Seaweeds: Distribution, Production and Uses

Chapter · November 2018

CITATIONS
0

READS
38

1 author:

K. Suresh Kumar
University of Allahabad, Allahabad,India
29 PUBLICATIONS **627** CITATIONS

SEE PROFILE

CHAPTER

6

SEAWEEDS: DISTRIBUTION, PRODUCTION AND USES

P.V. SUBBA RAO[1], C. PERIYASAMY[2], K. SURESH KUMAR[3], A. SRINIVASA RAO[4] AND P. ANANTHARAMAN[2]

ABSTRACT

Seaweeds, otherwise known as marine algae are primitive non-flowering photosynthetic macrophytes occurring in tidal regions of seas and oceans that occupy 71% of the globe and they are natural renewable resources. Green, brown and red seaweeds are generally distributed in the intertidal, tidal and subtidal regions respectively. Seaweed production through aquaculture in the world was 11.66, 16.83 and 19.90 million tons (fresh) in 2002, 2008 and 2010 respectively and in 2012 it was 23.78 million tons (fresh). *Kappaphycus alvarezii* production in the world was 1,83,000 tons (dry) in 2010 while it was 1, 490 tons (fresh) during the same period in India. Seaweeds formed part of human life from time immemorial and served as food, besides their use as feed, fodder and manure. Some of the edible seaweeds include species of *Porphyra, Palmaria, Undaria, Laminaria, Monostroma* and *Caulerpa* and possess desirable quantities of proteins, carbohydrates, fibre, minerals and vitamins, besides having biological compounds to combat diseases. *Ascophyllum sp, Macrocystis sp, Laminaria sp, Alaria sp, Palmaria sp* and *Pelvetia sp* are some of seaweeds used as fodder. Seaweeds are the only natural source for phytochemicals *viz*; agar, algin and carrageenan which have wide applications in various ways in day to day life of human beings. Species of *Gelidium, Gracilaria, Pterocladia, Gelidiella, Ahenpeltia* and *Acanthopeltis* are some agarophytes, while those of *Laminaria, Macrocystis, Ascophyllum, Durvillea, Ecklonia* and *Sargassum* are some alginophytes. Carrageenophytes include species of *Chondrus, Gigartina, Sarcothalia, Eucheuma* and *Kappaphycus*. The alginophytes mentioned here also serve as manure because they contain macronutrients (N, P, K, Ca, Mg, S), micronutrients (Zn, Cu, Mn) and growth regulators (auxins, gibberlins, cytokinins) necessary for plant growth.

Keywords: Seaweed, Marine Algae, Phycocolloids, Agar, Alginate, Carrageenan

[1]*Aquaculture Foundation of India, Madurai, Tamil Nadu / Guntur, Andhra Pradesh.*
Former Deputy Director/ Scientist-F and Group Leader, Marine Biotechnology & Ecology Discipline, Central Salt & Marine Chemicals Research Institute (CSIR), G. B. Marg, Bhavnagar, Gujarat.
[2]*Head Department of Botany, Pasumpon Muthuramalinga Thevar College, Melaneelithanallur 627953, Manonmanium Sundaranar University, Tirunelveli, Tamil Nadu .*
[3]*Department of Botany, University of Allahabad, Allahabad, Uttar Pradesh .*
[4]*Lecturer in Botany, Government Degree College, Mandapeta – 533 308, Andhra Pradesh*
Email: raokappaphycus@gmail.com; aqua.afi@gmail.com

Introduction

Plants are the primary producers for the precious life to run on earth. They form the basic direct food for the herbivores and indirectly to the carnivores and hence form part of food web / chain. They are classified into Phaenorogams and Cryptogams. The cryptogams are again divided into Thallophyta, Bryophyta and Pteridophyta. Algae and Fungi are grouped under Thallophyta. Algae are mostly aquatic and grow in various types of waters. Some algae occur in soil and air. They are the primitive group of plants evolved first in the universe and are microscopic as well as macroscopic commonly known as microalgae and macroalgae respectively. In general benthic, macrophytic algae present in marine environment (Seas/ Oceans) are called seaweeds. In the marine ecosystem, marine algae are the major primary producers. Macroalgae are bigger, having simple thallus structure without true leaf and roots. But they have pseudo roots known as hold fasts / rhizoids. They do photosynthesis through their thallus (Dawson 1966).

Needless to say, the taxonomic classification of algae is still the source of constant changes and controversies, in view of the recent new information provided by molecular techniques (Van den Hoek *et al*. 1995). The recent study by John (1994), suggests that there are around 36000 known species of algae and represent only about 17% of the existing species. According to Dring (1982) over 90% of the species of marine plants are algae and roughly 50% of the global photosynthesis on the plant group is algal derived (John, 1994). Thus every second molecule of oxygen the humans inhale is produced by an alga, and every second molecule of carbon dioxide they exhale is reused by an alga (Melkonian1995).

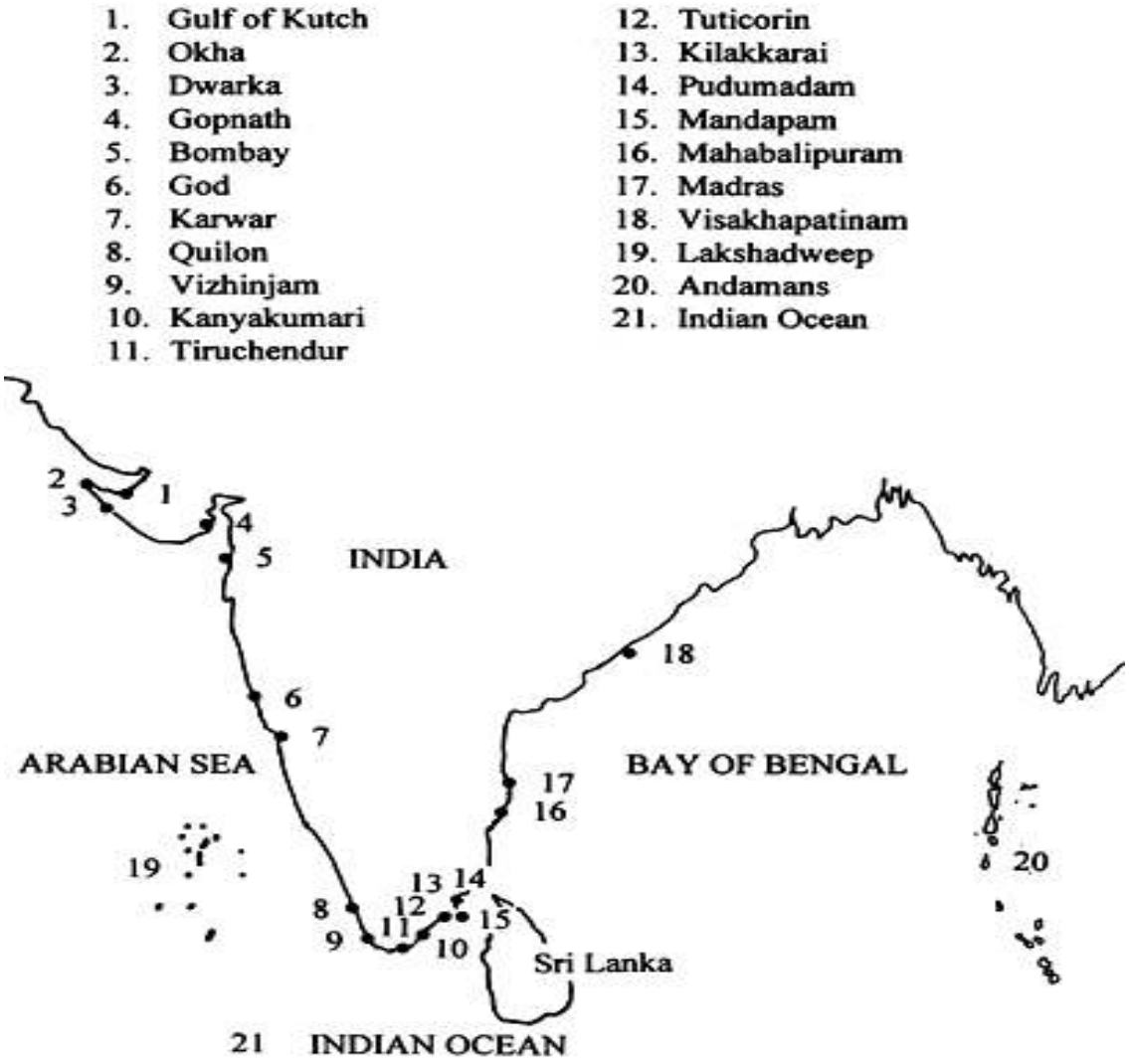
In earlier days, usages of these marine aquatic plants otherwise called weeds (Marine algae) were not understood well. Hence the name was given to these marine plants/ weeds as "Seaweeds". Now, the utilities of the marine plants (marine algae) have been studied well in various forms and are being used in day today life of human beings. The name "Seaweeds" is already popular among the scientists and people and so it is difficult to change the name "Seaweeds". But in scientific literature, some scientists use the term "Marine Plants" here and there and however the term 'Seaweeds" is widely accepted. More than the name, the utilization and plenty of applications of these seaweeds are important. Seaweeds naturally grow in seawater and their growth is greater where nutrition and sunlight are adequate. Earth has 71% of marine water and harbour huge quantity of marine plants. Marine plants include phytoplankton, cyanobacteria, seaweeds and sea grasses, and among these seaweeds are known for the better livelihood option to the coastal community (Subba Rao 2012). Seaweeds flourish in shallow or near shore waters of sea, estuaries and also in the brackish water environments, wherever dead corals, rocks, stones, pebbles and any other suitable substrata are available for their attachment. Further they are one among the renewable and economically valuable marine resources (Chapman and Chapman 1980, Tseng 1981). Subba Rao *et al.* (2009, 2016) have reviewed the benefits of seaweeds for human welfare in which the usage of seaweeds as human food, animal fodder, manure for crops, medicines and phycocolloids (agar, alginate and carrageenan) has been elucidated and this paper deals with the additional relevant information not covered in the earlier review.

