

MARICULTURE OF ECONOMICALLY IMPORTANT SEAWEED AND ITS UTILIZATION FOR THE DEVELOPMENT OF HIGH-VALUE PRODUCTS

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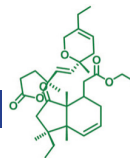
ABSTRACT

Seaweeds, classified as marine macroalgae, are integral components of marine ecosystems, contributing to biodiversity and providing numerous benefits. This text explores the diversity of seaweeds, with approximately 7000 red algae, 2000 brown algae, 1800 green algae, and 1500 blue-green algae species. Despite lacking specialized vascular systems and enclosed reproductive structures, seaweeds exhibit remarkable adaptability and contribute significantly to marine environments. Classified into three major groups based on pigmentation (Chlorophyta, Phaeophyta, and Rhodophyta), seaweeds employ photosynthesis using various pigments to convert solar energy into chemical energy. Their distribution in the ocean varies by depth, with red, green, and brown algae thriving in different zones. Taxonomically, seaweeds are classified based on pigment type, reserve food material, cell wall composition, flagella characteristics, and cell structure. Despite approximately 12,000 known seaweed species globally, only a fraction, about 0.1%, are commercially farmed, with Asia, especially China, dominating production. Seaweeds offer diverse applications in food, pharmaceuticals, bioenergy, and bioremediation. The recent rise in seaweed cultivation is driven by its sustainability, adaptability, and economic potential. Seaweeds are rich sources of bioactive compounds, explored in industries such as skincare, biofertilizers, and bioremediation. Additionally, seaweed cultivation presents opportunities for carbon sequestration and climate change mitigation.

Keywords: Seaweeds, Taxonomy, Commercial farming, Bioactive compounds

INTRODUCTION

Seaweeds, classified as marine macroalgae, play a vital role in marine ecosystems, contributing to biodiversity and offering numerous benefits. With approximately 7000 species of red algae, 2000 species of brown algae, 1800 species of green algae, and 1500 species of blue-green algae, seaweeds are diverse and widespread, ranging from intertidal zones to deep oceans. Their complex life history, distinct from plants, involves various reproductive strategies, including sexual and asexual phases, as well as alternation of generations.



Seaweeds differ from true plants due to the absence of a specialized vascular system and enclosed reproductive structures. Despite lacking roots, stems, leaves, and flowers, seaweeds exhibit remarkable adaptability and are essential contributors to marine environments. The three major groups of seaweeds, classified based on pigmentation, are Chlorophyta (green algae), Phaeophyta (brown algae), and Rhodophyta (red algae). Photosynthetic like true plants, seaweeds utilize pigments such as chlorophyll a, chlorophyll b, and accessory pigments to convert solar energy into chemical energy. Seaweeds exhibit a diverse range of colors due to pigments like fucoxanthin, xanthophyll, and phycobiliproteins. Their distribution in the ocean varies with depth, with red algae thriving in deeper waters, green algae in shallow areas, and brown algae occupying intermediate depths.

Taxonomically classified based on pigment type, reserve food material, cell wall composition, flagella characteristics, and cell structure, seaweeds are valuable resources with ecological significance. Approximately 12,000 seaweed species have been described globally, yet only a fraction, around 0.1%, are commercially farmed. Asia, particularly China, dominates global seaweed production, contributing over 95% of the total.

Seaweeds offer diverse applications, from food and pharmaceuticals to bioenergy and bioremediation. In recent years, seaweed cultivation has gained prominence due to its sustainability, adaptability, and economic potential. As a rich source of bioactive compounds, seaweeds are being explored for various industries, including skincare, biofertilizers, and bioremediation. Additionally, seaweed cultivation presents an opportunity for carbon sequestration and mitigating climate change.

This introduction highlights the significance of seaweeds, encompassing their taxonomy, distribution, ecological roles, and diverse applications. As we delve into the scientific exploration of seaweeds, their economic importance, and their potential for sustainable development, we uncover the multifaceted contributions of these marine macroalgae to our environment and human well-being.

SEAWEED AND ITS CLASSIFICATION

Around 7000 species of red algae, 2000 species of brown, 1800 species of green and 1500 species of blue green are recorded so far. Seaweeds are nothing but marine macroalgae found from the intertidal area to deep Ocean. The life history of algae is complicated, and this is what really differentiates them from plants. In fact, macroalgae can pass through life stages. So distinct that, in the past, they have been mistaken for separate species. Seaweeds are not grouped with the true plants because they lack a specialized vascular system like xylem, phloem, roots, stems, leaves, and enclosed reproductive structures like flowers and cones.

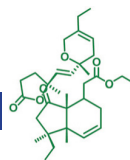


Seaweed reproduction can involve either exclusively sexual or asexual phases, while some species display an alternation of generations that involves both in succession. In the former, the seaweed produces gametes (egg and sperm cells) with a single set of chromosomes and, in the latter, spores containing two sets of chromosomes. Some species can also reproduce asexually by fragmentation. They are simple thallus and the whole plant are responsible to do all the activities like photosynthesis, reproduction, fluid transport and respiration.

