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Sea Vegetables: An Alternative Food Source: A Review

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ABSTRACT

Seaweeds or sea vegetables are the non-traditional vegetables largely produced and consumed by China, Japan, Korea, Indonesia, Philippines, Malaysia, Vietnam and other island countries. They are rich in essential nutrients, including minerals, vitamins, amino acids *etc*. making them a valuable addition to a balanced diet. Moreover, they have low caloric content and are free from cholesterol, essential for weight management and heart-healthy diets. Additionally, sea vegetables contain unique bioactive compounds such as polysaccharides, polyphenols and omega-3 fatty acids, which have antioxidant, anti-inflammatory and anti-cancer properties. Globally the demand for seaweed as vegetables along with its several value-added products are increasing day by day. The cultivation of seaweed is cost effective as it does not require seeds, fertilizers, pesticides, no freshwater and arable land. Sea vegetables can serve as bio filters by absorbing excess nutrients from aquatic ecosystems, thus promoting environmental sustainability in coastal aquatic system. To combat hunger, achieve food security and protect the environment, it is crucial to create public awareness on the health benefits and nutritional value of sea vegetables. More in-depth research and developments are required to commercialize, explore the diversity of sea vegetables, develop innovative culinary applications and establishment of quality and safety standards. The present review works highlights a comprehensive overview of seaweed diversity, nutritional composition, health benefits, diverse uses, cultivation methods and potential for developing processed products for food and agricultural industry.

Key words: Aquatic ecosystem, Food diversity, Nutritional security, Sea vegetables.

Seaweed or sea vegetables are group of marine algae that grow in ocean as well as in rivers, lakes and other water bodies. Seaweeds are classified as algal-photosynthetic organisms, they are microscopic, multicellular, eukaryotic, marine algae (micro-algae and macro-algae) that resemble plants but do not flower and lack developed tissues or roots. Worldwide, at least 145 species of macro-algae are consumed as food (Zemke-White and Ohno, 1999). Based on color it can be classified as brown (Phaeophyta), red (Rhodophyta) or green algae (Chlorophyta) which grows under aquatic condition (Table 1). Sea vegetables are nutrient dense loaded with vitamins, minerals and amino acids. Being low caloric content, rich in unique bioactive compounds such as polysaccharides, polyphenols and omega-3 fatty acids, it is suitable for weight management, heart-healthy diets and provides several health benefits. Globally seven countries namely China, Japan, Korea, Indonesia, Philippines, Malaysia and Vietnam contribute to the major seaweed production of the World. Due to the several health benefits provided by seaweed it has historically been used in a wide range of cuisines, including raw salads, soups, cookies, meals and condiments in Pacific islands like Indonesia, Philippines, Maori of New Zealand, Hawaii and Asian nations like China, Japan and Korea. The most commonly consumed seaweed vegetable are group large and leafy brown algae commonly known as kelps. The popular species of kelps used in Asian cuisine are of kombu (*Saccharina japonica/ Laminaria digitata*), wakame (*Undaria pinnatifida*), alaria (*Alaria esculenta*). The other popular sea vegetables are salicornia (*Salicornia europaea*), dulse (*Palmaria palmata*), nori (*Pyropia sp.*), Irish moss (*Chondrus crispus*), sea purslane (*Sesuvium portulacastrum*), hijiki (*Sargassum fusiforme*) and mozuku (*Cladosiphono kamuranus*), umibudou (*Caulerpa lentillifera*), aonori (*Monostroma* spp.) and nori (*Porphyra yezoensis*) (Table 2). In 2014, 7.7 million tons of Kombu (*Saccharina japonica*), 2.4 million tons of Wakame (*Undaria pinnatiida*) and 1.8 million tons of Nori (*Porphyra sp.*) which is particularly used in dry form in sushi preparation were produced. In recent years, due to the increasing health concerns and diversification of diet, several value-added products of seaweed like kelp pickle, kelp chips, kelp crunch, kelp jerky, kelp sauerkraut, smoked kelp powdered seaweed, dehydrated seaweed, frozen value added products (seaweed noodles and seaweed cubes) along with dishes like sushi, *hoshi-nori* is becoming popular in several western countries and other Asian countries (Anonymous, 2018). The value of global seaweed