Distribution of seaweeds

The seaweeds are distributed horizontally in different zonations viz. supra tidal (supra littoral), intertidal (littoral) and subtidal (sub littoral) regions of the seas and oceans (Stephenson and Stephenson 1949). Green seaweeds are most commonly found in the intertidal zone. Common green seaweeds are species of *Ulva* (sea lettuce), *Enteromorpha* (green string lettuce), *Chaetomorpha*, *Codium* and *Caulerpa*. Brown seaweeds inhabit in the tidal or upper subtidal zone. Common brown seaweeds are species of *Sargassum, Laminaria, Turbinaria* and *Dictyota*. Red seaweeds grow in subtidal waters. Common red seaweeds are species of *Gracilaria, Gelidiella, Eucheuma, Ceramium* and *Acanthophora*. The blue green algae grow in supra tidal region mostly as colonies and sometimes they occur as epiphytes on other algae. Common blue green algae are species of *Lyngbya, Spirulina* and *Oscilatorai* (Chapman and Chapman 1980, Dawson 1966, Levring *et al*. 1969, Tseng 2001).

Seaweed production

Fig 1. Important places of seaweeds occurrence on Indian coast



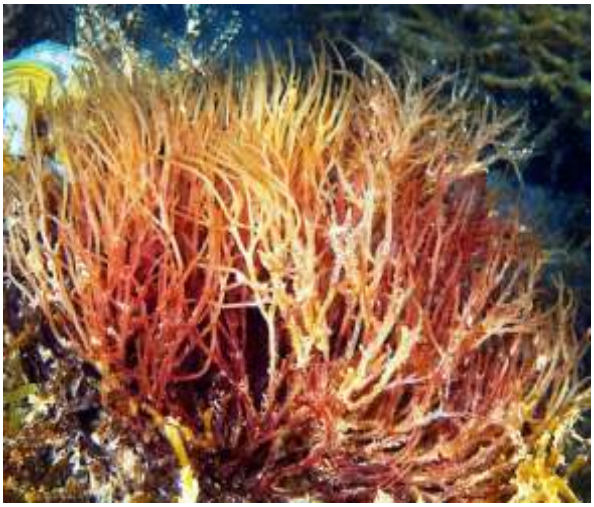
World status

There are 20000 species of marine plants reported in the world (May 1981). Among these marine plants, seaweeds are mainly used as an excellent source of phycocolloids such as agar, alginate and carrageenan, besides their use as food, fodder, feed and liquid seaweed fertilizers (Bio fertilizers). Worldwide, there are 42 countries with reports of commercial seaweed activity and 221 species of seaweeds are utilized commercially. Of these, 145 species are used for food and 110 species for phycocolloid production (Zimke – White and Ohno 1999). The global seaweed resources have been estimated as 1460 million tons (fresh weight) of brown algae and 261 million tons (fresh weight) of red algae. The total seaweed production has been estimated to be around 1721 X 10^4 tons (fresh weight) annually (Michanek 1975). The world production of commercial seaweeds has grown by 119 percent since 1984. World production of seaweed and other aquatic plants were 11, 03, 595 tons and 11, 04, 948 tons in 1998 and 2007 respectively. About 90% of seaweed production comes from culture based practices and China holds first rank in seaweed production, with *Laminaria* species accounting for most of its production. China is followed by North Korea, South Korea, Japan, Philippines, Chile, Norway, Indonesia and USA (FAO 2013). Globally the production of seaweed through aquaculture was 11.66, 16.83 and 19.9 million tons fresh in 2002, 2008 and 2010 respectively while seaweed biomass accounted for 23.0% of the world aquaculture output in 2007 (FAO 2012, Paul and Tseng 2012). However, world aquaculture production of seaweeds was 23.78 million tons fresh in 2012 (FAO 2014). *Kappaphycus alvarezii* production in the world was 1, 83, 000 tons (dry) in 2010 (Bixler and Porse

Fig 2. Seaweeds used as Food

Laminaria japonica

Undaria pinnatifida



Gracilaria coronopifolia

Codium edule

Fig 3. Seaweeds used as Fodder

Pelvetia canaliculata

Macrocystis sp

Fig 3. Continued…….

Alaria sp.

Palmaria sp.

2011). During the last decade, the seaweed products (Phycocolloids) industry has grown rapidly and is placed at 1.5 billion US$ and the demand for seaweeds and their products has been increasing, approximately at 10% per annum. This rapid growth is due to the wide application of seaweeds and their products in various industries such as food, pharmaceuticals, textiles, paper, agriculture, etc.,. The top 10 countries producing seaweeds through aquaculture in the world are China, Korea, Japan, Philippines, Indonesia, Chile, Taiwan, Vietnam, Russia and Italy (Bixler and Porse 2011).

Indian status

In India commercial exploitation of seaweeds commenced since 1966 for the production of agar and alginate (Oza and Zaidi 2001, Thivy 1960). Wild collection of red algae (*Gelidiella acerosa, Gracilaria edulis, G.crassa, G. folifera and G. verrucosa)* was from 240 to 1518 tons dry for agar production and that of brown algae (species of *Sargassum* and *Turbinaria*) was from 651 to 5534 tons dry for alginate and LSF production during 1978-79 to 2002-03 (Kaliaperumal *et al*. 2004). Seaweeds grow along the coastal waters of Tamilnadu, Gujarat, Andhra Pradesh, Orissa, West Bengal, Kerala, Maharashtra, Lakshadweep and Andaman Nicobar Islands. There are also rich seaweed beds around Mumbai, Ratnagiri, Goa, Karwar, Vizhinjam, Pulicot and Chilka (Fig. 1). However Tamil Nadu coast represents highest production of seaweeds (Subba Rao and Mantri 2006). Among 9900 species of seaweeds reported in the world (Khan *et al*. 2009), 1153 species including forms and varieties have been reported till date with total standing crop of 6,77,309 to 6,82,759 tons **(**wet weight) (Subba Rao and Mantri 2006). Seaweed production from aquaculture was 1490 tons fresh from *Kappaphycus alvarezii* in 2010 (Krishnan and Narayankumar 2013, Periyasamy *et al*. 2015**).** Seaweeds like *Gelidiella acerosa, Gracilaria edulis, G. dura* and *Enteromorpha compressa* have not gone for commercial production although viable cultivation technologies for these seaweeds have been developed (Subba Rao *et al*. 2004, Subba Rao and Mantri 2006).

