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Seaweeds: A Sustainable Marine Resource for Food, Feed, Medicine, and Industry: A Review

Surekha Parshram Rode[1] and Lubdha Abhijeet Kagale[2]
[1]Department of Botany, Prof. Dr. N. D. Patil Mahavidyalaya, Malkapur-Perid
[2]Department of Botany, Rajaram College, Kolhapur
Corresponding Author: rodesurekha@gmail.com

Abstract: *Algae are simple, photosynthetic, non-vascular organisms that lack true roots, stems, and leaves, yet exhibit diverse structural forms ranging from unicellular to complex thalli. Among them, macroalgae or seaweeds represent an important group of marine resources with significant ecological, nutritional, and economic value. Seaweeds are rich in essential nutrients such as vitamins, minerals, proteins, dietary fiber, and polyunsaturated fatty acids, making them an important component of human diets, particularly in Asian countries. Their bioactive compounds, including sulfated polysaccharides, exhibit a wide range of pharmacological properties such as antibacterial, antiviral, anticoagulant, antioxidant, and antitumor activities.*

In addition to their use as human food, seaweeds play a vital role in animal nutrition as feed supplements, improving growth, fertility, and product quality. They are also widely used as organic manure and biofertilizers, enhancing soil fertility and crop productivity. Industrially, seaweeds are a major source of hydrocolloids like agar, alginates, and carrageenan, which have extensive applications in food, pharmaceutical, and biotechnology industries. Furthermore, seaweeds possess medicinal properties and have been traditionally used to treat various ailments, including goiter, infections, and inflammatory conditions.

seaweeds are multifunctional marine resources with immense potential in food security, agriculture, industry, and medicine, highlighting the need for their sustainable utilization and further research into their diverse applications

Keywords: Algae are simple, photosynthetic, non-vascular organisms that lack true roots, stems, and leaves, yet exhibit diverse structural forms ranging from unicellular to complex thalli.

INTRODUCTION

India's long coastline of approximately 8115 km harbors a diverse range of marine flora, including numerous species of seaweeds (macroalgae), which play a significant role in oceanic primary productivity (about 2–10%). Although the global diversity of macroalgae is estimated to exceed 150,000 species, only a limited number have been identified, with around 624 species documented along the Indian coast.

Seaweeds are simple, thallus-based marine organisms that lack true roots, stems, and leaves. They commonly grow attached to hard substrates such as rocks and coral reefs. Their distribution is largely governed by light availability, leading to clear zonation patterns across the littoral regions. The upper littoral zone is dominated by resilient species, the mid-littoral zone mainly supports green (Chlorophyceae) and brown algae (Phaeophyceae), while the lower littoral zone is primarily composed of delicate red algae (Rhodophyceae).

Based on their pigmentation, seaweeds are categorized into three main groups: Chlorophyceae, Phaeophyceae, and Rhodophyceae, each exhibiting distinct biochemical characteristics. Worldwide, more than 250 seaweed species are commercially exploited, with nearly 150 species being used for human consumption, especially in Asian countries.

From a nutritional perspective, seaweeds are a valuable source of proteins, carbohydrates, polyunsaturated fatty acids, essential amino acids, vitamins, and minerals such as calcium, magnesium, potassium, and iodine. They

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also contain significant amounts of dietary fiber and ash. However, their nutritional composition varies depending on species, environmental conditions, and seasonal changes, with higher protein levels generally recorded during late winter and spring. Owing to their nutritional richness and industrial potential, seaweeds are increasingly considered an important resource for food and pharmaceutical applications.

II. UTILIZATION OF SEAWEEDS

1. Human food:

Seaweeds are consumed in various parts of the world including Japan, China and Korea where commercial cultivation of seaweeds prevails. In these countries seaweeds form major constituents of daily diet of people. They are consumed in the form of soups as well as salads. The intake of seaweeds in the diet is said to prevent hair loss in men and women and they are good for pregnant and lactating mothers because of their rich iron content. They are known as the medical food of 21st century. In Asian countries seaweeds are consumed as marine vegetables and represent an excellent source of essential vitamins A, B, B_{12}, C, D, E, riboflavin, niacin, pantothenic acid and folic acid. Watanabe *et al.* (1999) claimed that only two or three sheets of Nori (3g) are sufficient to satisfy the recommended daily intake of vitamin B_{12} for a normal adult (2µg/day).

