MAPPING OF TECHNOLOGIES FOR VALUE-ADDITION OF SEAWEEDS IN INDIA

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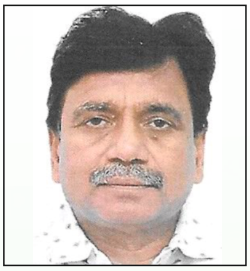
FOREWORD



The oceans cover more than two-thirds of the Earth's surface and are home to a variety of organisms with high biological and chemical diversity. About 250,000 known species resides in the marine ecosystem. The biodiversity in the marine environment is acknowledged as a huge reservoir of biological resources. These organisms could be utilized to produce a spectrum of novel products. Manufacturing of products from marine bioresources could potentially contribute towards the growth of blue bioeconomy, an emerging and innovative sector within the Blue Economy.

Seaweed, an important marine bioresource, is gaining greater attention in the recent times. Due to its rich nutrient source, seaweed could offer solutions to the ever-increasing nutritional requirements of the global population. Seaweed provides a broad range of ecosystem services and is considered as a natural-based solution for climate change mitigation. Seaweed is a unique source of many high value molecules with varied biological activities and has myriad industrial applications. The bioactive molecules derived from seaweed, could find a place in production of nutraceuticals and pharmaceuticals, as an active ingredient. Seaweeds could also contribute to the economic and social empowerment of coastal populations, especially the women folk, by creating employment and generate income.

Globally, seaweed culture is considered as one of the fastest growing sectors. Even though, Asia is the epicenter of global seaweed production, the contribution of India to the global seaweed production is scarce. As far as seaweed value-added products are concerned, India is highly dependent on imports. Thus, it is crucial for India to achieve self-reliance in the area of seaweed production and value-addition. In this scenario, seaweed value-addition technology development and adoption assume significance. Seaweed can also serve as the sink for carbon dioxide removal, hence supporting decarbonization initiatives of India.

Considering the importance of seaweed, TIFAC has initiated various interventions. A report on the prospects of seaweed cultivation and utilization in India was brought out in 2018. Subsequently, in 2021, a 'Seaweed Programme' with the aim of promoting commercial scale seaweed aquaculture and its processing for production of value-added products was launched. In order to achieve the objective of establishing a robust seaweed value-addition industry in India, mapping of indigenously developed technologies is highly imperative.

Mapping of seaweed value-addition technologies would provide opportunities to entrepreneurs/ industry to espouse suitable technological options and would provide insights to researchers as well as policy makers to identify and strategize future R&D areas. The systemic recommendations arrived in this report could act as a stepping stone in establishing a sustainable seaweed sector in India. I expect this report to be an excellent and comprehensive knowledge source for various stakeholders for structurally transforming the Indian seaweed sector and to become 'Atmanirbhar'.

Prof. Pradeep Srivastava
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EXECUTIVE SUMMARY

Seaweeds or macroalgae, often found in the marine ecosystem, are deemed as 'wonder plants of the sea', due to their ecological, social, and economic contributions. Considering the importance of seaweeds in the blue bioeconomy, this study explored the potential applications/ economic uses of seaweeds, comprehended the current scenario of global and Indian seaweed sector, delineated the status of seaweed value-addition industries/ products in India, collated seaweed value-addition technologies developed in India, analyzed the trends in development of seaweed value-addition technologies, studied the R&D trends in seaweed value-addition in India, and accordingly formulated recommendations for establishing sustainable seaweed value chains and to transform the Indian seaweed sector into a self-sustainable industry.

Seaweeds have been profoundly contributing to humans, since times immemorial. Seaweeds provide various ecosystem services such as oxygen production, nutrient cycling, carbon sequestration, shoreline protection etc. Seaweeds also have the potential to contribute towards sustainable healthy diets, achieve Sustainable Development Goals (SDGs) and provide sustainable livelihoods, especially for the coastal communities. Seaweeds are an ample source of macronutrients and micronutrients, thus have the potential to contribute towards global nutritional security. Seaweeds are also known to contain a variety of secondary metabolites, with wide-ranging biological activities.

Seaweeds have diverse applications and are used as food, functional foods, pharmaceuticals/ nutraceuticals, cosmetics, plant biostimulants, animal feed etc. Seaweeds are consumed directly as food as well as used as an ingredient in various preparations. The polysaccharides extracted from seaweeds are widely used in the food industry as functional ingredients. Pharmaceutical application of seaweeds encompasses treatment of various diseases like goiter, stomach disorders, influenza, mumps, osteoarthritis, kidney disease, cancer, diabetes, eye diseases etc. The sulfated polysaccharides present in seaweeds have the potential to impede replication of viruses belonging to the genera Coronavirus; hence seaweeds could be used to combat COVID-19 infections. Seaweed bioactives such as terpenoids, phenolic compounds, carotenoids, polysaccharides, mycosporin-like amino acids etc. are used in the production of cosmetics, as active ingredients. Due to the presence of various phytohormones such as cytokinins, auxins, gibberellins etc., seaweeds are used as plant biostimulant. Supplementation of seaweed in feed can reduce emission of enteric methane by ruminants and also results in enhanced growth and productivity of the animal. Seaweeds also find novel application in production of biofuels, bioplastics, medical textiles, solar cells, energy storage systems, bioink etc.

Globally, 35.76 million tons of fresh seaweed was produced in the year 2019 by 48 species cultured and/or collected from 49 countries. Out of the total seaweed production, 34.68 million tons was contributed by farmed seaweeds and the remaining 1.08 million tons by wild-collected seaweeds. The dominant species groups contributed to the production are Laminaria/Saccharina, Undaria, Kappaphycus/Eucheuma, Gracilaria, and Porphyra. The global seaweed production was dominated by Asia (97.38%); with China (56.75%), Indonesia (27.86%), Republic of Korea (5.09%), and the Philippines (4.20%) as the major producers. The global seaweed culture was dominated by China, Indonesia and Republic of Korea and seaweed production from wild collection was dominated by Chile, China and Norway.

Global trade of aquatic plants grew from USD 65 million in 1976 to about USD 1.3 billion in 2018. The major exporters of aquatic plants in 2018 were Indonesia, Chile and Republic of Korea and leading importers include China, Japan and the United States of America. As per an estimate, in 2020 the value of commercial seaweed market in the world was USD 14.8 billion, and the value is anticipated to reach between USD 21-24 billion in 2027. Currently, numerous players are present in the global seaweed processing/ value-addition market manufacturing diversified food and non-food products. Worldwide, innovative entrepreneurs have invested significantly in seaweed sector leading to creation of startups producing novel seaweed-based products like bioplastics, 3D printed vegan steaks, biopolymers, livestock feed supplement etc.

Globally, numerous projects and collaborations/ networks have been forged to develop a vast array of innovative technologies and novel products from seaweed and its commercialization. Some of the key projects are 'SeaGas Project' (biomethane production), 'Seaweed production systems with high-value applications' (isolation of bioactive compounds following biorefinery approach), 'BIOCARB-4-FOOD' (manufacturing carbohydrate-based extracts and fibers from residual biomass), 'ProSeaFood' (augmentation of digestibility and nutrient availability of brown seaweeds by application of advanced processing techniques), 'Seaweeds for Novel Applications and Products' (use of biorefinery processes to isolate alginates, cellulose, fucoidans, carrageenans etc.), 'PlastiSea' (development of bioplastic materials) etc.

In Indian waters, 844 species of seaweeds belonging to 217 genera of 69 families have been reported so far. Seaweed resources of India are mainly distributed in Tamil Nadu, Gujarat, Lakshadweep and Andaman and Nicobar Islands. Abundant seaweed beds are also observed in Maharashtra, Goa, Karnataka, Kerala and Odisha. Since early 1950s, Gelidiella acerosa and Gracilaria edulis were harvested commercially for manufacturing of agar and Sargassum, and Turbinaria for alginate production in India. Commercial farming of seaweed in India commenced with cultivation of Kappaphycus alvarezii by Pepsi Foods Ltd. at Mandapam, Tamil Nadu, with technical assistance from Marine Algal Research Station of CSIR-Central Salt and Marine Chemicals Research Institute (CSIR-

CSMCRI) in 2001. Subsequently, aquaculture of K. alvarezii was expanded to other regions of the state of Tamil Nadu as well as to other parts of the country including the state of Gujarat. While most of the efforts are focused on cultivation of Kappaphycus, farming of other seaweed species belonging to the genus Gracilaria, Hypnea etc. has also been attempted in India . In terms of wet weight, production of aquatic plants including seaweeds in India decreased from 34922 tons in 2009 to 27937 tons in 2018, contributing merely 0.08% to the global production. The quantity of seaweed and seaweed-based products imported to India greatly exceeds the exports. The value-addition of seaweed products exported from India is also very low, when compared to the products imported.

Most of the seaweed processing industries in India are micro-enterprises and mainly use wild harvested seaweeds as raw material. The main seaweed-based value-added products commercially manufactured in India are agar, alginate, carrageenan and plant biostimulant/ biofertilizer. Annual production of agar and alginate in India is 120 tons (30% of requirement), and 1000 tons (less than 40% of requirement) respectively. Carrageenan is manufactured In India from cultured Kappaphycus alvarezii and the annual requirement of carrageenan in India is estimated at 1500-2000 tons. Even though several players are present in Indian biostimulants market, the biostimulants are mostly imported and packaged and marketed in India. However, a few industries are indigenously producing plant biostimulants from Kappaphycus and Sargassum, with the technology developed by CSIR-CSMCRI, Bhavnagar.

A few industries are also producing seaweed-based nutraceuticals and functional foods. Various nutraceutical products/ formulations for treatment of diseases like arthritis, type-2 diabetes, hypothyroidism, dyslipidemia, hypertension, osteoporosis etc. developed and commercialized by ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Cochin, are available in the Indian market. Microencapsulated dietary supplement formulation of fucoidan and green tea extract, and carrageenan-based hand sanitizer, developed and commercialized by ICAR-Central Institute of Fisheries Technology (ICAR-CIFT), are being produced in India. Functional foods such as seaweed blended grape juice, seaweed cookies, seaweed supplemented yoghurt, etc., developed and commercialized by ICAR-CIFT are also manufactured in India. Production of seaweed-based cosmetics is in its nascent stage in India and only very few products, mostly belonging to skin care category, is being produced currently.

Key seaweed-based technologies ready for commercialization in India are antimicrobial ointment, probiotic nutraceutical to improve intestinal gut microflora, extract for use against non-alcoholic fatty liver disease, biodegradable films based on semi-refined kappa carrageenan, seaweed polysaccharides-based foot care gel, seaweed dietary fibre, seaweed incorporated extruded snacks, edible sachet bioplastics, fucoxanthin rich supercritical fluid extraction extract, seaweed tea, Kappaphycus alvarezii sap extractor etc. Seaweed-based technologies developed at pilot scale in India include seaweed incorporated chocolate, extraction of phycobiliproteins for food applications, polysaccharides extracted spent seaweed biomass for bioethanol production, immunostimulant for fish etc.

Major laboratory scale seaweed-based technologies developed in India are preparation of graded agarose, preparation of sprayable aqueous chitin formulations fortified with plant macronutrients, preparation of suture, seaweed noodles, conjugated alginate for biomedical applications, carrageenan-based ointment, seaweed-based composite scaffolds, seaweed jerky, preparation of seaweed polysaccharide nanoparticle, antibacterial composition against Aeromonas infection in aquaculture, anticoagulant peptide from Nori, nutraceutical capsule rich in polyphenols, extending shelf life of tomatoes by coating seaweed gel, extraction of ulvan from green seaweed and use as therapeutic agent etc.

During the last two decades (2001-2020), eighty-nine patent applications related to seaweeds were published in India, of which sixty-five were related to seaweed value-addition. However, only sixteen patents were granted in the area of seaweed value-addition in the last twenty years. Among the granted patents, five were granted to foreign entities and rest was awarded to Indian institutions. The fields of invention of awarded patents include biochemistry, chemical, pharmaceuticals, biotechnology, food, mechanical engineering, polymer technology, traditional knowledge biotechnology, and traditional knowledge chemical.

The major seaweed value-addition patents granted in India include production of carrageenan and carrageenan products, production of phycocolloid and liquid fertilizer from fresh seaweeds, biodegradable films based on semi refined kappa carrageenan, integrated process for biofuels production, preparation of antioxidant and anti-inflammatory concentrates from brown and red seaweeds, cosmetic composition containing brown seaweed extract, anti-inflammatory principles in a preparation of brown seaweeds, isolation of anticoagulant peptide from Porphyra hydrolysate, preparation of anti-oxidative edible film from fucoidan, nutritional rich chocolate composition, preparation of seaweed polysaccharide-based hydrophobic biocompatible ropes etc.

The research papers published by the Indian researchers on seaweed value-addition in the last decade (2011-2020) are broadly in the realm of human health and nutrition, agriculture, animal husbandry, and industrial applications. Studies on human health mostly investigated antimicrobial, anti-diabetic, anti-hypertensive, anti-cancer, neuroprotective, hepatoprotective, anticoagulant, biomedical, and disease control properties of seaweeds. Several researchers studied the effect of application of sap extracted from different seaweed species on various crops/ plants. The seaweed species investigated extensively for use as biostimulants were Kappaphycus alvarezii, Gracilaria edulis, and Sargassum wightii. Use of seaweeds as feed supplement for aquatic organisms, cattle, poultry etc. was also evaluated by various researchers. Numerous studies have explored application of seaweeds in water treatment, production of biofuels, bioplastics, textiles, alkaline fuel cells etc.

After considering aspects such as seaweed biomass supply, sustainable valorization for value-added product development, research and technology development, policies etc., recommendations were formulated with different implementation time frames. The major short-term recommendations include preparation of a national seaweed policy for establishing a sustainable and resilient seaweed industry in India, formulation of guidelines for leasing natural water bodies for seaweed aquaculture, providing crop insurance, providing minimum assured price for seaweed biomass, supplementation of seaweed in cattle feed to tackle methane emission from ruminants, developing seaweed friendly policy framework with required certification etc.

The medium-term recommendations consists of establishing seed banks for seaweeds under PPP mode; formation of a non-profit company for supply of quality seed materials; establishing seaweed parks in Gujarat and in the Islands of Andaman and Nicobar and Lakshadweep; development of robust, cost-effective, upstream production technologies for open ocean seaweed aquaculture; establishing a consortium of government, industry and R&D institutions to work in a mission mode for developing farming and processing technologies; establishing incubation centers; creation of 'Centres of Excellence in Seaweed Bioproducts Development' at R&D institutions and academic institutions; integration of seaweed into national biofuel policy/ programme etc.

The long-term recommendations comprise of supporting clinical trials and commercial production of seaweed-based pharmaceuticals; supporting large scale commercial production of seaweed-based biomaterials and bio-energy etc. The recommendations in the study report could radically transform the seaweed sector and could aid in establishing sustainable seaweed value chains and a self-reliant seaweed industry in India.

1.0 OVERVIEW

1.1 INTRODUCTION

Algae, a heterogeneous group of polyphyletic organisms belonging to the kingdom Protista, comprise of microscopic unicellular organisms, commonly named as microalgae, as well as macroscopic multicellular organisms, often referred to as macroalgae, and are ubiquitously distributed. The macroalgae or seaweeds are a divergent group of photoautotrophic eukaryotic flora inhabiting predominantly in the littoral and sublittoral zones of marine ecosystem. Unlike terrestrial plants, seaweeds lack true stem, leaves, roots and flowers. Also, they do not possess a vascular system and nutrients are absorbed directly through the surface tissues. Based on pigmentation, seaweeds are broadly classified as green algae or chlorophytes, brown algae or phaeophytes and red algae or rhodophytes. Green seaweeds have chlorophyll a and b as pigments, brown seaweed contains chlorophyll a and c and fucoxanthin and red seaweeds contain chlorophyll a and d, and phycobilins (phycoerythrin and phycocyanin). About 1,800 species of chlorophytes, 1,800 species of phaeophytes and 6,200 species of rhodophytes are present in the marine environment worldwide (Pereira, 2021).

Seaweeds have been contributing profoundly to the humans, right from the evolutionary time scales to the current times. Seaweed is expected to have played a crucial role in the evolution of humans to modern *Homo sapiens*. Dietary intake of seaweeds might have contributed to the essential nutrients for the early humans to evolve, millions of years ago (Cornish *et al.*, 2017). It is also believed that seaweeds had supported migration of early humans. According to the "Kelp Highway" hypothesis, a corollary to the coastal migration theory, the early humans have migrated to the Americas following a coastal highway of dense kelp, by utilizing its rich biodiversity (Erlandson *et al*., 2015). The archaeological evidence from Monte Verde, Southern Chile had revealed that the humans have been using seaweeds as food and medicine for about 14,000 years (Dillehay *et al*., 2008). According to Yang *et al*. (2017), the people of China have been utilizing red seaweeds as food and pharmaceuticals for nearly 1,700 years. Records have revealed consumption of seaweed in Japan around 1,500 years ago, during the Asukaand Nara Era (Buchholz *et al*., 2012). Utilization of seaweeds for medicine, clothing, food, shelter etc. by Aboriginal Australians has been recorded by Thurstan *et al.* (2018).

Seaweeds offer various valuable environmental services. The multiple ecosystem services provided by seaweeds include provisioning (primary production), regulating (nutrient cycling, carbon cycle regulation, wave attenuation, and coastal protection), supporting (photosynthesis and habitat), and cultural (aesthetic, recreational, spiritual, and educational value) (Thomsen & Zhang, 2020). In the marine ecosystem, seaweeds take up nutrients such as nitrogen, phosphorus etc. and remediate the anthropogenic nutrients (Roleda & Hurd, 2019), releases oxygen through photosynthesis, reduces hypoxia (Froehlich *et al*., 2019; Bhuyan *et al*., 2021; Gao *et al*., 2022) and prevents occurrence of toxic algal blooms (Imai *et al*., 2006).

Seaweeds sequester significant amounts of carbon in the ocean, can aid in reducing the rate of global warming (Kaladharan *et al*., 2009) and contributes considerably to climate change mitigation and amelioration of ocean acidification (Duarte *et al*., 2017; Xiao *et al*., 2021). The UN Global Compact (2021) has identified seaweeds as a nature-based climate solution. Globally, the estimated carbon assimilation potential of seaweeds is about 173 TgC/year (Krause-Jensen & Duarte, 2016). According to Kaladharan *et al.* (2009), seaweed biomass present in the Indian coast has the capacity to utilize 9,052 tCO_2 /d, against an emission of 365 tCO_2 /d, showing a net carbon credit of 8,687 t/d. As per N'Yeurt *et al.* (2012), utilizing 9% of global ocean surface for seaweed cultivation can annually sequestrate 53 billion tons of CO_2 and could restore atmospheric CO_2 to pre-industrial levels.