Uses

Seaweeds are used as human food, animal fodder, chicken (birds) and aqua (fishes) feed, manure and liquid seaweed fertilizer for crops, besides their use as phytochemicals (agar, agarose, alginate and carrageenan). They also serve as medicines and antioxidants (Subba Rao *et al.*2009).

As human food

Seaweeds were used as human food from 600 to 800 BC. In China they were used from prehistoric time. In China and Japan, they had been used as a stable diet for a very long period. Fresh, dried and processed seaweeds are utilized for human consumption. Many types of seaweeds are used as food in Japan, China, Philippines and other countries of Indopacific region. They are eaten as salad, curry, soup, or jam (Chapman and Chapman1980, Levring *et al*. 1969, Subba Rao *et al*. 2010, Tseng 2004).

Seaweeds otherwise known as "sea vegetables" are rapidly moving from Asian cultures, where for centuries they have been regarded as food for kings and gods. They are also known for their natural healing (foods) and even gourmet cuisine markets of the western world. They are traditionally consumed in Asia as "sea vegetables", but in the western countries, they have been used as sources of gelling or thickening agents. However western countries have begun to enjoy the taste and nutritional value of these vegetables (Escrig and Goni Combrodon 1999). Seaweed recipes are easy to prepare and are added to finished foods – soups, vegetables, dishes and salads. In some countries seaweed foods are very popular. The important food seaweeds are Kombu (*Laminaria japonica*), Wakame (*Undaria*), Nori (*Porphyra*), Ogo Kim Chee (*Gracilaria coronopifolia*), Gulamon sald (*Codium edule*/ *Gracilaria coronopifolia*) and Sunomono (*Gracilaria coronopifolia*) (Fig. 2) (FAO 2003).

Seaweeds used in China, Korea and Japan are purchased as a dried product. However there is also a market for some varieties of fresh seaweeds which are used as a salad vegetable or as garnishes for other dishes such as fish. Species of *Caulerpa, Eucheuma* and *GacilaIria* are used for this purpose, especially in some of the warmer Southeast Asian countries such as the Philippines, Malaysia, Thailand and Indonesia. Usually naturally growing seaweed species are collected and sold fresh in local markets. In Cebu (Philippines) *Caulerpa lentillifera* is cultivated in brackish water ponds and the fresh seaweed is sent by air to markets of Manila (Philippines) (Amosu *et al*. 2013). The use of different seaweeds in food and food formulations has been comprehensively reviewed by Subba Rao *et al*. (2007, 2010).

Seaweeds are richest source of proteins, lipids, carbohydrates, minerals, vitamins (A, B, C and Niacin) and antioxidants and are considered as valuable food supplement for humans of 21st century and serve as low calorie food (Kilinc *et al*. 2013, Subba Rao *et al*. 2007). Protein content in brown seaweeds is 5% to 15% while in red and green ones it is 10% to 30 % of dry weight. However in *Palmaria palmata* (dulse) and *Porphyra tenera* it is 35% and 47% of dry matter respectively (Arasaki and Arasaki 1983, Morgan *et al*. 1980). *Ulva petrusa* contains 20% to 26% and is consumed under the trade name "Aonori" by Japanese (Indegaard and Minsaas 1991). *Ulva* contains 10% to 26% of protein among the Indian seaweeds (Parthiban *et al*. 2013).

Currently approximately 15 - 20 edible seaweeds are marketed in Europe (Dawczynski *et al*. 2007). France has approved the seaweeds as vegetables and condiments (Kilinc *et al*. 2013). In India juice of *Ulva* species are used in the preparation of Hlva in southern parts of Tamil Nadu (Thirunelveli) (Subba Rao *et al*. 2009, 2016).

As Fodder

In many countries, raw (fresh) or processed seaweeds are regularly fed to animals like cow, goat, horses, etc. In Iceland, fresh seaweeds are commonly used as food for sheep, cattle, hen and horses. Seaweed forms almost the only food for certain animals, though it is sometimes given along with hay. Horses prefer basal or youngest parts of the fronds of *Laminaria saccharina*. Seaweeds are fed regularly to the sheep in Norway, Iceland and Europe, *Pelvetia sp, Rhodymenia palmate, Alaria* sp., *Fucus* sp., *Chondra filus, Ascophyllum* sp., *Macrocystis* sp., *Palmaria* sp. and *Laminaria* sp. are the major genera of seaweeds used as fodder in various countries (Fig. 3) (Boney 1965). When used in animal feed, cows have produced more milk and chicken eggs became better pigmented. Horse and other pet animals became healthier (White and Keleshian 1994). Tocopheral and Vitamin E in seaweeds increased the fertility rate and birth rate of animals. Feeds supplemented with seaweeds and *Spirulina* to layer chicks (White Leghorn) increased the number of eggs, their size and colour of the yolk (Chaturvedi *et al*. 1979). In Japan, Germany, UK and Norway, feeding trials in farm animals were done

with seaweeds as supplementary animal feed (Dave *et al*. 1987). Cattle fed with *Laminaria sp* based diet have gained more natural resistance to diseases such as foot and mouth. *Ulva lactuca, Enteromorpha compressa, Padina pavonica* and *Laurencia obtusa* are potential sources of dietary protein and lipid for fishes (Wahbeh 1997). *Kappaphycus alvarezii* and *Gracilaria heterocladia* in dry powdered form as diet, showed highest survival rate in the prawn, *Penaeus monodon* (Kotiya *et al*. 2011). The rare breed of primitive sheep on North Ronaldsay, Orkney (Schotland) survived under extreme conditions on the beach shore of North Ronaldsay with seaweed as virtually their sole feed source. Seaweed treated pasture forages have increased immunity in pigs and chicks. Some of the popular and commercialized seaweed based feed are: 1. Tasco 14 – a feed derived from *Ascophyllum nodusum,* benefits overall immunity of cattle. 2. Acadian – a kelp meal marketed by Mangrove Holsteins Limited proved to boost the immune system. 3. Pedigree – a carrageenan based dog feed marketed by MARS Company (Beas *et al*. 1988). Several macro algae such as *Ulva, Undaria, Ascophyllum, Porphyra, Sargassum, Polycavernosa, Gracilaria* and *Laminaria* are widely used in fish diets and their effects on growth of fishes have been well documented (Nakagawa and Montgomery 2007).

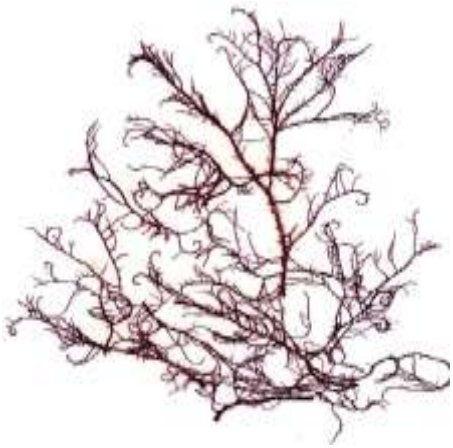
As Medicine

Seaweeds were considered to be of medicinal value in the orient as early as 3000 B.C. The Chinese and Japanese used them in the treatment of goiter and other glandular diseases. Romanians used the seaweeds for healing the wounds, burns and rashes. The British used *Porphyra* to prevent scurvy (Vitamin C deficiency diseases) during long voyages (Boney 1965, Mc Hugh 2003). Seaweeds in general are used as verimifuge and antiscorbutic, besides for curing cough, stomach, chest, bladder and kidney ailments (Boney 1965). *Coralline officinalis, Hypnea musciformis* and *Alsidium*

Fig 4. Seaweeds used for Medicine

Corallina officinalis

Pterocladia lucida



Hypnea musciformis

Gracilaria verrucosa

helminthocorton are used as vermifuges. *Chondrus* sp., *Gracilaria* sp., *Gelidium* sp., and *Pterocladia* sp. have been used to treat various stomach and intestinal disorders and also helped to relieve from constipation and other discomforts (Fig. 4). *Laminaria* is used as a pain killer and also to rectify the distend uterus. Some species of *Sargassum* are used for cooling and blood cleaning. *Sarconema* is used for controlling the goiter, a disease caused by the enlargement of Thyroid gland. *Gelidiella cartilagineum* is found to be effective against influenza B and mumps viruses. *Schizymenia pacifica* contained a sulfated polysaccharide in the carrageenan family, selectively inhibiting HIV reverse transcriptase (Levring *et al*. 1969, Mc Hugh 2003).