Like true plants, seaweeds are photosynthetic, they convert solar energy to chemical energy and produce carbohydrate with the help of pigment systems present in each cell of the thallus. Within their cells seaweeds have the green pigment chlorophyll, which absorbs the sunlight they need for photosynthesis. Chlorophyll is also responsible for the green colouration of many types of seaweed. In Chlorophyll Chl a is responsible for light reaction in the photosystem where as other chlorophyll pigments like chl b, c, d are accessories pigments which channel the solar energy photon to chl a. Similarly other pigments like xanthophyll, phycobiliprotein also present in seaweed and these pigments provides beautiful colours for seaweed. The red macroalgae normally grow at the greatest depths, typically as far as 30 meters down, the green macroalgae thrive in shallow water, and the brown algae in between. This distribution of species according to the depth of the water is somewhat imprecise, however; a given species can be found at a location where there are optimal conditions with respect to substrate, nutritional elements, temperature, and light. In exceptionally clear water, one can find seaweeds growing as far as 250 meters below the surface of the sea. It is said that the record is held by a calcareous red alga that was found at a depth of 268 meters, where only 0.0005 percent of the sunlight penetrates. Even though the waters at that depth may appear pitch-dark to human eyes, there is still sufficient light to allow the alga to photosynthesize. In turbid waters, seaweeds grow only in the top. Despite of the undeserved negative connotation associated with such a name, seaweeds play a fundamental role in marine ecosystems, where they have a multitude of beneficial effects.

The taxonomy of algae has been modified from 1935 till date. The earlier classification was based on five important characteristics

1. Type of pigments
2. Nature of reserve food material,
3. Type of cell wall material
4. Type, number, and attachment of flagella
5. Cell structure.

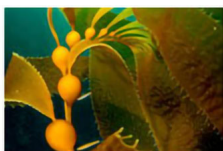


Seaweeds are classified into three major groups based on their pigmentation like brown algae (Phaeophyta), green algae (Chlorophyta), and red algae (Rhodophyta).

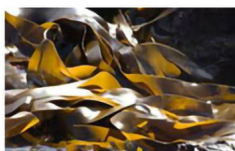
	Chlorophyta	Phaeophyta	Rhodophyta
Habitat	Marine, Freshwater & Terrestrial	Marine	Mostly marine & few freshwater
Pigments	Chl a & b, carotenoid	Chl a & c, Xanthophyll, Fucoxanthin & carotenoid	Chl a & d, carotenoid, Phycobiloprotein
Cell wall	Cellulose	Cellulose	Cellulose
Stored food	Starch	Alginic acid, Laminarin, Mannitol	Agar, carrageenan
Species	<i>Ulva, Enteromorpha, Caulerpa</i>	<i>Sargassum, Turbinaria, Padina</i>	<i>Gracilaria, Gelidiella, Hypnea, Kappaphycus</i>

BROWN ALGAE (PHAEOPHYTA)

It is a large group of algae consisting of 240 genera and over 1,800 species. 32 genera and 93 species are reported from India. About 99.7% of members are marine and a few grow in fresh water. They range from simple microscopic heterotrichous filament (Ectocarpus) to the largest alga like *Macrocystis pyrifera*, which attains a length of 60-90 meters. There is no unicellular or colonial form in brown algae, they are branched, and filamentous. Most of the plants are having a hold fast. Some of the higher brown algae have stipe and lamina. The brown colour of the algae is due to the dominance of xanthophyll pigments like fucoxanthin. It masks the other pigments like chl a & c (no chl b in Phaeophyta), β carotene, and other xanthophylls. It is the only alga having tissue differentiation into conducting tissues but there is no true xylem or phloem found as in higher plants. In general, they are larger and mostly found in temperate waters. Worldwide harvested biomass (wild and farmed) comes from a few numbers of *Laminariales* and *Fucales*.



Macrocystis pyrifera



Laminaria digitata



Sargassum longifolium



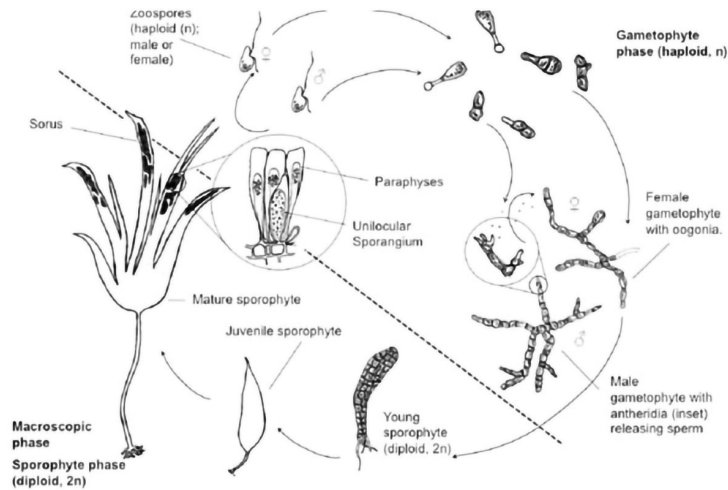
Sargassum wightii



Padina tetrastromatica



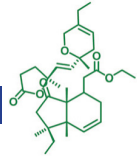
Turbinaria ornata



The life cycle of Laminaria (Courtesy: Edwards and Watson, 2015)

RED ALGAE (RHODOPHYTA)

The red algae are one of the most ancient groups of eukaryotic algae. A fossil record of 1.2 billion years old was found for Bangiomorpha sps. Red algae lack flagella in any stage of their life history as found in other algae. They have a complex life history, which usually involves the alternation of three generations gametophyte, carposporophyte and tetrasporophyte. Saunders & Hommersand (2004) and Yoon et al (2006) emphasized based on the molecular data produced in the last two decades which revolutionise the classification of red algae belonging to a single phylum (Rhodophyta) which subdivided into two subphyla (Cyanidiophytina and Rhodophytina), seven classes (Cyanidiophyceae, Bangiophyceae, Compsopogonophyceae, Florideophyceae, Porphyridiophyceae, Rhodellophyceae and Stylonematophyceae) and 33 orders.