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cultivation was 32.4 million tonnes (wild-collected and cultivated aquatic algae) of which farmed seaweeds represents 97.1% by volume. Among the seaweeds, 13% have been used for the production of hydrocolloids (polysaccharides), such as agar, alginate or alginic acid and carrageenan, while 75% are used for food and the remaining (12%) are used by agriculture industry (Hardouin *et al*., 2014). *Gelidiella acerosa* value is USD $1800 per dry tonne; *Gracilaria*s pp, *Sargassum* and *Turbinaria* value is approximately US $800 per dry tonne. India produced around 34,000 tonne of seaweed with production potential of 9.7 million tonnes (wet weight) per year. Since ancient times, seaweed has been part of the daily food of a large number of coastal people (Yang *et al*., 2010). Again, seaweed is consumed at a regular basis in many South-East Asian nations. *Ulva, Laminaria* and *Porphyra* are the popular seaweed species consumed traditionally by Asian population. However, in western diet seaweed have restricted use as food extracts and additives (MacArtain *et al*., 2007). The potential health benefits and lack of knowledge regarding consumption of seaweed challenges its use in the daily diet (Kadam *et al*., 2010). Kelp aquaculture sequesters carbon and removes nitrogen and phosphorus from local coastal ecosystems, achieving localized climate remediation alongside production of marketable ocean products (Hamadan *et al*., 2020). The supplementation of seaweed formulations enhances hemoglobin levels, relative abundance of lymphocytes and lymphocyte-to-neutrophil ratio and boosts the humoral immune response in crossbred calves Handique *et al*. (2021). Red algal

Table 1: Classification of seaweed based on color.

Phylum or class	Species	Selected common names
Cyanobacteria	*Spirulina platensis* (Gomont) Geitler = *Arthrospira platensis* Gomont	Spirulina
Chlorophyta (green algae)	*Chaetomorpha linum* (O.F.Müller) Kützing	Warakuzumo, flax brick weed (U.K.)
	Chlorella vulgaris Beyerinck	
	Ulva lactuca Linnaeus	Sea lettuce
	Enteromorpha prolifera O.F.Müller = *Ulva prolifera* (O.F.Müller) J. Agardh	
Rhodophyta (red algae)	*Eucheuma cottonii* Weber van Bosse = *Kappaphycus alvarezii* (Doty) Doty ex Silva	Elkhorn sea moss
	Gracilariopsis lemaneiformis (Bory de Saint-Vincent) E.Y.Dawson, Acleto and Foldvik	
	Palmaria palmata (Linnaeus) F. Weber and D.Mohr	Dulse
	Porphyra/Pyropia	Nori, gim, laver
	Porphyra umbilicalis Kützing	Nori, laver
	Pyropia columbina (Montagne) W.A. Nelson	Nori, southern laver
Phaeophyceae (brown algae)	*Ascophyllum nodosum* (Linnaeus) Le Jolis	Knobbed wrack
	Cystoseira barbata (Stackhouse) C. Agardh	
	Durvillaea antarctica (Chamisso) Hariot	Cochayugo
	Ecklonia cava Kjellman	Kajime
	Fucus spiralis Linnaeus	Spiral wrack
	Fucus vesiculosus Linnaeus	Bladder wrack
	Himanthalia elongata (Linnaeus) S.F.Gray	Sea spaghetti
	Laminaria hyperborea (Gunnerus) Foslie	Kelpie
	Laminaria japonica Areschoug = *Saccharina japonica* (Areschoug) C.E.Lane, C.Mayes, Druehl and G.W.Saunders	Sea Tangle, dasima
	Macrocystis pyrifera (Linnaeus) C.Agardh	Giant kelp
	Saccharina latissima (Linnaeus) C.E.Lane, C.Mayes, Druehl and G.W.Saunders	Sugar kelp, kombu
	Saccorhiza polyschides (Lightfoot) Batters	Furbelows
	Sargassum thunbergii (Mertens ex Roth) Kuntze	Sargassum
	Sargassum fusiforme (Harvey) Setchell	Hijiki
	Sargassum vulgare C.Agardh nom. illeg.	Beerentang
	Sargassum crassifolium J.Agardh = *Sargassum aquifolium* (Turner) C.Agardh	Binder's Sargassum weed
	Undaria pinnatifida (Harvey) Suringar	Wakame

Source: Shannon and Abu-Ghannam (2019).

seaweed (*Gracilaria corticate)* powder affects cent percent larval mortality against tobacco caterpillar (*Spodoptera litura*) at 72 hours of treatment (Dharanipriya and Kannan, (2020).