Seaweeds contain a high concentration of minerals such as magnesium, calcium, phosphorous, potassium and iodine (Jimenez and sanchez, 2000). Burtin (2003) found that seaweeds are one of the most important source of calcium and their content may be as high as 34 % dry weight. Soja (2006) stated that some variety of seaweeds is even richer in calcium than milk and the human body can utilize nutrients from algae. Shep (2001) reported that sea vegetables are a good source of magnesium which help to reduce high blood pressure and chances of heart attack.

Proteins are important and essential factor establishing the nutritional value of food. Their biological value is based on the adequate amount of essential amino acids. Seaweeds are known to possess a significant amounts of these nitrogenous compounds. They also contain a small amount of non-protein nitrogen which is the source of some compounds such as free amino acids, chlorophylls, nitrate and nitrite nitrogen, ammonium ions and nucleic acids (Lourenco *et al*., 2002). It has been reported that red and green seaweeds have a relatively high protein concentrations and the average content may reach up to 10-30% dry matter (Mebeau and Fleurence, 1993). Seaweeds posses small amount of lipids and those are mostly polyunsaturated omega-3 and omega-6 fatty acids. They have a high dietary fiber content.

Chemical composition of seaweeds varies with species, habitat, maturity and environmental conditions like water, temperature, light intensity and nutrient concentration in water (Ito and Hori, 1980; Mebeau and Fleurence, 1993; Marsham *et al*., 2007). Seaweeds are able to selectively absorb minerals from the surrounding seawater and accumulate them in their thalli (Ajmal *et al*., 2006). Seaweeds collected from the Persian Gulf generally contained higher concentration of all minerals examined, compared to common vegetables such as lettuce (*Lactuca sativa*) and spinach (*Spinacia oleracea*) (Kiuomars *et al*., 2012). Potassium and magnesium content in the examined seaweeds were comparable or higher compared to that found in spinach (with the exception of magnesium in red seaweeds) while content of other of minerals (Fe, Zn, Mn and Cu) in seaweeds were comparatively higher compared to that found in lettuce and spinach. Nutritional aspects of seaweeds in terms of fiber, minerals, lipids and vitamin content are studied by Macartain, *et al*. (2007) According to them a daily intake of eight gram dry seaweed is sufficient for potential nutrient supply.

Compared to land plants the chemical composition of seaweeds has been poorly investigated and most of the available information only deals with traditional Japanese seaweeds (Watanable and Nisizawa, 1984; Nisizawa *et al*., 1987). Recently marine algae have been exploited in Japan as raw material for manufacturing of many seaweed food products such as, jam, cheese, wine, tea, soup and noodles. They are also used as emulsifying agents in food (Ananthraman, *et al*., 2010).

Seaweeds from chlorophyceae (*Caulerpa lentilifera, C. taxifolia, Enteromorpha compressa, E. intestinalis, E. flexuosa, Ulva fasciata, U. lactuca, U. rigida*) and rhodophyceae (*Gracilaria folifera, G. edulis, Gelidiella*

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acerosa Hypnea musciformis H. valentiae, Kappaphycus alvarezii etc.) are rich in protein and carbohydrate (Arpon *et al*., 2006; Ratana-arporn and Chirapat 2006; Rajsulochana *et al.,* 2012a; Kokilam and Vasuki 2013; Parthiban *et al*., 2013). In Japan about 21 varieties of seaweeds are being used as sea vegetables in every day cookery. The thin delicate red seaweed *Porphyra* is processed and used as a culinary dish known as 'laver' in Britain and 'Nori' in Japan (Chapman and Chapman, 1980). Apart from this the Japanese use 'Kombu,' a preparation out of *Laminaria* and 'Wakame,' a preparation out of *Undaria*, in their daily diet.

III. FODDER

Seaweeds are a rich source of proteins, lipids, carbohydrates, trace elements, vitamins etc. and used as animal feed in many countries. Some experiments have shown that seaweed meal improves fertility and birth rate of animals. According to Stephenson (1974) this may be due to the presence of vitamin E (tocopherol). Seaweed meal has been found to improve the iodine content and color of egg yolk (Thivy, 1959). In the farming of milkfish, seaweed feeds have been used extensively (Thivy, 1959). *Enteromorpha clathrata* feed is used in prawn culture fields to improve their growth and survival rates (Krishnamurthy *et al*., 1982). It is found that seaweed meal upto 10% in the basic daily ration has beneficial effects on animals.

Chapman (1970) has reported the use of seaweeds by Greek and Romans as emergency ration for their livestock. Seaweed meal is given to the farm animals (cattle, poultry etc.) as a supplementary food source to increase animal productivity and nutrition. Nutritive value of different seaweed species used to feed farm animals is documented by Dhargalkar and Neelam (2005).