Gracilaria edulis



G. crassa



Sarconema filiforme



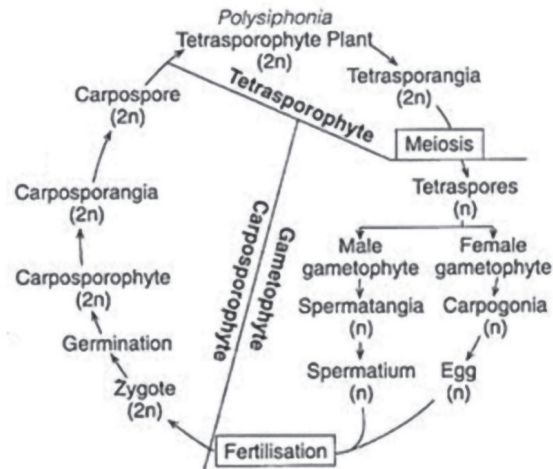
Kappaphycus alvarezii



Hypnea musciformis



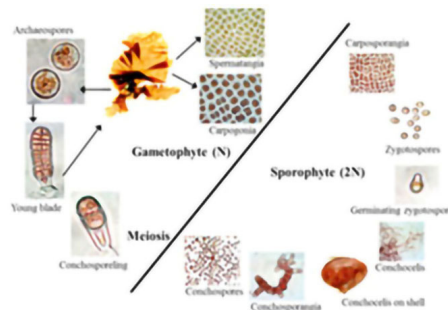
Acanthophora spicifera



Triphasic life cycle: Diplobiontic Type (*Polysiphonia*)



Porphyra sp

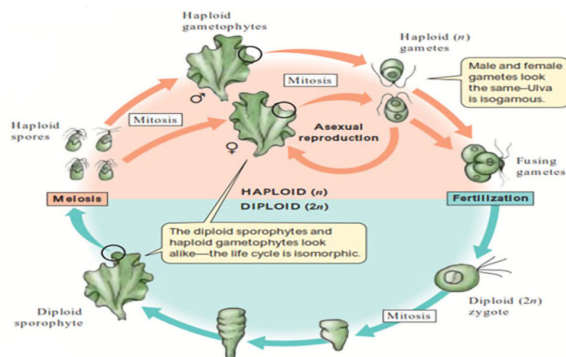
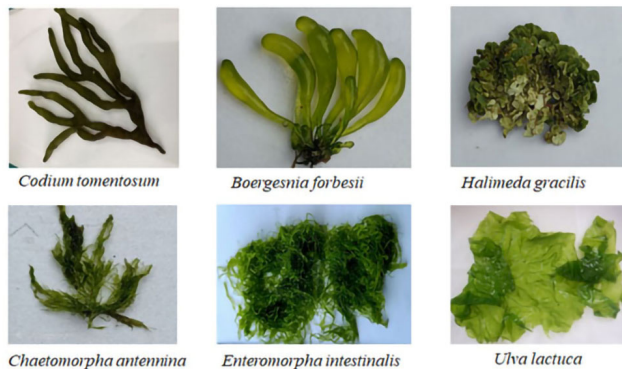


Life cycle of *Porphyra*

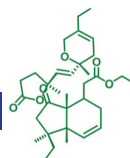


CHLOROPHYTA (GREEN ALGAE)

Chlorophyta is having more than 7000 species present in varying habitats from freshwater to marine, land and in arctic area. 90% of the chlorophycean algae are in freshwater. In recent years, based on DNA sequence data green algae do not form a homogeneous and coherent entity. They are part of a larger group called Viridiplantae, in which the land plants are also included (Lewis & McCourt, 2004). However, all marine green algae are classified in a common class, called Ulvophyceae. The Ulvophyceae are a very diverse group and include about 920 species, which are distributed in all seas of the world. In the green seaweeds, the body of the alga shows a great range of variation in morphology but usually its morphology varies from thin filamentous as found in *Cladophora* and *Chaetomorpha* or in the form of sheets in *Ulva* or siphonaceous like *Caulerpa*. Species of this genus consist of a creeping stolon (that grows attached to the rocky bottom), from which numerous erect fronds of variable shape arise. Siphonalean green algae are classified in two orders, Bryopsidales and Dasycladales, and are among the most ecologically successful seaweeds. The body of these algae is formed by one single giant cell, which contains numerous nuclei. There are few green algae which are calcareous like *Halimeda*.