Classification of sea vegetables

The edible seaweed family has considerable diversity and it is classified into three major groups based on color. Brown seaweed or kelp (Wakame) is traditionally used in cold salad or as topping on tofu, soups, sushi or in rice-based food. Algin is a versatile component found in kelp largely used as ingredient in toothpaste, shampoo, pharmaceuticals and even in ice-cream. It is basically sold in dry form. Dulse resembles red leafy lettuce and is sold as whole leaf, flakes, powder, or in seasoning. Kombu is a seaweed used in dashi, a traditional Japanese stock and its dried bonito flakes for miso soups. Kombu has enzymes that breakdown gas producing raffinose sugar found in legumes and other vegetables like brussels sprouts. The red alga commonly known as nori is mostly used as a sushi wrap or garnish. Green algae often referred as sea grass is also commonly used in several cuisines.

Nutritional importance of seaweed

Seaweed is a low-calorie, nutrient dense food and rich source of several vitamins like thiamin, riboflavin, vitamin C, D and K along with essential minerals like calcium, iron, iodine, magnesium, phosphorus, potassium, zinc, copper, manganese, selenium and fluoride and dietary fibers (Dhargalkar, 2015; Pereira, 2018; Rajapakse and Kim, 2011; Shannon and Abu-Ghannam, 2019), protein, essential amino acids and polyphenols, polyunsaturated fatty acids like omega-3 which exhibit antioxidant and anti-inflammatory properties (Panzella and Napolitano, 2017). Several phenolic compounds, presence of sulphated polysaccharides (Ruperez *et al*., 2002), polyphenolic compounds (Keyrouz *et al*., 2011) and antioxidant enzymes (Heo *et al*., 2005) imparts antioxidants property to the seaweed**.** Green seaweeds have a high concentration of carbohydrates and lipids whereas red seaweeds have abundant content of proteins. The mineral content ranges up to 36% of its dry weight (Subbiah *et al*., 2023). As seaweed constitutes of essential amino acids and high protein with trace metals and vitamins in considered as alternative food source in fish nutrition (Saleh, 2020). Seaweeds nutritional content vary according to the seaweed species, harvest location and time, wave exposition and water temperature. Terrestrial plants lack bioactive compound like phlorotannins and phycocyanin identified in seaweeds, it may have some health-promoting effects and may provide protection against cancer, hyperlipidemia and coronary heart disease (MacArtain *et al*., 2007). Seaweed is rich source of minerals, *Ulva sp* contain up to 3.25 g of calcium per kg of dry weight (Mac Artain *et al*., 2007) and *Laminaria digitata* (brown seaweed) is rich in iodine (up to 10 g per kg of dry weight). *Gracilaria salicornia* contain upto 948 mg of calcium per kg of dry weight and *Ulva lactuca* contains 2782 mg of calcium. Essential minerals beneficial for human nutrition such as Na, K, Ca, Mg, Fe, Zn, Mn and Cu are found in seaweed. The mineral content values of seaweed are much higher than the one found in terrestrial plants such as spinach (851 mg/100 dry weight), broccoli (503 mg/100 dry weight) and cabbage (369 mg/100 dry weight). Terrestrial plants lack bioactive compound like phlorotannins identified in seaweeds. Antioxidants are playing vital role in human health particularly cardio-vascular diseases, blood sugar, hypertension and several other health problems (Chatterjee, 2020). Studies showed high antioxidant capacity of a range of edible seaweeds (Yuan *et al*., 2005;

Table 2: Popular species of seaweeds consumed as vegetable.