Red seaweeds possess algal proteins called phycobiliproteins having antioxidant properties which could be beneficial in the prevention or treatment of neuro degenerative diseases caused by oxidative stress (Alzheimer's and Parkinson's) as well as in the treatment of gastric ulcers and cancers. They also contain poly unsaturated fatty acids called Omega 3 fatty acids and omega 6 fatty acids playing important role in the prevention of cardio vascular diseases, osteoarthritis and also diabetes (Valko *et al*. 2007). Besides, seaweeds are excellent source of known vitamins such as A, B especially B12, C, D, E and Vitamin K, as well as essential aminoacids. Nori (*Phorphyra*) is very rich in Vitamins A and C (Ryan Drum 2005). Seaweed polyphenols known as phlorotannins possess antioxidant activity and polyphenols extracted from brown and red seaweeds have shown antioxidant activity (Nakamura *et al*. 1996). Carotenoids are powerful antioxidants. Recent studies have shown the correlation between a diet rich in carotenoids and a diminishing risk of cardio vascular disease, cancer (ί carotene, lycopene) as well as Ophthalmological diseases (leutin, zeaxanthin). Many studies have explained that antioxidant property of red seaweed carotenoids and their role in preventing much pathology linked to oxidative stress (Valko *et al*. 2007, Yan *et al*. 2004).

As Phycocolloids

The cell wall of several seaweeds contain very interesting group of complex polysaccharides called phycocolloids. Among the various phycocolloids, Agar, Algin and Carrageenan are most important. International demand for these phycocolloids has been increasing day by day, because of their use in various industries (food, pharmaceuticals, textile, and beverage). The phycocolloid industries have expanded rapidly only after the Second World War. In 2009 about 86,100 MT of hydrocolloids were traded comprising 58% of carrageenan, 31% Alginates and approximately 11% Agar. World carrageenan production exceeded 50,000 MT in 2009 with the value of over US $527 million. About 10,000 MT with a value of $175 million of agar has been extracted worldwide (Bixler and Porse 2011). About 32,000 MT to 39,000 MT of alginic acid per annum has been extracted worldwide from approximately 50,000 MT (wet weight) annual production of kelp (Barsanti and Gualtieri 2006).

Agar

Agar is an important phycocolloid obtained from red seaweeds. In the world commonly used seaweeds for agar production include species of *Gelidium, Gracilaria, Gelidiella acerosa, Pterocladia capillaca, Pterocladia lucida, Ahenpeltia plicata, Acanthopheltis japonica, Ceramium hypnoides and*

Fig 5. Seaweeds used for agar production

Pterocladia capilaca

Gelidium corneum

Gelidiella acerosa

Gracilaria edulis

Ceramium boydenii (Levring *et al*. 1969, Mc Hugh 2003). In India, *Gelidiella acerosa, Gracilaria edulis, G. foliifera, G. crassa* and *G. dura* are used for this purpose (Fig. 5) (Siddantha *et al*. 1987, Thirupathi and Subba Rao 2004). Agar gels are stronger and resistant at low concentrations (1 to 1.5%) with only water and withstand even above 100^0 C (good sterilization) and may be used in wide range of pH (5 to 8). Agar gels could be repeatedly gelled (excellent reversibility) and melted without losing its property. The agar gels are superior to alginate ones because they are stable, not causing precipitation in the presence of cations as is observed in alginates with calcium. FAO/ WHO Codex Aluminates have permitted the use of agar in human food industry in countries such as United Kingdom, Germany, Russia, France and Poland. Food and Drug Administration (FDA) of United States (US) assigned agar as a grading of Generally Recognized as Safe (GRAS) (FAO 2003)**.**

Agar is used in various applications in food industries as thickening agents in the preparation of fruit salads, fruit jellies, yogurt, bakery products, as a preservative in canned foods and meat industry and in liquor industry to increase the viscosity. Higher concentration of agars is also used in fabricating moulds for sculpture, archeological and dental impressions (Mc Hugh 2003). Agar tends to decrease the concentration of blood glucose and exerts an anti aggregation effect on red blood cells and effects absorption of ultraviolet rays (Murata and Nakazoe 2001).

Agarose

Agarose also a polysaccharide obtained by the fractionation of agar (and the other fraction being agaropectin) produced from *Gelidium, Gelidiella* and *Gracilaria* species (Duckworth *et al*. 1971, Izumi, 1971, 1973). It is also directly produced from *Gracilaria dura* **(**Meena *et al*. 2007**)**. Renn (1984) described some of the applications of Agarose and they include immune - diffusion and diffusion techniques, conventional electrophoresis, reverse electrophoresis, immune electrophoresis or electro focusing, chromatographic techniques in gel chromatography, ion exchange chromatography, affinity chromatography or chromate focusing, bioengineering applications and microbiology and tissue culture.

Alginate

Alginate is yet another most important polysaccharide extracted from brown seaweeds viz., *Laminaria, Macrocystis, Sargassum* and *Ascophyllum*. *Laminaria* is very common and popular in Japan and Korea (Chapman and Chapman 1980, Levring *et al*. 1969). In Scotland, Norway and France, *Laminaria* is collected from the natural stock. In Chile and Australia, *Durvillea lessonia* and species of *Ecklonia* are collected and exported to US and UK alginate industries (Bixler and Porse 2011). In India, alginate yielding seaweeds include *Sargassum, Turbinaria, Dictyota, Padina, Cystoseira, Hormophysa, Colpomenia, Spatoglossum* and *Stoecospermum* and among these seaweeds *Sargassum* and *Turbinaria* are utilized as raw material for the commercial manufacture of alginate (Fig. 6) (Kaliaperumal 2006, Thirupathi and Subba Rao 2004). The polyelectrolytic property and the viscosity of alginates make them more suitable as an excellent stabilizing agent in the food industry. The alginate

Fig 6. Seaweeds used for Alginate production

Ascophyllum nodosum

Laminaria sp.

Sargassum sp.

Turbinaria sp.

(propylene glycol alginate) has been approved as a food additive for use as emulsifier, stabilizer or thickener in USA. The Joint Expert committee of Food additives of the Food and Agricultural organization of UN/ World Health Organization (WHO) has issued specifications for alginates and recommended an acceptable daily intake of 50mg alginic acid per kg body weight and 25mg propylene glycol alginate per kg body weight (Mc Hugh 2003). Alginate is also used as stabilizing and emulsifying agent, gelling agent, in film forming (binding and glazing agent), in medicinal applications, in textile products, in bio – engineering as well as in food, dairy, paper and rubber products (Bixler and Porse 2011, Mc Hugh 2003). Alginic acid decreases the concentration of cholesterol and exerts anti hypertension effect. It prevents absorption of toxic chemical substances and serves as a dietary fiber for maintenance of health in animals and humans (Kim and Lee 2008, Murata and Nakazoe 2001, Nishide and Uchida 2003). Alginate containing drugs like Graviscon (sodium alginate, sodium bicarbonate and calcium carbonate) suppress acidic refluxes, binding of bile acids and duodenal ulcers in humans (Khotimchenko *et al.* 2001). Alginates also have anti cancer properties (Murata and Nakazoe 2001)

Carrageenan

Carrageenans are complex sulphated polysaccharides. They are commercially important hydrocolloids, derived from various red seaweeds. The name carrageenan is derived from a small coastal town in Ireland, where commercial harvests of *Chondrus crispus* (Irish moss) were made in 19th century. It is the third most important hydrocolloid in the world after starch and gelatin and occurs as