An isomorphic life cycle of Ulva lactuca showing isomorphic alternation of generations



GLOBAL SCENARIO OF SEAWEED PRODUCTION

Although more than 12,000 species of seaweeds have been described till date, a tiny fraction of 0.1 % of these species are commercially farmed today. The FAO Fisheries and Aquaculture database lists 47 algae species produced by aquaculture from which 10 of these listed species are microalgae, 15 of the macroalgae species had no production in 2020, 10 macroalgae species had a production that is below a commercially relevant scale (<1.000 tonnes wet weight) in 2020. Therefore, only about 12 macroalgae (seaweed) species are currently commercially farmed and accounted for more than 95% of the global seaweed production by both volume and value in 2020. The main commercially farmed species can be summarised into five main seaweed species groups. They are *Laminaria* or Kelp, *Pyropia* or *Porphyra* sp, *Gracilaria*, *Kappaphycus* or *Euchomoids*, and *Undaria* . The world’s seaweed production mostly comes from the five major continents. Asia accounting for 97.38% and China ranks first in the world in terms of aquaculture production (56.82%) followed by Indonesia (28.6%), South Korea (5.09%), The Phillipines (4.19%), North Korea (1.9%), Japan (1.15%) and Malayasia (0.53%). North America accounts for 1.36% of the world's seaweed, and 95% of is obtained from natural resources. Chile contributes 0.3% of *Gracilaria* production.

Country	Production	Quantity in MMT (Wet weight)	Species cultivated
China	56.82%	18575.7	<i>Laminaria japonica</i> , <i>Gracilaria</i> and <i>Porphyra spp</i>
Indonesia	28.6 %	9320.3	<i>Eucheuma (Eucheuma spp.)</i> and <i>Gracilaria</i>
South Korea	5.09%	1710.5	<i>Laminaria japonica</i> , <i>Porphyra tenera</i> and <i>Undaria pinnatifida (wakame)</i>
Philippines	4.19%	1478.3	<i>Kappaphycus alvarezii</i>
North Korea	1.6%	553	<i>Laminaria japonica</i>
Japan	1.15%	389.8	<i>Porphyra tenera</i> , <i>Undaria pinnatifida</i> and <i>Laminaria japonica</i>
Malayasia	0.53%	174.1	<i>Kappaphycus alvarezii</i>

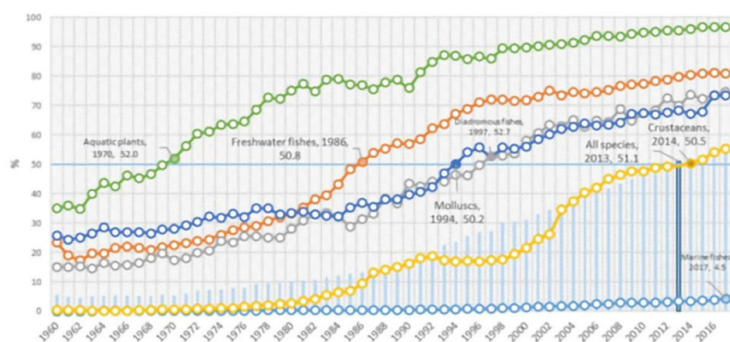


Vietnam	0.053%	19.3	<i>Caulerpa lentillifera</i> , <i>Gracilaria tenuistipitata</i> , <i>Gracilaria firma</i> , <i>Gracilariopsis bailinae</i> , <i>Kappaphycus alvarezii</i> , <i>Kappaphycus striatus</i> , <i>Euचेuma denticulatum</i>
India	0.02%	5.3	<i>Kappaphycus alvarezii</i> , <i>Gracilaria</i> , <i>Sargassum</i> , <i>Turbinaria</i> , <i>Hypnea</i> from wild
Bangladesh	NI	NA	<i>Gracilaria tenuistipitata</i>

Only 2.2 million tonnes of world seaweed production were contributed from wild collection and cultivation during 1969 but after half a century, the wild collection remained at 1.1 million tonnes whereas the production from cultivated seaweed has increased to 35.8 million tonnes in 2019 accounted for 97 per cent of the world seaweed production. World seaweed cultivation production tonnage increased 1,000-fold from 34.7 thousand tonnes to 34.7 million tonnes between 1950 and 2019 (Junning Cai, FAO, 2021).

ECONOMICALLY IMPORTANT SEAWEEDS OF INDIA

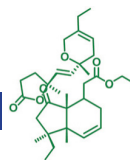
India has got 844 species of seaweed found from intertidal water to deep sea ocean. The Gulf of Mannar biosphere in Tamilnadu is having rich biodiversity of seaweed. The standing stock of seaweeds in India is estimated to be 2,60,876t. Among all the species 60 odd species are commercially important. But only a few species are cultivated on a commercial scale in India.



Global trends in farmed production of seaweeds

PROSPECTS OF SEAWEED CULTIVATION

Seaweed has emerged as one of the most promising resources due to its remarkable adaptability, short development period, and resource sustainability. Algal resources have reached a high stage of growth in the past years due to the increased output and demand



for seaweed worldwide. The multivariate use of seaweed in many industries like food, feed, pharmaceutical, nutraceutical, fodder, cosmetic, bio packaging, meat processing, textile, paint and physio-colloid become a demand-driven to opt for cultivation rather than wild harvest. Besides, they are also used for bioenergy, wastewater treatment and carbon sequestration. According to Dr Lynn Cornish: Based upon scientific publication metrics, bioprospecting efforts between 1965 and 2012 resulted in a total of 3 129 marine natural products (MNPs) or bioactive molecules from seaweeds (53 per cent from red seaweeds; 39 per cent from brown seaweeds; and 8 per cent from green seaweeds). However, the steps from discovery to development have been slow to materialize (Leal et al., 2013; Leal et al., 2020). As per the FAO report, The World export of seaweeds and seaweed-based hydrocolloids (by 98 countries) is USD 2.65 billion = USD 909 million of seaweeds + USD 1.74 billion seaweed-based hydrocolloids. With its ability to sink carbon, sustain marine biodiversity, employ women, and unlock value chains, seaweed farming demonstrates how development, climate, and nature work together to generate value and uplift communities. A new World Bank report examining ten emerging seaweed markets estimates their growth potential could be up to US\$11.8 billion by 2030.



