Seaweeds as a Source of Micro and Macro Nutrients

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Introduction

The term seaweeds is used to refer to an assemblage of a diversegroup of multicellular marine macroalgae that usually grow along the coastlinesof oceans mostly as benthic forms (occasionally as floating forms) across different geo-climatic regions. Seaweeds are generallyregarded as marine plants since they are photosynthetic and thus, have similar ecological roles as that of other plants. Nevertheless, seaweeds are distinct from other marine plants such as seagrasses and mangroves in that they lack true roots, leaves, stem, flowers, vascular tissue etc. All marine plants obtain their nutrients including micronutrients and other compounds directly from the seawater for their growth, proliferation and development. Therefore, the growth of these plants is generally dependent on the availability of nutrients and sunlight, and lack of availability of any of these would limit the growth and overall productivity of seaweeds.

The typical structure of seaweed consists of the foliose blade (also called as the frond), the stem-like stipe and the holdfast that attaches the plant to a hard substrate. The entire plant, therefore, is called the thallus. Variation in the structureof the thallus provides a great degree of diversity in form. Seaweeds exhibit a wide diversity in their thallus morphology ranging from the simple crusts, leafy blade, tubular to filamentous form with a simple branchingto more complex forms. The size of seaweeds ranges from a few centimeters to several meters. The temperate giant kelps grow as tall as 60 meters in length. The seaweed beds provide excellent habitat and food for several economically important shellfish and crustaceans, while rendering invaluable ecosystem services that play a central role in maintaining the health of oceans.Seaweeds, based on photosynthetic pigments, are broadly divided into three groups: chlorophytes or green algae, rhodophytes or red algae, and phaeophytes or brown algae. The green algae like land plants contain *chlorophylla* and *b* and require good levels of light. Therefore, these forms are mostly foundin littoral waters. The red seaweeds contain *chlorophyll a* and *d*, and phycobilins (phycoerythrin and phycocyanin) which collectively imparts characteristic red colour to thallus. Contrary to the green seaweeds, red seaweeds can survive with the least light and indeed requires low levels of light and thus can be found even in deepest under waters where blue light alone penetrates. In brown algae, *chlorophyll a* and *c* is present along with fucoxanthin which gives a browncolour. Like green seaweed, it does require sunlight but less of it. Therefore, it can be found growing in deeper waters (but not as deep as the red seaweed). Thus, the vertical and horizontal distribution of seaweeds is determined in part by the availability of sunlight and consequently varies by depth, latitude andseason. Temperature also affects the distribution of seaweeds. The greatest number of seaweed species is in tropical waters as compared to the temperate waters. The species diversity decreases from the tropical waters to temperate waters. Also, the temperate species are quite different from that of tropical flora and grow as perennials, i.e. growing longer duration for more than two years.

There are also several other distinct features in their evolutionary history, cell wall composition, cellular storage materials, reproductive strategies, life cycles distinguishing each major group of seaweeds. Contrary to land plants, seaweed cell walls are structurally complex and diverse in chemical composition. The amorphous matrix components dominate over crystalline skeletal components. As in higher plants, the most common skeletal polysaccharide is cellulose, a linear polymer of D-glucose with a β-1, 4 linkages. The matrix polysaccharides of seaweeds show great structural variability with significant eco-physiological and commercial interest. In chlorophyta, the matrix polysaccharides are either xylogalactoarabinans or glucurono xylo-rhamnans (ulvan) with varying sulphate contents. In rhodophytes, mainly linear sulphatedgalactans composed of two regularly repeated galactose units alternatively linked by β(1-4) and α (1-3) linkages or D-galactose alternatively linked by β (1-4) and α (1-3) linkages (agars and carrageenans) are found. The major matrix component in brown seaweeds (10-45% of the thallus dry wt) is a polyuronide made up of two β-1, 4-D-mannuronic acid and α-1, 4-L-guluronic acid (alginate).

The cellular storage materials -excess sugars synthesised as part of photosynthesis is converted into polymers and stored as food reserves in the cell as starches- also variesin terms of yield and composition among the groups of seaweeds. The chlorophycean members, like land plants, have starch consisting of amylose and amylopectin while rhodophycean with floridian starch (polymer of glucose, amylopectin, and glycogen) and phaeophycean with laminarian starch (polymer of glucose and mannitol). Some of these metabolites are found to have high bioactive functions while some (sugar alcohols) are known toprotect them from severe freezing climate.

