Human Welfare, Review

DOI: http://dx.doi.org/10.22159/ijpps.2016v8i10.12740

INTRODUCTION

Uses of Seaweed have been cited as early as 2500 y ago in Chinese literature [1]. It is being used in worldwide because it contains vitamins, minerals, and fiber. For at least 1,500 y, the Japanese were using a mixture of raw fish, sticky rice, and other ingredients in a seaweed called Nori. In Europe and North America, it has been used for the effectiveness of seaweeds on human health. It has been suggested that amongst other herbal products, seaweeds have curative powers for the treatment of tuberculosis, arthritis, colds and influenza. In earlier times, the therapeutic uses of seaweeds were limited to only traditional and folk medicines [2]. At the end of 1990s, the discoveries of bioactive compounds were made by using marine bacteria, invertebrates and algae [3]. Seaweed broadly says algae are a cheap source in the preparation of new chemicals followed by other marine invertebrates [4]. Seaweed played a milestone in pharmaceutical industries as well as modern biology during the year 1980 to 1995.

Many types of seaweed contain anti-inflammatory and anti-microbial agents. Their known medicinal effects have been taking for thousands of years; the ancient Romans used them to treat wounds, burns, and rashes. Anecdotal evidence also suggests that the ancient Egyptians may have used them as a treatment for breast cancer. Certain seaweeds possess powerful cancer-fighting agents that researchers hope will eventually prove effective in the treatment of malignant tumors and leukemia in people. While dietary soy was long credited for the low rate of cancer in Japan, this indicator of robust health is now attributed to dietary seaweed. These versatile marine plants and algae have also contributed to economic growth. In this review article, we have discussed a detailed account of study related to different uses and application of seaweed from ancient time to the modern era. We have covered an extensive study and information of seaweed and its uses with special reference to its nutritive value, medicinal property, pharmaceutical activity, pharmacology and industrial uses. The database contains more than 90 articles which include reviews, case study, Ph. D research, research article, annual reports and much more current research.

Seaweed resources

India is located on 08.04–37.06 N and 68.07–97.25 E, a tropical South Asian country has a stretch of about 7500 km coastline, excluding its island territories with 2 million km^2 Exclusive Economic Zone (EEZ) and nine maritime states (table 1). Approximately, 271 genera and 1153 species of marine algae, including forms and varieties have been enumerated till date from the Indian waters [5]. Seaweeds are macroscopic algae (non-flowering stemless water plant in Oriya Shaibala) found attached to the solid bottom substrate of rocks, dead corals, pebbles, shells and other plant materials. The seaweeds are found in relatively shallow coastal waters, estuaries, intertidal and deep sea areas up to 180 meters depth. Generally, they are classified into Chlorophyceae (green algae), Phaeophyceae (brown algae) and Rhodophyceae (red algae). There are more than 10 000 kinds of seaweeds with a potential of 7.5–8 million tons (wet weight) which are being produced along the coastal regions of the world [6]. About 40,000 tonnes of seaweeds are being exploited for the production of algin and agar every year. Review on the seaweed resources, cultivation and its utilization from different Indian coastal water has well documented by Subba Rao [5]. He also gave a long review on the present with past scenario. Seaweed resources along the Indian coast have listed in table 1. The distributions of species encountered during the surveys are represented in table 2. During these surveys, total standing crop varied from 6, 77, 308.87 to 6, 82, 758.87 tons (fresh weight) along the Indian coast. The seaweeds spreads along the Indian coastline and its nine maritime states and islands (Gujarat-1700, Maharashtra-572, Goa-104, Karnataka-280, Kerala-560, Tamil Nadu-980, Andhra Pradesh-960, Orissa-432, West Bengal-280, Andaman and Nicobar Islands-1500 (approx.), Lakshadweep Islands-120 (approx.) in km, table 3). The places of algal interest along coastal states of India are noted in the table. 3.