Commercially important seaweeds of India

KELP FARMING IN CHINA

Globally, China has the largest scale of kelp cultivation and production operations. However, its kelp aquaculture industry is suffering from declining germplasm diversity, degradation of agronomic traits, the presence of polluted environments, changing ocean conditions and increasing anthropological interference (Hu et al, 2021). More than 90 years of research and



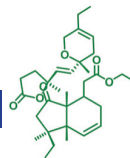
practice have led to enhanced techniques and improved facilities for kelp aquaculture (e.g. floating rafts to grow-out of sporophytes), techniques (e.g. production of summer seedlings; Tseng et al. 1955a; applications of fertilizer; Tseng et al. 1955b), breeding methods (e.g. selection and gametophyte cloning; Fang 1983) and seedling production using vegetative gametophytes (Zhang et al. 2008a; Xu et al. 2009). These have been researched, invented, re-invented and systematically synthesized into the Chinese kelp cultivation industrial machine. As a result, China has the largest scale kelp cultivation industry in the world.

NORI CULTIVATION IN JAPAN

The British scientist Dr. Kathleen Drew-Baker from Manchester University made the discovery that sparked off the exponential development of the nori cultivation industry in Japan when she established that the life history of *Porphyra umbilicalis* have another gametophytic stage called conchocelis phase involves Shell-boring.

KAPPAPHYCUS ALVAREZII CULTIVATION

Kappaphycus alvarezii (Doty) Doty. ex. P. Silva is the largest worldwide source of k-carrageenan in the phycocolloid industry. Annual commercial production has increased from less than 1000 t dry weight in 1969 to approximately 100,000 t worldwide in recent years (Ask & Azanza, 2002). It increased to appx 11 685 174 tons (wet weight) by 2019 in 25 countries which is the largest number of countries practicing this particular species cultivation. The market for carrageenan has been growing exponentially at a rate of 5% annually for the last 25 years (Bixler et al, 1996). Farming of *Kappaphycus* is more revenue-generating than shrimp, mud crab and Tilapia culture (de la Vega A, 1998) has become the major livelihood among the sea farmers of Philippines, Micronesia, Fij, East Africa China and India (Hurtado & Agbayani, 2000). The growth of *kappaphycus* is recorded from 400 per cent to 600 per cent in just 45 days in areas like Gulf of Mannar and Palk Bay with a DGR of 3-5%/day. Experimental farming of the same species which was cultured in Gulf of Mannar was tried in west coast of India exhibited very high growth rate and carrageenan yield (Reeta, 2001) with an average CGR of 12g/day and a yield of 50% crude carrageenan. About 200 tonnes of dried *kappaphycus* is produced a year by as many families. Each family earn Rs. 10,000-12,000 /month. Cultivation of *Kappaphycus* in Gulf of Mannar and Palk Bay has generated a lot of interest in the coastal fisherfolk to take up as an alternate avenue to generate income and improve their livelihood. The cultivation of *Kappaphycus alvarezii* was found profitable in the pilot projects started at Mandapam near Rameswaram and Tharuvaikulam near Tuticorinin Tamilnadu coast, Jagatsingpur in Odisha coast and in Gujarat coast.



SEAWEED FARMING

Seaweed farming can be done by following the method

1. Vegetative method of propagation
2. From reproductive spores
3. By micropropagation method

SEAWEED PRODUCT & UTILIZATION

- Biofertilizer
- Biofuel
- Iodine
- Antibiotics
- Ethanol
- Anticancer agents
- Medicines
- Agar-agar
- Carrageenan
- Vitamins



Seaweed products

SEAWEED AND BIOACTIVE COMPOUNDS

Seaweed extract contains components of polysaccharides, proteins, unsaturated fatty acids, pigments, and minerals (K, Mg, Ca, and Na) (Godlewska et al., 2016). They also contain polyphenols namely phlorotannin, bromophenol, flavonoid, and phenolic terpenoids (Kristanto et al., 2021) with antibacterial, antiviral and antifungal properties. In addition to macro-minerals, seaweed is a good source of trace elements such as iodine, iron, manganese, copper and zinc which, can be used as a health supplement. The active components from the seaweeds could be used as an antioxidant, antibacterial whitening agent, anti-ageing, and anti-acne, and also for moisturization in cosmetic industries Seaweed is a famous hydrating ingredient in skincare products. As a powerful humectant, seaweed draws moisture to skin cells, with potent polysaccharides absorbing water. This provides long-lasting, hydration for moisturized skin. Scientific studies have shown that high-purity, certified organic seaweeds



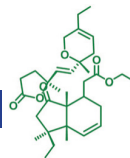
have shown that, at very low inclusion rates, the seaweed extracts improved skin wrinkles by 45%. Alginates, carrageenan, fucoidan, and chlorella polysaccharides are widely used because of their biocompatibility and availability. Phloroglucinol, fucoxanthin and fucoidan are bioactive compounds present in brown seaweed showing chemo preventive and chemotherapeutic effects against cancer.