Seaweeds attenuate waves advancing to the shore and protect shorelines from erosion and flooding (Morris *et al*., 2020). Zhu *et al.* (2021) demonstrated the coastal defense capability of suspended seaweed farms by damping wave energy. Seaweeds also act as an excellent habitat for numerous aquatic organisms and provide them shelter, food, spawning and nursery grounds (Eklöf *et al*., 2006; Hehre & Meeuwig, 2016; Walls, 2017; Langton *et al*., 2019; Theuerkauf *et al*., 2021; Corrigan *et al*., 2022). The importance of seaweed in supporting and maintaining biodiversity in the marine ecosystem had been observed by none other than Charles Darwin, the most famous naturalist and biologist in history.

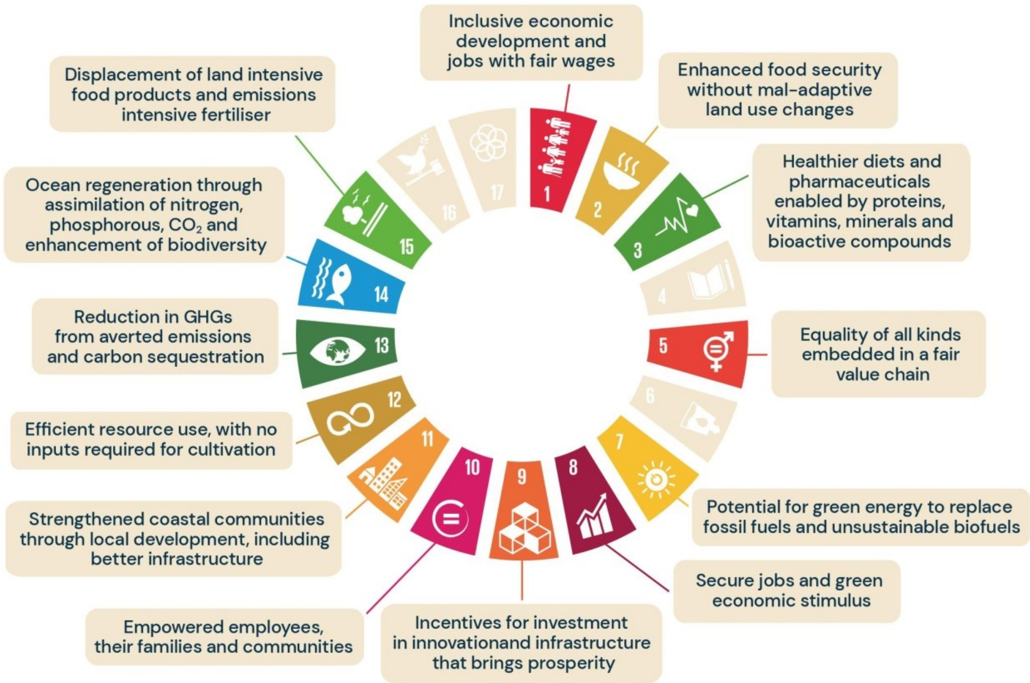
"The number of living creatures of all orders whose existence intimately depends on kelp is wonderful. A great volume might be written describing the inhabitants of one of these beds of seaweed…. I can only compare these great aquatic forests…with terrestrial ones in the intertropical regions. Yet, if in any other country a forest was destroyed, I do not believe so many species of animals would perish as would here, from the destruction of kelp"

- **Charles Robert Darwin, 1834**

Being a low-trophic species, farming of seaweeds is relatively less resource intensive, ecologically efficient (SAPEA, 2017) and have least deleterious impact on the environment (Parodi *et al*., 2018; Visch *et al*., 2020; Gephart *et al*., 2021; Jagtap & Meena, 2022). Indeed, seaweed aquaculture is environmentally benign, due to the ecosystem services bestowed by seaweed, and is a sustainable method of biomass production. Seaweeds can be cultured in seawater and does not require scarce resources such as fertile land, freshwater, and inputs like fertilizer. Seaweed farming is widely touted as an activity with low carbon footprint. Seaweeds grow faster and have yields higher than land plants. Seaweeds also occupy space more efficiently than terrestrial plants, with reference to biomass (Creed *et al.*, 2019).

Globally, seaweed farming is considered as one of the rapidly growing food production systems. The potential of seaweed aquaculture as a sustainable, healthy and nutritional food source to achieve food security has been highlighted by Farmery *et al*. (2021) and UNCTAD & FAO (n.d.). As per the World Bank Group (2016), large scale seaweed production for human consumption can transform the universal food security concepts. Hence, seaweeds are contemplated as a sustainable source of nutrients to achieve global nutritional security. Rawiwan *et al.* (2022) has highlighted the potential of seaweed as a sustainable substitute to terrestrial crops and animal proteins. According to Lehahn *et al.* (2016), in 2054 seaweed could cater up to 24% of the global plant protein requirement. As estimated by Spillias (2021), 10% substitution of human diets with seaweed could spare up to 100 Mha of natural lands globally.

Seaweed has the potential to contribute towards sustainable healthy diets and can be used as a tool to achieve the Sustainable Development Goals (SDGs). UN Nutrition (2021) has highlighted the potential of seaweeds to contribute towards sustainable healthy diets. The World Wildlife Fund, in collaboration with Knorr Foods, has prepared a list of future 50 foods that can make the people and the planet healthier and can lead to global food sustainability. The seaweed species *Porphyra umbilicalis* and *Undaria pinnatifida* have found a place in the list of future 50 foods (WWF, 2019). Against the backdrop of global pandemic of COVID-19, in order to create resilient food systems, seaweed had been identified as a novel future food, with minimal environmental impact (Sperling *et al.*, 2020; Tzachor *et al*., 2021). According to Hossain *et al.* (2020), seaweed can play a pivotal role in achieving 26 targets (out of 169 targets) and 8 goals (out of 17 goals) of the SDGs. Various contributions of seaweed to achieve the SDG goals are depicted in **Figure 1.1**.



Source: Vincent *et al.* (2020)

Figure 1.1: Contribution of Seaweed to Achieve SDG Goals

Recognizing the importance of seaweed, the Sustainable Ocean Business Action Platform of the United Nations Global Compact, in collaboration with the Lloyd's Register Foundation, has brought out a 'Seaweed Manifesto'. The manifesto envisages an upscaled, responsible and restorative seaweed industry, with considerable role in global food security, climate change mitigation, marine ecosystem support, employment generation and poverty alleviation to achieve SDGs. The manifesto was officially launched on the sidelines of the 2020 UN General Assembly (UNGC & Lloyd's Register Foundation, 2020).

Cultivation of seaweed requires comparatively simpler technologies, modest capital investment, and has shorter culture cycles with higher returns (Valderrama *et al*., 2015). Thus, seaweed aquaculture could be used as a tool to provide sustainable livelihood, empower women and reduce poverty among coastal communities. Acknowledging the prospects of uplifting the social and economic conditions of the populations living in coastal areas, the international development agencies are fostering seaweed aquaculture globally (Trono *et al*., 1980; Ahmed *et al*., 2022). Recently, the African Development Bank has emphasized the potential of seaweed aquaculture to improve the socio-economic condition in the African countries (ANRC, 2022). Globally, the impacts of seaweed aquaculture on the socio-economic development of coastal communities have been documented by Agyarko (2017), Hussin & Khoso (2017), Naidu & Pandaram (2018), Ginigaddara *et al*. (2018), Rimmer *et al*. (2021) etc.

1.2 NUTRITIONAL PROFILE OF SEAWEEDS

Seaweeds are an important source of nutrients. The macronutrients and micronutrients present in seaweeds include carbohydrates, proteins, lipids, vitamins, and minerals. Considerable variations are observed in the chemical composition of seaweeds, depending on species, maturity stage, geographical origin, environmental factors (habitat, light, salinity, temperature, season) etc. (Michalak & Chojnacka, 2009; Maehre *et al*., 2014; Banerjee *et al*., 2020).

Carbohydrates mostly constitute the structural as well as storage component of the cell. Based on species, amount of carbohydrate in seaweed varies between 20% and 76%, on dry weight basis (Holdt & Kraan, 2011). Various classes of carbohydrates present in seaweeds include alginate, carrageenan, ulvan, laminarin, cellulose/hemicellulose, and fucoidan (Goñi *et al*., 2020). Even though seaweeds have significantly higher carbohydrate content, a large portion of it is available in the form of polysaccharide dietary fiber. The dietary fiber content in seaweeds is about 25% to 75%, on dry weight basis (Jiménez-Escrig & Sánchez-Muniz, 2000). The soluble fiber fraction represents about 55% to 70% of total dietary fiber of seaweeds (Rajapakse & Kim, 2011). *Chondrus* and *Porphyra* are the genus with maximum soluble dietary fiber content (15 % to 22 %). The highest content of insoluble dietary fibers is seen in the genus *Fucus* (40 %) (Fleury & Lahaye, 1991).

The protein in seaweeds constitute up to 47% of dry weight. The important amino acids available in seaweed protein are aspartic acid, glycine, glutamic acid, alanine, proline, and arginine (Černá, 2011). Green seaweeds belonging to the genus *Ulva* and *Caulerpa* are rich sources of amino acids such as arginine and glycine (Ganesan *et al*., 2020). However, red algae have lower levels of amino acids such as leucine and isoleucine and the brown algae are often deficient in amino acids such as methionine, cysteine and lysine (Dawczynski *et al*., 2007; Maehre, 2015). The protein yield for macroalgae is in the range of 2.5 tons to 7.5 tons per hectare per year, which is about two to five times more than the yield of wheat or legumes (O' Connor *et al*., 2020).

The lipid content in seaweeds is up to 5% of its dry matter (Khotimchenko, 2005). The lipid composition in seaweeds has generated significant interest due to its high polyunsaturated fatty acid contents; especially α-linolenic acid, octadecatetraenoic acid, arachidonic acid, and eicosapentaenoic acid (Dawczynski *et al*., 2007). The number of fatty acids present in red seaweeds and green seaweeds are thirty-three and twenty-nine respectively (Fouda *et al*., 2019).

Seaweeds contain high level of water-soluble vitamins as well as lipid-soluble vitamins. The production of vitamins in seaweeds is influenced by environmental factors, particularly exposure to sunlight (Leandro *et al*., 2020). Seaweeds are rich in vitamin B (especially B1 and

B12), vitamin A and vitamin E (Peñalver *et al*., 2020). High level of vitamin B12 is present in seaweeds like *Ulva* and *Porphyra* (Leandro *et al*., 2020).

Minerals account up to 40% of dry weight in seaweeds (Peñalver *et al*., 2020). Major minerals present in seaweeds include phosphorus, calcium, potassium, sodium, iodine, magnesium, iron etc. Calcium contributes about 4% to 7% of seaweed dry matter. Seaweeds are a well-known food source with rich iodine content (Teas *et al*., 2004). The brown seaweeds contain high level of iodine (1,500 ppm to 8,000 ppm), whereas red seaweeds and green seaweeds have low iodine content (Rajapakse & Kim, 2011). The contents of iron and copper in seaweeds are even higher than that of foods like meat and spinach (Vasuki *et al*., 2020).

1.3 BIOACTIVE COMPOUNDS IN SEAWEEDS AND ITS FUNCTIONAL PROPERTIES

In addition to the primary metabolites, an array of structurally diverse novel secondary metabolites with potential functional properties is also found in seaweed. These bioactive compounds are primarily produced under various stress conditions resulting from fluctuations in environmental parameters like temperature, salinity, nutrients, exposure to ultraviolet radiation, pollution etc. The major bioactive compounds present in seaweeds include polysaccharides, peptides, polyunsaturated fatty acids (PUFA), phenolics, sterols, carotenoids, terpenes, dibutanoids, acetogenins alkaloids etc. (Balboa *et al.*, 2013; Yu *et al*., 2014; Chakraborty & Joseph, 2016; Chakraborty *et al.*, 2018). The important biological activities attributed by these bioactive compounds are depicted in **Figure 1.2**.

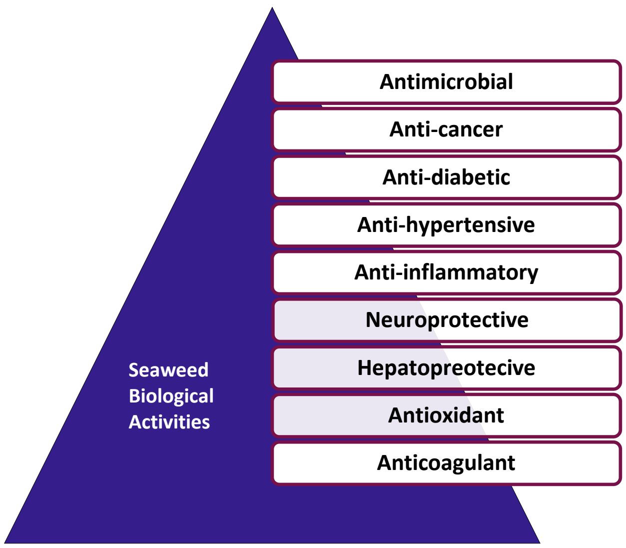


Figure 1.2: Biological Activities of Seaweeds

Broadly, seaweed polysaccharides can be classified as structural cell wall polysaccharides, mucopolysaccharides and storage polysaccharides. The major structural polysaccharides present in red seaweeds are sulfated galactans (agar, agarose, and carrageenan). However, sulfated mannans or neutral xylans are found as structural polysaccharide in certain red seaweeds (Usov, 2011). The polysaccharides available in brown seaweeds include laminarin, alginate and fucoidan (Dobrinčić *et al*., 2020). The major matrix sulfated polysaccharides produced by green algae are ulvans, galactans and arabinogalactans (Popper *et al*., 2011). The sulfated polysaccharides exhibit many valuable biological properties like anticoagulant, antiviral, antioxidant, anti-tumour, immunomodulating, anti-hyperlipidemic and anti-hepatotoxic (Wang *et al*., 2014).

The bioactive peptides present in seaweeds are mostly sequences of two to thirty amino acids and its biological properties are depended on its composition and sequence of amino acids. The biological activities of peptides include antioxidant, antimicrobial, anti-hypertensive, anti-hyperglycemic, anti-cholesteremic, anti-thrombotic, anti-obesity, immunomodulatory properties etc. (Lafarga *et al*., 2020; Admassu *et al*., 2018). One of the biologically important peptides available in seaweeds is lectins. Lectins are a category of proteins or glycoproteins having the capacity to bind specifically and reversibly to carbohydrates (Hori *et al*., 2000). Lectins mainly exhibit biomedical activities like antiviral, anti-cancer, antimicrobial, anti-inflammatory, anti-nociceptive and acaricidal activities (Singh & Walia, 2018).

The PUFA content in seaweeds greatly varies among the species. Brown seaweeds are having the highest quantity of PUFA, followed by green seaweeds and red seaweeds (Ganesan *et al*., 2019a). The biological properties of omega 3 fatty acids and omega 6 fatty acids are anti-hyperlipidemic, anti-hypertensive, anti-inflammatory, anti-cancer etc. (Kendel *et al*., 2015).

Phenolic compounds comprise of a heterogeneous category of secondary metabolites present in seaweeds. The most inimitable seaweed polyphenol compound is phlorotannins. Other polyphenolic compounds include bromophenols, phenolic terpenoids, flavonoids, and mycosporine-like amino acids (Cotas *et al*., 2020). Among marine algae, Laminariaceae family is the most abundant source of phlorotannins (Rengasamy *et al*., 2020). Most of the phenolic compounds display extensive biological properties like anti-inflammatory, antimicrobial, antiviral, anti-allergic, antioxidant, neuroprotection, anti-cancer, anti-diabetic etc. (Chakraborty *et al.*, 2015; Cotas *et al*., 2020).

Sterols act as the major structural constituent of seaweed cell membranes. Sánchez-Machado *et al.* (2004) reported that the major sterols found in brown seaweeds are fucosterol and fucosterol derivatives. The major sterols present in red seaweeds comprise of cholesterol and cholesterol derivatives and in green seaweeds the major sterols are ergosterol and 24-ethyl cholesterol. The biological properties of sterols include antioxidant, antiviral, anti-cancer, cardioprotection, anti-obesity etc. (Hentati *et al*., 2020).

Carotenoids present in seaweeds consist of two groups namely xanthophylls and carotenes. Fucoxanthin, the xanthophyll carotenoid found in seaweed lipids, has been studied extensively due to its health benefits. The health benefits of fucoxanthin include biological properties such as antioxidant, anti-cancer, anti-inflammatory, anti-obesity, anti-diabetic, neuroprotection etc. (Kim & Pangestuti, 2011).

Halogenated compounds are a group of bioactive secondary metabolites observed in seaweeds. Halogenated organic molecules, based on their structural characteristics, are generally categorized into terpenoids, non-terpenoid C15-acetogenins (ACGs), indoles, and phenols/ aromatics (Wang *et al*., 2013a). Among halogenated compounds, halogenated terpenes and bromophenols have exhibited the highest potential for new drug development (Rosa *et al.*, 2020).

1.4 STUDY OBJECTIVES

The objectives of the study are as follows:

a) To explore the potential applications/ economic uses of seaweed

b) To comprehend the current scenario of global and Indian seaweed sector

c) To examine the status of seaweed value-addition industries/ products in India

d) To identify seaweed value-addition technologies developed in India

e) To analyze the trends in the development of seaweed value-addition technologies

f) To study R&D trends in seaweed value-addition in India

g) To formulate recommendations for establishing sustainable seaweed value chains and for achieving self-sustainability in Indian seaweed industry

1.5 METHODOLOGY

The study methodology involves literature mining and review, identification of relevant stakeholders including R&D/ academic institutions and industries, collection of information/ data from secondary and primary sources, collation, consolidation, interpretation, and analysis. Literature was reviewed to comprehend different facets of seaweed such as types of seaweed, significance, nutritional profile, presence of bioactive compounds and its functional properties, applications/ uses, markets and trade scenario, development and production of value-added products, patent scenario, R&D trends etc.

The secondary information/ data includes research articles from online journals, studies/ reports available in the public domain, databases, news and information from the internet and other sources. Primary data was collected from organizations, domain experts and other stakeholders through personal communications. The list of contributors of primary information is given in **Annexure-1**. The information on imports and exports of seaweeds were obtained from the 'Export Import Data Bank Version 7.1 – Tradestat' of Department of Commerce, Ministry of Commerce and Industry, Govt. of India.