Utilisation of Seaweeds

Seaweeds as Food

The food value of seaweeds depends on the proteins, minerals, trace elements and vitamins. Marine algae have almost all essential amino acids required in the human food. Genus *Acanthophora*, *Caulerpa, Codium, Enteromorpha, Eucheuma, Gracilaria, Laminaria, Laurencia, Macrocystis, Monostroma, Porphyra, Ulva* and *Undaria* constituted protein-rich algae and consumed as a salad, soup and curry in China, Indonesia, Japan, Korea, Malaysia, Philippines, and Thailand. Species of *Ulva*, *Enteromorpha*, *Monostroma* and *Porphyra* are added in soup in China, Japan, and Korea, while *Laminaria*and *Undaria*are eaten in dried form. In the Philippines, *Caulerpalentillifera*is consumed as salad while *Codiumtomentosum, Eucheuma denticulatum* and *Kappaphycus alvarezii* in the form of curry. Several algal food products are in use in Southeast Asian countries that include jellies from *Gelidiella*a nd *Gracilaria*; jams from *Enteromorpha* and *Ulva*; pickle from *Acanthophora, Gracilaria*, *Hypnea* and *Laurencia* species. Agar is added in the preparation of foodstuffs such as tomato sauce, ice cream, jelly, lime jelly and marmalade.

Seaweeds as Nutrition Supplement

Seaweeds are more nutritional plants than land-based higher plants. Seaweeds do not have a circulatory system, leaves, roots, and stem,so it does not waste energy.It is the culinary delicacy in traditional Japanese and Chinese diet. Chinese utilizes highest seaweed species in their diet than any other ethnic group in the world. The recent report released by the Ministry of Health, Labour and Welfare, Japan (2015) indicate that the life expectancy for men and women in 2014 is the highest ever recorded in the world. The average life expectancy for Japanese men is 80.5 years of age, while for women; life expectancy was calculated at 86.83 years of age. *(Source: Delaney et al., 2016)*. The Okinawa Prefecture of Japan has among the world's longest-lived population. The evidence of longevity comes from a combination of two important indices, namely average life expectancy, and that of the centenarian ratio (number of centenarians per one hundred thousand). They use kombu in large proportion in their daily diet.The interesting study revealed that maximum patenting (182 patents) being carried out under the category of food additives and beverages followed by their applications in nutraceuticals during 1836 to 2008

Seaweed Polysaccharides

Green algae (Chlorophyceae) contain sulphatedgalactans and acidicpolysaccharide. *Ulva* species contain a high amount of polysaccharides, i.e. 65% of dry weight. Brown algae (Phaeophyceae) yield alginic acid, fucoidanand laminarin. Red algae (Rhodophyceae) give agar, carrageenan, floridean and porphyran.

Dietary Fibres

Marine algae are a rich source of water-soluble (alginic acid, agars, furonan, laminarin and porphyran) and water-insolublefibres (cellulose, mannans andx ylan) which contain some valuable nutrients and also behave as functional foods. These fibres play an active role against obesity, cholesterol and large intestine cancer). In algae, high amount of dietary fibers (% dry weight) reported exceed those for wheat bran, ranging from 23.5% (*Codium reediae*) to 64.0% (*Gracilaria* spp) *Porphyra umbilicalis* contains slightly more fiber (3.8%) than bananas (3.1%)

Protein and Amino Acids

Seaweed protein contents differ greatly from phylum to phylum. Brown algae contain 5-16 % of protein while green algae have 10-30% of protein and red algae possess 15-20% of protein. Some red seaweeds such as *Palmaria palmata*and *Porphyra tenera* contain 36% and 48% of proteins respectively, are comparable with 35% content of soybeans. The protein in *Ulva* species is in the range of 15- 20%. The free amino acids are composed of alanine, amino butyric acid, citrulline, hydroxyproline, ornithine, and taurine. The edible algae have almost similar essential amino acid composition. Some have a high level of arginine e.g., *Porphyra tenera, Ulva pertusa* and *Undaria pinnatifida. Porphyra*species contain up to 70 % dry weight protein along with all of the essential amino acids that human cannot synthesize such as leucine, lysine, methionine, threonine, tryptophan, and valine compares well with egg albumin.

Lipids and Fatty Acids

Seaweed lipid contents are polyunsaturated fatty acids with omega-3 and omega -6 acids, which are important to prevent cardiovascular diseases, diabetes, and osteoarthritis. Green algae contain alpha-linolenic acid, while brown and red algae are rich in eicosapentaenoic acid and docosahexaenoic acid. Alpha-linolenic acid, eicosapentaenoic acid anddocosahexaenoic acid are omega-3 fatty acids, which are important for human physiology. Different types of sterols are reported from seaweeds. Green algae contain cholesterol, methylene cholesterol and β- sitosterol. Desmosterol, cholesterol, sitosterol, fucosterol and chalinasterol are common in red algae. Brown algae contain a high level of fucosterol. *Laminaria* and*Undaria* species contain 83-97%

of fucosterol of total sterol (0.66 - 2.32 mg/g dry weight). *Palmaria* and *Porphyria* species reported to possess 87-93% desmosterol of total sterol (0.08 - 0.33 mg/g dry weight).