Fig 7. Seaweeds used for Carrageenan production

Kappaphycus alvarezii

Eucheuma denticulatum

Chondrus crispus

Acanthophora spicifera

cell wall matrix material in various species of red seaweeds (Mc Hugh 2002). Carrageenans are sulphated galctans classified according to the presence of 3, 6 –anhydrogalctose on the 4 –linked residue and based on the number and position of sulphate group they are of four types: *kappa, iota, beta* and *lambda*. *kappa* carrageenan is extracted from *Kappaphycus alvarezii* (*cottonii* of the trade). *iota* carrageenan from *Eucheuma denticulatum* (*spinosum* of the trade), *beta* carrageenan from *Betaphycus gelatinae* (*gelatinae* of the trade) and *lambda* carrageenan from *Acanthophora spicifera* (Fig. 7) (FAO 2013, Neish 2003). The carrageenan industry mainly depends on warm water seaweeds *viz*., *Kappaphycus alvarezii* and *Eucheuma denticulatum.* Cold water red seaweed species like *Gigartina skottsbergii*, *Sarcothalia crispata* and *Chondrus crispus* are used to extract special carrageenans that cannot be supplied by warm water *Kappaphycus* and *Eucheuma* (Bixler and Porse 2011). Other carrageenan yielding seaweeds include *Iridaea* and *Hypnea* (Chapman and Chapman 1980)

Carrageenan makes use of its both hydrophilic and anionic properties. Anionic property of carrageenan influences the hydrophilic nature. Carrageenan applications are increasing day by day due to its wide range of properties. More than 250 applications are identified in different fields such as food products and processing, pharmaceutical industry, cosmetics, etc., (Bixler and Porse 2011; Mc Hugh 2003). The carrageenan market is worth US$ 527 million with most carrageenan used as human food grade semi refined carrageenan (90%) and the rest going into pet food. From human health perspective it has been reported that carrageenan has antitumour and antiviral properties (Skoler-Karpoff *et al*. 2008, Vlieghe *et al*. 2002, Yan *et al*. 2004, Zhou *et al*. 2006).

Carrageenan gels from *Chondrus crispus* could block the transmission of the HIV virus as well

as other STD viruses such as gonorrhea, genital warts and the herpes simplex virus (HSV) (Caceres *et al*. 2000, Carlucci *et al*. 1997, Luescher-Mattli 2003, Witvrouw and De Clercq 1997). In addition, they are good candidates for their use as veginal microbicides as they do not exhibit significant levels of cytotoxicity or anticoagulant activity (Buck *et al*. 2006, Zeitlin *et al*. 1997). The most active carrageenan has approximately one fifteenth the activity of heparin (Hawkins *et al*. 1962). The hypoglycaemic effect of carrageenan may be useful in the prevention and management of diabetes (Dumelod *et al*. 1999).

The use of carrageenan for food applications started almost 600 years ago. Due to its long and safe history of use, it is generally recognized as safe (GRAS) by experts from US Food and Drug Administration (21 CFR 182.7255) and is approved as a food additive (21 CFR 172.620). The World Health Organization (WHO) Joint Experts Committee of Food Additives has concluded that it is not necessary to specify an acceptable daily intake limit for carrageenans (Van de Velde *et al.* 2002). Carrageenan with not less than 5mpas viscosity of at 1.5% concentration and 75A^{0}C (US Food and Nutrition Board 1981) had been demonstrated to be safe.

In Indian waters, the following seaweeds are listed under different types of carrageenan yielding seaweeds *viz*., *Kappa* carrageenan from *Hypnea musciformis*, and *Hypnea valentiae*, *Iota* carrageenan from *Solieria robusta* and *lamda* carrageenan from *Acanthophora spicifera, Grateloupia indica, Halymenia porphyroides, Halymenia venusta, Laurencia papillosa* and *Sebdenia polydactyla,* (Subba Rao *et al.* 2009). However they are not yet exploited for the production of carrageenan.

As Manure

Seaweeds have been initially connected directly or indirectly with human beings as a source of food, fodder and manure from time immemorial (600BC) especially in densely populated countries. They are rich in potassium salts, micro and macro nutrients as well as growth hormones, adding manural value essential for major agricultural crops (Thivy 1961). The seaweeds are used as bio-fertilizers because of their benefits as soil conditioners and green manure (Booth 1964). The potential of seaweeds is known not only for the macro nutrients such as Nitrogen, Phosphorus, Potassium, Calcium, Magnesium and Sulphur but also for its trace elements like Zn, Cu and Mn and plant growth regulators namely Auxins, Gibberellins and Cytokinins (Rengasamy 2004).

Major brown seaweeds used for fertilizer are *Ascophyllum, Macrocystis, Laminaria, Ecklonia, Durvillaea, Cabophyllum, Himanthalia, Sargassum* and *Turbinaria* and red seaweeds include *Pachymenia, Lithothamnion, Phymatolithon* (Fig. 8) (Boney 1965). The value of seaweeds as an agricultural fertilizer has been demonstrated, especially by coastal farmers with ready access to seaweeds (Booth 1965). The first reference to such use appeared in Roman writings from the second century AD. Seaweed fertilizers are now commercially available in several trade names such as Maxicrop (United Kingdom), Geomill (France), Algifert (Norway), Kelpak 66 (South Africa) and Seasol (Australia) (Subba Rao *et al*. 2016). In India, Thivy (1958, 1960) first reported the use of seaweeds as manure for the growth and better yield of vegetables and crops and showed increased yield in Bhendi applying *Hypnea* compost along with cow dung and ash.

Seaweed fertilizers have been found to be superior to chemical fertilizers because of the high level of organic matter, which aids in retaining moisture and minerals in the upper soil level making available to the roots (Wallen Kemp 1955). Seaweed fertilizers from various seaweeds on various crops have been studied and the results have shown increased yields. Seaweeds directly used as fertilizer on coconut, palms and coco plants have resulted in better yields (Richardson 1958). Seaweed extracts have been used in sweet corn, tomato, okra and sweet potato (Aitken and Senn 1965), peanuts and sweet potatoes (Tseng 1973), green chilies and turnip (Dhargalkar and Untawale, 1980). *Phaseolus vulgaris* (Featonby- Smith and Van Staden 1984), Maize, Cholam, Ragi and Kambu (Subramanian 1987), green gram, black gram and rice (Kannan and Tamilselvan 1990), *Zizyphus mauritiana* (Rama Rao 1991), Cucumber and tomato (Whapham *et al*. 1993) giving optimum yields. Recently Liquid Seaweed Fertilizer (LSF) extracted from *Kappaphycus alvarezii* when applied as foliar spray across the Indian peninsula on different crops (rice, wheat, black gram, green gram, sugar cane, tomato, bhendi) showed an increase in yield from 10% to 40% **(**US Patent No: 6893479 B2, 2005). Singh *et al*. (2015) has showed that 10% foliar spray of LSF from *Kappaphycus alvarezii* to rice crop is productive and

Fig 8. Seaweeds used for Manure production

Ascophyllum nodosum

Macrocystis angustifolia

Turbinaria sp.

Sargassum sp.

remunerative giving higher profitable yield. Further it is concluded that the foliar application of 2.5% LSF either from *Kappaphycus alvarezii* or from *Gracilaria edulis* could curtail the 50% fertilizer requirement of the crop. Nowadays some seaweed biofertilizers *viz.*, Aqua Sap from *Kappaphycus alvarezii* (Aquagri processing private Limited, New Delhi), Organic 6 from *Sargassum* spp (SNAP Alginate and Natural Products, Ranipet), Phycolinn from *Sargassum, Turbinaria* and *Kappaphycus* (Linn Plantae Private limited, Madurai) are popular in the market (Periyasamy *et al.* 2015, Subba Rao 2016).

Other Uses

Fucoidans are a group of polysaccharides (fucans) widely found in the cell walls of brown seaweeds and are not found in other algae and higher plants (Enoki *et al*. 2003). Fucoidan stimulates the

immune system in several ways, and the numerous important biological effects of fucoidans are related to their ability to modify cell surface properties (Usov *et al*. 2001) and inhibition of viral replication along with stimulation of the immune system (initiate and adaptive) functions (Hayashi *et al*. 2008). Antioxidant activity has been demonstrated in marine algae *viz*., *Porphyra haitanesis* (Zhang *et al*. 2003), *Ulva pertusa* (Qi *et al*. 2005a, 2005b), *Fucus vesiculosus* (Ruperez *et al*. 2002), *Ecklonia kurome* (Hu *et al*. 2001), *Kappaphycus alvarezii* (Sureshkumar *et al*. 2008) and *Enteromorpha compressa, E. linza* and *E. tubulosa* (Ganesan *et al*. 2011).