To understand technology development trends, the patents related to seaweeds were retrieved from the official Indian patent database, Indian Patent Advanced Search System (inPASS). Title and abstract searches were carried out on the entire set of patents, filed between 2001 and 2020, using the keywords seaweed or macroalgae. This search identified all the patents related to seaweeds. From this, a sub-sample of patents related to seaweed value-addition was segregated. Further, based on the status of the patent application, the patents were categorized as granted, published/ under consideration for approval, and withdrawn/ abandoned/ refused and accordingly studied in detail.

The scientific literature database Web of Science was used to perform a systematic review of research publications related to seaweeds. A bibliographic search of the available literature published between January 01, 2011 and December 31, 2020 was conducted. The search was directed using search terms/ keywords ‘seaweed’ or ‘macroalgae’ and was limited to the research publications from Indian institutions/ organizations. The articles were classified into different categories, depending on the applications. The research publications were tracked to understand the emerging ideas and current research trends in seaweed value-addition in India. This would be useful in formulating future technology development/ upscaling strategies.

1.6 REPORT STRUCTURE

The report is organized into 9 chapters. The first chapter provides an overview of seaweeds and deals with study objective, methodology, coverage, etc. The applications/ uses of seaweeds are highlighted in Chapter-2. Global seaweed market and Indian seaweed sector are delineated in Chapter-3 & Chapter-4 respectively. Chapter-5 outlines status of seaweed processing industry and products in India. Indigenously developed seaweed value-addition technologies, with different readiness levels, is covered in Chapter-6. Trends in development of seaweed value-addition technologies are examined through patent analysis in Chapter-7. Seaweed value-addition R&D trends in India are outlined in Chapter-8. The final chapter deals with conclusions and recommendations for Indian seaweed industry to become self-reliant or “AtmaNirbhar”.

2.0 SEAWEED APPLICATIONS

Since seaweeds possess structurally diverse bioactive compounds with unique properties, they are increasingly used globally for varied commercial applications. Seaweeds are used as food, pharmaceuticals, nutraceuticals, functional foods, cosmetics, plant biostimulants, animal feed, industrial raw material etc. The application areas of seaweeds can be broadly categorized into human nutrition and health, agriculture, animal husbandry, industrial products, and novel products (**Figure 2.1**).

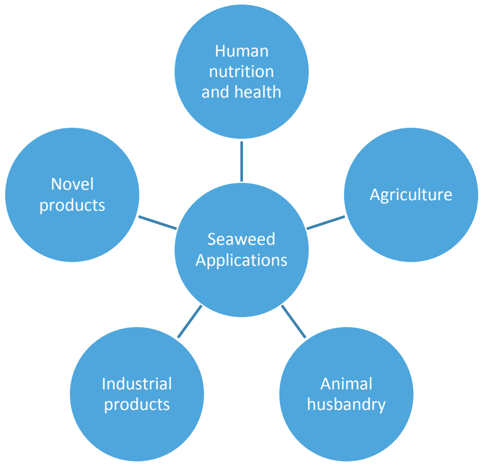


Figure 2.1: Applications of Seaweed

2.1 HUMAN NUTRITION AND HEALTH

Food

Since pre-historic times, the coastal communities use to consume seaweeds as food. In Japan and China, seaweeds were consumed as food since fourth century and sixth century respectively (McHugh, 2003). Seaweeds are used in traditional Japanese cuisine "shojin ryori" for flavour and also as seasoning condiments in a range of dishes (Tsuji, 1980; Fujii, 2005). Seaweeds are also consumed traditionally in many other Asian countries such as South Korea, Indonesia, North Korea, the Philippines, and Malaysia (Ganesan *et al*., 2019a). Recently, consumption of seaweeds is gaining popularity in the Americas and Europe, due to the functional properties possessed by seaweeds (Bocanegra *et al*., 2009).

In India, direct consumption of seaweed is scarce. However, *Gracilaria* and *Acanthophora spp.* are used in the preparation of porridge in the coastal states of Kerala and Tamil Nadu (Dhargakar, 2014). Since decades, seaweed *Gracilaria edulis* is being used for preparing gruel, in the coastal regions of Tamil Nadu (Chennubhotla *et al.*, 1981). Juice of *Ulva* species is used for preparing halwa in the southern Tamil Nadu (Subba Rao *et al*., 2009; 2016). Agar is used in the preparation of 'Jigarthanda', a cold beverage having its origin in the South Indian city of Madurai in Tamil Nadu, for providing thick consistency. Seaweed in the form of pickle and fry are consumed in the Lakshadweep islands of Kadmat and Minicoy (Ranjana, 2022).

Functional Food

The diversified structures and properties of bioactive compounds in seaweeds have drawn huge attention in exploring the production of seaweed-based functional foods. Alginates, which are utilized for gelling, emulsifying, coating etc. in the food industry, have potential to reduce toxicity of colonic luminal contacts, decrease intestinal absorption rate and protect the surface membranes of stomach and intestine from potential carcinogens (Brownlee *et al*., 2005; Szekalska *et al*., 2016). The protein hydrolysates from seaweeds exhibit high ACE-inhibitory activity. Thus, seaweed protein hydrolysate fractions could be used in developing functional foods for controlling hypertension and/or oxidative stress (Paiva *et al*., 2017). Incorporation of mannitol, extracted from seaweed, in food did not produce hyperglycemia in humans and resulted in very low glycemic index (Grembecka, 2015). Hence, mannitol could be used as a sweetener for diabetes patients.

Worldwide, continuous consumption of meat products containing saturated fat, salt, and artificial additives have resulted in heart-related disorders and obesity. Seaweed could be incorporated as a healthy alternative ingredient in meat products. Addition of seaweeds in meat products such as frankfurters, patties and restructured steaks significantly lowered the saturated fat and salt levels and further increased the contents of fiber and polyunsaturated fat (Cofrades *et al*., 2017), resulting in healthier meat. Seaweed *Sargassum wightii* can be incorporated in the ready-to-eat dried tuna jerky as a functional ingredient. Such introduction enriches the fish product with fiber, macro minerals, and trace elements and improves its antioxidant and microbial quality (Hanjabam *et al.,* 2017). Incorporation of seaweed to cereal-based food products can result in increased dietary intake of essential nutrients (Shannon & Abu-Ghannam, 2019). Addition of *Caulerpa racemosa* has enhanced the nutritive and antioxidant value of semi-sweet biscuits (Kumar *et al.*, 2018). The protein, fat, fibre, ash and fucoxanthin contents were improved when pasta was prepared by integrating seaweed *Undaria pinnatifida* in semolina (Prabhasankar *et al*., 2009).

Medicine

Over the years, seaweeds are used for preparing traditional medicines in Japan, China, Egypt and India. For about 2,000 years, traditional Chinese medicine has been using *Sargassum spp*. in the treatment of goiter (Liu *et al*., 2012). *Ulva pertusa* is used in Chinese traditional medicine for treating hyperlipidemia, urinary diseases, and sunstroke (Qi *et al*., 2006). In the oriental medicine, seaweed *Codium fragile* was used in the treatment of dysuria, dropsy, and enterobiasis (Sanjeewa *et al*., 2018) and *Gloiopeltis tenax* was used in the treatment of diarrhoea and colitis (Zheng *et al*., 2012).

Laminaria stick is used to help soften and dilate the cervix, either before a surgical abortion or to aid in childbirth. Red seaweeds *Hypnea musciformis*, *Corallina officinalis*, and *C. rubens* are used as vermifuges (Mathew, 1991). Kim *et al*. (2008) had found that supplementation of seaweed can lower the occurrence of cardiovascular disease in diabetes patients. Kishida *et al*. (2020) has established a negative relationship between consumption of seaweed and death due to cardiovascular diseases, in the Japanese population.

Sodium alginate, extracted from seaweed, is the active ingredient in Gaviscon Double Action Mint Oral Suspension, used to treat symptoms resulting from the reflux of acid, bile and pepsin into the oesophagus. Sodium alginate is also the active ingredient in Lamina-G PLUS Suspension, manufactured by Seoul based Taejoon Pharm Co. Ltd., used to treat symptoms resulting from the reflux of acid, heartburn etc. The active ingredient in Algitec, used for treating heartburn and acid reflux, is also sodium alginate. Gastralgin, used to treat duodenal ulcer, contains alginic acid and sodium alginate as active ingredients (Kraan, 2012).The active ingredient in Gastrotuss® Baby syrup, used to treat gastroesophageal and/or laryngoesophageal reflux in babies and children, is magnesium alginate (Polat *et al*., 2021).

Marinomed Biotech AG, an Austrian company, has developed an innovative antiviral drug called Carragelose®, using iota-carrageenan from red seaweed. Carragelose® provides protection against a host of respiratory viruses. The drug provides a protective layer on the mucosa of the nose and throat, hence can trap viruses entering nasal and pharyngeal cavity and protect the mucosal cells. Carragelose® is marketed as an OTC drug since 2008 (Martins *et al*., 2014).

Sodium oligomannate (GV-971), an oral oligosaccharide extracted from brown seaweed, developed by Shanghai Green Valley Pharmaceuticals had received approval from National Medical Products Administration (NMPA) of China in November 2019 for treating Alzheimer’s disease. According to Xiao *et al.* (2021), the phase 3 clinical trial has established the efficacy of GV-971 in improving cognitive functions. GV-971 modulates gut microbiota and improves cognitive functions of Alzheimer’s disease patients by inhibiting amyloid-β fibril formation (Seo *et al*., 2019) or by inhibiting neuroinflammation (Wang *et. al*., 2019c). Zhang *et al.* (2022) investigated the efficacy of GV-971 and found that it is equally or more effective than Donepezil, the commonly used drug for treating Alzheimer's disease.

Haikun Shenxi Capsule, with fucoidan as active ingredient, has been used for treating chronic renal failure. In 2003, the medicine manufactured by Huinan Changlong Co. Ltd. received approval from China Food and Drug Administration, as a traditional Chinese medicine (Wang *et al*., 2019a). The carotenoid fucoxanthin extract from seaweed *Undaria pinnatifida* is the active ingredient in Xanthigen®, developed by Nektium Pharma S.L. for managing weight (Polat *et al*., 2021).

Arterosil®, a dietary supplement developed by the USA-based Calroy Health Sciences, LLC, is used to maintain a healthy vascular system. This patented product stabilizes and regress vulnerable plaque by protecting and restoring endothelial glycocalyx, a natural lining that protects vascular endothelium. The active ingredient available in Arterosil® is a sulfated polysaccharide namely rhamnan sulfate, extracted from green seaweed *Monostroma nitidum*. Another patented dietary supplement used for restoring, regenerating, and protecting endothelial glycocalyx is Endocalyx Pro™, developed by USA-based Microvascular Health Solutions, LLC. The active ingredient in Endocalyx Pro™ is fucoidan sulfate, derived from brown seaweed *Laminaria Japonica*.

The alginates, derived from seaweed, are used as an excipient in drug manufacture and the demand is on rise in the industry. While alginates are used as texturizing and gelling agent in soft gels, they are used to prevent disintegration in solid dose forms. In pharma industry, agar-agar and carrageenan are used as a vegetarian substitute to animal-based inactive ingredient like gelatin. Alginic acid is an inactive ingredient in Metaxalone, used for muscle relaxation. Glyburide (an oral blood-glucose-lowering drug) and Tarka (used to treat hypertension), contains sodium alginate as one of the inactive ingredients. Aricept ODT, a cholinesterase inhibitor used to treat Alzheimer’s disease, contains carrageenan and mannitol as inactive ingredients. Bromocriptine (used in the treatment of hyperprolactinemia), Dexilant (used to reduce the amount of acid in stomach), and Jalyn (used in the treatment of benign prostatic hyperplasia) contains carrageenan as one of the excipients (Polat *et al*., 2021).

COVID-19 Prevention/ Treatment

The biologically active metabolites present in macroalgae have the capacity to tackle SARS-CoV-2 and similar viruses (Bhatt *et al*., 2020). The polysaccharides present in seaweeds exhibits wide range of antiviral activities and unique antiviral mechanisms (Chen & Huang, 2018). Seaweed polysaccharides have the capacity to prevent entry and replication of corona virus (Pereira & Critchley, 2020; Shefer *et. al*., 2021; Yim *et al.*, 2021). Zhang *et al.* (2021) demonstrated the capability of polysaccharide extracted from brown seaweed *Ecklonia kurome*, used in Chinese traditional medicine, to block the activity of an enzyme necessary for transcription and replication of coronavirus.

Hans *et al*. (2021) reviewed the antiviral activity of various sulfated polysaccharides like agar, alginates, fucoidan, carrageenan, ulvan etc., extracted from seaweeds, and their promising use in prevention of COVID-19. Andrew & Jayaraman (2021) demonstrated the potential use of sulfated polysaccharides as drugs, adjuvants and nutritional supplements in the treatment of corona virus disease. Kuznetsova *et al*. (2021) accentuated the prospects for use of sulfated polysaccharides as anticoagulant and antithrombotic compounds for treating hemostasis disorders observed in patients infected with COVID-19. Chen *et al.* (2020) highlighted the relevance of sulfated oligosaccharide from seaweed in inhibition/ treatment of pulmonary fibrosis in COVID-19 patients.

Kwon *et al*. (2020) investigated the effectiveness of fucoidan, against the virus causing COVID-19, and found that seaweed extract is having more potency than Remdesivir, an antiviral drug approved for emergency use to treat acute COVID-19 infection. After studying the mechanisms of radical scavenging and various bioactivities of fucoidan, Pozharitskaya *et al*. (2020) established the potential use of fucoidan as a therapeutic agent to treat patients suffering from COVID-19. Morokutti-Kurz *et al*. (2020) found that iota-carrageenan, extracted from seaweed, could inhibit COVID-19. Bansal *et al*. (2020) further established the potential clinical use of iota-carrageenan as a nasal spray against COVID-19. Song *et al*. (2020) also demonstrated the potential of fucoidan and iota-carrageenan to inhibit the infection of COVID-19.

Barre *et al.* (2020) established the potential of lectins from seaweed, as probes for detection and immobilization of coronavirus and to stop the replication and fusion events of SARS-CoV-2. Cheepsattayakorn & Cheepsattayakorn (2020), Ghanbari *et al.* (2020), Cai *et al*. (2020), Decker *et al.* (2020), and Shohag *et al.* (2021) indicated/ demonstrated the potential/ effectiveness of griffithsin, a seaweed-derived lectin, against SARS-CoV-2. Firdaus *et al*. (2020) found that rhamnetin, a bioactive compound present in *Sargassum sp*., has the capacity to inhibit replication and transcription of virus causing COVID-19. Muteeb *et al*. (2020) screened different compounds isolated from seaweed and had concluded that callophysin A could be used as a scaffold for developing a powerful inhibitor/ drug against coronavirus. Jha *et al*. (2020) also highlighted the effectiveness of seaweed in combating COVID-19.

The research articles authored by Firdaus *et al*. (2020), Muteeb *et al*. (2020), Barre *et al.* (2020), Pozharitskaya *et al*. (2020), Jha *et al*. (2020), Chen *et al.* (2020), Pereira & Critchley (2020) etc. have been included in the website of World Health Organization (WHO), under the segment

'COVID-19 Global literature on coronavirus disease' for information/ knowledge sharing and to aid the world in the fight against COVID-19 pandemic. Inclusion of these publications in WHO website clearly reflects the importance and endorsement of the potential use of bioactive compounds derived from seaweed to fight against COVID-19, by the global guardian of public health.

The infection of COVID-19 in Hokkaido, Japan was very low initially and it was widely believed that the low level of infection was probably attributed to seaweed consumption, which is prevalent traditionally, and regular intake of iodine. However, spurts in COVID-19 infections were observed in the populations subsequently. This indicates that seaweed had aided the populations in Hokkaido to reduce the infection in the initial period, but just seaweed consumption was not enough to contain the disease (Pereira & Critchley, 2020).Tamama (2020) also highlighted the effect of seaweed consumption in limiting the harshness of COVID-19 infection in the Japanese population.

Biomedical Applications

The properties such as remarkable retention capabilities, tunable active units, swelling, and colloidal features of seaweed polysaccharides have made them ideal materials for use in biomedical applications like targeted drug delivery, wound healing, tissue-engineering etc. (Bilal & Iqbal, 2020). Hydrogels prepared from carboxymethylagarose (CMA), a derivative of agarose, serves as a unique platform for oral drug delivery for cancer therapy (Khan *et al*., 2019). Due to the structural similarity with extracellular matrices of living tissues, alginate hydrogels are extensively used in healing wound, delivery of bioactive agents like small chemical drugs and proteins, and cell transplantation. Dressing of wound with alginate can minimize the infection of bacteria at wound site, and aid in healing the wound (Lee & Mooney, 2012).

Ulvan, in combination with poly (D-lactic acid), has the potential to create new scaffolding for bone tissue engineering applications (Alves *et al*., 2012). Ulvan-cellulose can be used in enhancing the wound healing due to diabetics (Madub *et al.*, 2021). Laminarin, after augmenting the biological activity by biochemical modification, could be utilized for biomedical applications like drug/gene delivery, tissue engineering etc. (Zargarzadeh *et al*., 2020). Microparticles and hydrogels, with potential biomedical applications, can be produced by methacrylation of laminarin (Castanheira *et al*., 2020).

Cosmetics

Seaweeds are often used as an ingredient in the production of cosmetics. Seaweeds are either used as additives contributing to organoleptic properties, used in stabilization and preservation of the product or as active ingredients that fulfils the cosmetic function and activity (Bedoux *et al*., 2014). Polysaccharides are used in cosmetics as a gelling agent, viscosity adjuster, thickener, and emulsifier. Polysaccharides hydrates the skin, thus can prevent formation of wrinkles (Kanlayavattanakul & Lourith, 2014). Polyunsaturated fatty acids like linoleic acid and arachidonic acid protects the skin against peeling of epidermis and eczema (Agatonovic-Kustrin & Morton, 2013). Vitamins (A, B, C, D, and E), available in seaweeds, are widely used in skincare products (Jesumani *et al*., 2019). Phlorotannins, the most important phenolic compound present in seaweed, is well known for applications such as anti-melanogenesis, and anti-ageing (Norzagaray-Valenzuela *et al*., 2017; Wang *et al*., 2019b). The natural pigments found in seaweeds have gained abundant attention in cosmetics. Xanthophyll is used as a colour source for the cosmetics (Mathew & Ravishankar, 2018).