IV. MANURE

In coastal areas throughout the world, use of seaweeds as a manure is a common practice. Carbohydrates present in seaweeds improve water holding capacity of the soil. Seaweeds get decomposed easily adding organic matter to the soil which is beneficial for the growth of soil microorganisms. Application of seaweed manure can maintain a high level of nitrogen in the soil. Seaweed manure directly or as compost was found to be superior to conventional farmyard manure (Chennubhotla *et al*., 1987). It was observed that nitrogen fixing capacity of organic nitrogen from *Ulva lactuca* is higher compared to farmyard manure (Mehta *et al.,* 1967).

Seaweed extracts have successfully used as a foliar spray for inducing faster growth in agriculture and horticulture. Large quantities of *Gracilaria* and *Caulerpa* are being used as manure for coconut plantations in Kerala and Tamil Nadu in India (Mathew, 1991).

V. INDUSTRIAL USES OF SEAWEEDS

A hydrocolloid is a non crystalline substance with very large molecules which dissolve in water to form a thickened solution. Red and brown seaweeds produce hydrocolloids namely agar, alginates and carrageenan which are water soluble carbohydrates that are used to thicken (increase the viscocity of) aqueous solutions to form gels (jellies) of varying degrees of firmness, to form water soluble films and to stabilize some products such as ice-cream. These products are difficult to synthesize chemically because of formidable chemical barriers and hence for these commercially important products seaweed resources are used (Dhargalkar and Pereira, 2005). The demand of phycocolloids in the Indian market is much higher than what is produced and therefore phycocolloids are imported from other countries like Norway, Scotland, Chile, China, Spain, Japan, France and the Philippines.

Agar-Agar:

It is gelatinous colloidal carbohydrate present in the cell walls of some red algae. It is a mixture of two polysaccharides, agarose and agaropectin. This substance has the property of forming gel on cooling. The best known use of agar is as a solidifying agent in bacteriological culture media. Apart from this it is used in various industries (Anon, 1990).

Agar yielding seaweeds are called agarophytes and some important agarophytes of Indian waters are *Gelidiella acerosa, Gracilaria edulis, G. corticata, G. crassa, G. folifera* and *G. verrucosa*.

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Algin:

Algin is a polysaccharide occurring in the cell walls of brown algae. It consists of D- mannuronic acid and 2-guluronic acid in various proportions. The sodium, potassium and magnesium salts of alginic acid are soluble in water and they give a viscous liquid without gel formation (Anon, 1990).

Algin yielding seaweeds are called alginophytes and important among them in India are species of *Sargassum* and *Turbinaria.*

Carrageenan:

Certain red algae produce gel like extracts called agaroids. They differ in their properties and chemical nature from agar. Carrageenan comes under this group. Organic sulphate content in these compounds is very high. Pure solution of agaroids is viscous and does not form gel when cooled. Inorganic and organic solutes can alter the properties of agaroids and improve their gelling power.

Important carrageenan yielding seaweeds of India are *Gigartina acicularis, Hypnea musciformis,* species of *Acanthophora, Laurencia, Sarconema, Spyridea* and *Chondria*.

Apart from these seaweeds yield phycocolloids of lesser importance such as mannitol, laminarin, fucoidan etc. which are valuable in specific uses.

VI. MEDICINAL USES

Seaweeds have been used to treat cough, wounds, gout, venereal disease etc. Seaweed extracts have shown to strengthen the nervous system and enrich the blood system. They also have ability to lower the blood plasma cholesterol level and are said to be the best natural source for dietary iodine (Dhargalkar and Neelam, 2005). Range of iodine in Indian seaweeds is 0.02- 0.024% on dry weight basis ((Thivy, 1958)).

Various red algae like *Corollina officinalis, C. rubens* and *Alsidium helminthocorton* are being employed as vermifuge from ancient times. Dulse (*Palmaria palmata*) is being used in the treatment of goiter (Umamaheswara Rao, 1970). Extracts of *Chondrus crispus* and *Gelidium cartilagineum* have been found to be active against influenza B and mumps virus (Garber *et al.,* 1958).

Agar is used in manufacture of dental impression mould. Alginates when injected into the lung cavities of tuberculosis patients, stop internal bleeding (Thivy, 1958).

Sargassum and *Laminaria* can clear heat, transform phlegm, soften hardness and dissipate nodules. They can also promote urination and reduce edema. In clinical practice, they are often used together to treat nodules such as goiter and scrofula (Yang, 2002).

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