Minerals

Seaweeds are also an important source of a variety of minerals of nutritional importance. Seaweeds have high calcium, iodine, iron, potassium, phosphorus and sodium.Genus *Porphyra* contains high Fe, ranges from (0.2–0.7 g/100 g). High manganese is reported from *Pseudofalla ciatenera,* i.e. 33.2–409 μg/g dry weight.Seaweeds are a good nutritional source for iodine, particularly in foods deficient regions. *Laminaria* and *Saccharina* species are traditionally used for treating thyroid goitre due to their high iodine contents.

Vitamins

Some red seaweed, e.g. *Palmaria palmate* and *Porphyra tenera* have a large quantity of vitamins A, B_1, B_2 and B_{12}. β-carotene (pro-vitamin A) found in *Codium fragile,* and*Gracilaria chilensis* exceeds those measured in carrots. *Ulva* and *Pyropia* sp. contain considerable amounts of vitamin B_{12}*Gracilaria changii*, *Himanthalia elongate,* and *Porphyra umbilicalis* contain same levels of vitamin C as of tomatoes and lettuce. The vitamin-C content of brown seaweed *Eisenia arborea* (34.4 mg/ 100 g dry wt) matches those reported for mandarin oranges. The Vitamin C contents of brown and green algae ranges from 50 to 300 mg/100 g dry weight, are comparable to *Petroselinum crispum* (Fuss. i.e. parsley 2009).Brown algae contain vitamin E higher than green and red seaweeds. *Ascophyllum* and *Fucus* sp. contain 200 - 600 mg of tocopherols/kg of dry weight. *Macrocystis pyrifera* contain similar levels of α-tocopherol (vitamin E) as compared with vitamin E rich plant oils such as *Elaeis guineensis*J acq. (palm oil), *Helianthus annuus* L. (sun flower seed oil) and *Glycine max* (L.) Merr. (soybean oil).

Seaweeds as Medicine

Seaweeds are rich in the antioxidant vitamins C and E, in higher concentrations than land plants. Vitamin C prevents from scurvy, while vitamin E helps to manage neurological problems due to poor nerve conduction and anaemia due to oxidative damage to red blood cells. Algae iron is more readily absorbed by the human body as compared with higher land plants due to its blue pigment, phycocyanin, which forms soluble complexes with iron and other minerals during digestion. The phenolic-rich extracts obtained from *Alaria, Ascophyllum, Palmaria, Ulva* species are not only natural antioxidants but also inhibit digestive enzymes and achieve anti-diabetic effects. *Laminaria* species (kelp) contain up to 13 times more calcium than milk and powerful antioxidants. *Fucoxanthin* and *fucoidan* kelps are rich in vitamin B*,* C and K1 with high mineral contents of magnesium, potassium and iron.

Seaweeds in Industrial Uses

Agar, algin and carrageenan are the three major polysaccharides obtained from seaweeds. Agar is extracted from red algae such as *Gracilaria, Gelidiella, Gelidium,* and *Pterocladia*; while carrageenan from *Eucheuma, Gigartina* and *Hypnea.* Algin is obtained from brown algae like *Sargassum* and *Turbinaria, Ascophyllum, Cystoseira, Lallinaria, Macrocystis.* These polysaccharides have more than 200 industrial uses.

The physical properties and texture of agar gel determine its application, especially in the food and pharmaceutical industries. Agar with gel strength of about 400 $g.cm^2$ is generally used in various food products. Agar with about 800 $g.cm^2$gel strength is being used in biotechnological and pharmaceutical industries as a substrate for bacteriologic culture and tissue culture eukaryotic cell research. Carrageenan is having major industrial use as ingredients for gelling, thickening and stabilizing food, pharmaceuticals, cosmetics, hand and body lotions, shampoo, soap, toothpaste, gel fresheners and many other consumer products.Alginates, extracted from brown seaweeds, are used by the textile industry as thickeners for the paste containing dye. The chemical and pharmaceutical industries utilize alginate and carrageenan as immobilizing agents for various biocatalysts in commercial synthesis and conversion reactions. In the paper industry, alginate is used for surface sizing applications to give a continuous film surface. Xanthophyll has a large application in the colouration of cosmetic and drugs.