Nutritional value and biochemical composition of seaweed

Seaweeds are nothing but the wealth of Ocean or we can say that these are the marine living resources. It's a good source of minerals, vitamins, proteins, carbohydrates and fibers [36]. The minerals like sodium, calcium, magnesium, potassium, chlorine, sulphur, phosphorus and micronutrients such as iodine, iron, zinc, copper, selenium, molybdenum, fluoride, manganese, boron, nickel and cobalt are plenty in different species of seaweed. Apart from that, it's a good source of iodine generally highest in brown seaweed. The calcium and protein content varies from species to species but has low-fat content. Generally, green and red seaweed has high protein content (up to 30%), whereas lower (up to 15%) was found in brown seaweeds [37]. But during the Mandapam coast survey, the highest protein content was found in brown algae as compared to

green and red. This may also be varied depending on the habitat and according to the depth. Protein content varies among different genera and also in different species of the same genus which has been cited in table 4.

Table 1: Seaweed resources studied by different authors along the Indian coast along the Indian coast

Area	Annual yield in tonnes (fresh wt.)	Source
Gujarat		
Gulf of Kutch	1,00,250*	Desai1967 [7]
Gulf of Kutch	4000	Chauhan and Krishnamurthy1968[8]
Okha to Dwarka and Vumani reef	1011	Bhandari and Trivedi1975[9]
Adhatra reef	60	Sreenivasa Rao *et al.* 1964[10]
Saurashtra	282–610	Chauhan and Mairh1978[11]
Maharashtra		
Konkan	315	Chauhan1978[12]
Entire coast	20,000	Untawale 1979*et al.*[13]
Goa		
Donapaula to Chapora	255	Untawale 1983*et al.*[14]
Kerala	1000	Chennubhotla 1988*et al.*[15]
Tamil Nadu		
Madras coast	690	Umamaheswara Rao1973[16]
Cape Comorin to Colachal	5	Koshy and John1948[17]
Calimare to Cape Comorin	66,000	Chacko and Malu Pillai1958[18]
Pamban	1000	Verma and Krishna Rao1962[19]
Palk Bay	631	Umamaheswara Rao1973[16]
South east coast	20,535	c. f. Untawale *et al.*1983[14]
Gulf of Mannar	33,000*	Desai1967[7]
Entire coast (intertidal)	22,044	Anon.1978[20]
Entire coast (subtidal)	75,375	Kaliaperumal *et al.*1998[21]
Andhra Pradesh	7500	Anon.1984[22]
Orissa		
Chilka lake	5	Mitra1946[23]
Chilka lake	2,69,700*	Rath and Adhikari, 2004 [24]
Lakshadweep	4955–10,077	Anon.1979[25]
Gujarat	12.15	Bhandari and Trivedi1975[9]
Gulf of Mannar Islands	61.54	Subba Rao and Ganesan (Unpublished Report)
Andaman		
South Andaman	19,111	Muthuvelan *et al.*2001[26]
Middle and North Andaman	6817	Muthuvelan *et al.*2001[27]
Little Andaman	120	Gopinathan and Panigrahy1983[28]
Drift seaweeds	1260.18	Krishnamurthy1969[29]
Total	6,77,308.87 to 6,82,758.87	

Source: Subba Rao* and Vaibhav A. Mantri, 2006 [5], (All values are in tons (fresh weight)

Table 2: Species composition encountered during different surveys along the Indian coast

State	Green	Brown	Red	Blue-green	Total Source	Literature
Gujarat	29	24	39	Nil	92	Chauhan and Mairh 1978[11]
Gujarat (subtidal)	Nil	Nil	Nil	Nil	35	Dhargalkar and Deshmukh 1996[30]
Maharashtra	11	11	14	Nil	36	Chauhan 1978[12]
Karnataka*	16	10	16	1	43	Agadi 1985[31]
Kerala	13	3	17	2	35	Chennubhotla *et al.*1988 [15]
Tamil Nadu (intertidal)	113	83	225	5	426	Anon.1978[20]
Tamil Nadu (subtidal)	8	8	12	1	29	Kaliaperumal *et al.*1998[21]
Andhra Pradesh	23	7	34	1	65	Anon.1984[22]
West Bengal*	9	Nil	5	Nil	14	Mukhopadhyay and Pal 2002[32]
Orissa* (Chilka lake)	8	Nil	6	Nil	14	Sahoo *et al.*2003[33]
Lakshadweep Islands	33	10	39	Nil	82	Anon.1979[25]
Great Nicobar Island*	18	15	18	Nil	51	Ravindran *et al.*2004[34]
South Andaman Islands	29	15	11	Nil	55	Muthuvelan *et al.*2001[27]
Middle and North Andaman Islands	11	11	5	Nil	27	Muthuvelan *et al.*2001[26]
Diu*	27	14	29	Nil	70	Mantri and Subba Rao 2005[35]

