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

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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 anti-infective activity. 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

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 industry as well as modern biology during the year 1980 to 1995.

Many types of seaweed contain anti-inflammatory and antimicrobial 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 nutritional 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 km² 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 alginate and agar every year. Review on the seaweed resources, cultivation and its utilization from different Indian coastal water has well documented by Sabba 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.

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                           | 1,00,250*                          | Desai 1967 [7]                              |
| Gulf of Kutch                     | 4,000                              | Chauhan and Krishnamurthy 1968 [8]          |
| Okha to Dwarka and                 | 1,011                              | Bhandari and Trivedi 1975 [9]              |
| Vumani reef                       | 60                                 | Sreenivas Rao et al. 1964 [10]              |
| Saurashtra                        | 282–610                            | Chauhan and Maith 1978 [11]                 |
| Maharashtra                       |                                    |                                             |
| Konkan                            | 315                                | Chauhan 1978 [12]                           |
| Entire coast                      | 20,000                             | Untawale 1979 et al. [13]                  |
| Goa                               | 255                                | Untawale 1983 et al. [14]                  |
| Donapaula to Chhapa               | 1,000                              | Chenmubhotla 1988 et al. [15]              |
| Tamil Nadu                        |                                    |                                             |
| Madras coast                      | 690                                | Unmamaheswara Rao 1973 [16]                |
| Cape Comorin to Colachal          | 5                                  | Koshly and John 1948 [17]                  |
| Calimare to Cape                  | 66,000                             | Chacko and Malu Pillai 1958 [18]           |
| Comorin                           |                                    |                                             |
| Pamban                            | 1,000                              | Verma and Krishna Rao 1962 [19]            |
| Palk Bay                          | 631                                | Unmamaheswara Rao 1973 [16]                |
| South east coast                  | 20,535                             | c.f. Untawale et al. 1983 [14]             |
| Gulf of Mannar                     | 33,000*                            | Desai 1967 [7]                              |
| Entire coast (intertidal)         | 22,044                             | Anon. 1978 [20]                             |
| Entire coast (subtidal)           | 75,375                             | Kaliaperumal et al. 1998 [21]              |
| Andhra Pradesh                    | 7,500                              | Anon. 1984 [22]                             |
| Orissa                            |                                    |                                             |
| Chilka lake                       | 5                                  | Mitra 1946 [23]                            |
| Chilka lake                       | 2,69,700*                          | Rath and Adhikari, 2004 [24]               |
| Lakshadweep                       | 4955–10,077                        | Anon. 1979 [25]                             |
| Gujarat                           | 12,15                              | Bhandari and Trivedi 1975 [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                  | 6817                               | Muthuvelan et al. 2001 [27]                |
| Andaman                           |                                    |                                             |
| Little Andaman                    | 120                                | Gopinathan and Panigrahy 1983 [28]        |
| Total                             | 677,308.87 to 6,82,758.87          | Krishnamurthy 1969 [29]                    |

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 Maith 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    | Aghul 1985 [31] |
| Kerala                     | 13    | 3     | 17  | 2           | 35    | Chenmubhotla 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    | Rawindran 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]
Rhodophyceae members generally have high carbohydrate content than Phaeophyceae 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 other cases, the Phaeophycean group has 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 tenerinum* (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%), *Copoperna 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* (3.25%), *C. tomentosum* (2.5%), *C. sinuosa* (2.35%) and *S. wightii* (2.35%). The minimum lipid concentration was recorded from *E. intestinalis* (1.33%) followed by *P. gymnospora* (1.4%), *S. Tenerinum* (1.46%) and *U. lactuca* (1.6%) [41].

| 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            | Mahan (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          | Kradabad Island (9.14 N and 79.13 E), Idinthakari (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            | Sundarban (21.33 – 22.45 N and 88.06 – 89.05 E) |
| Andaman and Nicobar Islands | 1500    | 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)

| State/Habitat | Latitude/Longitude |
|---------------|--------------------|
| Sundarban     | 21°33’ N and 89°06’ E |
| Visakhapatnam | 17°44’ N and 83°23’ E |
| Kutubpur      | 27°54’ N and 88°06’ E |
| Tuticorin     | 8°20’ N and 78°55’ E |
| Mandapam      | 11°55’ N and 70°55’ E |