Biofuels from Seaweeds

The carbohydrate content of seaweed, about 50% of dry mass, can be used in biofuel production. Production of energy inseaweed can be as simple as microbial anaerobicdigestion to produce methane or as complex asa microbial breakdown of lignins and other complex carbohydrates into simple sugars for use in ethanolproduction. An annual harvest of 500million dry tons of seaweeds with 50% carbohydratecontent could produce about 1.25 billion megawatt-hours worth of methane or liquid fuel. The worldused about 85 billion megawatt-hours of energy fromfossil fuels in 2012, so energy production from theseseaweed products would equate roughly to 1.5% ofcurrent energy use from fossil fuels (IEA 2014). In terms of gas yield per tonnage,the largest size seaweed *Laminaria* sp. to biogas achieves yields of 22 m^3 per tonne of seaweed.In terms of energy yield per hectare -Current state-of-the-art seaweed-to-methane achieves a yield of 171 GJ/ha.

Seaweed-based Crop Bio stimulants

The use of sap of different seaweeds as plant growth stimulant is gaining momentum for sustainable agricultural productivity. Most of the seaweed-basedagri products available in the market (mostly imported) are manufactured from brown algae.

Global Market Value of Seaweeds

Global aquaculture production of aquatic plants in 2015 was 29.4 million tonnes with an estimated commercial value of US$4.8 billion. Seaweeds dominate the production of aquatic plants. In 2015, aquatic plants farming counted for 27.7% in the total production volume of global aquaculture in the world. Initially, seaweeds were most often used for domestic purposes as food and feed, whereas later, industrial uses (gels, fertilizers) emerged (Delaney et al., 2016).The global seaweed processing industry is estimated to use some 27 million tonnes of seaweeds annually, collected as ‘wild harvest’ or cultivated in offshore and onshore farms. The bulk of seaweed produced globally is from aquaculture, categorized as cultivated production (FAO, 2016). Wild harvest of seaweeds only accounted for about less than five percent of total seaweed production in the year 2015. Wild harvest includes harvesting of seaweeds by hand or collection of beach cast/drift algae. There is a large and diverse array of applications and uses of macroalgal products. The seaweed hydrocolloid (agar, alginate, and carrageenan) industry showed 2–3% growth per year with the Asia-Pacific region increasingly dominating the raw material and manufacturing aspects of the industry. The seaweed industry is estimated to have an annual value of US$4.8 billion, the largest share of which is human food products (FAO, 2016). The remaining US$1.058 billion is largely based on seaweed hydrocolloids (Porse and Rudolph, 2017), At least 221 species of seaweeds are exploited globally, with 145 species for food and 101 species for phycocolloid production. These include 32 chlorophytes, 125 rhodophytes and 64 phaeophytes.

Indian Scenario

Wild harvest

India has a long coastline and more than 7,500 km coastline is rich in algal diversity and resources. There are about 840species of seaweeds have been reported. Indian coastline is bestowedwith larger stretches of suitable areas for cultivation and communities of traditional fisherfolk who have interest in seaweed cultivation. In spite of all these advantages, commercial cultivation has not been taking place as being practised in South-East Asian countries. Seaweed raw material for seaweed-basedphycocolloid industries are mainly gathered from wild stocks.

In India, *G. acerosa* and *G. edulis*are being commercially harvested for agar production and *Sargassum,* and *Turbinaria*are harvested for alginate production since the early 1950s. These algae are harvested from 20 islands and the mainland coast of Gulf of Mannar and Palk Bay, Southeast coast of India. A broad (approximately 300 meters wide) and long stretch (approximately 140 km long) of coralreef runningparallel to the islands and reef in the coastalregion of Gulf of Mannar from Kilakkarai to Valinokkamsupports the growth of *Sargassum*spp, *Turbinaria* spp., *G. acerosa* and *G.edulis*.

Similarly, the coastline of Palk Bay from Mallipattinam (in Pudukkottai District) to Devipattinam (in Ramanathapuram District)harbours rich resources of *Gracilariasalicornia* and *Gracilariaedulis*. Commercial harvest of these seaweeds from the reef of Gulf of Mannar islands and mainland coast is donemostly during spring tides of the full moon and new moon days. About 5000 women in the age group of 18-35 with primary level education are harvesting the seaweeds from the reef. Seaweeds harvested from the Gulf of Mannar island reef and the mainland are collected in the boat and brought to the shore. Agents or middle men are procuring the seaweeds from the harvesters on the shore itself and selling the seaweeds to the industry.

Landings of Agar yielding seaweeds viz. *Gelidiella acerosa* and *Gracilaria edulis* during 2003 to 2016 showed gradual depletion of their resources. *G. acerosa*is firmly attached to the hard substrata and difficult for uprooting the alga while *G. edulis* is attached to the muddy and sandy bottom which can be uprooted easily. Landings of alginate yielding seaweeds viz. *Sargassum* spp. And *Turbinaria* spp during 2003 to 2006 showed heavy fluctuations.Nevertheless, hundreds of thousands of tonnes of *Sargassum* and *Turbinaria* are available in the resources, only few thousand tonnes are being harvested annually.

Reference

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