2.2 AGRICULTURE

The use of seaweeds in agriculture operations has a long history. Seaweeds have been globally used as fertilizer in coastal areas for centuries. However, in recent years, there is an emerging interest in utilizing seaweed as biofertilizers in agriculture as well as horticulture, due to transition from conventional farming to organic farming. The biostimulant potential of seaweeds is primarily attributed by the presence of phytohormones like cytokinins, gibberellins, auxins, brassinosteroids, abscisic acid etc. (Ghaderiardakani *et al*., 2019). Major seaweeds that are utilized for biofertilizer production include brown seaweeds belonging to genus *Sargassum*, *Macrocystis*, *Ascophyllum*, *Laminaria*, *Fucus*, *Ecklonia*, *Durvillaea*, *Cabophyllum*, *Himanthalia*, *Dictyopteris*, and *Turbinaria* and red seaweeds belonging to genus *Pachymenia*, *Lithothamnion*, and *Phymatolithon* (Boney, 1965; Baweja *et al.*, 2016). Seaweed biofertilizers are used in different forms such as powder, liquid extract, and granules.

Seaweed fertilizers/ biostimulants can induce a host of plant responses like improved plant vigour, improved seed germination, improved flowering and yield, enhanced growth, better uptake of water and nutrients, improved fruit setting, improved fruit quality, superior nutritional composition of edible product, increased postharvest shelf life, enhanced frost and salinity resistance, increased resistance against pathogens etc. (Rathore *et al.*, 2009; Trivedi *et al.*, 2017; Nabti *et al.*, 2017; Layek *et al*., 2018; Łangowski *et al*., 2019; Al-Juthery *et al*., 2020; Francesca *et al*., 2020). Use of seaweed sap can enhance the content of nutrients such as carbohydrate, protein, phosphorus, potassium etc. in various crops (Layek *et al*., 2015; Yaseen *et al*., 2017). Seaweed sap application has been found helpful in reducing the chemical fertilizer usage (TIFAC, 2018) and also in stimulating the microbes in soil, resulting in enhanced nutrient availability to plants (Ghosh *et al*., 2015).

2.3 ANIMAL HUSBANDRY

As early as first century BC, seaweeds were used as livestock feed by the Greeks. In Norway, *Ascophyllum* is used in the feed of pig (Kaladharan, 2006). In Iceland, raw seaweeds are normally fed to cattle, sheep, horse, and hen. Major seaweed species used as fodder in different countries include *Ascophyllum sp.*, *Pelvetia sp*., *Laminaria sp*., *Rhodymenia palmate*, *Lithothamnion sp., Macrocystis sp.*, *Alaria sp.*, *Palmaria sp.*, *Fucus sp.*, *Sargassum sp., Chondra filus*, *Ulva sp.* etc. (Boney, 1965; Makkar *et al*., 2016). Some of the seaweeds have the potential to act as protein and energy source for the livestock, while others with several bioactive molecules, could function as prebiotic for increasing the productivity and for maintaining optimal health in monogastric as well as ruminant livestock (Makkar *et al*., 2016).

Addition of seaweed *Sargassum wightii* (20%) in the feed of lactating Sahiwal cows had demonstrated an increase in milk yield (Singh, 2008). Supplementation of *Kappaphycus alvarezii* in the diet of cows resulted in improved immunity and persistency of lactation (NDRI, 2019). *Ascophyllum nodosum* supplementation in dairy cow feed improved utilization of energy and also exhibited hepatoprotective effect (Karatzia *et al*., 2012). Incorporation of seaweed by-products in feed had exhibited improved erythropoiesis and cellular immunity in crossbred calves (Munde *et al*., 2018). Raje *et al*. (2019) established the application of brown seaweed as a functional additive in goat feed for enhanced utilization of minerals. Supplementation of seaweeds in pig feeds resulted in improved health, immune system, antioxidant status, gut health and meat quality (Makkar *et al*., 2016; Corino *et al*., 2019).

Ruminant animals produce considerable amounts of greenhouse gas methane, as part of their normal digestive processes. Seaweed, when incorporated into the feed, inhibits methanogens in the rumen and thereby has the potential to reduce the emission of methane by livestock (Abbott *et al*., 2020). The in vitro study by Kinley *et al.* (2016) demonstrated that incorporation of less than 2% dried *Asparagopsis taxiformis* to cow feed can bring down methane emissions by 99%. Roque *et al*. (2019) observed 67% reduction in methane production by cows, when seaweed *A. armata* was included in the diet. Supplementation of 0.20% *A. taxiformis* in beef cattle ration resulted in 98% reduction in enteric methane emissions and 42% weight gain (Kinley *et al.*, 2020). The in vivo study by Li *et al*. (2016) demonstrated 80% decline in methane production in sheep, while fed on diet incorporated with *A. taxiformis*.

Supplementation of seaweed in poultry diets positively influence the growth and health profile of poultry. Incorporation of seaweeds in broiler diets had led to improved growth and breast meat quality and resulted in reduced abdominal and subcutaneous fat (Wang *et al*., 2013c). Seaweed supplementation also augmented the health of broiler by acting as a prebiotic (Cañedo-Castro *et al*., 2019), enhanced immune response, and decreased the rate of mortality (Choi *et al*., 2014). Seaweed supplementation in laying hens feed resulted in improved laying performance, immunity, quality of egg, hatchability etc. (Wang *et al*., 2013b; Bratova & Ganovski, 1982). Supplementation of seaweeds in laying Japanese quail diets improved egg-laying performance, enhanced total antioxidant capacity in blood serum and considerably reduced total lipids and cholesterol in serum and yolk (Zeweil *et al*., 2019).

Use of plant ingredients for preparing aquaculture feeds has gained a lot of interest. Seaweeds can be used as a novel ingredient in the production of formulated aqua feeds. As per Chopin (2019), twenty-nine seaweed species from 13 genera have been used as a substitute to fishmeal in aqua feeds. Seaweed species having the potential to supplement fish feeds include *Ulva lactuca*, *Enteromorpha compressa*, *Porphyra sp.*, *Sargassum sp*., *Padina pavonica*, *Gracilaria sp*., *Laurencia obtuse, Ascophyllum nodosum*, etc. (Wahbeh, 1997; Morais *et al*., 2020; Jusadi *et al.*, 2021). Generally, seaweed substitution in aqua feeds ranges between 5-15%. However, substitution levels have even reached 50% for some of the species. Incorporation of *Ulva lactuca* (5%) in the diet of tilapia *Oreochromis niloticus* had demonstrated enhanced growth rate, immunity, and feed utilization (Natify *et al*., 2015). When seaweeds *Ulva fasciata* and *Enteromorpha flaxusa* were incorporated in the artificial feed, rabbit fish fry showed improved growth rate and reduced feed cost (Abdel-Aziz & Ragab, 2017).

2.4 INDUSTRIAL PRODUCTS

Hydrocolloids

Since 1945, seaweeds have been used to produce hydrocolloids such as agar, alginate, and carrageenan (Delaney *et al*., 2016). Brown and red seaweeds are used for producing agar, alginate, and carrageenan. Seaweeds belonging to the genus *Gelidium*, *Gracilaria*, *Pterocladia* and *Gelidiella* are mainly used to produce agar. Agar is extensively used in baking and confectionery industries as stabilizer and thickener. Agar finds application in dentistry, for manufacturing dental casts and use as a surgical lubricant (Abraham *et al*., 2018). Agar is also used as a constituent in mouthwashes (Gates, 2010).

Seaweeds belonging to the genus *Macrocystis*, *Ascophyllum*, *Turbinaria* and *Sargassum* are the most important alginate sources. Alginates are used as industrial raw material due to its water retaining, gelling, viscosifying, and stabilizing properties. Alginates are used in industries such as dairy, bakery, and meat as gelling, thickening and stabilizing agent. Alginates are also used as a binder in animal feeds, plasticizer in cement, thickening agent in paints etc. (Abraham *et al*., 2018).

Important seaweed species used in industrial production of carrageenan are *Chondrus crispus*, *Sarcothalia crispata*, *Eucheuma denticulatum*, and *Kappaphycus alvarezii* (Naseri *et al.,* 2019). The major application for carrageenan is in dairy industry. Addition of kappa-carrageenan to cottage cheese prevents whey separation. Kappa carrageenan is used in manufacturing of air freshener gels and iota carrageenan is used in the manufacture of toothpaste (McHugh, 2003).

Waste Water Treatment

Seaweeds are increasingly used as biosorbent to treat wastewater, due to their biodegradable and nontoxic nature. Biosorption using seaweeds have been found to be effective in removing contaminants like pigments and dyes from textile, paper, and printing industry; as well as heavy metals from various industries such as metallurgy, electrolysis, electroplating etc. The capability of seaweeds to bind trace metals is attributed by the sulfated polysaccharides present in seaweed cell wall (Arumugam *et al*., 2018). Seaweed species used as biosorbents for removal of pigments and dyes include *Ulva lactuca*, *Caulerpa stapeliiformis*, *Chlorella vulgaris*, *Systoceira stricta* etc. (Oualid *et al*., 2020).

2.5 NOVEL PRODUCTS/ USES

Seaweeds can be used to produce various novel products such as biofuels and bioplastics, which are environment friendly and can accelerate the transition to a circular economy. Seaweeds can also be used in production of medical textiles, solar cells, energy storage systems, bioink etc.

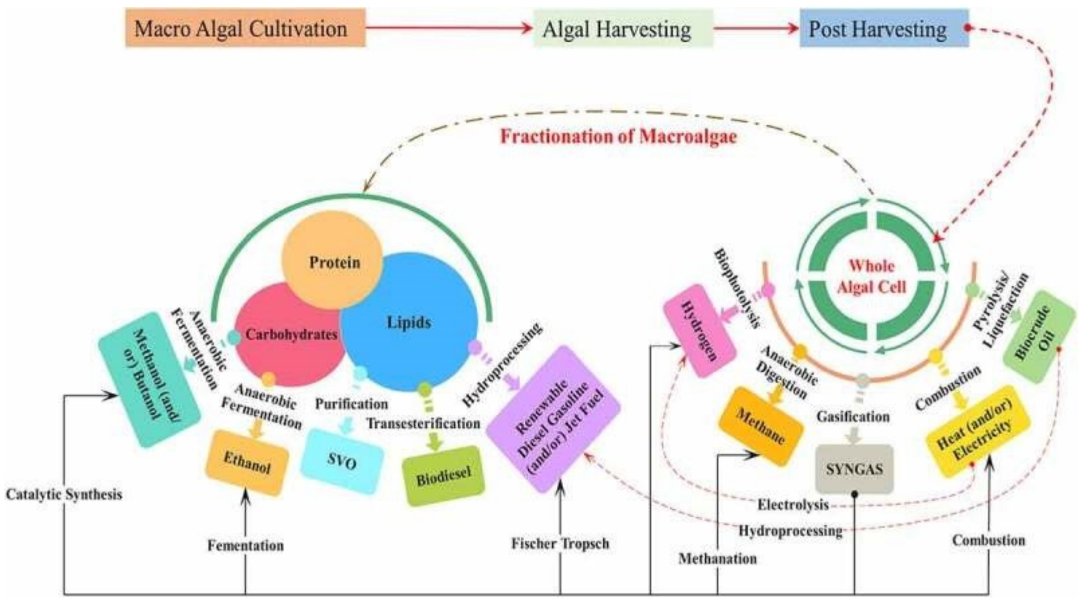
Biofuels

Seaweeds are gaining increasing attention as a prospective feedstock for biofuels. The worldwide interest in biofuel production from seaweed biomass emanate from the fact that seaweeds are third generation feedstock (**Figure 2.2**) and have advantages such as presence of high carbohydrate content which can be used for producing ethanol, absence or low lignin content, higher photosynthetic efficiency than terrestrial biomass etc. Seaweeds does not directly compete with human food supply, does not compete for arable land, does not require freshwater, and does not require fertilizer (Rajkumar *et al*., 2014; del Río *et al*., 2020). As per del Río *et al*. (2020), under specific conditions, seaweed yields two times higher biofuel than sugarcane and five times than corn.

Source: Papakonstantinou *et al.* (2021)

Figure 2.2: Generations of Biofuel

Seaweed biomass is being utilized for manufacturing different types of biofuels like ethanol, biodiesel, butanol, biomethane, biohydrogen etc. Various processing techniques such as direct combustion, pyrolysis, gasification, transesterification, hydrothermal liquefaction, fermentation and anaerobic digestion are being used to manufacture seaweed-based biofuels. Bioethanol and biobutanol are produced by fermentation, biodiesel is produced by transesterification and methane is produced through anaerobic digestion. The process of biofuel production, envisaged in a coordinated seaweed processing plant, is given at **Figure 2.3**. In recent years, based on availability and ease of cultivation and harvesting, the promising seaweed feedstocks identified for biofuel production are *Kappaphycus*, *Gelidium*, *Gracilaria*, *Sargassum*, *Laminaria* and *Ulva* (Ramachandra & Hebbale, 2020).



Source: Sharmila *et al.* (2021)

Figure 2.3: Process of Biofuel Production from Seaweed

The production of liquid biofuel such as bioethanol involves various steps such as pre-treatment, hydrolysis and fermentation (Ramachandra & Hebbale, 2020). The techniques/ pathways mostly used in seaweed fermentation include separate hydrolysis and fermentation and simultaneous saccharification and fermentation (Offei *et al.,* 2018). Even though technologies are available for conversion of seaweeds to ethanol, currently the production is not cost-effective. Hence, the future of commercial-scale production of ethanol from seaweeds depends on evolution of novel processing technologies and creation of an appropriate policy framework.

Apart from liquid biofuels, seaweeds can also be used to produce biogas (biomethane) and biohydrogen, used as a gas fuel or for electricity generation (Jones & Mayfield, 2011). Seaweed species such as *Saccharina latissima* and *Laminaria digitata* are some of the major species having potential for biomethane production through anaerobic digestion, due to their high biomethane yield (Tabassum *et al*., 2017). Amosu (2016) had further demonstrated viable production of Liquefied Petroleum Gas (LPG) utilizing seaweed *Ulva armoricana*.

Bioplastics

Seaweed is a sustainable alternative for producing large-scale biopolymer. Seaweed polysaccharides like alginate, carrageenan and agar have mostly been used in production of edible coatings and films (Tavassoli-Kafrani *et al*., 2016; Mostafavi & Zaeim, 2020). The film-forming biopolymers derived from seaweeds are non-toxic, easily degradable and biocompatible and shows high rigidity and low deformability (Doh, 2020). The bioplastic films from seaweed display comparatively low water vapour barrier properties and mechanical strength in comparison to conventional non-renewable polymers. Hence, seaweeds are generally mixed with other components to enhance the properties of seaweed films (Abdul Khalil *et al*., 2017). The edible film from seaweeds is used in the form of sachets, pouches etc. in the food industry for packing seasoning cube, chocolate, frozen foods, bakery products etc.

Medical Textiles

Natural fibers, especially polysaccharides, have been considered as the most promising material for producing wound dressing products. Products based on alginate, a linear unbranched polysaccharide extracted from brown seaweed, are currently the most popular dressing products used in wound management, since it has numerous advantages over traditional cotton-based products. Alginate is reported to have high absorbency of exudates. Due to its gel forming property, alginate dressing can absorb the exudates, provide beneficial wound moist environment, and permits enough water vapour and oxygen exchange, which are very much critical in augmenting wound healing (Williams, 1999). The gelling feature of alginate also aids in taking out the dressings without pain. Alginate has fluid absorption capacity of 15 to 20 times its weight. Hence, alginate dressings can be used for moderate to heavy exudates (Bello & Philips, 2000). The commercially available alginate-based dressings include Algicell™, Guardix-SG®, AlgiSite M™, SeaSorb®, Comfeel Plus™, Algivon®, Kaltostat™, FibracolTMPlus, Sorbsan™, Hyalogran®, Tegagen™, Tromboguard® etc. (Aderibigbe & Buyana, 2018).

Solar Cells

Third generation solar cells like dye-sensitized solar cells (DSSC), have been transpired as an affordable substitute to photovoltaic solar cells. Ruthenium metal complexes, the widely used inorganic sensitizers in DSSC, have drawbacks of high cost and low molar extinction coefficient (Kanaparthi *et al*., 2012). Due to abundant availability of photosynthetic pigments reserves, seaweeds have been recently used as alternative sensitizers in DSSC (Calogero *et al*., 2014). The pigments Chlorophyll c1 and Chlorophyll c2 in the brown seaweed *Undaria pinnatifida* yielded an efficiency of 3.4% and 4.6% when applied in DSSC (Wang *et al*., 2007).

Energy Storage Systems

Seaweed is contemplated as a sustainable alternative material for applications in energy storage systems. Seaweeds can be used to prepare porous carbon materials for use as electrodes in supercapacitors, lithium-ion batteries and fuel cells. The carbon produced from seaweeds and seaweed derivatives like seaweed fibre, sodium alginate, carrageenan etc. are used as electrode material in supercapacitors (Raymundo-Piñero *et al*., 2006; Divya *et al.*, 2019; Li *et al*., 2019; Jiang *et al*., 2021). Kovalenko *et al.* (2011) fabricated lithium-ion battery anode, with higher reversible capacity, by combining alginate with silicon nanopowder. Shin *et al*. (2019) examined the use of agar as a separator membrane and binder in lithium-ion battery. Kappa-carrageenan was used to prepare a thin flexible film and was used to produce proton-conducting battery devices (Nithya *et al*., 2020). Susilawati *et al.* (2021) established the potential use of powdered seaweed as a gel for converting wet batteries into dry batteries.

Bioink

In additive manufacturing, generally, materials derived from petroleum are used as raw materials. However, biomaterials from renewable sources are emerging as a sustainable alternative to petroleum derived raw materials. Various seaweed-based biomaterials such as alginate and agarose have been explored for use as bioink in 3D printing. Alginate when mixed with water forms a viscous gum, which can be further formed into a hydrogel by cross-linking with calcium ions. Unlike plastic, which is available in many colors, alginate is almost colourless. Hence, mica powder is added to alginate to produce bioink with diverse colours (American Chemical Society, 2021).

Alginate in combination with synthetic polymer Pluronic has been used to formulate bioink for 3D printing of bone and cartilage (Armstrong *et al*., 2016). Markstedt *et al.* (2015) had used an alginate-nanocellulose bioink for bioprinting of cartilage tissue. Yang et *al.* (2018) and Dravid *et al.* (2022) demonstrated bioprinting of cartilage tissue with bioink prepared from agarose-alginate mixture. Bioink with wound healing capabilities has been developed by adding ulvan to gelatin methacryloyl by Chen *et al*. (2021). Marques *et al.* (2022), for the first time, has prepared bioink from κ-carrageenan and used it for producing 3D bioprinted scaffolds.

Seaweed-based bioinks are being commercially manufactured by Cellink, Sweden (CELLINK Bioink); Merck KGaA, Germany (TissueFab® bioink); Allevi, Inc. USA; Foldink Life Science Technologies, Armenia (Col/SA Bioink); 3DPL, Canada etc.