SEAWEED AS BIOFERTILIZER

Seaweed has more than 60 elements which are not found in any of the land plants. Due to its rich mineral content and trace elements, seaweed can be used as a potential source of bio fertilizers. It can also be used as a soil conditioner. The seaweed has great potential to absorb the nutrients. It provides resistance to the plant from fungal disease and reduces the incidence of insect attacks as well as increases productivity. Seaweed extracts increase self-life of the plant. On the other hand, seaweed can be used as LSF or as conditioner



Seaweed powder was used for horticultural crop showed increase in productivity, leaf area index, more chlorophyll and improve in size of vegetables. 57 families of a Rameswarpur village in Odisha were adopted for Bio-intensive kitchen garden and terrace gardening for organic farming using Liquid seaweed fertilizer. Seaweed was also used for preparation of liquid seaweed fertilizer which can be used as a potential insecticidal property and resistance to fungal disease.



SEAWEED AND ENVIRONMENT

Seaweeds have shown tremendous interaction with the pollutants that dumped into the sea, excess of which could adversely affect the growth and physiology and might lead to destruction of habitat. Seaweeds have a remarkable capacity to detoxify serious organic pollutants such as trinitrotoluene (TNT) or polycyclic aromatic hydrocarbons, heavy metals and radionuclides. Thus, it plays an important role in protecting the ecological health of marine life. Thus, seaweed is being used in polyculture system and also in IMTA. Seaweed is the most important carbon sink in the ocean. According to Suzuki (1997) the total area of marine plant beds in the world is about 600,000 km². The estimates of global production of marine plant beds to be 460,000,000 tons of carbon a year. This figure is equivalent to 23 percent of the amount of oceanic carbon dioxide uptake (Siegenthaler and Sarmiento, 1993). China comprises 77 % of the total production of the seaweed. The global production by seaweed cultivation in terms of carbon would be about 600,000 tons. Thus, seaweed cultivation in coastal waters will help in carbon fixation and seaweed acts as a carbon sink. Besides there is lot of opportunities for developing other algae like *Asparagopsis taxiformis* a native species from Kollam water which is rich in iodine. In 2014, researchers at CSIRO and James Cook University demonstrated that feeding ruminants a diet containing one to two percent red seaweed reduced their methane emissions by over 90 percent. Out of 20 types of seaweed tested, the findings spurred further investigation into its effects on ruminant animal enteric methane production.

In 2016, the same team showed that 2-5% of seaweed biomass effectively reduced production by 98-100% (Kinley, Robert et al., 2016) *in vitro*. And in a separate study, identified the bioactive in *A. taxiformis*. While dichloromethane extract was the most potent bioactive, reducing methane production by 79%, bromoform and dibromochloromethane had the highest activity inhibiting methane production, and only bromoform is present in sufficient quantities to be effective. In 2020, they showed that a 0.2% addition of *A. taxiformis* to cattle's feed reduced the livestock's methane emissions by over 98%. In 2021, a team from UC Davis found that additions of 0.25% and 0.5% reduced cattle's enteric methane emissions by 69.8% and 80% respectively (Roque, B.M et al., 2021). *A. taxiformis* showed the most promise, with nearly 99 percent effectiveness. In India too ICAR-CMFRI with National Institute of Animal Nutrition has found out the effectiveness of seaweed on reducing methane emission in cattle.

SEAWEED FOR BIOREMEDIATION

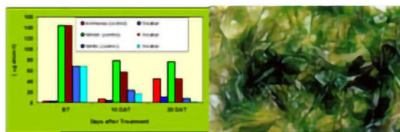
The aquatic vegetation is an important factor in the self-cleansing capability of the water. This vegetation includes microscopic algae as well as macroscopic plants such as duckweeds, water hyacinths, seaweeds etc. Most of the metabolites are removed through assimilation by these plants through biological conversion. Macroalgae have been shown to rapidly reduce



Mariculture of Seaweeds and Development of High-Value Products

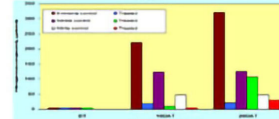
the concentrations of dissolved nutrients from shrimp pond effluent and simultaneously grow and provide a significant amount of the needed oxygen to the farms. Seaweeds not only participate in the bioremediation of nutrient enriched coastal waters, but are also a high-value crop that diversifies sources of revenue and labor force of the aquaculture industry. Effluents from intensive farming contain much organic matter, nitrogen compounds, phosphorus and other nutrients lead to eutrophication. Nutrient load of the water encourages toxic plankton blooms and mortality of the aquatic animals. The effluent from aquaculture pond without treatment can pollute the other receiving natural waterbodies. Nutrient-rich waters, in the vicinity of fish farms, also favour the growth of opportunistic annual algae, such as *Enteromorpha*, *Cladophora* causing severe biofouling, restricting water and nutrient circulation, decreased light penetration, and increased sedimentation of organic matter. The environmental sustainability of aquaculture in general and shrimp farming in particular has received increasing attention in recent years.