Seaweed species	Common names
Alaria esulenta	Dabberlocks, Bladderlocks, Edible Kelp, Honeyware, Winged Kelp, Henware, Murlins, Stringy Kelp, Horsetail kelp
Himanthalia	Sea Spagheti, Sea thong, Thongweed, Butonweed, Sea Haricots, Thongweed *elongate*
Hizikiafusi formae	Hijiki, Haitso, Chiautsai, Haititun, Hai toe din, Haitsao, Hoi tsou, Nongmichae
Laminaria digitata	Tangle, Sea girdles, Tangle tail, Wheelbangs, Sea wand, Sea war, Tangle, Ho Kelp, Kelp, Strap wrack, Oarweed, Oar weed, Horsetail tangle, Sea Girdle
Laminaria japonica	Kombu, Hai Dai, Hai Tai, Kunpu, Royal Kombu, Makombu, Kombu, Oki-Kombu, Uchi Kombu, Moto-Kombu, *or Sacharina japonica* Umiyama-Kombu, Hoiro-kombu
Undaria pinnatifida	Wakame, Qundaicai, Sea mustard, precious sea grass, Miyok
Chandrus crispus	Irish sea moss, Iersmos, Carragheen, Carragheen Moss, Dorset weed, Pearl moss, Jelly Moss, Rock Moss, Gristle moss
Palmaria palmata	Dulse, Dillisk, Dillesk, Crannogh, Water Leaf, Sheep Dulse, Creathnach, Saccha, Sol, Darusu, Sou Sol, Botelho-comprido, Dillisc, Sheep's weed, Sea devil, Horse seaweed
Porphyra umbilicalis, *Porphyra yezoensis, Porphyra tenera*	Nori, Laverbread, Purple laver, Sloak, Slook, Laver, Tough

Source: Rioux *et al*. (2017).

Wang *et al*., 2009; Gupta *et al*., 2011). *In vitro* studies have also suggested a potential for phenolic compounds from seaweeds to inhibit the action of digestive enzymes.

Sea vegetables in human health

Seaweed can be extensively used for food, feed, industrial, agricultural, cosmetics and pharmacological purpose due to the presence of wide range of secondary metabolites like sesquiterpenes, diterpenes, triterpenes and bioactive compounds like phlorotannins (polyphenolic compound), laminarin, fucoidan, alginic acid (polysaccharides) and lipids like long-chain omega-3 (n-3) polyunsaturated fatty acids (PUFAs), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Cohen *et al*., 1995), that have certain protective, therapeutic and health-promoting properties. The bioactive compound content varies according to the color fucoidan, a bioactive molecule found in brown algae, is now commercially available as a nutraceutical product due to its antibacterial, antiviral, anti-inflammatory, anticoagulant and antithrombotic effects. Rhodophyta extract (red algae), carrageenans and agar are widely exploited in medical and pharmaceutical industries. Agar is utilised in biomedicine as an anti-coagulant agent as well as suspension component in medication solutions and in prescription medicine. Carrageenans can be exploited for the production of antitumoral therapies, due to their antitumor immunity activation. Chlorophyta (green algae) are rich in ulvan, a sulphate polysaccharide commonly used in biomedicine, cosmetic and pharmaceutical industries but also as emulsifiers, stabilizers and thickeners in food products. Due to the adoption of westernized dietary food habits which include calorie dense foods, decreased time spent in physical activities, technologically assisted household chores and sedentary lifestyle there is an increase incidence of obesity and other health risks worldwide. As a result of epidemiological research contrasting the diets of Japanese and Western population it has been seen that seaweed consumption leads to reduced incidence of chronic diseases like cancer, hyperlipidemia and coronary heart disease (CHD). According to WHO nearly 17.9 million people died from cardiovascular diseases (CVDs) in 2019, representing 32% of all global deaths. The brown seaweeds (*Laminaria* and *Ascophyllum sp.*) are the source of fucoidan and laminarin which has shown anti-coagulant properties (Berteau and Mulloy, 2003), antioxidant property (Heo *et al*., 2005) anti-inflammatory (Ostergaard *et al*., 2000) that may aid in the prevention of CVD. In Traditional East Asian Medicine to treat breast cancer several iodine rich seaweeds such as *Porphyra* (nori), *Undaria* (wakame) and *Laminaria* (kombu) is used and its iodine content ranges from 80 to 2,500 µg/g (Cann *et al*., 2000). Osteoporosis is a disease characterized by low bone mass, deterioration of bone tissue and disruption of bone micro architecture; it can be considerably reduced by dietary changes that enhance the consumption of calcium-rich foods in order to support bone health maintenance. It is quite likely that dietary supplies of calcium from marine source will aid to enhance calcium consumption. Some seaweed has a higher content of calcium than other dietary sources on a wt/wt basis: for instance, the calcium content of *Ascophyllum nodosum* (575.0 mg/100 g wet weight), *Laminaria digitata* (364.7 mg/100 g wet weight) and *Ulva* spp. (325.0 mg/100 g wet weight) exceeds that of whole milk (115.0 mg/100 g weight) (Mac Artain, 2007).