3.0 GLOBAL SEAWEED SCENARIO

Even though, a large number of seaweed species exist globally, only a small number are being utilized commercially. About 221 species of seaweeds (32 green seaweeds, 125 red seaweeds and 64 brown seaweeds) are commercially exploited worldwide. Nearly 145 species of seaweeds are used as food and 101 species for producing phycocolloids (Zemke-White & Ohno, 1999). In the early days, seaweed requirement was exclusively met by harvesting from the wild. However, during the last five decades a swift growth in aquaculture production of seaweed has been observed (Buchholz *et al*. 2012). Globally, twenty-seven species of seaweeds were cultivated commercially in 2019 (FAO*,* 2021a). Even though seaweeds are farmed across the world, the commercial seaweed aquaculture is primarily concentrated around Asia. In the Asian countries, the scale of operation of seaweed aquaculture ranges from small family run ventures to large scale industrial projects.

3.1 SEAWEED PRODUCTION

Seaweed production in the world increased from 0.56 million tons in 1950 to 35.76 million tons in 2019, on fresh weight basis, with more than three-fold growth in the last two decades. An annual increase of 2.46 million tons was observed in the global seaweed production (which includes production from aquaculture as well as wild collection) between 2018 and 2019, with a growth rate of 7.4% (FAO, 2020a; FAO, 2021a). The global seaweed production in 2019 was contributed by 48 species cultured and/or collected from 49 countries. Eighteen species of brown seaweeds from twenty countries contributed 17.07 million tons, on wet weight basis. Twenty species of red seaweeds from forty-three countries contributed 18.44 million tons and eight species of green seaweeds from twelve countries contributed 0.03 million tons. Species under the category 'seaweeds not elsewhere included (nei)' from ten countries contributed 0.22 million tons. The world seaweed production was dominated by five species groups namely *Laminaria/Saccharina*, *Undaria*, *Kappaphycus/Eucheuma*, *Gracilaria* and *Porphyra* (Cai, 2021).

In 2019, Asian region dominated the world seaweed production with a contribution of 97.38%. Both the Americas as well as Europe contributed around 1% to the global production, whereas Africa and Oceania each accounted less than 0.5% of the global production (Cai *et al*., 2021b). Seaweed production by various regions and their contribution to global production in 2019 is given in **Table 3.1**.

Table 3.1: Seaweed Production by Region and Contribution to Global Production (2019)

Region	Seaweed Production (Tons wet weight)	Global Share (%)
Asia	34,826,750	97.38
Americas	487,241	1.36
Europe	287,033	0.80
Africa	144,909	0.41
Oceania	16,572	0.05
Total	**35,762,504**	**100.00**

Source: Cai *et al.* (2021b)

Seaweed production, in terms of wet weight, by various countries and their contribution to global seaweed production in 2019 is provided in **Table 3.2**. China topped the global seaweed production with a contribution of 56.75%, and was followed by countries such as Indonesia (27.86%), Republic of Korea (5.09%), and the Philippines (4.20%) (Cai *et al.*, 2021b). Globally, seaweed sector in China and Indonesia are considered as mature, since they had been farming seaweed and was receiving government assistance, as early as 1940s (Bradly *et al*., 2021). The Philippines exhibited a downward trend in seaweed production since mid-2000s, due to various factors including attack by pest and occurrence of disease, which was further compounded by climate change (Mateo *et al*., 2020).

Table 3.2: Seaweed Production by Country and Contribution to Global Production (2019)

Sl. No.	Country	Seaweed Production (Tons wet wt.)	Share of global production (%)
1	China	20,296,592	56.75
2	Indonesia	9,962,900	27.86
3	Republic of Korea	1,821,475	5.09
4	Philippines	1,500,326	4.20
5	DPR of Korea	603,000	1.69
6	Chile	426,605	1.19
7	Japan	412,300	1.15
8	Malaysia	188,110	0.53
9	Others	551,196	1.54
	Total	**35,762,504**	**100.00**

Source: Cai *et al.* (2021b)

The global production of cultured seaweeds was 34.68 million tons in 2019, on wet weight basis, with a value of USD 14.7 billion. Seaweed produced through aquaculture contributed about 29% of aquaculture production in the world in 2019, in terms of volume, and about 5.4%, in terms of value. In the last three decades, more than eight times growth occurred in the global seaweed production from aquaculture, on fresh weight basis. Between 2000 and 2019, the world production of cultured brown seaweeds grew from 8.56 million tons to 16.39 million tons and production of red seaweeds increased from 1.97 million tons to 18.25 million tons. However, production of green seaweeds declined from 34,000 tons to 16,696 tons (Cai, 2021; FAO, 2021a).

Globally, farmed seaweeds accounted for 96.97% of the total seaweed production in 2019. In Asia, 99.10% of seaweed production was through aquaculture. Contribution of aquaculture to total seaweed production in Africa and Oceania exceeded 80%. However, seaweed production in Europe and Americas was mostly through wild collection and the share of aquaculture in the total production was merely 3.88% and 4.69% respectively. In countries such as Malaysia, Tanzania, DPR of Korea, Solomon Islands, Papua New Guinea, and Kiribati seaweed was produced exclusively through aquaculture. The contribution of aquaculture to total seaweed production was more than 99% in countries like the Philippines, Indonesia, Republic of Korea, and China. However, seaweed production through aquaculture was meager (less than 1% of total production) in Norway, France, Ireland and Mexico. In countries such as Australia, Canada, Iceland, and Peru seaweed production were solely from wild collection (Cai *et al.*, 2021b).

Global production of cultured seaweeds, on wet weight basis, by major producers in 2019 and their share in global production are provided in **Table 3.3**. China accounted for about 58% of global seaweed aquaculture production and was followed by Indonesia, Republic of Korea, and the Philippines. The dominance of China in global seaweed mariculture production decreased from 77.65% in 2000 to 58.02% in 2019. However, Indonesia exhibited stellar growth by increasing its contribution from just 1.94% in 2000 to 28.60% in 2019 (FAO, 2021a). This growth was contributed by increased production of species such as *Kappaphycus alvarezii* and *Eucheuma spp.*, resulting from the national policy for supporting seaweed aquaculture (Bradly *et al*., 2021). The share of the Republic of Korea in global seaweed aquaculture production grew moderately from 3.53% in 2000 to 5.23% in 2019 (FAO, 2021a). In the Republic of Korea, more than 90% of seaweed is farmed in the Province of Jeonnam, situated in the southwestern region (Park *et al*., 2021).

Table 3.3: Global Production of Farmed Seaweeds by Major Producers (2019)

Sl. No.	Country	Farmed Seaweed Production (Tons wet weight)	Share of global Production (%)
1	China	20,122,142	58.02
2	Indonesia	9,918,400	28.60
3	Republic of Korea	1,812,765	5.23
4	Philippines	1,499,961	4.33
5	DPR of Korea	603,000	1.74
6	Japan	345,500	1.00
7	Malaysia	188,110	0.54
8	Tanzania	104,620	0.30
9	Chile	21,679	0.06
10	Viet Nam	13,300	0.04
11	Others	49,657	0.14
	Total	**34,679,134**	**100**

Source: FAO (2021a)

In the global aquaculture production, red seaweeds and brown seaweeds were the second and third largest species groups respectively, in terms of wet weight, in 2019. Among the major farmed aquatic species groups, brown seaweeds exhibited a higher growth rate of 9.43% between 2018 and 2019, when compared to the average growth rate of 3.74% of all the species groups. However, the growth of red seaweeds declined (-0.5%) between 2018 and 2019. The decline in red seaweeds was attributed by 3.12% decrease of *Kappaphycus/ Eucheuma*, which contributed about 64% of global farmed red seaweed in 2019 (FAO, 2021b).

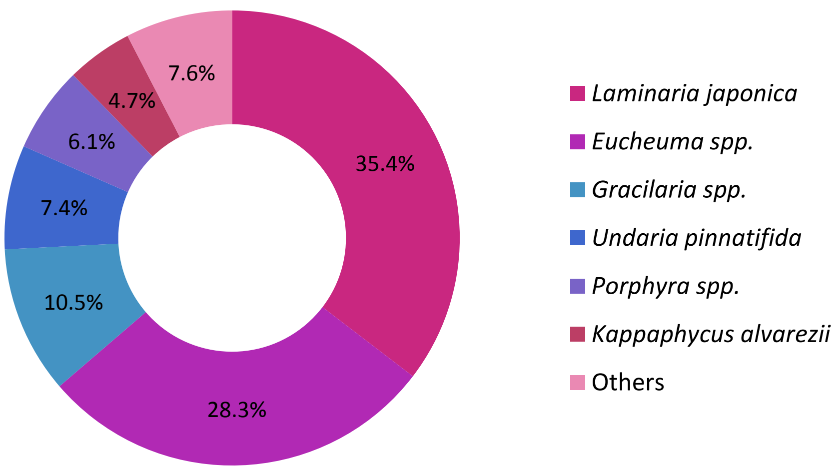
The quantity of various seaweed species produced globally through aquaculture in 2019 is given in **Table 3.4** and their share to total production is depicted in **Figure 3.1**. The major species contributing to global farmed seaweed production include *Laminaria japonica* (35.4%), *Eucheuma spp.* (28.3%), *Gracilaria spp.* (10.5%), *Undaria pinnatifida* (7.4%), *Porphyra spp.*

(6.1%), *Kappaphycus alvarezii* (4.7%) etc. Indonesia and the Philippines accounted for 84% and 13% respectively of *Kappaphycus/ Eucheuma* production, in terms of quantity. China was the major producer of *Gracilaria* (96%), followed by Indonesia. China and the Republic of Korea contributed 71% and 20% respectively to *Porphyra/ Pyropia* production. China accounted for 79% of global farmed *Undaria* (Cai *et al.*, 2021b; FAO, 2021a). Some of the seaweed species like *Undaria pinnatifida*, *Porphyra spp*. and *Caulerpa spp*. were cultured principally for use as human food (FAO, 2020b).

Table 3.4: Species-wise Production of Global Farmed Seaweeds (2019)

Sl. No.	Seaweed Species Group	Production (Tons)
1	*Laminaria japonica*	12,273,519
2	*Eucheuma spp.*	9,817,689
3	*Gracilaria spp.*	3,638,554
4	*Undaria pinnatifida*	2,563,477
5	*Porphyra spp.*	2,123,040
6	*Kappaphycus alvarezii*	1,625,164
7	Phaeophyceae	1,252,264
8	*Porphyra tenera*	861,083
9	*Sargassum fusiforme*	303,797
10	*Eucheuma denticulatum*	179,360
11	Other species	41,186

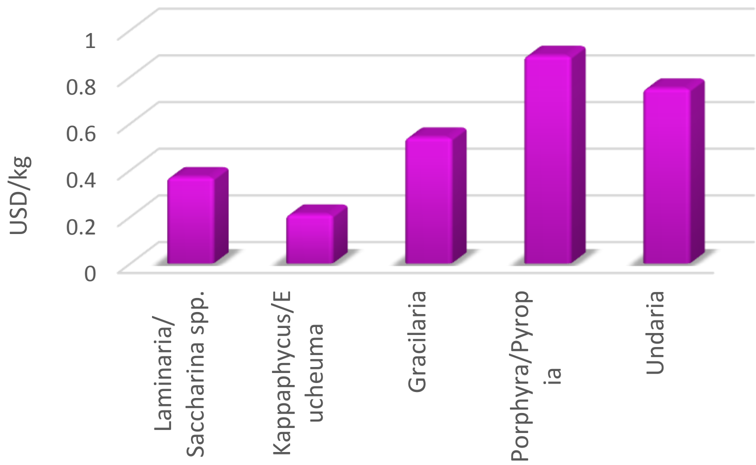
Source: FAO (2021a)



Source: FAO (2021a)

Figure 3.1: Share of Various Seaweed Species to Global Farmed Seaweed Production (2019)

Among the major seaweed species groups, in 2019, the highest value was contributed by *Laminaria/ Saccharina* spp. (USD 4.6 billion), followed by *Porphyra/ Pyropia* (USD 2.7 billion), *Kappaphycus/ Eucheuma* (USD 2.4 billion), *Gracilaria* (USD 2.0 billion) and *Undaria* (USD 1.9 billion) (Cai *et al.*, 2021b). The average first-sale price, on wet weight basis, of brown seaweeds, red seaweeds, and green seaweeds in 2019 were USD 0.47/kg, USD 0.39/kg, and USD 0.79/kg respectively. The average price of major cultivated seaweed species groups, on wet weight basis, is given in **Figure 3.2**. The price ranged between USD 0.89/ kg (*Porphyra/ Pyropia*) and USD 0.21/ kg (*Kappaphycus/ Eucheuma*) (Cai *et al*., 2021a).



Source: Cai *et al.* (2021a)

Figure 3.2: Average Price of Major Seaweed Species Groups Farmed Globally (2019)

The global production of wild collected seaweeds decreased from 1.33 million tons in 1990 to 1.08 million tons in 2019, on wet weight basis. However, an increase of 0.12 million tons was observed between 2018 and 2019. In 2019, brown, red and green seaweeds contributed 0.68 million tons, 0.19 million tons and 0.02 million tons respectively to the world wild collected seaweed production, on wet weight basis. The major producers of wild collected seaweeds in 2019 are given in **Table 3.5**. Chile was the major producer with a contribution of 37.38%, followed by China (16.10%), and Norway (15.05%). The top three countries aggregately accounted for nearly 70% of the total production (Cai, 2021; FAO, 2020a).

Table 3.5: Global Production of Wild Collected Seaweeds by Major Producers (2019)

Sl. No.	Country	Wild Collected Seaweed Production (Tons wet weight)	Share of global Production (%)
1	Chile	404,926	37.38
2	China	174,450	16.10
3	Norway	163,080	15.05
4	Japan	66,800	6.17
5	France	51,300	4.74
6	Indonesia	44,500	4.11
7	Peru	36,348	3.36
8	Ireland	29,500	2.72
9	India	18,400	1.70
10	Iceland	17,533	1.62
11	Others	76,534	7.06
	Total	**1,083,370**	**100**

Source: Cai (2021)

3.2 SEAWEED TRADE

The trade of aquatic plants grew from USD 65 million in 1976 to about USD 1.3 billion in 2018. The major exporters of aquatic plants in 2018 were Indonesia, Chile and the Republic of Korea and the leading importers include China, Japan and the United States of America (FAO, 2020b). In 2018, more than 60% of seaweeds, in terms of value, were exported by OECD countries (UNGC & Lloyd's Register Foundation, 2020). The phycocolloid sector was the major application segment between 1970s–1990s, but currently, it contributes only 11.4% in terms of volume and 10.8% in terms of value. Seaweed as food for human consumption is the principal category contributing 77.6% of volume and 88.3% of value. The phyco-supplement industry is a fast-emerging component and contributes 11.0% of volume and 0.9% of value (Chopin & Tacon, 2021).

The global exports and imports of seaweeds in 2021, under various Harmonized System (HS) codes, are given in **Table 3.6** (HS Code: 121220 - "Seaweeds and other algae; of a kind used primarily for human consumption, fresh or dried, whether or not ground"), **Table 3.7** (HS Code: 130231 - "Mucilages and thickeners; agar-agar, whether or not modified, derived from vegetable products"), **Table 3.8** (HS Code: 262100 - "Slag and ash; including seaweed ash (kelp), n.e.s. in chapter 26"), **Table 3.9** (HS Code: 380830 - "Herbicides, anti-sprouting products and plant-growth regulators; put up in forms or packings for retail sale or as preparations or articles"), and **Table 3.10** (HS Code: 391310 - "Polymers, natural; alginic acid, its salts and esters, in primary forms") respectively.

Table 3.6: Global Exports and Imports of Seaweeds Under HS Code: 121220 in 2021

Rank	Export			Import		
	Country	Value ('000 USD)	Quantity (Tons)	Country	Value ('000 USD)	Quantity (Tons)
1	St. Vincent and the Grenadines	174.90	5.37	Egypt	556.17	37.33
2	Trinidad and Tobago	59.35	18.07	Nigeria	338.01	50.11
3	Grenada	16.94	1.53	Trinidad and Tobago	191.11	57.75

Source: WITS (2022)

Table 3.7: Global Exports and Imports of Seaweeds under HS Code: 130231 in 2021

Rank	Export			Import		
	Country	Value ('000 USD)	Quantity (Tons)	Country	Value ('000 USD)	Quantity (Tons)
1	China	82,315.14	6,252.36	Japan	38,537.86	1,603.78
2	Spain	42,388.39	1,640.32	USA	35,751.76	1,833.82
3	European Union	36,044.24	1,361.73	European Union	30,090.88	1,760.92
4	Chile	27,485.98	1,207.77	China	22,027.06	1,537.75
5	Morocco	23,798.72	764.98	Russian Federation	15,955.17	1,139.17

Source: WITS (2022)

Table 3.8: Global Exports and Imports of Seaweeds under HS Code: 262100 in 2021

Rank	Export			Import		
	Country	Value ('000 USD)	Quantity (Tons)	Country	Value ('000 USD)	Quantity (Tons)
1	China	201,888.88	639,175.00	European Union	115,499.09	428,384.00
2	India	85,133.10	5,785,400.00	Germany	72,439.08	526,133.00
3	European Union	34,318.30	849,232.00	USA	43,456.40	733,097.00
4	USA	31,733.92	94,120.00	Netherlands	31,548.69	71,918.10
5	Germany	25,547.50	751,128.00	Japan	16,206.84	27,243.00

Source: WITS (2022)

Table 3.9: Global Exports and Imports of Seaweeds under HS Code: 380830 in 2021

Rank	Export			Import		
	Country	Value ('000 USD)	Quantity (Tons)	Country	Value ('000 USD)	Quantity (Tons)
1	China	4,931,556.12	1,411,050.00	Brazil	1,298,479.06	185,665.00
2	European Union	1,667,003.18	164,276.00	Canada	916,861.67	170,358.00
3	India	1,627,264.78	173,926.00	Australia	817,546.27	N. A.
4	USA	1,565,597.46	188,379.00	France	629,666.83	69,578.40
5	France	1,374,019.42	93,063.00	Germany	567,416.19	51,699.30

N. A - Not Available
Source: WITS (2022)

Table 3.10: Global Exports and Imports of Seaweeds under HS Code: 391310 in 2021

Rank	Export			Import		
	Country	Value ('000 USD)	Quantity (Tons)	Country	Value ('000 USD)	Quantity (Tons)
1	France	37,074.21	2,929.39	European Union	79,419.24	6,471.06
2	European Union	36,682.14	5,624.50	USA	60,992.80	3,805.21
3	Japan	28,787.20	1,670.30	Japan	25,538.05	2,264.70
4	Chile	22,506.88	1,353.54	Italy	22,780.56	2,100.21
5	Netherlands	15,065.25	4,560.55	Germany	21,973.81	2,239.51

Source: WITS (2022)

3.3 SEAWEED MARKET PROJECTION

The rising awareness about diversified applications and health benefits of seaweeds/ seaweed-based products is expected to catalyze global seaweed market growth in the years to come. The emerging use of seaweeds in areas such as biofuel production and wastewater treatment are anticipated to further propel the growth in the world seaweed market. Based on various estimates, the value of global seaweed market is projected to reach between USD 21.0 and 24.0 billion in 2027. Various forecasts on value and growth rate of global seaweed market are given in **Table 3.11**.

