



International Journal of Biology Sciences

ISSN Print: 2664-9926
 ISSN Online: 2664-9934
 NAAS Rating (2026): 4.82
 IJBS 2026; 8(5): 166-169
www.biologyjournal.net
 Received: 13-02-2026
 Accepted: 15-03-2026

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Seaweed: An innovation in global food sector

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DOI: <https://www.doi.org/10.33545/26649926.2026.v8.i5c.844>

Abstract

Seaweed is traditionally consumed in countries like Japan, China, and South Korea. This is now gaining worldwide recognition as a sustainable, nutritious, and climate-friendly food source. Global cultivation of algae, dominated by seaweeds, grew by half a million tonnes in 2025. However, India is in the infant stage of the seaweed culture. About 200 species are being commercially cultivated along the coasts of Tamil Nadu, Gujarat and around Lakshadweep and Andaman & Nicobar Islands. Now the expansion of cultivation going along the coastal line. India has set an ambitious target to produce over 1.12 million metric tonnes (MT) of fresh seaweed by 2025-26 under the Pradhan Mantri Matsya Sampada Yojana (PMMSY). The main varieties include Chlorophyta (green algae), Phaeophyta (brown algae) and Rhodophyta (red algae). This initiative aims to scale up production from roughly 34,000-74,000 tonnes currently, with a long-term goal of fostering a major industry for coastal livelihood. The present review highlights the various types of seaweeds and their potential applications and uses.

Keywords: Seaweed cultivation, marine algae, sustainable aquaculture, coastal livelihoods, PMMSY

Introduction

Seaweeds are macroscopic benthic marine algae growing in marine and shallow coastal waters and brackish water habitats up to a depth of 118 - 120 m where negligible amount of photosynthetic light is available (Chapman, 1970; Okazaki, 1971)^[5, 6]. They are primitive type of plants can be very tiny, or quite large, growing up to 30 meters long. Seaweeds found attached to rocks in the intertidal zone, washed up on the beach and floating on the ocean's surface. It's widely used as food, fertilizer, animal feed, and in industry, and it plays an important ecological role in marine ecosystems. Seaweeds are found in the coastal region between high tide to low tide and in the sub-tidal region up to a depth where 0.01% photosynthetic light is available (Dhargalkar, 2004)^[11].

Seaweeds are often considered as sea vegetables because of their nutritional values and one of the most important renewable resources found in the marine environment. Seaweeds have been used as animal feed since ages. Seaweeds have been mentioned in Chinese literature for 2500 years ago (Tseng *et al.*, 2004)^[27]. Greeks were using seaweeds as animal feed in as early as first century BC. However, its use as feed was localized in coastal European countries such as Ireland, Iceland, Norway, France, Spain, and Portugal (McHugh, 2003; Kumar and Kaladharan, 2007)^[21]. In many parts of the world, they are frequently used as food and feed ingredients, and in several European and Asian countries, as well as Japan, China, and Korea, they are considered a delicacy (Mir *et al.*, 2018). Due to the rapid increase of world population in current scenario, the globe will need to produce 50-70% more food to sustain current consumption patterns (Dey *et al.*, 2025)^[9, 23].

In Asia, seaweeds have been used for centuries in salads, soups and as low-calorie dietetic foods. The dietary fibre which constitutes 25-75% of the dry weight of marine algae and represents their major component, is primarily soluble fibre (Jimenez-Escrig and Sanchez-Muniz, 2000, Premarathna *et al.*, 2022)^[25]. Nowadays, dietary fibre from different food sources is in focus as they decrease the risk of coronary artery disease. The capacity of seaweed polysaccharides to lower serum cholesterol levels seems to be due to their ability to disperse in water, retain cholesterol and related physiologically active compounds and inhibit lipid absorption in the gastrointestinal tract (Jimenez-Escrig and Sanchez-Muniz, 2000)^[18]. Over 20,000 species of seaweeds are found globally, yet only 221 (1.1%) are used commercially.

This includes 145 species for food consumption and 110 species for the production of phycocolloids (Chennubhotla *et al.*, 2013, Yadav *et al.*, 2020) [7, 30].

Marine macroalgae have been used as food for centuries, especially in Asian coastal regions (Bast, 2014 & Wilding *et al.*, 2021) [2, 29]. In recent years, seaweed has gained global attention as a nutrient-dense, sustainable, and functional food with applications in animal feed, bio-based products, pharmaceuticals, and aquaculture due to its nutritional aspects. Edible seaweeds provide a substantial source of dietary fibre, protein, vital fatty acids, vitamins, minerals, and a variety of useful polysaccharides (Bhaskar & Miyashita, 2005, Rajasulochana *et al.*, 2010) [3, 26]. Additionally, seaweeds are also gaining importance as healthy food for human consumption as it is one of the best sources of both water and lipid soluble vitamins like thiamine, riboflavin, β -carotene, and tocopherols. The Japanese have been eating raw fish, sticky rice, and other foods in combination with seaweed called as “Nori” for at least 1,500 years (Pati *et al.*, 2016) [24]. Apart from their utility as a source of food, food derivatives, proteins, etc., in India seaweeds are mostly employed for the industrial production of phycocolloids such as agar-agar, alginate, and carrageenan, but not for culinary purposes (Dhargalkar & Pereira, 2005) [12].