Mannitol is an important sugar alcohol which is present in many species of brown algae, especially in *Laminaria* and *Ecklonia*. It is used in pharmaceutical industry, in making chewing gum, in the paint and varnishes Industry, in leather and paper manufacture, in the plastic industry and in the production of explosives. It is used in a variety of foods, candies and chocolate flavored compound coatings because it replaces sucrose to make sugar free compound coatings. Sugar free chocolates are especially popular for people with diabetes, a growing problem in modern society (Kraan 2012). Further it is the preferred incipient for chewable tablets due to its favorable feel in the mouth. It is non carcinogenic and may be used in pediatric and geriatric food products as it will not contribute to tooth decay (Nabors 2004).

Laminarin is a glucan and a linear polysaccharide found in fronds of *Laminaria* / *Saccharina, Ascophyllum, Fucus* and *Undaria*. It has been shown to be as safe surgical dusting powder, and as tumour inhibiting agent and as an anti coagulant in the form of sulphate ester (Miao *et al*. 1999). It lowers the levels of total cholesterol, free cholesterol, triglyceride and phospholipid in the liver (Miao *et al*. 1999, Renn *et al*. 1994a, 1994b). Ulvan is derived from the original terms ulvin and ulvacin introduced with reference to different fractions of water soluble sulphated polysaccharides of *Ulva lactuca*. The cell wall polysaccharides of ulvales represent 38% to 54% of the dry algal matter (Lahaye 1998). Two major kinds have been identified and they are water soluble ulvan and insoluble cellulose like material. *Monostroma* ulvans have been patented for the treatment of gastric ulcers (Arasaki *et al*. 1984, Nagaoka *et al*. 2003). *Porphyra* contains sulphated polysaccharide called porphyrin, a complex galactan. *Palmaria palmata* does not produce matrix galactans but produces Xylans accounting for 35% of the dry matter (Lahaye *et al*. 1993).

Seaweeds are also a source of bioethenol as they contain quite a good quantity of carbohydrates (more than 60% dry wt.) essential for production of bioethanol through fermentation process. Butanol is an alternative to ethanol with a higher energy content (butanol 29.2 MJ/L ethanol 19.6 MJ/L), compared to gasoline (32 MJ/L). It is used to supplement both gasoline and diesel fuels and could be handled with existing infrastructure (Fortman *et al*. 2008). Recently bioethenol production was documented from *Kappaphycus alvarezii* (Khambhaty *et al*. 2012) and its economic feasibility is yet to be established. Seaweed like *Kappaphycus alvarezii* also serve in bioremediation to clean waste water by removing toxic metals like cadmium, copper etc., (Sureshkumar *et al*. 2007).

Conclusion

Seaweeds are primitive macrophytic benthic marine algae present in tidal regions of the seas/oceans. Green, brown and red seaweeds are found in the intertidal, tidal and subtidal regions respectively. Of 221 economic seaweeds, 145 for food and 110 for phycocolloid production are utilized. World production of seaweeds through aquaculture was 23.78 million tons fresh in 2012 (FAO 2014). Seaweeds have been used as food directly or indirectly as an ingredient in food formulations because they contain considerable amounts of proteins, carbohydrates and fibre, besides possessing antioxidant, antimicrobial and anti-inflammatory compounds that help to combat common health alignments. Moreover certain diseases *viz*., cancer, inflammation, arthritis, diabetes, hypertension and cardiovascular ailments are prevented by eating seaweeds as they contain biologically active compounds like phlorotannins, carotenoids, alginic acid, fucoidan etc., Seaweeds also serve as fodder because of high nutritional value. The only natural source of phytochemicals (agar, algin and carrageenan) is seaweeds, which have multifarious uses (agar in biotechnology, alginate as stabilizer and emulsifier in food industry and carrageenan in food and pharmaceutical industries). Having micronutrients and growth hormones they also serve very best as manure to improve the quantity and quality of agricultural crops providing healthy food for human beings. In addition they form a source for

bioehtenol production and aid in bioremediation removing toxic metals from waste water.

Acknowledgements

The authors would like to express their gratitude to Late. Prof. T. A. Sharma, Former Head Department of Botany, Panjabi University, Patiala, Punjab for his constant inspiration and encouragement for executing this type of review articles. The authors would also like to extent their thanks to the scientists and staffs of Aquaculture Foundation of India, Madurai, Tamil Nadu/ Guntur, Andhra Pradesh for their timely help.

References

Aitken JB and Senn TL (1965) Seaweed product as a fertilizer and soil conditioner for horticultural crops. Bot Mar 8: 144 – 148.

Amosu AO, Deborah V, Robertson A, Gavin WM, Anderson RJ and Bolton JJ (2013). South African Seaweed culture: A sustainable development example for other African coastal countries. African J Agric Res 8 (43): 5268 – 5279.

Arasaki S and Arasaki T (1983) Low calorie, high nutrition vegetables from the sea. To help you look and feel better. Japan Pub Inc Tokyo 39 – 42.

Arasaki FT, Mino N and Kuroda M (1984). The protein value in human nutrition of edible marine algae in Japan. Hydrobiologia 116/ 117: 513 – 516.

Barsanti L and Gualtieri P (2006) Algae anatomy, Biochemistry and Biotechnology. Taylor and Francis Group LLC. Boca Raton, London, New York, CRC Press.

Beas GH, Beltrones DA and Contreras H (1988) In situ rumial digestibility and degradability of *Macrocystis pyrifera* and *Sargassum spp*. In bovine livestock. Mar Sci 24 (4): 463 – 481.

Bixler HJ and Porse H (2011) A decade of change in the seaweed hydrocolloids industry. J Appl Phycol 23, 321 - 335.

Boney E (1965) Aspects of the biology of the seaweeds of economic importance. Adv Mar Biol 3: 105 – 253.

Booth E (1964) Trace elements and seaweeds. Proc. 4th International seaweed symposium. Pergaman Press, Oxford. Pp 385 – 392.

Booth E (1965) The manorial value of seaweed. Bot Mar 8: 138 – 143.

Buck ChB, Thompson CD, Roberts JN, Muller M, Lowy DR and Schiller JT (2006) Carrageenan is a potential inhibitor of papillomavirus infection. PLoS path 2 (7) 671 – 680.

Caceres PJ, Carlucci MJ, Damonte EB, Matsuhiro B and Zuniga Ea (2000). Carrageenans from Chilean samples of *Stenogramme interrupta* (Phyllophoraceae): structural analysis and biological activity. *Phytochemistry* 53: 81 – 86.

Carlucci MJ, Pujol CA, Clancia M, Noseda MD, Matulewicz MC, Damonte EB and Cerezo AS (1997). Antiherpetic anticoagulant properties of carrageenans from the red seaweed *Gigartina skottsbergii* and their cyclized derivatives: correlation between structure and biological activity. Internatl J Biol Macromol 20: 97 – 105.

Chapman VJ and Chapman DJ (1980) Seaweed and their uses. Chapman and Hall Edition, New York: Pp 334.

Chaturvedi DK, Varma SS and Khare SP (1979) Studies on feeding marine algae (*Gracilaria* meal) in laying white leghorn birds. Proc. (Abstract) Int. Seaweed Symp. Marine Algae of the Indian Ocean region, CSMCRI, Bhavnagar, India. Pp 51.

Dave MJ, Parekh RG, Ramavat BK, Doshi YA and Chauhan VD (1987) Protein content of red seaweeds from Gujarat coast. Seaweed Res Utiln 10(1): 17 - 20.

Dawczynski C, Schubert R and Jahreis G (2007) Aminoacids, fattyacids and dietary fibre in edible seaweed products. J Food Chem 103: 891 – 899.

Dawson EY (1966) Marine Botany: An Introduction. Holt, Rinehart and Winston, Inc. New York. Pp 371.

Dhargalkar VK and Untawale AG (1980) Some observations of effect of seaweed liquid fertilizer on the higher plants. Proc.Nat. Work. Algal systems. Indian Society of Biotechnology, IIT, New Delhi.

Dring MJ (1982) The biology of marine plants. Edward Arnold publishers Limited, London. Pp 199.