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

| 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 ornata               | 14.68   | Mandapam coastal regions            |
| Chlorophyceae (Green algae) | Ulva lactuca                | 3.25    | Mandapam coastal regions            |
|                      | Ulva rigida                   | 6.64    | Chilka                              |
|                      | Enteromorpha intestinalis       | 6.13    | Mandapam coastal regions            |
|                      | Codium tomentosum              | 28.06   | Sea of Marmara                      |
|                      | U. rigida                     | 27.7    | Sea of Marmara                      |
|                      | U. lactuca                    | 18.78   | Rameshwaram                         |
|                      | Gracilaria folifera            | 6.98    | Mandapam coastal regions            |
|                      | Gracilaria verrucosa           | 9.47    | Mandapam coastal regions            |
|                      | Hypnea valentiae              | 8.34    | Mandapam coastal regions            |
|                      | Kappaphycus avaruzii           | 8.51    | Massawa region, Red sea             |
|                      | Gracilaria canaliculata        |         |                                    |

Source: Compiled From Published Reports

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

| Family               | Seaweed species | Carbohydrate | Area/Habitat and source                      |
|----------------------|-----------------|--------------|----------------------------------------------|
| Phaeophyceae (Brown algae) | Dictyota dichotoma | 10.63%       | Tuticorin coast [Puthiban, 2013] [38]         |
|                      | Turbinaria conoides | 23.9     | Mandapam coast [Manivannan, 2008] [41]       |
|                      | Sargassum tenerinum | 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]       |
|                      | Colopomenia sinoisu | 22.46     | Mandapam coast [Manivannan, 2008] [41]       |
| Chlorophyceae (Green algae) | E. intestinalis   | 28.58     | Sunderban [Chakraborty and Santra 2008] [39] |
|                      | U. lactuca        | 30.58     | Sunderban [Chakraborty and Santra 2008] [39] |
|                      | Codium tomentosum  | 23.84     | Mandapam coast [Manivannan, 2008] [41]       |
|                      | H. valentiae      | 35.27     | Sunderban [Chakraborty and Santra 2008] [39] |
|                      | Acanthophora spicifera | 20.47   | Mandapam coast [Manivannan, 2008] [41]       |
|                      | G. folifera       | 22.32     | Mandapam coast [Manivannan, 2008] [41]       |

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 kune 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 carbohydrates, vitamins A, B, B2 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., Macroystis sp., Porphyra sp., Graciola sp., Euchema sp., Laurencia sp. and Ascophyllum 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 are 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 seaweed 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 have 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]. Yuvraj et al. [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 epidermidis, Bacillus subtilis and Bacillus cereus, Klebsiella pneumoniae and Enterobacter aerogenes [52]. The Gracilaria corticata, Sargassum wightii and Turbinaria ornata 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 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 it rate of growth. It includes reduction of plasma cholesterol, binding of biliary steroids, antioxidant 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 pretreatment with aqueous of Ulva fasciata.

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. Tenerinum    | 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, Chakraborty 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       | Rajasabchana et al. 2012 [43]                        |

Source: Compiled from Published Reports
Antiviral activity
A scientist from many countries of the world showed antiviral activities against human infectious diseases like Herpes, polio, respiratory syncytial virus, human immunodeficiency virus (HIV), Herpes simplex virus (HSV), and others. The use of marine algae as these are food which results in physical retardation in people. We can overcome 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 *Pterocladiella*. 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. Alginate is 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.

Alginate
Alginate is used to improve the quality of paper texture. It is being used as a potential ingredient in frozen foods, stabilizer in ice cream, reactive base in reactive dye printing of textiles. Alginate and carrageenan are also 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 *Pterocladiella*. 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. Alginate is extracted solely from brown seaweeds while agars and carrageenans are extracted only from red seaweeds.