India has good potential for seaweed farming, especially along the Tamil Nadu, Gujarat, Andhra Pradesh, and Lakshadweep coasts, with species like *Kappaphycus* and *Gracilaria*. There are also rich seaweed beds around Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhinjam and Pulicat in Tamil Nadu and Chilka in Orissa (Kaliaperumal, 1993) [19]. Out of approximately 700 species of marine algae found in both inter-tidal and deep-water regions of the Indian coast, nearly 60 species are commercially important. Agar

yielding red seaweeds such as *Gelidiella acerosa* and *Gracilaria sp.* are collected throughout the year while algin yielding brown algae such as *Sargassum* and *Turbinaria* are collected seasonally from August to January on Southern coast.

The surveys conducted by Central Salt and Marine Chemicals Research Institute (CSMCRI) and Central Marine Fisheries Research Institute (CMFRI), along with other research organizations, have clearly demonstrated that the coastal belts of South India possess abundant and diverse seaweed resources (Gopalakrishnan., 2024) [14]. On the West Coast, especially in the state of Gujarat, abundant seaweed resources are present on the intertidal and subtidal regions (Dhargalkar & Deshmukhe, 1996) [10]. These resources have great potential for the development of seaweed-based industries in India which are nutritional important in the diet.

Basically, depending upon the photosynthetic pigments in seaweeds, these were classified into three major divisions such as Chlorophyta (green algae), Phaeophyta (brown algae) and Rhodophyta (red algae) (Chapman & Chapman, 1980) [5, 6]. There are about 900 species of green seaweed, 4000 red species and 1500 brown species found in nature (Dawes, 1998) [8]. As the natural seaweed can be had fresh, cooked, dried or as a supplement diet.

- 1. Chlorophyta (Green algae):** Rich in chlorophyll, common in shallow waters. Example: *Ulva*, *Enteromorpha*
- 2. Phaeophyta (Brown algae):** Large seaweeds (kelps), rich in iodine and alginates. Example: *Laminaria*, *Sargassum*, *Undaria*
- 3. Rhodophyta (Red algae):** Source of agar and carrageenan. Example: *Porphyra*, *Gracilaria*, *Gelidium*

Table 1: List of some commercial seaweeds

Category	Scientific Name	Common Name
Brown algae:	<i>Alaria esculenta</i>	Winged kelp, bladder locks
	<i>Ascophyllum nodosum</i>	Knotted wrack, egg wrack
	<i>Fucus serratus</i>	Serrated wrack, toothed wrack
	<i>Fucus spiralis</i>	Flat wrack, Spiral wrack
	<i>Fucus vesiculosus</i>	Bladder wrack
	<i>Halopteris scoparia</i>	Sea flax weed
	<i>Himanthalia elongata</i>	Thong weed
	<i>Laminaria digitata</i>	Atlantic kelp
	<i>Laminaria hyperborea</i>	Tangle
	<i>Saccharina japonica</i>	Royal kombu
	<i>Sargassum fusiforme</i>	hiziki
	<i>Padina pavonica</i>	Peacocks tail
Red algae	<i>Undaria pinnatifida</i>	Sea mustard
	<i>Chondrus crispus</i>	Japanese wireweed
	<i>Erythrogllossum laciniatum</i>	Red laver
	<i>Gracilariopsis longissima</i>	Chinese nori
	<i>Palmaria palmata</i>	Sea lettuce
	<i>Porphyra dioica</i>	Black laver
	<i>Porphyra umbilicalis</i>	Nori
	<i>Neopyropia tenera</i>	Gim
	<i>Neopyropia yezoensis</i>	Open sea nori
	<i>Vertebrata lanosa</i>	Wrack siphon weed
Green algae	<i>Chaetomorpha linum</i>	Flax brick weed
	<i>Rhizoclonium riparium</i>	Rooting green thread weed
	<i>Ulva lactuca</i>	Sea lettuce
	<i>Ulva linza</i>	Doubled ribbon weed
	<i>Ulva rigida</i>	Sea lettuce

Source: Banach *et al.*, 2020 [1]