Table 3.11: Global Seaweed Market Value & Growth Forecast - 2027

Sl. No.	Seaweed Value (USD billion)	CAGR & Forecast Period	Source
1.	21.2	9.1% (2020 to 2027)	Meticulous Research (2021)
2.	23.04	5.8% (2020 to 2027)	Fortune Business Insights (2020a)
3.	24.0	7.1% (2020 to 2027)	Research and Markets (2020)

According to the estimates of Research and Markets (2020), the value of commercial seaweed market in the world was USD 14.8 billion in 2020 and is anticipated to reach USD 24.0 billion by 2027. The market size of China is expected to reach USD 5.3 billion by 2027. Other notable markets, Japan and Canada are estimated to grow at a Compound Annual Growth Rate (CAGR) of 3.9% and 6.4% respectively, during 2020-2027. Germany is anticipated to grow at a CAGR of about 4.6%. The global market of red seaweed is forecasted to reach USD 13.2 billion by 2027, with a CAGR of 7.1%. The brown seaweed segment is anticipated to grow at a CAGR of 7.4% during 2020-2027. The global market for green seaweed is projected to grow at a CAGR of 5.5% with USA, Canada, Japan, China and Europe propelling the growth. China would remain the fastest growing regional market. The Asia-Pacific market, led by Australia, India, and South Korea, is anticipated to reach USD 3.3 billion by 2027, while Latin America is projected to grow at a CAGR of 7.2% during 2020-2027 (Research and Markets, 2020).

The market projections, in terms of value and growth rate, of different seaweeds products globally are given in **Table 3.12**.

Table 3.12: Global Market Projections for Seaweed Products

Sl. No.	Product	Value & Year	CAGR & Forecast Period	Source
1.	Seaweed Powder	USD 0.48 billion (2024)	4.9% (2019-2024)	ReportsWeb (2019)
2.	Seaweed Extracts	USD 4.45 billion (2028)	5.9% (2020-2028)	Market Research Future (2021a)
3.	Seaweed Biostimulants	USD 5.35 billion (2027)	10.65% (2020–2027)	Fortune Business Insights (2020b)
4.	Seaweed Hydrocolloids	USD 2.3 billion (2024)	N. A.	Industry Experts (2019)
5.	Seaweed Protein	USD 0.98 billion (2026)	13.2% (2020-2026)	MarketsandMarkets (2021)
6.	Seaweed Snacks	USD 2.80 billion (2028)	8.7% (2021-2028)	Fior Markets (2021)
7.	Agar Agar Gum	USD 0.35 billion (2025)	3.6% (2016-2025)	Grand View Research (2017)
8.	Carrageenan	USD 1.25 billion (2030)	5.8% (2020-2030)	Market Research Future (2021b)

N. A. - Not Available

3.4 MARKET PLAYERS AND PRODUCTS

Global seaweed value-added products market is represented by a great number of players. In order to gain a broad overview of the global market, an indicative list of companies, along with the diverse value-added seaweed-based products manufactured by them, operating in Europe (**Table 3.13**), the Americas (**Table 3.14**), Asia-Pacific (excluding India) (**Table 3.15**), and Africa (**Table 3.16**) are listed.

Table 3.13: Seaweed Processing Companies in Europe and their Value-Added Products

Name of the Company	Value-Added Products
Denmark	
FermBiotics	Pet food supplement (Petferm™)
Jens Møller Products ApS	Seaweed caviar (Cavi·Art® &Tosago®), seaweed pearls (Food·art®) etc.
Melissa Organic Skincare	Cosmetics (skin care products)
Nordisk Tang	Seaweed beer, rum, snacks, truffle, seaweed salt, seaweed spice etc.
Seaman Seaweed Chips	Seaweed chips
Wavy Wonders	Seaweed snacks
Estonia	
Est-Agar AS	Furcellaran
Vetik OÜ	Phycoerythrin
Finland	
Origin by Ocean	Sodium alginate (Caerulo), fucoxanthin (Axureo), fucoidan (Cumatilo), laminarin (Livido), sunscreen etc.
France	
Agrimer	Liquid fertilizer, Animal feed supplement, cosmetics etc.
Algaia	Carrageenan, alginate, plant biostimulant, specialty seaweed extracts
Algopack	Bioplastics
Algotherm	Cosmetics
Bretagne Cosmétiques Marins	Cosmetics
Eranova	Bioplastics
Gelyma	Cosmeceuticals (skin care products)
Nexira	Dietary supplements (ID-alG™ - weight loss solution)
NUQO Feed Additives	Animal feed supplement
Penn Ar Bed Company - Marine Biotechnologies	Seaweed biostimulant, seaweed fertilizer etc.

Name of the Company	Value-Added Products
Phytomer	Cosmetics
Seppic SA	Cosmetics (Hair care - BIORESTORER™ PF, BIOENERGIZER™ P BG PF; Skin care - AMBRE OCEANE™ SPE, ASPAR'AGE etc.)
Sobigel S. A.	Agar
Thalion	Cosmetics
The Plantin Company	Seaweed liquid fertilizer
Timac Agro International	Plant biostimulant
Germany	
BAK Handelsbetrieb	Agar
C.E. Roeper GmbH	Agar, carrageenan
Compo Expert GmbH	Plant biostimulant, liquid NK fertilizer, organic-mineral NK fertilizer
Neomed Pharma GmbH	Plant biostimulant, animal feed supplement, cosmetics etc.
Neupert Ingredients GmbH	Agar agar, alginates, carrageenan
NOF Europe GmbH	Cosmetics ingredient (ECKLEXT® BG)
Nordic Oceanfruit	Seaweed salads, toppings, burger patties etc.
Smartfiber AG	Seaweed Yarn (SeaCell™, Smartcel™)
Viva Maris GmbH	Seaweed sauces, pasta, bread spread, sausage alternatives etc.
Iceland	
Marea	Bioplastics
Taramar ehf.	Cosmetics (skin care products)
Zeto ehf.	Cosmetics (skin care products)
Ireland	
AlgAran Seaweed Products	Seaweed capsules, flakes, anti-ageing serum, shampoo, face cream, body lotion, cleansing lotion, hand cream, lip balm etc.
Arramara Teoranta	Animal feed supplement, plant biostimulant, soil conditioner etc. (Titan®)
BioAtlantis Ltd.	Plant biostimulant
Brandon Products Ltd.	Plant biostimulant
C-Bio Limited	Plant biostimulant
Celtic Sea Minerals Ltd.	Animal feed supplement
Connemara Organic Seaweed Company	Cosmetics, seaweed fertilizer, food supplement etc.
Donegal Seaweed	Seaweed fertilizer, plant biostimulant

Name of the Company	Value-Added Products
Emerald Isle Seaweed	Seaweed flake capsules, seaweed granules, seaweed fertilizer, animal feed
Fruit Hill Farm	Seaweed fertilizer, animal feed supplement
Irish Seaweeds	Seaweed facial wrap, powder bath, smoked seaweed snacks, seaweed herbs, seaweed capsules
Nutramara Ltd.	Cosmeceutical & nutraceutical formulations, fucoidan etc.
Ocean Harvest Technologies Limited	Animal nutritional supplement
Oilean Glas Teoranta	Seaweed meal, plant biostimulant etc.
Origin Spirits Ireland Ltd	Seaweed whiskey
Plantruption	Seaweed burger
RÍ NA MARA Irish Seaweed Cosmetics	Cosmetics
Sealac Ltd	Seaweed-based electrolyte for pigs & livestock, seaweed meal for equines, seaweed powder for calf etc.
Seavite Bodycare Ltd.	Cosmetics
Shamrock Farm Enterprises	Seaweed fertilizer, animal feed supplements
This is Seaweed	Seaweed flakes
Wild Irish Seaweeds Ltd.	Seaweed sprinkles, smoothie, powder, cosmetics etc.
Italy	
B&V srl	Agar, sodium alginate, carrageenan
Biolchim SPA	Plant biostimulant
Valagro SpA	Plant biostimulant
Netherlands	
Caldic B.V.	Agar-agar, alginate, carrageenan etc.
Koppert Biological Systems	Plant biostimulant
Olijck	Seaweed ravioli and tagliatelle, seaweed burgers etc.
The Dutch Weed Burger BV	Seaweed burger
UmaMeats	Seaweed burger, sausage etc.
Norway	
Algea AS	Plant biostimulant, animal feed ingredient
Alginor ASA	Mannitol, fucoidan, cellulose, alginate, polyphenols, carotenoids, amino acids, laminarin , bioplastics etc.
AlgiPharma AS	Pharmaceuticals
B'ZEOS AS	Seaweed-based biolplastic
NovaMatrix	Ultrapure alginate, peptide-coupled alginate, sodium hyaluronate

Name of the Company	Value-Added Products
SJY Seaweed	Seaweed snacks
Poland	
Biotrem	Seaweed-based tableware and packaging
Portugal	
Bodyocean	Cosmetics (Skin care)
Iberagar S.A.	Agar-agar and carrageenan
Inclita Seaweed Solutions	Seaweed-based bioactive ingredients
Lusalgae	Cosmetics (Sealgae®)
Spain	
Algabase	Cosmetics
Atlántica Agrícola	Plant biostimulant
Compañia Española de Algas Marinas (CEAMSA)	Carrageenan, alginate
Futuralga	Seaweed-based disposable multiform containers
Hispanagar, S.A	Agar, agarose etc.
Industrias Roko S.A.	Agar-agar
La Espiral Verde	Cosmetics
Sweden	
Algine Products Sweden	Food supplements
Seatrients	Seaweed smoothies
Switzerland	
Lonza	Agarose (SeaPure®)
Mibelle AG Biochemistry	Cosmetics (Helioguard™ 365 - UV-screening active to protect against photo-aging)
Nestlé S.A.	Seaweed-based shrimp (Garden Gourmet Vrimp)
Polygal AG	Sodium alginate
United Kingdom	
Abakus Foods	Seaweed snacks
Aethic	Cosmetics (Aethic Sôvée® - prepared from mycosporine-like amino acids Photamin®)
Biosynth Carbosynth	Agar, Alginate, Carrageenan
Born Maverick Alt Pro Ltd.	Seaweed-based prawns and scallops
Dà Mhìle Distillery	Seaweed gin

Name of the Company	Value-Added Products
Dorwest Herbs Ltd.	Animal feed supplement
Ekogea UK Limited	Sanitiser for animal bedding and housing, animal feed ingredient, plant biostimulant etc.
Faith in Nature Ltd.	Cosmetics
FlexSea	Bioplastics
Haeckels	Cosmetics (skin care)
Hebridean Seaweed Company	Seaweed meal, liquid seaweed fertilizer extracts etc.
Ilex EnviroSciences Ltd	Plant biostimulant
Indigrow Ltd.	Plant biostimulant
ishga	Cosmetics
Isle of Harris Distillers Ltd	Seaweed gin
Kelp Industries Ltd.	Bioplastics
Maiiro Limited	Cosmetics (skin care – Kelpogen5TM)
Mara Seaweed	Seaweed flakes, seaweed strips, seaweed powder
Marine Biopolymers	Alginate
Orkney Seaweed Company Ltd	Seaweed fertilizer
Pangaia Materials Science Limited	Seaweed fiber fabrics
Phoenix and Providence	Cosmetics (Skin care)
Plantsea Ltd.	Bioplastics
Portsmouth Brewery	Seaweed beer – 'Selkie'
REN Clean Skincare	Cosmetics (Body scrub, body oil, body wash, hand wash etc.)
Seagreens Ltd.	Seaweed-based capsules, seaweed salt, salad etc.
Seaweed Agogo	High protein seaweed snacks, seaweed popcorn, seaweed herb mixes etc.
Seaweed Organics	Cosmetics (Skin & hair care)
Shanty Spirit Ltd.	Seaweed vodka
Shore Seaweed	Seaweed snacks, seaweed pestos and tapenades
Stan Chem International Ltd.	Plant growth promoters, animal nutritional supplement
The Cornish Seaweed Company Ltd.	Seaweed flakes, dried seaweed, cosmetics (body polish, bath soak, foot cream, body lotion, seaweed soap etc.)
The Shropshire Seaweed Company	Seaweed fertilizer
UPL Europe Ltd.	Plant biostimulant
Vollebak	Seaweed fiber fabrics
Williams Bros. Brewing Co.	Seaweed beer – 'Kelpie'

Table 3.14: Seaweed Processing Companies in the Americas and their Value-Added Products

Name of the Company	Value-Added Products
Barbados	
Red Diamond Compost	Seaweed fertilizer
Rum and Sargassum Inc.	Bio-CNG
Brazil	
AgarGel	Agar-agar and carrageenan
Algii	Cosmetics
Oceana Minerals	Bio-mineral complex for animal nutrition (LITHONUTRI®), Seaweed fertilizer (ALGEN®) etc.
Canada	
Acadian Seaplants Ltd.	Plant biostimulant, animal feed supplements, edible seaweed, nutraceuticals, functional food, cosmetics etc.
innoVactiv Inc.	Nutraceutical (InSea2® - blood glucose control), cosmeceutical (VivenSea™ - anti-ageing) etc.
Lucas Meyer Cosmetics	Cosmetics – 'Aldavine™ 5X '
North Atlantic Organics	Animal feed supplement, plant biostimulant etc.
Sea Pür Seaweed Products	Seaweed fertilizer
Seaflora Organic Thalasso Skincare	Cosmetics
Sheringham Distillery	Seaweed gin – 'Seaside Gin'
The Newfoundland Distillery Co.	Seaweed gin
Tofino Brewing Co.	Seaweed beer – 'Kelp Stout'
West Coast Marine Bio-Processing Corp.	Plant biostimulant
Chile	
Agar del Pacífico S.A.	Agar
Amarea	Seaweed snacks
Extractor Naturales Gelymar S.A.	Carrageenan, alginates
Nun Spa	Seaweed pasta
Quelp	Seaweed burger, nuggets and meatball
Jamaica	
Awganic Inputs	Goat feed
Mexico	
Agarmex	Agar-agar

Name of the Company	Value-Added Products
Algas Marinas, S.A. de C.V.	Plant biostimulant
Algas y Bioderivados Marinos, S.A. de C.V.	Seaweed fertilizer (Agrokelp®, AgroKelp Plus®), plant biostimulant (Nutrikelp®), cosmetics (Dermakelp®) etc.
Algas y Extractos del Pacifico Norte AEP S.A. de C.V.	Seaweed fertilizer, plant biostimulant (NPKelp®), soil improver (Kelproot®) etc.
Dianco México, SAPI de CV	Biofertilizers, soil improver etc.
Grupo Dakatso de México, S.A. de C.V.	Seaweed-based concrete (SARGACRETO®)
Palau BioQuim, S.A. de C.V.	Seaweed fertilizer, plant biostimulant etc.
Química Sagal, S.A. de C.V	Seaweed fertilizer, plant biostimulant etc.
Salgax Biotecnologia Marina Aplicada	Seaweed fertilizer, cosmetics (skin care) etc.
Tecniprocesos Biologicos, S.A. de C.V.	Seaweed fertilizer, plant biostimulant etc.
Peru	
PSW S.A.	Plant biostimulant, animal feed additive, nutraceuticals etc.
Saint Barthélemy	
Sargasse Project	Paper pulp
Saint Lucia	
Algas Organics	Plant biostimulant
USA	
12 Tides	Seaweed snacks
AEP Colloids	Agar-agar, alginates, carrageenan etc.
Akua	Kelp Jerky, kelp pasta, kelp burger etc.
Algeon Materials	Biolplastics
Annie Chun’s Inc.	Seaweed snacks, seaweed crisps (Roasted seaweed snacks layered over crispy brown rice chips)
Atlantic Sea Farms	Seaweed burger
Barnacle Foods	Kelp sauce, salsa, pickle, flakes, chocolate etc.
Barnet Products, LLC	Alginate (‘Phycosaccharide AI’)
Blue Ocean Barns	Animal feed supplement
Blue Point Brewing Company	Seaweed beer - ‘Prop Stopper’
Brandt Consolidated Inc.	Liquid fertilizer enriched with seaweed extract
Cargill Inc.	Wide range of carrageenan, Specialty seaweed powder (WavePure®)
CP Kelco	Kappa carrageenan, iota carrageenan, lambda carrageenan
Crabtree & Evelyn Ltd.	Cosmetics (Hair care)

Name of the Company	Value-Added Products
Cup of Sea	Seaweed tea
Dang Foods Company	Seaweed rice chips
The Estée Lauder Companies Inc.	Cosmetics (Skin care – 'Crème de la Mer')
gimMe Health Foods Inc.	Roasted seaweed snacks, seaweed sheets
Ingredients Solutions, Inc.	Carrageenan, alginate, agar-agar
International Flavors & Fragrances (IFF)	Alginate (Protanal®), Seaweed flour (SeaFlour) Seaweed oil for preparing perfume (Seaweed Absolute)
Jayone Foods Inc.	Roasted seaweed snacks, seaweed salad
JetNet Corporation	Edible film (Nutrafilm™) for increasing shelf life of meat, poultry, dairy products etc.
Kuleana Inc.	Seaweed-based seafood
Lonza Rockland Inc.	Agarose
Maine Coast Sea Vegetables, Inc.	Raw seaweed, seaweed flakes, seaweed granules, seaweed powder
Marshall Wharf Brewing Company	Seaweed beer – 'Sea Belt'
Maxicrop USA Inc.	Plant biostimulants
New Wave Foods	Seaweed-based vegan shrimp (New Wave Shrimp™)
Ocean's Halo	Seaweed sheets with unique flavours, vitamins, minerals, soup base, seaweed salt, deep seawater drink with kelp extract etc.
One Ocean Beauty	Cosmetics
Oregon Dulse	Seaweed-based protein powder
Primary Ocean, PBC	Bioplastic and organic fertilizer
Rootless	Seaweed-based nutraceuticals
Samudra Skin & Sea	Skincare (Face cream, soap, body butter etc.)
Sea Green Organics LLC.	Plant biostimulant
SeaSnax	Seaweed sheets, seaweed salad, seaweed flakes
Sundog Productions LLC.	Seaweed-based textile dye
Sway Innovation Co.	Bioplastics
Symbrosia Inc.	Animal feed supplement
The Seaweed Bath Co.	Cosmetics
Umaro Foods, Inc.	Seaweed-based bacon