Seaweed as bio-stimulants

Using seaweed as manure directly after composting or burning for farming is an ancient method that was popular amongst Romans and later on utilized by Britain, France and Spain (Thirumaran *et al*., 2009). Worldwide utilization of seaweed liquid fertilizer (SLF) and seaweed granules in organic agriculture is gaining momentum. Both seaweed liquid fertilizer (SLF) and seaweed granule are derived from seaweed extract, the latter is made into granule by covering it with exceptional formula of humic acid along with high fulvic content. Most commonly used seaweed species to produce bio-stimulant extracts are classified as brown algae (*Ascophyllum nodosum*). Seaweed extracts are capable of improving nutrient availability and productivity and can be used as foliar or soil applications (Table 3). In comparison to the chemical fertilizers the seaweed liquid fertilizers (SLF) are good source of potassium (Kingman and Moore, 1982) and the extract contains growth promoting hormones (IAA, IBA and cytokinins), trace elements (Fe, Cu, Zn, Co, Mo, Mn, Ni), vitamins, antibiotics and amino acids (Booth, 1965; Challen and Hemingway, 1965; Stephen *et al*., 1985; Crouch and Staden, 1993) which are proved to have a growth promoting effect, imparts abiotic and biotic stress resistance on plants, tend to improve soil physical properties like water holding capacity by altering the nature of soil (Crouch and Staden, 1993). As seaweed manure is rich in potassium Begum *et al*. (2018); Kingman and Moore (1982) and the extract contains growth promoting hormones (IAA, IBA and cytokinins), trace elements (Fe, Cu, Zn, Co, Mo, Mn, Ni), vitamins, antibiotics and amino acids (Booth, 1965; Challen and Hemingway, 1965; Stephen *et al*., 1985; Crouch and Staden, 1993). The seaweed extract have several growth promoting effects of on seed germination (Kumar *et al*., 1993), vegetative growth (Sekar *et al*., 1995), yield, quality and biochemical characteristics of several crops (Table 4). *Sargassum* seaweed extract (15% S-SWE) application significantly increases higher bacterial, actinomycetes and total microbial population in soil (Kumari *et al*., 2024). Application of seaweed along with combinations of other organic nutrient sources produces maximum plant height, number of primary branches and dry weight of the nodules in French bean (Rai *et al*., 2021). Several species of seaweeds used in agriculture and horticultural crops are listed below:

Industrial importance of seaweed products

Seaweed polysaccharides

Seaweeds are rich in carbohydrates and concentration up to 76% of the algae dry weight was reported. Seaweed

polysaccharides are water-soluble and very hydrophilic. (Garti *et al*., 2001; Dickinson *et al*., 2003). Most seaweed polysaccharide are contained within algae cell wall, with the exception of the storage polysaccharide, which is found in the plastid. The extra-cellular matrix of seaweed plays crucial structural role and it acts as a physical barrier against the effect of the sun, ice and waves. Depending upon the seaweed species additional polysaccharide such as laminarin starch and floridean starch maybe be present in chloroplast and cytoplasm respectively. The primary energy source in seaweed is stored carbohydrates, which is comparable to human glycogen. Xylans, agar, carrageenan or alginates, are the type of seaweed polysaccharides extensively procured in the food industry as clarifying, gelling, emulsifying, stabilizing, thickening and flocculating agents in various food products such as ice cream, yogurt, candy, meat product, beverages (Mancini *et al*., 2000; Wendin *et al*.,1997; Gujral *et al*., 2001). In general, there are three types of carrageenan: kappa, iota and lambda carrageenan (Hamdan *et al*., 2020). However, some reports suggested that some of the seaweed polysaccharides contain an anti-nutritional substance that reduces the digestion of protein. Protein *in vitro* digestibility can be greatly increased by first enzymatic digestion combined with the appropriate polysaccharidases or microorganisms. *Kappaphycus alvarezii* (Tropical red seaweed) and *Hypnea musciformis* are both utilized as a source for the extraction of the commercially important phycocolloid kappacarrageenan (κ-carrageenan) whereas *Sarconema filiforme* is utilized to extract α-carrageenan, iota-carrageenan and pyruvated α-carrageenan.