Qualitative survey only, Source: Subba Rao and Vaibhav A. Mantri (2006)[5]

Table 3: Distribution of seaweeds in different maritime state/union territories along the Indian coast

State	Coastline (km)	Places of algal interest
Gujarat	1700	Okha (22.15 N, 69.1 E), Dwarka (22.14 N, 69.1 E)
Maharashtra	572	Malvan (16.03 N and 73.30 E)
Goa	104	Panaji (15. 03 N and 73. 55 E)
Karnataka	280	Karwar (14.48 N and 74.11 E)
Kerala	560	Quilon (8.54 N and 76.38 E), Varakala (8.28 N and 76.55 E)
Tamil Nadu (including Pondicherry)	980	Krusadai Island (9.14 N and 79.13 E), Idinthakarai (8.10 N and 77.43 E)
Andhra Pradesh	960	Visakhapatnam (17.44 N and 83.23 E), Pulicat lake (13.20–13.40 N and 80.14–80.15 E)
Orissa	432	Chilka lake (19.50 N and 85.30 E)
West Bengal	280	Sundarbans (21.33–22.45 N and 88.06–89.05 E)
Andaman and Nicobar Islands	1500 (approx.)	6–14 N and 92–94 E
Lakshadweep Islands	120 (approx.)	8–12 N and 72–74 E

Source: Subba Rao* and Vaibhav A. Mantri (2006)[5]

Chlorophyceae members generally have high carbohydrate content than Rhodophyceae and Phaeophyceae [38] but this may also vary according to the species type and habitat. For example; the maximum carbohydrate content was recorded in the green seaweed *E. intestinalis* 28.58 % and the minimum was found to be 10.63% in brown seaweed of *Dictyota dichotoma* [38]. In green seaweed of *U. lactuca* (35.27%) and *E. intestinalis* (30.58%) also contain higher carbohydrate content [39].

The Seaweeds collected from the Maharashtra coast and Kovalam coast of India noted the maximum value of carbohydrate content in Rhodophyceae than in Phaeophyceae and Chlorophyceae. This may be due to higher phycocolloid content in their cell walls [40]. In other cases, the Phaeophycean group gas the high carbohydrate content followed by green algae and red algae. The order of carbohydrate content in Mandapam coast (table 5) was such as *Turbinaria conoides* (23.9%), *Sargassum tenerimum* (23.55%), *Sargassum wightii* (23.50%) followed by green alga *E. intestinalis* (23.84%) and the red algae *H. valentiae* (23.60%), *Acanthophora spicifera* (23.54%). The minimum carbohydrate content was observed from green alga *Codium tomentosum* (20.47%) followed by brown algae *Padina gymnospora* (21.88%), *Colpomenia sinuosa* (22.46%) and the red alga *Gracilaria folifera* (22.32%) [41].

Marine macroalgae contained a low amount of lipids. In Mandapam coastal survey (table 6), maximum lipid content was observed from *E. clathrata* (4.6%) followed by *G. folifera* (3.23%), *C. tomentosum* (2.53%), *C. sinuosa* (2.337%) and *S. wightii* (2.337%). The minimum lipid concentration was recorded from *E. intestinalis* (1.33%) followed by *P. gymnospora* (1.4%), *S. Tenerimum* (1.46%) and *U. lactuca* (1.6%) [41].