Duckworth M, Hong KC and Yaphe W (1971) The agar polysaccharides of *Gracilaria* species. Carbohyd Res 18: 1 – 9.

Dumelod BD, Ramirez RPB, Tiangson CLP, Barrios EB and Panlasigui LN (1999) Carbohydrate availability of arroz caldo with lambda carrageenan. Internatl J Food Sci Nutr 50(4) 283 – 289.

Enoki T, Sagawa H, Tominaga T, Nishiyama E, Komyama N and Sakai T (2003) Drugs, foods or drinks with the use of algae derived physiologically active substances. US Patent 0105029 A1.

Escrig JA and Goni Combrodon I (1999) Nutritional evaluation and physiological effects of edible seaweeds. Arch Latinoam Nutr 49 (2): 114 – 120.

FAO (2003) A guide to the seaweed industry, FAO fisheries technical paper 44, Rome.

FAO (2012) The state of World Fisheries and Aquaculture. ISBN: 978 – 92 – 5 – 107225 – 7.

FAO (2013) Valderrama D, Cai J, Hishamunda N and Ridler N (Eds) Social and economic dimensions of carrageenan seaweed farming. Fisheries and Aquaculture Technical Paper no. 580, Rome, FAO. Pp 5 – 59

FAO (2014) Fish statj–Software for Fishery Statistical Time series. Retrieved from http://www.fao.org/fishery/statistics/software/fishstatj/en

Featonby-Smith BC and Van Staden J (1984) The effect of seaweed concentrate and fertilizer on growth and the endogenous cytokinin content of *Phaseolus vulgaris*. S Afr J Bot 53: 125- 1 28.

Fortman JL, Chhabra S, Mukhopadhyay A, Chou H, Lee TS, Steen E and Keasling JD (2008) Biofuels alternatives to ethanol: pumping the microbial well. Trends Biotech 26: 375 – 381.

Ganesan K, Suresh Kumar K and Subba Rao PV (2011) Comparative assessment of antioxidant activity in three edible species of green seaweed, Enteromorpha from Okha, Northwest Coast of India. Innovative Food Sci Emerg Technol 12:73-78.

Hawkins WW, Leonard VG, Maxwell JE and Rastogi KS (1962) A study of the prolonged intake of small amounts of EDTA on the utilization of low dietary levels of calcium and iron by the rat. Canad J Biochem Physiol 40: 391 – 395.

Hayashi L, Yokoya NS, Ostini S, Pereira RTL, Braga ES and Oliveira EC (2008) Nutrients removed by *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) in integrated cultivation with fishes in recirculating water. Aquacult 227: 185 – 191.

Hu JF, Geng MY, Zhang JT and Jiang HD (2001) An in vitro study of the structure activity relationships of sulfated polysaccharides from brown algae to its antioxidant effect. J Asian Nat Prod Res 3: 353 – 358.

Indegaard M and Minsaas J (1991) Animal and Human nutrition. In: M.D. Guiry and G. Blunden (Eds.) Seaweed Resources in Europe: Uses and Potential. John Wiley and Sons. Pp: 21 – 64.

Izumi K (1971) Chemical heterogeneity of the agar from *Gelidium amansii*. Carbohyd Res 17: 227 – 230.

Izumi K (1973) Structural analysis of agar type polysaccharides by NMR spectroscopy. Biochem Biophys Acta 320: 311 – 317.

John DM (1994) Biodiversity and conservation: an algal perspective. The phycologist 38: 3 - 15.

Kaliaperumal N, Kalimuthu S and Ramalingam JR (2004) Present scenario of seaweed exploitation and industry in India. Seaweed Res Util 26, 209 - 215.

Kaliaperumal N (2006) Commercial cultivation of agar yielding red seaweed *Gracilaria edulis*. National workshop on seaweed farming and processing for food. Kilakarai, India. Pp 28 – 35.

Kannan L and Tamilselvan C (1990) Effect seaweed manures of *Vigna radiata* L (Fabaceae). In: Perspective in phycology (Prof. MOP Iyenger Centenary Celebration volume) Raja Rao, V.N (Ed.). Today and Tomorrows Printers and Publications, New Delhi, India. Pp 427–430.

Khambhaty Y, Mody K, Gandhi MR, Thampy S, Maiti P, Brahmbhatt H, Eswaran K and Ghosh PK (2012) *Kappaphycus alvarezii* as a source of bioethanol. Bioresource Technol 103: 180 – 185.

Khan W, Usha PR, Sowmyalakshmi S, Jithesh MN, Prasanth RD, Hodes M, Critchley AT, Craigie JS, Norrie J and Balakrishnan P (2009) Seaweed extracts as biostimulants of plant growth and development. J Plant Growth Regul 28:386-399.

Khotimchenko YS, Kovalev VV, Savchenko OV and Ziganshina OA (2001) Physical chemical properties, physiological activity and usage of alginates, the polysaccharides of brown algae. Russian J Marine Biol 27 (1) 53 – 64.

Kim IH and Lee JH (2008) Antimicrobial activities against methicillin resistant ***Staphylococcus aureus*** from macroalgae. J Indus Engg chem 14(5): 568 – 572.

Kilinc B, Cirik S, Turan G, Tekogul H and Koru E (2013) Seaweeds for food and Industrial Applications. http://dx.doi.org/10.5772/53172. Chapter 31 Pp: 735 – 748.

Kotiya AS, Gunalan B, Jetani KJ, Solanki JB and Kumaran R (2011) Comparison of ***Penaeus monodon*** (Crustaceae, Panaeidae) growth between commercial feed vs commercial shrimp feed supplemented with *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) seaweed sap. AACL Bioflux 4 (3): 292 – 300.

Kraan S (2012) Algal Polysaccharides, Novel Application and outlook Chapter 22, INTECH. http://dx.doi.org/10.5772/51572. Pp: 489 - 532.

Krishnan M and Narayanakumar R (2013) Social and economic dimensions of carrageenan seaweed

farming in India. . In: FAO - Social and economic dimensions of carrageenan seaweed farming. Valderrama D, Cai J, Hishamuda N and Ridler N (Eds). Fisheries and Aquaculture Technical Paper No. 580. Rome. Pp 163-184.

Lahaye M, Michel C and Barry JL (1993) Chemical, physiochemical and in vitro fermentation characteristics of dietary fibres from ***Palmaria palmate*** (L) Kuntze. Food Chem 47(1): 29 – 36.

Lahaye M (1998) NMR spectroscopic characterization of oligosaccharides from two *Ulva rigida* ulvan samples (Ulvales, Chlorophyta) degraded by a lyase. Carbohydrate Res 314 (1-2) 1- 12.

Levring T, Hoppe HA and Schmid OZ (1969) Maine algae - A Survey of research and utilization. Cram de Grutjter 1: 421.

Luescher-Mattli M (2003) Algae, a positive source for new drugs in the treatment of HIV and other viral diseases. Curr Med Chem 2: 219 – 225.

May RM (1988) How many species are there on earth. Earth Sci 241: 1441 – 1449.

Mc Hugh DJ (2002) Prospects for seaweed production in developing countries. FAO Fisheries Circular. No: 968. Rome, FAO. Pp 28.

Mc Hugh DJ (2003) A guide to seaweed Industry, FAO Fisheries Technical paper.No.441. Rome, FAO. Pp 105.

Melkonian M (1995) Introduction: XI - XIII. In: Algae, environment and human affairs. W. Wiessner, E. Schnepf, and R.C. Starr (Eds.). Biopress Ltd., Bristol: Pp 258.

Meena R, Siddhanta AK, Prasad Kamalesh, Ramavat BK, Eswaran K, Thiruppathi S, Ganesan M, Mantri Vaibhav A and Subba Rao PV (2007) Preparation, characterization and benchmarking of agarose from *Gracilaria dura* of Indian waters. Carbohydrate Polymers 69: 179–188.

Miao HQ, Elkin M, Aingorn E, Ishai Michaeli R, Stein CA and Vlodavsky I (1999) Inhibition of heparanase activity and tumor metastasis by laminarin sulfate and synthetic phosphorothioate oligodeoxynucleotides. Internatl J Cancer 83 (3) 424 – 431.