Seaweed protein

Amino acids are the building blocks of proteins, considered as essential macronutrients and found in larger quantities in different species of seaweed. *Palmaria yezoens is* and *Palmaria palmata* are the two red seaweeds species containing 47% of protein and 35% of protein of dry weight, respectively. Whereas the green seaweeds, such as *Ulva lactuca (*sea lettuce), contain lower protein (10-25% of dry weight) and brown algae, such as *L. japonica*, have the lowest protein content (5-12% of dry weight) (Table 6). *Palmaria palmata* (red seaweed) are also the rich source of amino acids like methionine (4.5 g amino acid/100 g of protein) and *Laminaria digitata*, *U. pinnatifida* (brown seaweed) contain comparatively lesser protein than red seaweed species (1.6 g amino acid/100 g of protein), (Fleurence *et al*., 2010) (Table 5). In addition, the red seaweeds also contain a red protein pigment called R-phycoerythrin (RPE) which is used as food colourant in Asia, present at a high level (12% of dry weight).

Seaweed dietary fibre

Seaweed under different sub-classification vary in dietary fibre content. Brown seaweeds contain alginates, fucans and laminarans in dietary fibre; red seaweeds contain galactans, agar and carageenans; whereas green seaweeds contain soluble ulvans and other insoluble fractions such as cellulose. Red seaweed such as *Porphyra sp* (Nori) contain upto 49.8% of dietary fibre and brown seaweed *Hizikia fusiforme* (Hiziki) contain upto 62% of dietary fibre as per dry weight.

Seaweed lipids

In contrast, the edible seaweeds are characterized by low levels of lipids, generally between 1.5 and 3.3% of dry weight.

Methods of seaweed cultivation

Floating bamboo raft method

A bamboo raft (8-10 cm in diameter and 3 × 3 m) is used as the main frame for cultivation. The angular portions are

Table 3: Different species of seaweeds used in organic crop production.

Seaweed species	Algal type	Application
Ascophyllum nodosum	Brown algae	Plant growth stimulant
Macrocycstis pyrifera	Red algae	Plant growth stimulant
Ecklonia maxima	Brown algae	Plant growth stimulant
Durvilleaant arctica	Brown algae	Plant bio-stimulant
Durvillea protatorum	Brown algae	Plant growth stimulant
Porphyra perforate	Red algae	Plant growth stimulant
Fucus vesiculosus	Brown algae	Plant growth stimulant
Caulerpa paspaloides	Green algae	Plant growth stimulant
Sargassum heterophyllum	Brown algae	Plant growth stimulant
Nereocystis spp.	Red algae	Plant growth stimulant
Chara globularis	Brown algae	Plant growth stimulant
Sargassum muticum	Brown algae	Plant growth stimulant
Enteromorpha prolifera	Green algae	Plant growth stimulant
Cyanidium caldarium	Red algae	Plant growth stimulant
Laminaria digitata	Brown algae	Plant growth stimulant
Ulva lactuca	Green algae	Growth retardant

Source: Panda *et al.* (2012).

Table 4: Effect of seaweed as organic bio-stimulants.