Table 4: Biochemical composition of different seaweed species (protein in %) from various coasts of India

Family	Seaweed species	Protein	Area/Habitat
Phaeophyceae (Brown algae)	*Padina gymnospora*	17.08	Mandapam coastal regions
	Sargassum tenerimum	12.42	Mandapam coastal regions
	Sargassum coriifolium	16.07	Bay of Bengal, St. Martin's Island
	Padina tenuis	8.32	
	Turbinaria ornate	14.68	Mandapam coastal regions
Chlorophyceae (Green algae)	*Ulva lactuca*	3.25	Mandapam coastal regions
	Ulva rigida	6.64	Chilika
	Enteromorpha intestinalis	16.38	Mandapam coastal regions
	Codium tomentosum	6.13	Mandapam coastal regions
	U. rigida	28.06	Sea of Marmara
	U. lactuca	27.7	Sea of Marmara
Rhodophyceae (Red Algae)	*Gracilaria folifera*	6.98	Mandapam coastal regions
	Gracilaria verrucosa	9.47	Mandapam coastal regions
	Hypnea valentiae	8.34	Mandapam coastal regions
	Kappaphycus alvarezii,	18.78	Rameshwaram
	Gracillari canaliculata	8.51	Massawa region, Red sea

Source: Compiled From Published Reports

Table 5: Biochemical composition of different seaweed species (Carbohydrate in %) from various coasts of India

Family	Seaweed species	Carbohydrate	Area/Habitat and source
Phaeophyceae (Brown algae)	*Dictyota dichotoma*	10.63%	Tuticorin coast (Parthiban, 2013)[38]
	Turbinaria conoides	23.9	Mandapam coast (Manivannan, 2008)[41]
	Sargassum tenerimum	23.55	Mandapam coast (Manivannan, 2008)[41]
	Sargassum wightii	23.50	Mandapam coast (Manivannan, 2008)[41]
	Padina gymnospora	21.88	Mandapam coast (Manivannan, 2008)[41]
	Colpomenia sinuosa	22.46	Mandapam coast(Manivannan, 2008)[41]
Chlorophyceae (Green algae)	E. *intestinalis*	28.58	Tuticorin coast (Parthiban, 2013)[38]
		30.58	Sunderban (Chakraborty and Santra 2008)[39]
		23.84	Mandapam coast(Manivannan, 2008)[41]
	U. lactuca	35.27	Sunderban (Chakraborty and Santra 2008)[39]
	Codium tomentosum	20.47	Mandapam coast (Manivannan, 2008)[41]
Rhodophyceae (Red algae)	*H. valentiae*	23.60	Mandapam coast (Manivannan, 2008)[41]
	Acanthophora spicifera	23.54	mandapam coast (Manivannan, 2008)[41]
	Gracilaria folifera	22.32	mandapam coast (Manivannan, 2008)[41]

Source: Compiled from Published Reports

Table 6: Biochemical composition of different Seaweed species (Lipid in %) from various coasts of India

Family	Seaweed species	Lipid in %	Area/Habitat and source
Phaeophyceae (Brown algae)	*C. sinuosa*	2.337	Mandapam coast, Manivannan *et al.* 2008[41]
	S. wightii	2.337	Mandapam coast, Manivannan *et al.* 2008[41]
	P. gymnospora	1.4	Mandapam coast, Manivannan *et al.* 2008[41]
	S. Tenerimum	1.46	Mandapam coast, Manivannan *et al.* 2008[41]
Chlorophyceae (Green algae)	*E. clathrata*	4.6	Mandapam coast, Manivannan *et al.* 2008[41]
	E. intestinalis	1.33	Mandapam coast, Manivannan *et al.* 2008[41]
	E. intestinalis	7.13	Sunderban, Chakraborthy and Santra (2008)[39]
	U. lactuca	1.6	Mandapam coast, Manivannan *et al.* 2008[41]
	U. rigida	12	Satpati *et al.* 2011[42]
	C. tomentosum	2.53	Mandapam coast, Manivannan *et al.* 2008[41]
Rhodophyceae (Red algae)	*G. folifera*	3.23	Mandapam coast, Manivannan *et al.* 2008[41]
	K. alvarezii	1.09	Rajasulochana *et al.* 2012[43]

Source: Compiled from Published Reports

In some study, it was revealed that the lipid content of U. rigida is 12% [42] and in *K. alvarezii* it was 1.09% [43]. In India along Tuticorin coast survey, green seaweed *E. intestinalis* showed the high lipid content (7.13%) and red seaweed *G. verrucosa* marked the minimum lipid content [39]. Seaweeds contain both water-and fat-soluble vitamins. The vitamins like B1, B2, B3, B6, B8, B9, B12, C and E are available in significant amount in different species of algae.