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 diabelon isolated from *Laminaria diabolica* causes the development of a fertilized envelope around unfertilized eggs of the seaurchin *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 spingosine derivative from *Gelidella acerosa* as a post-coital contraceptive in studies on pregnant rats and development of embryos. For example, caulerpenyne, a sesquiterpene from *Caulerpa taxifolia*, affects eggogenesis, 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 *Digenia* (red alga) act as a 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 antifulcer, 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 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].

Seaweeds used as organic manure
Seaweeds have been widely used as manure. In common; seaweed has sufficient amount of micronutrients, growth promoting hormones, potassium, nitrogen and humic acids. Preparations of these materials in seaweed make them as excellent fertilizer [80-82].

Fertilizer and water disinfectant
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.

Seaweeds as food supplement 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*, *Gelidium*, *Hypnea* and *Sargassum* is added as feed for fish and prawn culture. The feed is 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].

Seaweeds used as organic manure
Seaweeds have been widely used as manure. In common; seaweed has sufficient amount of micronutrients, growth promoting hormones, potassium, nitrogen and humic acids. Preparations of these materials in seaweed make them as excellent fertilizer [83]. Species of *Laminaria*, *Ascopbylum*, *Sargassum* are used as an organic manure and are biodegradable, non-toxic, non-polluting and non-hazardous to invertebrates and vertebrates. Pr emakumara *et al.* has been used as vermifuges (killing intestinal worms, such as Ascaris) or anthelmintics [46, 75]. The kainic acid produced from the extract of *Digenia* (red alga) act as an efficient vermifuge activity against Ascaris worm without causing any side effects to the patient [76].
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 prevented by allowing water, rich in dissolved fertilizers, to seep into nearby lakes and streams, or by the introduction of seaweed 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 |
|--------------------------|----------|----------|-----------------|----------|-----------|
| *Gracilaria corticata*   | +        | +        |                 |          |           |
| *Sargassum cinereum*     | -        | -        | +               |          | +         |
| *Sargassum ilicifolium*  | -        | +        | +               |          | +         |
| *Porphyra vietnamensis*  | +        | +        |                 |          |           |
| *Colpomenia sinuosa*     | -        | -        | +               | -        | +         |
| *Spatoglossum asperum*   | -        | -        | +               | -        | +         |
| *Padina tetrastromatica* | -        | -        | +               | -        | +         |
| *Gaultheria sertularioides* | +   | +        |                 |          |           |
| *Stoechospermum marginatum* | -   | -        | +               | -        | +         |
| *Chaetomorpha media*     | +        | +        |                 | -        | +         |
| *Laminaria digitata*     | -        | -        | +               | -        |           |
| *Jania adhaerens*        | -        | -        | +               | -        | -         |
| *Laurencia papillosa*     | +        | +        |                 | +        |           |
| *Eucheuma uncinatum*     | +        | +        |                 |          |           |
| *Hyphnea musciformis*    | +        | +        |                 |          |           |
| *Dictyopteris australis* | -        | -        | +               | -        | +         |
| *Centroceros clavulatum* | +        | +        |                 | -        | -         |
| *Chondrus crispus*       | +        | +        |                 | -        | -         |
| *Gelidiella acerosa*     | -        | -        | +               | -        | -         |
| *Amphiroa fragilissima*  | -        | -        | +               | -        | -         |
| *Macroystis pyrifera*    | -        | -        | +               | -        | +         |
| *Hydroclathrus clathratus* | - | -        | +               | +        |           |
| *Ulva fasciata*          | +        | +        |                 | -        | +         |
| *Dictyota dichotoma*     | +        | +        |                 | -        | -         |
| *Enteromorpha compressa* | +        | +        |                 |          | -         |
| *Chladoroph fusicollaris* | +   | +        |                 | -        |           |
| *Monostroma oxypermum*   | +        | +        |                 |          | -         |
| *Sodium fraigile*        | +        | +        |                 |          | -         |

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 around the world as well as from world scenario. This paper describes the detail account on the seaweeds 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, acnè-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 anti-bacterial, anti-cancer, anti-fungal, anti-diabetic, analgesic, anti-diabetic, 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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