Crop	Seaweed	Dosage	Character improved	Reference
Spinach	*Ascophyllum nodosum*	0.5% (foliar spray)	▪ These results indicated that under mild drought stress *A. nodosum* seaweed extract enhanced spinach growth by improving leaf water relations, maintaining cell turgor pressure and reducing stomatal limitation, which in turn led to large leaf area and high photosynthetic rate.	Xu *et al.* (2015)
Lettuce	*Ascophyllum nodosum*	0.2% (foliar spray)	▪ Growth yield and quality of organic lettuce has increased over the control	Saha *et al.* (2020)
Tomato	*Sargassam tenerrium*	0.6% (foliar application) 0.8%	▪ Produced the tomato plant's optimum development and output. ▪ Greater number of leaves, a maximum of leaf area and a greater number of roots	Sasikala *et al.* (2016)
Carrot	*Ascophyllum nodosum*		▪ Seaweed extract application can result in an increase in soil microbial activity associated with increased yield in carrots.	Alam *et al.* (2014)
Radish	*Zonaria* sp.	(0.5%, 1%, 2%, 5% and 10%)	▪ At lowest concentration of seaweed extract (0.5%) with 12 and 24 hours of incubation 100% germination was recorded. In pot culture experiment and laboratory bioassay enhanced the root length (30%), shoot length (63%), root diameter (227%), leaf area (86%), fresh weight (65%) and dry weight (91%), protein, carbohydrates and vitamin C was recorded with 2% concentration in comparison with control and other concentrations.	Maheshwari (2017)
Brinjal	*Gracilaria salicornia*, *Padina gymnospora*, *Padina boergesenii*, *Gelidiella acerosa*	20-40%	▪ Study showed that SLEs may replace phytohormonessince they were simple to extract and provided rapid, high-frequency mass propagation.	Satish *et al.* (2015)
Cherry tomato	Powhumus® (PH),		▪ In conclusion, single and combined use of high-purity fulvic acid and PGPR had positive effects on the growth of cherry tomato in fertile soil and under stressed conditions.	Turan *et al.*, 2021
Potato	*Kappaphycus alvarezii* and *Gracilaria edulis*	5%, 10%	▪ Results suggested that the application of seaweed sap at higher concentration along with the recommended dose of fertilizer improved both nutrient (N, P and K) uptake and quality traits in terms of ascorbic acid, reducing sugar content, and specific weight of potato tuber.	Garai *et al.*, 2021

Table 5: Comparison of the methionine content of several food sources.

Food sources	*Palmaria palmata*	*Porphyra tenera*	*Grateloupiat ururturu*	*Ulva pertus*	*Undaria pinnatifida*	*Laminaria japonica*	Soybean	Reference
	4.5	1.1	2.0	1.6	2.0	1.4	1.2	Fleurence *et al.* (2010)

Table 6: Composition of different seaweed species.

Seaweed species	Polysaccharide (%)	Protein (%)	Lipid (%)	Ash (%)
Ulva sp.	15-65	4-44	0.3-1.6	55
Laminaria longicruris or Saccharina longicruris	38-61	3-21	0.3-2.9	15-45
Ascophyllum nodosum and *Fucus vesiculosus*	42-70	1.2-17	0.5-4.8	18-30
Undaria pinnatiida	35-45	11-24	1-4.5	27-40.14
Sargassum sp.	68	9-20	0.5-3.9	44
Chondrus crispus	55-66	6-29	0.7-3	21
Porphyra sp.	40-76	7-50	0.12-2.8	7-21
Gracilaria sp.	36; 62-63	5-23	0.4-2.6	8-29
Palmaria palmata	38-74	8-35	0.2-3.8	12-37

Values are expressed in percentage (%) of dry weight.
Source: Fleurence (2010).

diagonally fixed with the help of supporting bamboos (neraly 120 cm long) for keeping it intact. The rafts in clusters are tied with an anchor to fix them and maintaining their buoyancy. Bottom netting is provided to avoid drifting of material as well as to minimize grazing. Total 20 plantings of about 100-150 g fresh weight each are planted on polypropylene ropes (3 mm) a regular interval by raffia or braider. The seeded ropes are tied parallel to each other at 15-cm intervals at both the ends to opposite bamboo. Each raft with 20 such ropes thus will have an initial seeding weight of 60 kg fresh weight. The seedlings are carried out on shore and seeded rafts are transplanted into the open sea subsequently. Harvesting is generally carried out after 45 days. This method is recommended where the water moment is gentle and popularly adopted in areas such as the North Ramanathapuram district of Tamil Nadu.