Seaweed as food

Seaweeds are used in many maritime countries, particularly in Asia, Japan, Korea and China as a source of food, industrial applications and for fertilizer. The current uses of seaweeds are as human foods, cosmetics, fertilizers and for the extraction of industrial gums and chemicals. In Japan, kombu and kunbu in Chinese (The common food item with low cost but highly nutritious) is used in the preparation of soups, fish, meat dishes and also as a vegetable with rice. 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. As the seaweed has high protein content as it is being used by many of the countries like Japan, China, Korea, Malaysia, Thailand, Indonesia, Philippines and other South East Asia. 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 [37]. Some of the seaweeds are also taken in dried form.

Seaweed as beauty enhancer

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. Seaweed baths as a treatment for arthritis, rheumatism and other aches and pains. Many companies producing a seaweed powder (made mainly from *Ascophyllum nodosum*) for beauty and body care products containing seaweed extracts. A number of compounds extracted from seaweeds are thought to be of value in various cosmetic applications and some are now becoming commercially important.

Medicinal and pharmacological properties

From prehistoric times; seaweeds has been widely used as food [44, 45] as these are the chief source of vitamins and minerals [46]. The extracts and its products are effective nutritional supplements [47]. Apart from the nutritional support it has also used against various biological diseases like antimicrobial, antiviral, antifungal, anti-allergic, anticoagulant, anticancer, antifouling and antioxidant activities [48]. Yuvaraj [49], described the marine brown alga i. e *Sargassum wightii* have the anti-tumor, anti-inflammatory, antioxidant and antibacterial activities.

Antioxidant activities

Seaweeds have good antioxidant properties, which play a major role to fight against various diseases like cancer, chronic inflammation, atherosclerosis and cardiovascular disorder and ageing processes [48]. It also prevents the rate of cancer cell formation [50].

To control heart disease and stroke

Use of seaweed can help in Reduction of plasma cholesterol, which may reduce the risk of cardiovascular disease [51].

Antimicrobial and antifungal activity

The methanol crude extracts of *Gracilaria corticata* having good usefulness against the antimicrobial and antifungal activities. Among different solvent extracts like methanol, acetone, chloroform, and hexane-ethyl acetate, methanol showed the highest antibacterial activity against different pathogenic bacteria such as *Staphylococcus aureus, Streptococcus pyogenes, Streptococcus epidermis, Bacillus subtilis and Bacillus cereus, Klebsiella pneumoniae* and *Enterobacter aerogenes* [52]. The *Gracilaria corticata, Sargassum wightii* and *Turbinaria ornate* also have a good source of antimicrobial agent [53]. Similarly, ethanol extract showed maximum antibacterial activity against *Staphylococcus* species as compared to methanol extracts against *Escherichia coli*, *Staphylococcus* and *Proteus* species [54].

Anti-inflammatory property

Methanol extracts of the seaweeds *Undaria pinnatifida* and *Ulva linza* have a better inflammatory activity while tested against mouse ear edema and erythema. *Edema* was strongly dormant by the seaweeds *Undaria pinnatifida* and *Ulva linza*. These two seaweeds also showed the greatest suppression of erythema [55].

Seaweeds as anticancer agents

Seaweeds are the most important reservoirs of new therapeutic compounds for humans. Different types of seaweed extracts have been experimentally proved to reduce or to destroy the effectiveness of cancer. The dietary intake of seaweed has also been implicated as a potential protective agent in the aetiology of breast cancer [56]. The brown algae *Fucus spp*. has shown activity against both colorectal and breast cancers [57]. An anticancer effect of different seaweeds on human colon and breast cancers has been well documented by Ghislain *et al.* 2014[57]. In ancient times, Chinese was used *Laminaria* sp. in the treatment of cancer and it has also been recorded in ancient ayurvedic texts [58]. Seaweed in a diet plays an active role in reducing the risk of breast cancer and another type of cancer. A series of mechanism in which; cancer could be reduced or retards its rate of growth. It includes reduction of plasma cholesterol, binding of biliary steroids, antioxygenic activity, binding of toxic materials, induction of apoptosis, inhibition of cell adhesion, the addition of important trace minerals to the diet.