Nitrogenous compounds of shrimp effluent treated with seaweeds

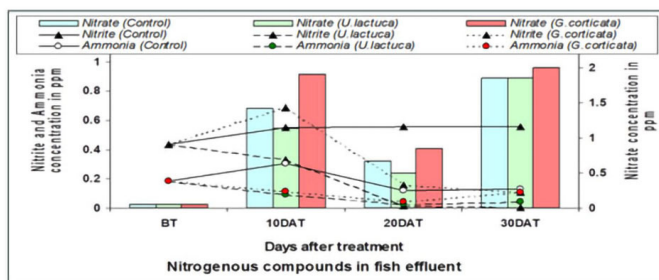


Treatments	0-10 DAT	0-20 DAT	10 DAT/control	20 DAT/control
Ammonia	+27.73	+72.47	-36.47	-75.00
Nitrate	-59.93	-68.99	-26.37	-41.32
Nitrite	-73.93	-96.65	-30.17	-70.89

Shrimp and seaweed polyculture *Penaeus Indicus* and *Ulva reticulata*

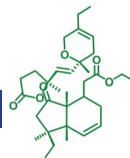


Treatments	0-10 DAT	0-20 DAT	10 DAT/control	20 DAT/control
Ammonia	+74.14	+77.86	-91.46	-93.10
Nitrate	+56.86	+95.78	-92.51	-14.73
Nitrite	+92.64	+98.68	88.90	-37.78



Percentage increase or decrease in toxic nitrogenous waste in the fish effluent

	0-10 DAT	0-20 DAT	10 DAT/control	20 DAT/control
Ammonia				
<i>G. corticata</i>	-39.00	-84.00	-63.50	-75.60
<i>U. lactuca</i>	-48.90	-82.00	-69.00	-73.00
Nitrate				
<i>G. corticata</i>	+95.72	+92.97	-20.60	-54.00
<i>U. Lactuca</i>	+95.06	+88.09	-35.60	-72.00
Nitrite				
<i>G. corticata</i>	+29.90	-63.70	-14.70	-71.00
<i>U. lactuca</i>	-23.90	-96.00	-52.00	-96.90



In the experiment conducted by CMFRI, it is understood that the available ammonia in ETP or in polyculture system is converted to nitrite and nitrate by nitrifying bacteria but the accumulation of nitrate in *G.corticata* after 20 days of treatment can be used as the source of nitrogen for crop productivity in biofertilizer. Combination of green and red algae will help to reduce the toxic nitrogen efficiently from the system. Already some work has been carried out in CMFRI-CIBA (DBT project) to isolate these bacteria to use as probiotics.



INTEGRATED FARMING OF SEAWEED AND SHRIMP BY ICAR-CMFRI

SEAWEED FOR BIOMINING

Seaweed biomining is again a recent concept where the heavy metals in the polluted water can be recovered when it passed through the dried seaweed powder. Among the three major group of seaweed, brown algae are found to be the best biosorbents. The removal of heavy metals like copper, lead zinc and cadmium from the polluted water was studied in brown algae. The cell wall of brown algae generally contains cellulose, the structural support alginic acid and the polymer of mannuronic acid and guluronic acid and salts of sodium, potassium, magnesium, calcium and sulphated polysaccharides (Romera et al 2007). Heavy metals like copper and zinc were also detected in the effluent water. *Sargassum* could accumulate the zinc 17.6 (mg/kg) and copper 1.96 (mg/kg) whereas *Kappaphycus* could accumulate 76.06 mg/kg of zinc and 16.64 mg/kg of copper from the effluent (Vani & Reeta ,2021). Earlier reports also explained that *Kappaphycus alvarezii* is a good biosorbent for the removal of nutrients (Rathode et al., 2014) and heavy metals (Kang et al., 2011) from the aqueous environment. Bioremediation is a suitable solution of such hazardous waste at the source level by a cost-effective method and suggest the industries to adopt the method so that the industry will be benefited of treatment of their effluent before releasing to the natural environment/reusing the most important commodity like fresh water and also to mining the heavy metals through Phyto mining. Simultaneously, it will protect the natural water from pollution and maintain synergy with the aquatic flora and fauna.



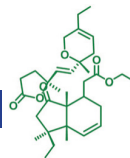
BIOENERGY FROM SEAWEED AND MICROALGAE

Due to the ever-increasing demand of fossil fuel affected by barging population, industrialization and transport system, A stage has reached where an alternate source of energy is required to meet the demand. Microalgae are one such resource considered as the third-generation biofuel due to its size, multiplication and the space for growth. Micro algae are single celled diverse organisms usually considered as the sun driven factory for production of biofuel from its fatty acids, methanol by anaerobic digestion and hydrogen by photosynthesis. The algae can complete its life cycle within a very short span of 12-30 days and reached to a peak stage of growth for harvest which can have multivariate use from biofuel to methanol and proteins. Besides they are the rich source of unsaturated fatty acid like DHA and EPA, astaxanthin, Beta carotene and zeaxanthin which gives a competition on the biofuel production. Thus, the microalgae especially the marine microalgae can be considered as one of the renewable sources of energy. Marine microalgae constitute 40% of the global carbon fixation and are the primary producer in the food chain to sustain the entire marine fauna.