Table 3.15: Seaweed Processing Companies in Asia-Pacific (Excluding India) and their Value-Added Products

Name of the Company	Value-Added Products
Australia	
Alg Seaweed	Seaweed condiments and snacks
Australian Kelp Products Pty Ltd	Seaweed fertilizer, animal feed supplement (Sea Biscuits® StockAid), carrageenan, alginate, agar etc.
FutureFeed Pty Ltd	Animal feed supplement
NatraSol Sea Products	Plant biostimulant, Anim al feed supplement etc.
Phyco Health	Food supplements (seaweed fibre, protein), cosmetics (skin care products), food (seaweed snacks, pasta) etc.
Purify Co Pty Ltd	Cosmetics
Seasol International Pty Ltd	Liquid seaweed fertilizer
SeaStock Pty Ltd	Livestock feed supplement
Venus Shell Systems	Functional food ingredient , nutraceuticals, wound dressing etc.
YelpKelp Pty Ltd	Dog feed supplement
China	
Andi-Johnson Group	Agar, carrageenan
Beijing Leili Marine Bioindustry Inc.	Seaweed fertilizer
Foodmate Co. Ltd.	Carrageenan
Greenfresh Food Co. Ltd.	Agar, Carrageenan
High Hope Foods (Nanjing) Co. Ltd.	Carrageenan, sodium alginate, agar-agar
Hong Kong Sheli Ltd.	Carrageenan, agar, sodium alginate
Lauta Ltd.	Carrageenan
Leili Agrochemistry Co. Ltd.	Seaweed fertilizer
Mingfu Fujian Agar Co Ltd.	Agar
Nantong Oceans Flavor Food Co. Ltd	Seaweed snacks
Qingdao Bright Moon Seaweed Group Co. Ltd.	Sodium alginate, calcium alginate, alginic acid, functional food ingredients etc.
Qingdao Gather Great Ocean Algae Industry Group Co. Ltd.	Sodium alginate, carrageenan, agar, propylene glycol alginate, seaweed feeds, seaweed fertilizers, seaweed foods etc.
Qingdao Ocean Algae Industry Group Co. Ltd.	Alginate, alginic acid, carrageenan, agar, seaweed fertilizer etc.
Qingdao Seawin Biotech Group Co. Ltd.	Seaweed extract, seaweed water soluble NPK fertilizer, seaweed granular fertilizer etc.
Shandong Topsea Seaweed Industrial Co., Ltd	Alginic acid, Sodium alginates

Name of the Company	Value-Added Products
Yan Cheng Hairui Food Co. Ltd.	Roasted seaweed, seasoned seaweed, seaweed roll
Yantai Jiate Bio-Tech. Co., Ltd.	Seaweed Foliar Fertilizer, Plant Growth Regulator etc.
Yantai Sheli Hydrocolloids Co. Ltd.	Carrageenan, agar, sodium alginate etc.
Fiji	
Sea & Soil	Seaweed fertilizer, cosmetics etc.
Indonesia	
CV. Agar Sari Jaya	Agar-agar
CV. Karagen Indonesia	Carrageenan
PT. Agar Swallow	Agar & Carrageenan
PT. Agarindo Bogatama	Agar
PT. Algalindo Perdana	Carrageenan
PT. Amarta Carrageenan	Carrageenan
PT. Bantimurung Indah	Carrageenan
PT. Beautiful Bantimurung	Semi-refined Carrageenan
PT. Buanatama Fajar Abadi	Carrageenan
PT. Cahaya Cemerlang	Carrageenan
PT. Centram	Carrageenan
PT. Emerald Seaweed Indonesia	Agar
PT. Galic Artabahari	Carrageenan
PT. Gumindo Perkasa Industri	Carrageenan
PT. Hydrocolloid Indonesia	Carrageenan
PT. Indo Seaweed	Carrageenan
PT. Indoflora Cipta Mandiri	Agar-agar and carrageenan
PT. Indoking Aneka Agar - Agar Industri	Agar-agar
PT. Indonusa Algaemas Prima	Carrageenan
PT. Java Biocolloid	Agar-agar (RA® Series)
PT. Kappa Carrageenan Nusantara	Carrageenan, agar
PT. Rote Karaginan Nusantara	Carrageenan
PT. Satelit Sriti	Agar-agar
PT. Seaweedtama Biopac Indonesia	Bioplastics
PT. Sri Gunting Pratama	Agar-agar
PT. Surya Indoalgas	Agar

Name of the Company	Value-Added Products
PT. Wahyu Putra Bimasakti	Carrageenan
Israel	
Haifa Group	Plant biostimulant, soluble NPK fertilizers enhanced with seaweed extracts
Seakura	Seaweed cracker, nutritional supplements etc.
Sealaria Ltd.	Cosmeceuticals (skin care products)
Japan	
Asahi & Co.,Ltd.	Agar
Green Science Alliance Co. Ltd.	Bioplastics
KIMICA Corporation	Sodium alginate, ammonium alginate, potassium alginate, alginic acid etc.
Maruesu Corporation	Seaweed snacks
Nisshinbo Holdings Inc.	Seaweed-based bioplastic
SWF Co. Ltd.	Cosmetics
Ventuno Co. Ltd.	Health food, cosmetics etc.
Malaysia	
Tacara Sdn Bhd	Kappa and iota carrageenan products for food & non food industries
New Zealand	
Abron Ltd.	Fertilizer
AgriSea New Zealand Ltd.	Animal feed supplement, plant biostimulant, seaweed salt etc.
BioSea	Plant biostimulant
CH4 Global Inc.	Animal feed supplements
Eco Ora Ltd.	Dietary supplement
Enzalg	Dietary supplement
Farmlands Co-operative Society Ltd.	Plant biostimulant
Kelpn Limited	Bioplastics
Kereru Brewing Company	Seaweed beer (Kereru Karengose Salty)
KiwiWakame	Food condiments
New Zealand Mānuka Group	Agar
New Zealand Seaweeds	Agar, plant biostimulant, liquid fertilizer (KōFERT BIO-PLUS) etc.
New Zealand Southern Pacific Seaweed Company	Health supplement
Pacific Harvest Seaweeds	Seaweed flakes, seaweed powder, seaweed strips, agar

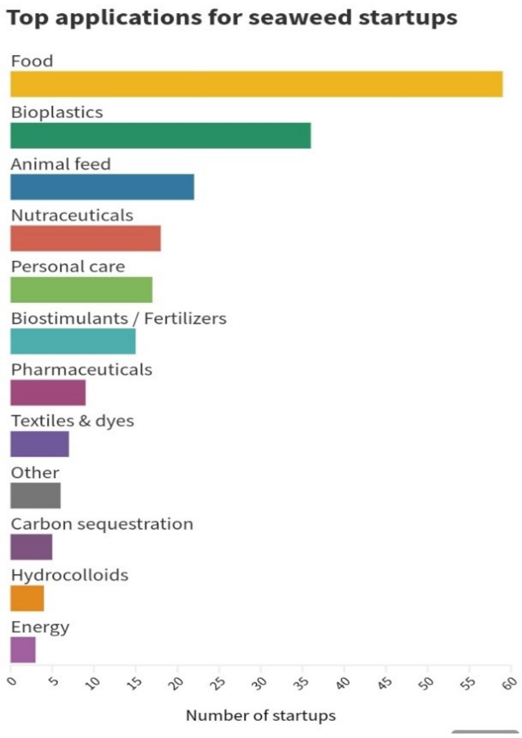
Name of the Company	Value-Added Products
Syrene Skincare NZ Limited	Cosmetics
VOYA NZ	Cosmetics
Waikaitu Ltd.	Plant biostimulant
Philippines	
Accel Carrageenan Corporation	Carrageenan
Agarophyta Philippines, Inc.	Carrageenan, agar-agar
Asiagel Corporation	Agar, agarose etc.
CEAMSA Asia, Inc	Carrageenan, Alginate etc.
Cebu Carrageenan Corp	Semi-refined carrageenan
Froilan Trading Corp	Semi-refined carrageenan
Geltech Hayco, Inc.	Carrageenan
Mangan by Imán	Seaweed snacks
Marcel Carrageenan	Carrageenan
MCPI Corporation	Carrageenan
Shemberg	Carrageenan
TBK Manufacturing Corporation	Carrageenan
W Hydrocolloids, Inc.	Carrageenan (RICO® Carrageenan)
Zamboanga Carrageenan Manufacturing Corporation	Semi-refined carrageenan
Republic of Korea	
Botamedi Inc.	Nutraceuticals, cosmetics, personal hygiene products etc. (prepared from polyphenol extract SEANOL®)
Cheongdo Agar Agar Mfg Co. Ltd.	Carrageenan, Agar-agar
Dysskorea Co., Ltd.	Seaweed snacks, roasted seaweed etc.
Haewon Biotech Inc.	Mannitol, alginic acid, fucoidan, fucoxanthin, nutraceutical ('Antiv Fucan' – immune booster) etc.
Manjun Seaweed	Seaweed snacks
Marine Innovation Co., Ltd.	Seaweed-based plates, cups, egg cartons/ trays, fruit trays, coffee carriers etc.
MSC Co. Ltd.	Carrageenan and agar-agar
Myeong Shin Agar-Agar Co. Ltd.	Agar-agar
The Garden of Naturalsolution	Cosmetic ingredients (Seactive™) etc.
Singapore	
Nutri-San Pte Ltd.	Animal feed supplement

Table 3.16: Seaweed Processing Companies in Africa and their Value-Added Products

Name of the Company	Value-Added Products
Morocco	
Setexam	Agar-agar
Seychelles	
Seaweed Seychelles	Plant growth promoter, soil conditioner
South Africa	
Danlink Ingredients (Pty) Ltd	Carrageenan
Kelp Products International (Pty) Ltd	Liquid fertilizer, plant biostimulant (Kelpak®)
Afrikelp	Plant biostimulant
Tunisia	
Selt Marine Group	Agar-agar, carrageenan

3.5 SEAWEED-BASED STARTUPS

There are growing numbers of new breed innovators investing in seaweed sector, also known as "Seaweed-prenuers". Globally, the growth in number of seaweed-based startups was very slow till 2015 and a rapid growth was observed thereafter. Considering the technology readiness level, more than half of all the startups are in pre-revenue stage i.e., research or pilot stage, followed by scaling-up stage i.e., validation and scale-up. Only very few seaweed-based startups are in the mature stage. Taking account of the value chain, majority of the startups are focusing on manufacturing of high value products from seaweed biomass followed by farming and harvesting. The major applications for seaweed startups include food, bioplastics, animal feed, nutraceuticals etc. (**Figure 3.3)**. Europe is dominating in the number of seaweed-based startups globally, followed by the Americas (Phyconomy, n.d.).



Source: Phyconomy

Figure 3.3: Segregation of Seaweed-Based Startups Based on Applications

A cross section of seaweed-based startups across the world and the innovative/ unique products manufactured by them are described below:

Rhodomaxx

Rhodomaxx Sdn Bhd, Malaysia

With a mission to produce affordable and sustainable seaweed-based products for the bio-based economy, Rhodomaxx was incorporated in April 2018 at Sabah, Malaysia. Various seaweed-based products developed are bioplastics, mineral feed supplement, plant growth regulator and trace element extract. The seaweed-based bioplastic packaging of Rhodomaxx is a heat sealable product, which can be coloured and printed. The seaweed mineral feed supplement targets livestock including layers, breeder hens and dairy cattle. The plant growth stimulator and trace element extract, with growth stimulants and bioavailable trace elements, enhances crop productivity.

Novameat, Spain

Spanish startup Novameat, founded in 2017, produces seaweed-based vegan steak using tissue engineering and bioprinting. This vegan product not only resembles a steak, but also has comparable nutritional quality and consistency. The steak is produced using patented micro-extrusion technology, which generates fibres with size ranging from 100 microns to 500 microns in diameter. The ingredients of the steak include peas, rice, and seaweed. The startup also produces vegan chicken breast by coalescing the vegetable proteins into a paste and then 3D printing them. This process costs less than USD 3 for producing 100 g of plant-based meat and the time taken for the same is only 30 minutes.

Seamore Holding BV, the Netherlands

Seamore is a food startup company located in Amsterdam, the Netherlands, founded in January 2015, producing seaweed-based food products. The products of Seamore include seaweed wraps, seaweed pasta, seaweed bacon, seaweed chips, and seaweed bread. Seaweed wraps are prepared with 50% wakame (*Undaria pinnatifida*) and Himanthalia seaweed (*Himanthalia elongate*). The wraps, prepared from organic seaweeds, contains 25% more fiber and 19% more protein, than regular wheat wraps. Seaweed pasta is prepared using handpicked seaweed from Connemara, Ireland. The pasta is gluten-free, high in fiber, organic, and contains 80% fewer calories than regular pasta per 100 g serving. Seaweed bacon is a plant-based substitute for bacon and is organic and gluten-free. Seaweed chips produced by Seamore is the world's first seaweed tortilla chips, prepared with 35% seaweed. In 2018, Seamore launched the world's first seaweed bread. The healthy bread is prepared using a unique process that integrates 35% seaweed into the dough.

Oceanium Limited, UK

Oceanium, a startup based at the European Marine Science Park in Oban, Scotland, was founded in June 2018 with a mission to establish a sustainable seaweed farming industry and to develop plant-based food products and sustainable packaging. Oceanium is primarily focusing on development of two streams of products namely home compostable food packaging and natural food ingredients and nutrition products. The biopackaging material developed by Oceanium can be disposed off along with food waste, which can be further composted for soil health or can be digested anaerobically for energy production.

Notpla Limited, UK

Notpla, a London-based sustainable packaging startup, offers packaging alternatives to single use plastics. Notpla produces 'Ooho', a flexible packaging material for beverages and sauces, from seaweed and plants. It can either be biologically degraded (within a period of 4-6 weeks), or can be consumed, making it ideal for on-the-go consumption. Ooho had been used at various running races, helping marathons to become environment friendly and offers the runners easy-to-use water packets. The bioplastic pouch from Notpla was used by runners at the 2019 London Marathon. The seaweed-based bioplastic capsule supplied by Notpla is being used by Chivas Brothers International Limited, Scotland for packing The Glenlivet whisky. 'Sachets', a plastic free packaging solution developed by Notpla with take-away industry in mind, can be composted along with left-over food waste. Notpla also produces waterproofing and grease proofing cardboard takeaway boxes namely 'Notpla Liner'.

Evo & Co., Indonesia

Evo & Co., founded in 2016 at Jakarta, is a sustainable company providing plastic free alternatives from seaweed. Their mission is to create more biodegradable alternatives to single-use plastic products using seaweed and to enhance the livelihoods of seaweed farmers in Indonesia. Evo & Co. began their journey by developing seaweed-based edible cup namely "Ello Jello" under the 'Evoware' brand. The edible cup is produced in various flavours such as orange, green tea, peppermint etc. and can be used up to seven days, if stored under refrigerated conditions. Evo & Co. also produces seaweed-based biopackaging material for packing coffee, cereal, soap, chopstick, etc. under the 'Evoware' brand. Two types of packaging products are been offered - one is heat sealable for making into a sachet, and another is non-heat sealable material used for wrapping. The packaging product has a shelf life of two years, when stored at a dry area.

Loliware, USA

Loliware is a New York-based startup, founded in 2015, producing edible seaweed-based straws which can break down rapidly for efficient composting and can biodegrade within few weeks when kept in water. Loliware launched the first hypercompostable, edible drinking straw in the world namely 'Lolistraw'. Loliware is engaged in production of new types of straw such as bent straw for juice boxes, biodegradable cup, utensil etc. Loliware is credited with investment by the Ocean Solutions Accelerator of the Sustainable Ocean Alliance.

Algopack, France

Algopack is a startup based in Saint-Malo, Brittany manufacturing bio-based materials made from brown seaweed. Through a patented process, Algopack has evolved two technologies for production of biodegradable granules, utilizing seaweed polymer. The first product 'Algopack®' is a bio-compostable and biodegradable granule produced exclusively from seaweed. The second product 'Algoblend®' is produced by combining 50% plastics and 50% seaweed-based plastics. Due to reduction in manufacturing temperature, production of Algoblend® results in saving of 25% energy.

Oimo, Spain

Oimo (Organic - Intelligent - Malleable - Objects), founded in 2019 at Barcelona, is an eco-design and new materials startup. Oimo has developed a seaweed-based bioplastic composition compatible with existing plastic injection moulds, allowing traditional plastic manufacturers to produce fully biodegradable plastics that can be decomposed in less than a month. Wide range biomaterials namely bioplastic ring can holders for four or six-pack beverages (Oimo Ring) and a near-transparent film used in food packaging (Oimo Film) are currently being offered by Oimo. The products of Oimo are prepared using seaweed, natural sugars, and vegetable oils. Oimo was the ACCIO Startup Capital Winner 2019 and also won the Global Techbase New Materials Award Guangzhou 2019.

FutureFeed Pty Ltd, Australia

FutureFeed, a startup formed in February 2020, is involved in commercialization of an innovative livestock feed supplement, produced from seaweed *Asparagopsis*, which can improve the productivity of livestock and decrease enteric methane emissions. FutureFeed was established by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to hold the IP rights of seaweed-based animal feed supplement technology developed by CSIRO, Meat and Livestock Australia, and James Cook University. FutureFeed has received the 2020 Curt Bergfors Food Planet Prize, as recognition for creating a sustainable food system which assists in attaining stability of the planet.

AlgiKnit, USA

AlgiKnit, the New York-based biomaterials company founded in the year 2017, produces degradable yarns and ecologically sustainable wearable textiles from these yarns, as an alternative to conventional textiles. The degradable yarns are produced from seaweed *Laminaria digitata*. Alginate, extracted from seaweed, in combination with other renewable biopolymers is used to manufacture durable and degradable yarns. These yarns can be used across fashion industry including manufacturing of textiles, footwear etc. These yarns can also be integrated into packaging and home furnishings. The company is being supported by agencies such as National Geographic, startup accelerator RebelBio etc. AlgiKnit had won the National Geographic Chasing Genius Award in the Sustainable Planet category in 2017.

Penrhos Bio, UK

Penrhos Bio, a joint venture between Unilever plc and Innova Partnerships formed in 2019, envisages creating self-cleaning surfaces with application in wide range of industries. Furanone derived lactam from red seaweed *Delisea Pulchra* is used to prevent formation of biofilms by microorganisms on the surfaces, by disrupting their communication. The product can be used to prevent growth of fungus in washing machines, produce self-cleaning banknotes and medical devices, protect ship hull from slime and fouling, produce odourless shoes etc. At present, the company is working with license partners in the areas of banknotes and dental applications. The company possesses the exclusive license to utilize the anti-biofilm technology developed by Unilever plc and its collaborators, in the last decade.