Antidiabetic activity

Aqueous extract of *Ulva fasciata* was shown a good remarkable difference while treated against diabetic rats as compared to other standard medicine. Abirami, 2013[59] experimented over a 28 d of oral treatment against infected rats. He found a significant decrease in blood glucose and glycosylated hemoglobin level while pre-treatment with aqueous of *Ulva fasciata.*

Antiviral activity

A scientist from many countries of the world showed antiviral activities against human infectious diseases like human immunodeficiency virus (HIV), Herpes simplex virus (HSV) types 1 and 2 and respiratory syncytial virus (RSV) by using *Aghardhiella tenera* and *Nothogenia fastigiata* sp. [60-62]. 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 [63].

Antibiotic activity

The presence of antagonistic or chemical compounds in algae makes them functional as antibiotics. These compounds are useful against various diseases such as viral, bacterial and fungal [46]. Several experiments and patents were carried out in ancient times by researchers to find out these chemical compounds which basically fall in categories of phaeophyceae, chlorophyceae and rhodophyceae [64, 65]. The compounds include fatty acids, bromophenols, tannins, phloroglucinol, terpenoids and halogenated compounds [66].

Cellular growth activity

The compound derived from *Eucheuma serra* have been successfully implemented on mouse lymphocytes using lectins to stimulate non-dividing cell of mitosis [67].

Effects on fertilization and larval development

The lectin diabolin isolated from *Laminaria diabolica* causes the development of a fertilized envelope around unfertilized eggs of the sea urchin *Hemicentrotus pulcherrimus*, thus preventing cleavage [68, 69]. Terpenoids are also known for their effects on fertilization and subsequent various seaweed-derived compounds affect fertilization and larval or embryonic development in both invertebrates and vertebrates. Premakumara *et al.* [70] identified a sphingosine derivative from *Gelidiella acerosa* as a post-coital contragestative agent in studies on pregnant rats and development of embryos. For example, caulerpenyne, a sesquiterpene from *Caulerpa taxifolia*, affects embryogenesis, larval development and metamorphosis of the sea urchin *Paracentrotus lividus* [71, 72]. It also interferes with microtubule-dependent events during the first mitotic cycle of sea urchin eggs and affects regulation of intracellular pH in sea urchin eggs and sea bream hepatocytes [73, 74].

Vermifuge activity

In addition to the antibiotic effect of algal extracts, certain marine algae have been used as vermifuges (killing intestinal worms, such as Ascaris) or anthelmintics [46, 75]. The kainic acid produced from the extract of *Digenea* (red alga) act as an efficient vermifuge activity against Ascaris worm without causing any side effects to the patient [76].

Antitumor activity

Compounds extracted from several species of marine blue-green algae have been successfully tested against lymphocytic leukemia and Ehrlich ascites tumor in mice [77].

Anti-ulcer wound healing and hepatoprotective activities

Kulandhaisamy and Murugan [78] has experimentally proved and reported seaweeds like *Gracilaria crassa*, *Laurencia papillosa* and *Turbinaria ornata* have a good antiulcer, wound healing and hepatoprotective activities. In their study, they found *L. papillosa* showed highest protection (81%) followed by *Gracilaria crassa* (76%) against gastric as comparable to the standard drug ranitidine (90%).

Goitre treatment

Goitre disease is caused due to the low concentration of iodine in food which results in physical retardation in people. We can overcome to this disease by the use of marine algae as these are tremendous sources of iodine. Vitamin deficiency can also be prevailing by use of seaweed supplements in the diet [79].

Industrial use

Agar or "agar-agar" which is well known in southeast Asia but it was discovered in Japan, where it is popularly known as "kanten". Agar is used as a solid substrate for the growth of bacteria and fungi. 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 comprise 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. 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*. Seaweed industrial gums, also known as 'seaweed hydrocolloids,' extracted from seaweeds fall into three categories: alginates (derivatives of alginic acid), agars and carrageenans. Alginates are extracted solely from brown seaweeds while agars and carrageenans are extracted only from red seaweeds.

Agar agar

It is commonly used as in inert carrier of nutrients in Biotechnology and microbiology. This can also used in cakes, chocolates, candies, jellies, jams, juices, coffee, wafers, liquors, salad dressing etc. As a stabilizer, it is being used in sauces, a solidifying agent, emulsifier and laxative. In the manufacture of photographic film, paint, batteries, graphite, glue etc.