Monoline method

Longline or monoline method. This is modified traditional off-bottom farming, having few similarities with the raft method. Seedlings of about 100-150 g fresh weight are attached to a rope by raffia or braider between anchors. The main rope is 6 to 8 mm in diameter and about 20 m in length. The longline ropes are kept afloat in water with the help of floats tied at regular intervals and anchoring is done on both ends. Timber of casuarina, eucalyptus, bamboo, *etc*. is used for anchoring. Poles are erected at 3 m interval in a square manner and 12 mm polypropylene rope is tied in any two parallel directions (depending upon tidal current). The seeded ropes (3 mm) are then tied in 10 cm intervals. Care needs to be taken to ensure that the seaweed always remains submerged (0.5 m below the surface) and receives sufficient sunlight. Generally, seeding in this case is done in the water itself to avoid seedling loss which may occur if ropes are seeded on the shore and dragged into the sea. This farming technique is recommended for moderate wave action and particularly in areas with low density of grazers. It is popularly adopted in South Ramanathapuram, Pudukkottai and Tuticorin districts of Tamil Nadu.

Tube net method

Higher wave action may cause drifting of germlings in the early growth phase or considerable crop loss in the pre-harvest stage where seeding attains highest weight. Thus, the tube net method holds great promise. The tube nets (15 cm diameter; mesh size of 2.0 cm) of 25 m length are held floating in the water column below the surface with an appropriate number and size of floats at regular intervals. Anchor stones (about 30 kg) are used at each end to hold the tube nets steady in the water column; if required, additional anchors of appropriate size and weight can be fixed intermediately. The seed material of 20 kg fresh wt is loaded into the tubes with the aid of a 1.0– or 1.5 m long plastic pipe acting as a funnel or a hopper. The pipe diameter should be little less than that of tube net for efficient seeding. The plastic pipe is inserted into the tube and the entire tube is pulled down, so that the mouth of plastic pipe stands out of the tube. The tube net is pulled down from the bottom of the plastic pipe carefully, in such a way that seedling material gets loaded into the tube sequentially leaving no gap between the seedlings. This process is continued till the entire tube net is seeded with algal biomass

Challenges in seaweed production

Challenges in commercial near-shore seaweed farming include the need for high-temperature-tolerant strains, lack of disease resistant strains, eutrophication caused due to human sewage from major municipalities and small town, run-off from land-based agriculture, thermal power plants and chemical factories, lack of sustainable and best cultivation practices. In developing nation like India expansion of seaweed cultivation ground is a major constraint due to the water use conflicts with fish landing centers and commercial fishing activities and ban in dry seaweed export hinders farmers from attaining premium price for their produce.

CONCLUSION

A large number of people in the globe are suffering from hidden hunger and malnutrition, which impair growth and prevent children from reaching their physical and intellectual excellence. To combat these problems sea vegetables can be considered as a potential alternative food source to combat malnutrition, attain food security

and serve as an alternative food source globally. In recent years extensive research has been carried out to determine the possibility of seaweed usage in the biofuel, nutraceutical and food additive industries. Contemporary research has identified sea vegetables as a valuable medicinal plant with potential for multipurpose uses and also as a source for preparing raw materials of pharmaceutical and cosmetic industries. The oil extracted from the algae can be used for biodiesel production and the residual biomass obtained are rich in sugar content that can be used for bioethanol production. Seaweed bio-stimulants are extensively used in agricultural crops to increase crop yield and quality, which reduces the use of chemical fertilizers in soil and helps to enhance soil fertility. The vast Indian coastline has the tremendous potential to commercially cultivate and promote indigenous seaweed-based technology for the production of fresh seaweed vegetables, different processed products and bio-stimulants to attain sustainable means of livelihood and economic development of the coastal people. Identifying suitable cultivable and scalable seaweed strains for pharmaceutical and cosmetic applications needs to be selected and cultivated at large scale through industrial collaborations. Policymakers must give top priority to the role of sea vegetables as food source as well as raw material for the industry. Only through a collaborative efforts that will reach across the value chain, will realize the dream of hunger free world.

Conflict of interest

The authors declare that there is no conflict of interest.

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