Seaweeds have long been important contributors to food security and livelihoods around the world, delivering benefits through diverse food and non-food applications. Its food uses are especially relevant in Asia, which has a history of over 2000 years of consuming the commodity either fresh as salads in Malaysia and Indonesia or processed as “Nori” (Cai *et al.*, 2021)^[4]. The nutritional benefits of seaweed depend on the type (brown, green or red) and whether it's raw, cooked or dried. Overall, seaweed has ten times higher minerals of many vegetables. They are rich in polysaccharides, a type of carbohydrate, that is used by the food industry as a thickener and emulsifier. These polysaccharides also act like dietary fibres and promote gut health as a prebiotic food source for beneficial gut bacteria. Seaweed is a good source of follows:

a) Proteins

- Protein content ranges from 5-47% on dry weight
- Red and green seaweeds generally have higher protein content
- Rich in essential amino acids (lysine, methionine, threonine)

b) Carbohydrates

- Major component (30-60%)
- Includes dietary fibres such as alginate (brown seaweed), carrageenan (red seaweed) and agar (red seaweed)
- Helps in digestion and gut health

c) Lipids

- Low total fat (1-5%)
- Rich in polyunsaturated fatty acids (PUFAs)
- Contains omega-3 fatty acids (EPA, DHA) beneficial for heart health

d) Vitamins

Seaweeds are excellent sources of vitamin A (β -carotene), vitamin C, vitamin E, vitamin K and B-complex vitamins (B₁, B₂, B₆, B₁₂).

e) Minerals

Seaweeds are exceptionally rich in minerals like Iodine - supports thyroid function, Calcium, Iron, Magnesium, Potassium, Zinc and Selenium.

Mineral content is often 10-20 times higher than in terrestrial vegetables.

Uses of seaweed

- **Human food:** nori, wakame, kombu (common in Asian diets)
- **Aquaculture & agriculture:** organic fertilizer, soil conditioner, feed additive
- **Industry:** agar, alginate, carrageenan (food, pharma, cosmetics)

Environmental benefits

- Carbon sequestration
- Nutrient removal (useful in integrated multi-trophic aquaculture - IMTA)
- Coastal habitat and shoreline protection

Health benefits of seaweed

Seaweed's natural plant chemicals (phytochemicals) and low calories and fat make it a nutritional powerhouse or superfood.

Lowers risk of certain diseases

Seaweed has several nutrients that help prevent disease, including polyphenols and omega-3 fatty acids. It's also high in carotenoids like beta-carotene and lutein. Some studies suggest that polyphenols in seaweed act as antioxidants, helping protect against the damaging effects of free radicals (Michalak *et al.*, 2022)^[22]. Cell damage from free radicals can lead to cancer, autoimmune disease, Alzheimer's disease and other life-changing conditions.

Improves gut health

Seaweed is rich in polysaccharides. This carbohydrate acts like dietary fiber and serves as a food source (prebiotic) for healthy bacteria in the gut. Seaweed has other healthy fibres including cellulose.

Industrial applications of seaweed

Saccharina japonica have been largely applied in the bio-oil production, which can be used as a combustion fuel for green electricity generation (Zeb *et al.*, 2017)^[31]. Red seaweed extracts like *Gracilaria salicornia* were used as a raw material for the synthesis of bioplastic film (Hi *et al.*, 2016), as a multiproduct source for biotechnological, nutraceutical, and pharmaceutical applications with *Gracilaria gracilis* (Francavilla *et al.*, 2013)^[13] and as a flavour supplement like savoury source for seafood products with *Gracilaria fisheri* (Laohakunjit *et al.*, 2014)^[20]. Other seaweeds like carrageenan are used to make traditional medicinal teas and cough medicines to cure cold, bronchitis, chronic cough with *Chondrus crispus* and to cure diarrhoea, constipation and dysentery by *Mastocarpus stellatus* red seaweed species (Holdt and Kraan, 2011)^[17]. The red algae, namely Gelidium and Gracilaria, are commercially important in the agar industry and provide bioremediation properties when cultured in effluent waters. Hanjabam *et al.* (2017)^[15] investigated the nutritional impact of adding seaweed to jerky, a snack made from tuna, a marine species.

Conclusion

India's coastline harbours an extensive diversity of seaweed species, presenting a rich resource of bioactive compounds and essential minerals with numerous health benefits. Despite seaweed being widely consumed in Western and East Asian countries, it remains relatively underutilized in the Indian subcontinent. The ongoing depletion of marine resources in Indian waters, there is an increasing need to explore unconventional resources such as seaweed to develop commercially valuable food products. Seaweed is a highly nutritious, functional, and sustainable food resource with immense potential to address nutritional security, especially in coastal regions. With proper cultivation, processing, and awareness, seaweed can play a major role in future food systems, aquaculture, and public health. Seaweed, offers promising potential due to its nutritional richness and functional properties, which make it suitable for value-added products in the food industry as per present market demand.

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