Alginates

Alginate is used to improve the quality of paper texture. It is being used as a potential ingredient in frozen foods, stabilizer in ice creams, reactive base in reactive dye printing of textiles. Alginates also widely used in many pharmaceutical industries as a stabilizer. It acts as an emulsifier for many food products in food industries such as an additive in instant food drinks, to keep food particle liquid in the mixture. It also helps as natural latex creaming and thickening of rubber [80-82].

Renewable energy supplier

The unexploited seaweed biomass is utilized for the production of biogas and it has been practiced in most of the developed countries [83]. The biogas used for different purposes such as cooking, heating or electricity generation.

Seaweed as food complement for farm animals

Seaweeds are used for complementary food to the farm animals such as cattle, poultry and other farm animals. Seaweed builds resistance to disease by ensuring a complete balance of micronutrients. They also assist in decreasing the rate of mastitis and cow fever [84]. It also improves fat level and iodine content in milk and in yield milk products. Seaweed also enhances the fertility and birth rate of animals and also improves yolk colour in eggs [85]. The food prepared from the species of *Gracilaria, Gelidiella, Hypnea* and *Sargassum* is added as feed for fish and prawn culture. The feed has enriched with minerals, amino acids and carbohydrates which promotes for maintaining water quality in aquaculture [86]. Seaweeds can also be employed as water disinfectant in aquaculture as it recycles fish waste polluted water [83].

Seaweed used as organic manure

Seaweed has been widely used as manure. In common; seaweed has sufficient amount of micronutrients, growth promoting hormones, potassium, nitrogen and humic acids. Presences of such materials in seaweed make them as excellent fertilizer [83]. 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.

Seaweeds in domestic sewage treatment

Seaweeds are capable of removing most of the nutrients efficiently from the waste waters. Under standard treatment process, seaweed can remove nutrients like nitrogen and phosphorus from domestic sewage. In aquaculture, it is being used to avert the effluent by shrimp culture which helps to prevent from eutrophication. The red seaweeds *Gracilaria verrucosa* have the higher efficiency to remove BOD and COD level whereas green seaweed *Ulva fasciata* has more efficiency for removal of ammonia [87].

Wastewater treatment

In modern times the seaweeds are used in the treatment of sewage and some agricultural wastes to reduce nitrogen and phosphorus containing compounds before the release of these treated waters into rivers or oceans. In other words, we can say to check eutrophication in freshwater, brackish water and marine environment. Eutrophication is the enrichment or excess deposition of nutrients in terms of minerals, nitrogen and phosphorus containing materials. Eutrophication can occur naturally, but it can be accelerated by allowing water, rich in dissolved fertilizers, to seep into nearby lakes and streams, or by the introduction of sewage effluent into rivers and coastal waters. This will lead to the unwanted and excessive growth of aquatic or marine plants. Another important feature of many types of seaweed is their ability to take up more phosphorus than they require for maximum growth. Intertidal and estuarine species are the most tolerant, especially green seaweeds such as species of *Enteromorpha* and *Monostroma*.

Removal of toxic metals from Industrial wastewater

The other application is for the removal of toxic metals such as copper, nickel, lead, zinc and cadmium from industrial wastewater. Metals come either from natural sources or from mining or disposal of industrial wastes. Brown seaweeds such as *Sargassum*, *Laminaria* and *Ecklonia* and the green seaweeds *Ulva* and *Enteromorpha* have more efficient to accumulate of toxic metals. So it's a biological indicator of heavy metal pollution.

Other uses

Seaweeds are not only used in the pharmacological and clinical application but also used in Poultry and cattle farming. It is a primary source of food for many marine organisms. It has a good water-binding capacity. It increases texture; improve fat replacement, product yields and helps in analogue seafood binding. It is being used in Dairy products e. g. chocolate milk, frozen desserts, UHT milks, flans, puddings, low-fat cheese and cheese analogue. It also provides cocoa suspension, milk stability, emulsion stability and for milk gelling. Its other uses include; cold milk powders, diet powder mixes and nutritional beverage mixes. In toothpaste, it provides structure without masking flavours, resistant to enzymatic breakdown.