Michanek G (1975) Seaweed resources of the ocean. FAO Fish Tech Rep 138: 1-126.

Morgan KC, Wright JLC and Simpson FJ (1980) Review of chemical constituents of the red algae *Palmaria palmate*. Econ Bot 34: 27-50.

Murata M and Nakazoe J (2001) Production and use of marine algae in Japan. Jarq Japan Agric Res 35(4): 281–290.

Nabors LOB (2004) Alternative sweeteners. Agro Food industry Hi Tech 15(4) 39–41.

Nagaoka M, Shibata H, Kimura Takagi I and Hashimoto S (2003) Oligosaccharides derivatives and process for production of the same. United States Patent 6: 645-940.

Nakamura T, Nagayama K, Uchida K and Tanaka R (1996) Antioxidant activity of phlorotannins isolated from the brown alga Eisenia bicyclis. Fish Sci 62: 923-926.

Nakagawa H and Montgomery WL (2007) Algae. In: Dietary supplements for the health and quality of cultured fish. Nakagawa, H., S. Sato and. D. Gatlin III (Eds.). CABI North American Office Cambridge, MA 02139, USA. 133-168.

Neish I (2003). ABC of *Eucheuma* seaplant production. Monograph 1–0703, Suriya Link Pp 1–80.

Nishide E and Uchida N (2003) Effects of *Ulva* powder on the ingestion and excretion of cholesterol in rats. In: Chapman A.R.O., R. J. Anderson, V.J. Veeland and I. R. Davison (Eds.), Proceedings of the 17th International seaweed symposium, Oxford University, Oxford. Pp 165 – 168.

Oza RM and Zaidi SH (2001) A revised check list of Indian marine algae. CSMCRI, Bhavnagar. Pp 296.

Parthiban C, Saranya C, Girija K, Hemalatha A, Suresh M and Anantharaman P (2013) Biochemical composition of some selected seaweeds from Tuticorin coast. Adv Appl Sci Res 4(3): 362-366.

Paul NA and Tseng CK (2012) Seaweed and microalgae aquaculture, Farming aquatic animals and plant. Second edition, John, S and C Lucas (Eds.), South gate, Blackwell Publishing Ltd.

Periyasamy C, Anantharaman P and Subba Rao PV (2015) Experimental Farming of *Kappaphycus alvarezii* (Doty) Doty with income estimates at different sites in Mandapam Region, Palk Bay, Southeast Coast of India. J Appl Phycol 27: 935–944.

Qi HM, Zhang QB, Zhao TT, Chen R, Zhang H and Niu XZ (2005a) Antioxidant activity of different sulfate content derivatives of polysaccharide extracted from *Ulva pertusa* (Chlorophyta) in vitro. Internatl J Biol Macromol 37 (4) 195 – 199.

Qi HM, Zhao TT, Zhang QB, Li Z, Zhao ZQ and Xing R (2005b) Antioxidant activity of different molecular weight sulfated polysaccharides from *Ulva pertusa* Kjellm (Chlorophyta). J Appl Phycol 17 (6) 527 - 534.

Rama Rao K (1991) Effect of seaweed extract on *Zizyphus mauratiana* Lamk. J Ind Bot Soc 71: 19 - 21.

Rengasamy R (2004) Cultivation of shrimp with seaweeds. National workshop on seaweed farming and processing for food. Kilakarai, India. pp 44 – 46.

Renn DW (1984) Agar and agarose: Indispensable partners in biotechnology. I & E C Product Research and Development 23:17-21.

Renn DW, Noda H, Amano H, Nishino T and Nishizana K (1994a) Antihypertensive and antihyperlipidemic effects of funoran. Fisheries Sci 60: 423 – 427.

Renn DW, Noda H, Amano H, Nishino T and Nishizana K (1994b) Study on hypertensive and antihyperlipidemic effect on marine algae. Fisheries Sci 60: 83 - 88.

Richardson WR (1958) Preliminary investigations on the utilizations on the utilization of marine algae in the C aribbean.Pro.3rd Int. Seaweed Symp. Pp 49 -50.

Ruperez P, Ahrazem O and Leal JA (2002) Potential antioxidant capacity of sulfated polysaccharides from the edible marine brown seaweed *Fucus vesiculosus*. J Agric Food Chem 50 (4) 840–845.

Ryan Drum (2005) Island herbs and B.C. Kelp, Warldron Island, WA 98297–0025.

Siddantha AK, Shanmugam M, Ramavat BK and Modi KH (1987) Agar from *Gracilaria dura* of the West coast of India. Seaweed Res Utilin 19: 95–100.

Singh SK, Thakur R, Singh MK, Singh CS and Pal SK (2015) Effect of fertilizer level and seaweed sap on productivity and profitability of rice (*Oryza sativa*). Indian J Agron 60 (3): 69–74.

Skoler-Karpoff S, Ramjee G, Ahmed K, Altini L, Plagianos MG and Friedland B (2008) Efficacy of carraguard for prevention of HIV infection in women in South Africa: a randomized, double blind, placebo controlled trial. The Lancet 372 (9654) 1977 – 1987.

Stephenson TA and Stephenson A (1949) The universal features of zonations between tide marks on rocky coasts. J Ecol 37: 289–305.

Subba Rao PV (2012) Seaweed Biodiversity and Conservation. Proc. Symp. on Biodiversity Status & Conservation Strategies with reference to NE India. Published by Manipur Univ. ISBN: 978-81-923343-1-8. Pp 1-7.

Subba Rao PV, Eswaran K and Ganesan M (2004) Cultivation of Agarophytes in India: Retrospect, prospects and future strategies. Seaweed Res Utilin 26 (Special issue): 181–184.

Subba Rao PV and Mantri VA (2006) Indian seaweed resources and sustainable utilization: Scenario at the dawn of a new century. Curr Sci 91(2): 164-174.

Subba Rao PV, Mantri VA, Ganesan K and Suresh Kumar K (2007) Seaweeds as a human diet: An emerging trend in the new Millennium. In Advances in Applied Phycology, R. K. Gupta and V. D. Pandey (Eds), Daya Publishing House, New Delhi. Pp 85-96.

Subba Rao PV, Ganesan K and Suresh Kumar K (2009) Seaweeds: A Survey of Research and Utilization. In: Algal Biology and Biotechnology (Eds.) Khattar, J.I.S., D. P. Singh and I. K. Gurpreet Kaur. International Publishing house, PVT Ltd. New Delhi, Banglore. Pp 165-178.

Subba Rao PV, Ganesan K and Suresh Kumar K (2010) Application of seaweeds as food: A scenario. *In* Algal Biotchnology New Vistas. Mihir Kumar Das (Ed), Daya publishing house, Delhi. Pp 77-92.

Subba Rao PV, Periyasamy C, Rama Rao K and Srinivasa Rao A (2016) Seaweed for Human Welfare. Seaweed Res Utilin 38: 1-12.

Subramanian SK (1987) Studies on the effect of seaweed liquid fertilizer (SLF). International symposium on Phycology, University of Madras. Abst V33.

Sureshkumar K, Ganesan K and Subba Rao PV (2007) Phycoremediation of heavy metals by the three color forms of *Kappaphycus alvarezii*. J Hazardous Mat 143: 590–592.

Suresh Kumar K, Ganesan K and Subba Rao PV (2008) Antioxidant potential of solvent extracts of *Kappaphycus alvarezii* (Doty) Doty - an edible seaweed. Food Chem 107: 289- 295.

Thirupathi S and Subba Rao PV (2004) Manufacture of agar and algin in India. Seaweed Res Utiln. 26. Special Issue: 171-173.

Thivy F (1958) Economic seaweeds. Int. Fisheries of west coast of India. S. Jones (Ed) 1- 8.

Thivy F (1960) Seaweed utilization in India. In the proceedings of the symposium of Algology. New Delhi. Pp 345–365.

Thivy F (1961) Seaweed manure for perfect soil and soiling Welds. Salt Res. Indus1: 1 - 4.

Tseng CK (1973) Seaweed resources of North America and their utilization. Econ Bot 1: 69 - 97.

Tseng CK (1981) Commercial cultivation. In: Lobban C.S. and M. J. Wynne (Eds). The Biology of Seaweeds. Univ Calif Press, Berkeley. Pp 71-80.