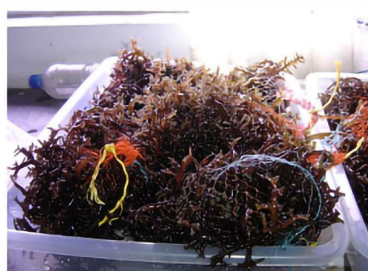
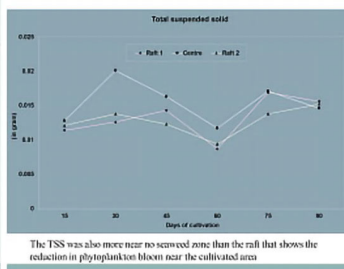
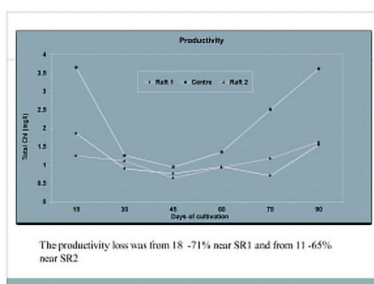
Seaweeds represent one of the promising resources of the oceans with immense social, economic, and environmental benefits. Seaweeds being non-lignocellulosic, are considered as third-generation biofuel feedstock along with microalgae. Compared to microalgae, seaweeds are least explored for biofuels, especially biodiesel, due to their low lipid content. Still, they are the potential source of biomass for other forms of biofuels. The availability and sustainable production of seaweed biomass has been the primary concern to make seaweed biofuel viable. It is evident from the past research works that seaweeds with 80%–90% water content are more suitable for anaerobic digestion and fermentation to produce biogas and bioethanol respectfully. Seaweed contains 80–90 wt.% of water thus they are more suitable for anaerobic digestion and fermentation to produce biogas and bioethanol (Nagula et al., 2022) but, raw, and dried seaweed can be converted into biofuels using chemical and thermochemical procedures. But always there is a conflict for food verses fuel. Both micro and macro algae are rich source of nutrient and a source of healthy diet so using these resources for fuel is definitely gives a second thought.

NUTRIENT LIMITATION DUE TO SEAWEED FARMING

- It is reported that with the production of 1 t wet weight of seaweed, 25-79 kg (Average 52 kg) of carbon and 2.5-6.2 kg (average 4.4 kg) of nitrogen can be removed from the sea.
- If the production of seaweed ranged from 30-120t/ha it will remove 1560-6240 kg of carbon and 132-528 kg of nitrogen from 20000 t of seawater within 1 ha cultivated area within 2m depth.



- This removal is almost 16.5 times higher than the indicated level of eutrophication by nitrogen.
- Thus, to balance method has to be adopted to sustain the ecosystem with production and optimal nutrient availability.
- Nutrient uptake is very high by *Kappaphycus* and may compete with other species for nutrient.
- Recent incidence of loss of crop in Gulf of Mannar may be due to nutrient depletion.
- Regular monitoring of water quality and biodiversity study at commercial farming site of *Kappaphycus*
- Continuous farming of *Kappaphycus* in an area may lead to productivity loss and require crop holiday at least for a month in each crop.
- Shifting of farm area after continuous culture.
- Regular fortification is necessary in the culture site to have sustainable growth of seaweed.



This work was carried out in the seaweed culture site at Narakkal by ICAR-CMFRI.

BIO INVASION

Bio invasion is again a threat to Coastal biodiversity. There are reports on the development of *Kappaphycus* on coral reef area of Krusadai Island (Kamalakaran et.al, 2014). Chandrasekaran et al. (2008) observed that *K.alvarezii* had successfully invaded and established on both dead



and livecorals in Krusadai Island, India. Mandal et al., 2010 also reported the establishment of few fragments on the coral reef area of Gulf of Mannar. According to Zemke-White and Smith (2006), the genus *Kappaphycus* was introduced in 19 tropical countries and *Eucheuma* into 13 tropical countries. After 30 years of commercial cultivation, bio invasion was reported in Philippines. From the 19 tropical countries only two have reported bio invasion. The most studied case of the impacts of *K. alvarezii* cultivation in the tropics is from Hawaii. Shifts from coral to algal domination on reefs may lead to the loss of biodiversity. Indiscriminate use of plastic bottles as floats is again a matter of concern in seaweed farming. From the studies of ICAR-CMFRI, it was understood that *Kappaphycus* has never developed any reproductive structure in Indian waters thus establishment of seaweed through spores is not possible. There is always environmental concern and authorities have taken proper guidelines to cultivate the species in Indian water. Definitely due to high growth rate, high carrageenan yield and quality this species formed an alternate livelihood for the coastal fishers.

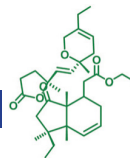


SEAWEED MARKET AND INDIA'S POSITION ON SEAWEED RESEARCH

The Indian requirement of agar, alginate carrageenan per annum is about 400 tonnes, 1,000 tonnes & 1,500–2,000 tonnes respectively. Taking the demand, the total annual seaweed requirement in dry weight basis is 4,000 tonnes of agar yielding algae; 5,000 tonnes of alginate yielding algae and 4,500 to 6,000 tonnes of carrageenan yielding algae. On fresh weight basis the demand will be 40000 t of agarophytes, 50000 t of alginophytes and 60000 ton of carrageenophytes. Currently there are 46 seaweed-based industries – 21 agar industries (10 functional) and 25 alginate industry (12 functional) (Subba Rao and Vaibhav Mantri, 2006). In Tamil Nadu there are around 35 industries mostly located at Madurai, Ranipet, Kankeyam, Paramakudi, Nilakottai and Thirunellar. There are few industries reported at Kerala, Karanataka and Gujarat.

CONSTRAINTS OF SEAWEED CULTIVATION

- The industries are not able to flourish due to non-availability of seaweed biomass.
- Non availability of protected bay for farming



- Seed is the major constraint
- Transportation of seed material from one place to other
- Frequent cyclone and natural disasters
- Mechanisation of farming
- Offshore farming

Although ICAR-CMFRI has developed the potential mariculture sites for seaweed culture, it is essential to do the feasibility studies and find out the suitable period of farming keeping in view the above constraints.



SUGGESTED READINGS

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