In pet foods, it binds water, provides structure and prevents fat separation in canned, retorted products. Its wider use includes controlled release products e. g. air freshener gels. It provides structure and controlled release of active ingredients such as perfume in a water gel base. The different uses of various seaweeds are represented in table 7.

Table 7: The list of some commercially important seaweed used for different purposes

Species	Food	Feed	Industrial uses	Medicine	Fertiliser
Gracillaria corticata	+	+	+	-	-
Sargassum cinereum	-	-	+	+	+
Sargassum ilicifolium	-	+	+	+	+
Porphyra vietnamensis	+	+	-	-	-
Colpomenia sinuosa	-	-	+	-	+
Spatoglossum asperum	-	-	+	-	+
Padina tetrastromatica	-	-	+	-	+
Caulerpa sertularioides	+	+	-	-	-
Stoechospermum Marginatum	-	-	+	-	+
Chaetomorpha media	+	+	-	-	+
Laminaria digita	-	-	+	+	-
Jania adhaerens	-	-	-	+	-
Laurencia papillosa	+	+	+	-	+
Eucheuma uncinatum	+	+	+	-	-
Hypnea musciformis	+	+	+	-	-
Dictyopteris australis	-	-	+	-	+
Centroceros clavulatum	+	-	+	-	-
Chondrus crispus	+	-	+	-	-
Gelidiella acerosa	-	-	+	-	-
Amphiroa fragilissima	+	-	-	-	+
Macrocystis pyrifera	-	-	+	+	+
Hydroclathrus clathratus	-	-	+	-	+
Ulva fasciata	+	+	-	+	-
Dictyota dichotoma	+	+	+	-	-
Enteromorpha compressa	+	+	-	+	-
Cladophora fascicularis	+	+	-	-	-
Monostroma oxyspermum	+	+	-	-	-
Codium fragile	+	+	-	+	-

Source: Compiled from Published Reports

Role of seaweeds in marine ecosystem

Apart from these above uses, seaweeds play a major role in maintenance and balancing of marine food chain. It provide nutrients and energy for marine animals either directly when fronds are eaten or indirectly when it decompose into fine particles and are taken up by filter-feeding animals. Beds of seaweed provide shelter and habitat of coastal animals for whole or part of their lives.

They are important nurseries for numerous commercial species such as the rock lobster, abalone and green-lipped mussel.

CONCLUSION

This review article involved a thorough study of different literatures from India as well as from world scenario. This paper describes the detail account on the seaweed uses from ancient times to modern era. Seaweeds are chief resource of essential vitamins, trace elements, proteins, lipids, polysaccharides, enzymes and minerals. Although seaweed and its products have a wide range of application in pharmaceutical, clinical and industrial sector but regular uptake of seaweed may not be safe as it could be contaminated by heavy metals. The brown algae i.e. Bladderwrack is a potential source of heavy metals and with high iodine content which may lead to toxic. Regular uptake of bladderwrack may result in the abnormalities in thyroid, acne-type skin lesions, increased salivation, stomach irritation and may also and may affect the blood sugar level. There is no side effect when red marine algae is used whereas a few side effects have been reported from green algae as it can accumulate heavy metals from the surrounding contaminated water and could be toxic to body[88]. 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 agent [89]. Red and brown seaweeds are considered as a rich source of bioactive secondary metabolites such as steroids, flavonoids, glycosides, alkaloids and insecticides related active metabolites are of great medicinal value [90]. Therefore we can use these herbal plant and their products to cure different diseases as it has no side effect as compared to allopathic drugs [91].

There are a number of research work have been done on seaweed and their uses from many parts of the world. Most of the work has been done with special reference to its nutritive value, medicinal property, pharmaceutical, pharmacology and industrial uses. The main objective of writing this review is to provide information in all fields related to uses and application of seaweed both in past and present scenario. Coastal area-wise distribution and resources were also made for better understanding. This is an attempt to provide information in the field of science and awareness for a common man about such a great noble resources.

CONFLICT INTERESTS

Declared none

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How to cite this article

- Mitali Priyadarsini Pati, Satyabrata Das Sharma, Lakshman Nayak, Chita Ranjan Panda. Uses of seaweed and its application to human welfare: a review. Int J Pharm Pharm Sci 2016;8(10):12-20.