Rum and Sargassum Inc., Barbados

Rum and Sargassum Inc. is a spinoff startup company of University of the West Indies Cave Hill Campus founded in the year 2017 at Saint James, Barbados. The company is producing bio-CNG from *Sargassum*, which is abundantly found on the seashore of Barbados, to achieve the target of fossil fuel-free Barbados by 2030. The alternative transportation fuel is produced using *Sargassum*, wastewater from rum distilleries, and Black Belly sheep manure. The wastewater generated in rum industry is ideal for producing bio-methane via anaerobic digestion.

Nam-Oceanic Kelp Production Enterprise, Namibia

Nam-Oceanic Kelp Production Enterprise (NamKelp), a startup company located at Windhoek, utilizes seaweeds collected from wild to produce highly nutritious commercial chicken feed products and supply the feed supplements to farmers in Namibia. The startup is formally launching the product into the market under the brand name 'Ochanya Chicken Feed'. The long-term plan of the company includes seaweed culture and production of other value-added products.

4.0 INDIAN SEAWEED SECTOR

India is endowed with a coastline of 8118 km with abundant seaweed resources. In Indian waters, 844 species of seaweeds belonging to 217 genera of 69 families have been reported (Kaladharan & Jayasankar, 2003). Among the seaweeds present in India, 434 species are red seaweeds, 216 species are green seaweeds, and 194 species are brown seaweeds (Krishnan & Narayanakumar, 2010b). Highest number of seaweed species was documented from Tamil Nadu, followed by Gujarat, Maharashtra, Lakshadweep, Andhra Pradesh and Goa (Venkataraman & Wafar, 2005).

More than 0.26 million tons of wet harvestable seaweed biomass is available in the Indian marine waters. Tamil Nadu is having the highest seaweed standing stock followed by Andaman and Nicobar Islands, Gujarat, Maharashtra and Lakshadweep Islands. Abundant seaweed beds are also seen in Andhra Pradesh (Visakhapatnam), Odisha (Chilka), Goa, Kerala (Varkala, Ashtamudi and Vizhinjam) and Karnataka (Karwar) (**Table 4.1**). The distribution of seaweed resources along the Indian coast is depicted in **Figure 4.1**. The seaweed biomass in the Indian waters comprises of 70% green seaweeds, 16% brown seaweeds, and 14% red seaweeds (Kaladharan & Jayasankar, 2003).

Table 4.1: Seaweeds Standing Stock in India

Sl. No.	State/ Union Territory	Quantity in wet wt. (Tons)
1	Tamil Nadu	97,416
2	Andaman & Nicobar Islands	90,939
3	Gujarat	20,155
4	Maharashtra	20,000
5	Lakshadweep Islands	19,345
6	Andhra Pradesh	7,500
7	Orissa	2,521
8	Goa	2,000
9	Kerala	1,000
TOTAL		**260,876**

Source: Kaladharan & Jayasankar (2003)

Source: Kaladharan & Kaliaperumal (1999)

Figure 4.1: Distribution of Seaweed Resources Along Indian Coast

4.1 SEAWEED PRODUCTION IN INDIA

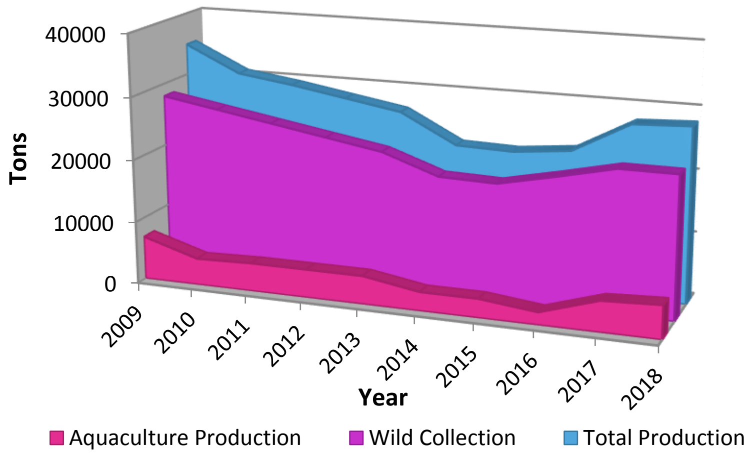
In India, since early 1950s, *Gelidiella acerosa* and *Gracillaria edulis* are harvested commercially for manufacturing agar and brown seaweed *Sargassum* and *Turbinaria* for producing alginate. Seaweeds are generally collected during the spring tides of full moon and new moon days, from twenty islands as well as from the mainland coast of the Gulf of Mannar and Palk Bay, located in the Southeast coast of India. Seaweeds are harvested from natural beds, mostly by women, from more than 2,000 households. The harvested seaweeds are then gathered using boats and transported to the shore. The agents/ middlemen acquire seaweed biomass from harvesters on the shore and further sell it to processing industries (Mathew & Ravishankar, 2018). About 500-600 tons dry weight of wild agarophytes are harvested along the Tamil Nadu coast (Mantri *et al*., 2019). Seaweeds harvested from the natural stocks are having an estimated annual market value of about at Rs.27 crores (Lok Sabha Secretariat, 2021). Even though seaweeds are traditionally harvested from natural stocks, depletion of natural resources due to overharvesting coupled with habitat destruction have necessitated the need for seaweed culture in India.

Seaweed aquaculture in India commenced with farming of *Gracilaria edulis*, because of its excessive capacity to regenerate (Kaladharan *et al*., 2019b). Subsequent to acquisition of *Kappaphycus alvarezii* from Japan by CSIR-CSMCRI, cultivation of *K. alvarezii* was started in India. After conducting trials at Port Okha during 1989-1996, *K. alvarezii* culture was initiated at Mandapam during 1995-1997. Experimental cultivation of seaweed continued till November 2000 (Mantri *et al*., 2017). In 2001, Pepsi Foods Ltd., for the first time, started extensive commercial farming of seaweeds in India at Mandapam, Tamil Nadu, with technical assistance from Marine Algal Research Station (MARS) of CSIR-CSMCRI. Pepsi Foods cultivated *K. alvarezii* through a contract farming system. Subsequently, pilot scale culture of *K. alvarezii* was started at Port Okha, Mithapur and Beyt Dwarka in Gujarat in 2004. Pepsi Foods extended the cultivation of *K. alvarezii* to Tuticorin District in Tamil Nadu in 2005. Farming was further expanded to the districts of Tanjore and Pudukkottai in Tamil Nadu in 2006 and 2007 respectively. Tube net farming was introduced in five sites (Sarkeshwar, Madvad, Simar, Navibandar, and Miyani) in the state of Gujarat during the year 2013. Aquaculture Foundation of India, in 2015, started tube net farming in different sites of Visakhapatnam district (Thimmapuram, Chepala and Mangamaripeta), and Vizianagaram district (Yerra Musalayapalam, Mukkam and Neelagaddapetta) in the state of Andhra Pradesh (Mantri *et al*., 2017).

While most of the efforts were focused on cultivation of *Kappaphycus*, several other species of seaweeds are also farmed in India for manufacturing carrageenans, bacteriological grade agar, food grade agar and agarose (Veeragurunathan *et al*., 2016; Mantri *et al*., 2019). *Gracilaria edulis*, *Acanthophora spicifera* and *Hypnea valentiae* have been cultivated at Minicoy Lagoon at the Union Territory of Lakshadweep using single bottom coir rope method and single bottom nylon rope technique. *Hypnea musciformis* was cultivated in rafts at Chorward near Veraval (Mohammed, 2016). Farming of *Sarconema filiforme*, on a pilot scale, was carried out along the Mandapam coast, using bamboo raft technique (Ganesan *et al*., 2015). *Gracilaria dura*, a source of agarose, was cultivated along the Gujarat coast of Simar using the tube-net method. Tube net cultivation of *Gracilaria crassa*, an important agarophyte, was also attempted (Ganesan *et al*., 2019b).

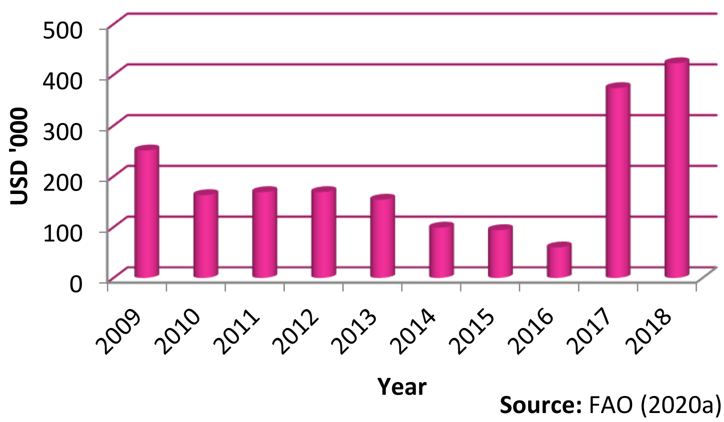
In terms of wet weight, production of aquatic plants including seaweeds in India (which constitute production from both wild collection and aquaculture) decreased from 34,922 tons in 2009 to 27,937 tons in 2018. Since 2009, total production decreased gradually till 2015 and an increasing trend was observed thereafter (**Figure 4.2**). In 2018, India contributed 0.08% to the global production. The production from wild collection decreased from 28,000 tons in 2009 to 22,635 tons in 2018 (**Figure 4.2**). The contribution of India to global production of seaweeds and other aquatic plants from wild collection remained at less than 3% in the last decade. The contribution of India in 2009 and 2018 was 2.5% and 2.4% respectively.

Among the seaweeds available in India, nearly 60 species are having commercial importance. However, large scale commercial farming of only two to three species is being carried out currently. In India, commercial scale seaweed aquaculture is mostly undertaken in the states of Tamil Nadu and Gujarat and to a smaller extent in the states of Maharashtra and Odisha (Lok Sabha Secretariat, 2021). Aquaculture production of aquatic plants including seaweeds in India decreased from 6,922 tons in 2009 to 5,302 tons in 2018 (**Figure 4.2**). Even though the quantity of aquatic plants produced through aquaculture in India had declined, its value had increased from USD 0.25 million in 2009 to USD 0.42 million in 2018 (**Figure 4.3)**. The contribution of India to global farmed aquatic plants production is negligible. In 2018, India contributed 0.02% in terms of volume and 0.003% in terms of value (FAO, 2020a).



Source: FAO (2020a)

Figure 4.2: **Production of Aquatic Plants Including Seaweeds in India (2009-2018)**



Source: FAO (2020a)

Figure 4.3: Value of Aquatic Plants Produced Through Aquaculture in India (2009-2018)

Johnson *et al.* (2020) had identified a total of 23,970 ha area suitable for seaweed farming along the coast of India. The state wise details of potential sites identified for seaweed culture in India is given at **Table 4.2**.

Table 4.2: Potential sites identified for seaweed culture along Indian coast

State	No. of locations identified	Area of potential sites (Ha)
Gujarat	9	10,316
Diu	5	700
Maharashtra	12	2,724
Goa	4	120
Karnataka	14	1,579
Kerala	7	80
Lakshadweep Islands	11	213
Tamil Nadu	187	5,048
Andhra Pradesh	49	1,215
Odisha	14	1,525
West Bengal	5	450
Total (All India)	**317**	**23,970**

Source: Johnson *et al*. (2020)

4.2 SOCIO-ECONOMIC BENEFITS OF SEAWEED SECTOR

According to Immanuel & Sathiadhas (2004), optimal harvest of wild seaweed resources can provide employment to about 20,000 individuals in the coastal communities, both in harvesting as well as in post-harvest activities. Seaweed aquaculture in one-million-hectare area, within the territorial waters of India, has the potential to provide employment to at least 15 million individuals (TIFAC, 2018). Krishnan & Narayanakumar (2013) projected that India could produce one million tons of dried seaweed and could offer employment to about 2,00,000 families. According to Narayanakumar & Krishnan (2011), seaweed sector has the potential to create nearly 7,65,000 person-days of employment in Ramanathapuram District of Tamil Nadu.

According to Johnson *et al.* (2017), seaweed culture by fisherfolk in Ramanathapuram District, Tamil Nadu had yielded an annual family income between Rs.50,000/- and Rs.1,00,000/-, with a profit margin of 60%. When seaweed culture was taken up as a family venture, a monthly income of Rs. 21,300/- was realized (Nikita *et al*., 2021). As per Rajesh *et al.* (2020), farming of *Kappaphycus* (45 rafts; 6 cycles) can annually generate a supplemental income of Rs.1,07,190 for the small fisher folk associations/ cooperatives in India. In Ramanathapuram district of Tamil Nadu, a female worker in seaweed farm earns a daily income of Rs.200/- (for four-hour work), average monthly income of Rs.6,000 and an annual income of Rs.42,000/-. Equal wages were earned by men and women for the same hours of work (Nikita *et al*., 2021). According to LINAC

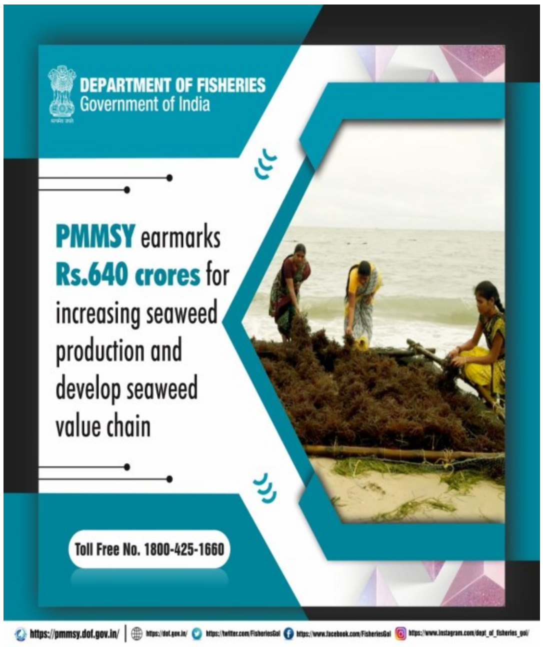
(2021), the fisherwomen used to fetch a monthly income of Rs.5,000/- by gathering seaweed from the natural habitats. However, after shifting to seaweed farming, the fisherwoman is earning an average monthly income of Rs.17,100/-. Hence, switching from seaweed collection to seaweed farming has the potential to provide more than threefold increase in income for the fisherfolk.

Zuniga-Jara & Marin-Riffo (2016) conducted a bio-economic analysis of individual and artisanal farming of *Kappaphycus alvarezii* in India and observed a positive Net Present Value (NPV) of six month, after the commencement of business, and an Internal Rate of Return (IRR) of 210%. Kaladharan *et al.* (2019a) estimated a Benefit Cost Ratio (BCR) of greater than two for seaweed aquaculture. Mantri *et al.* (2022) assessed the economic feasibility and profitability of *Kappaphycus alvarezii* culture on floating bamboo raft, monoline tubular net, and monoline net-bag, along the Eastern coast of India. Farming on floating raft has the least pay-back period. The pay-back period for raft culture was 0.10 years, 0.21 years and 0.22 years for production periods of 1 year, 5 years and 10 years respectively. The IRR ranged from 456% to 857% for bamboo raft culture, from 304% to 567% for monoline tubular net culture and from 168% to 309% for monoline net-bag culture.

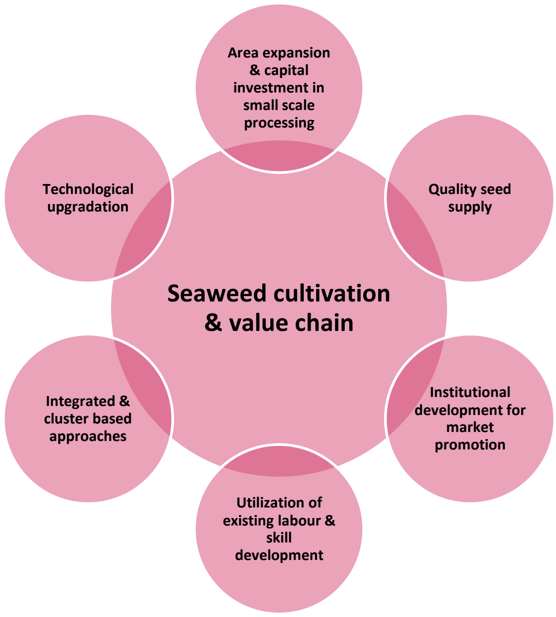
The abovementioned studies have established the viability of seaweed culture as a sustainable income source as well as the potential of seaweed culture to supplement the income of fisher folk. Thus, seaweed sector has the capacity to uplift the coastal communities from low-income conditions to enhanced levels of employment-income consumption relationships (Krishnan & Narayanakumar, 2010a).

4.3 FOCUS OF GOVERNMENT OF INDIA ON SEAWEED SECTOR

Seaweed culture and utilization is being considered as a priority area by the Government of India (GoI). Seaweed cultivation, which is having the potential to generate huge employment, is being promoted under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), a flagship scheme of GoI launched during September 2020 to achieve blue revolution through sustainable and responsible development of fisheries sector in India. Under PMMSY, it is envisaged to transform seaweed farming and value chain in the country, thereby drastically enhancing the production from current levels to about 11.2 lakh tons (on wet weight basis) by 2024-2025 (Ranjan, 2020). The strategies envisaged for seaweed aquaculture and value chain under PMMSY is depicted in **Figure 4.4**. An investment of Rs.640 crores (a direct investment of Rs.354 crores for seaweed cultivation and Rs.286 crores for additional activities till FY 2024-25) have been earmarked under PMSSY for the promotion of seaweed culture.



Source: Department of Fisheries, GoI



Adopted from DoF (2022)

Figure 4.4: Strategies for Seaweed Cultivation and Value Chain under PMMSY

During 2020-2022 (till November 30, 2021), under PMMSY, approval was provided for establishing 54,000 raft culture units in the states of Andhra Pradesh (26,000 units), Gujarat (1,000), Karnataka (10,000), Maharashtra (4,000), and Tamil Nadu (13,000). The total cost of establishing the rafts were Rs.810 lakhs, of which the share of GoI was Rs.255.6 lakhs. A total of 63,531 units for seaweed culture with monoline/ tube net have been approved by DoF in the states of Andhra Pradesh (41,200), Karnataka (21,000), Maharashtra (800), and Tamil Nadu (531), during 2020-2022 (till November 30, 2021). The total cost of establishing the units were Rs.5082.48 lakhs, of which Rs.1449.53 lakhs was GoI share (DoF, 2022). The National Fisheries Development Board (NFDB), under Department of Fisheries (DoF), GoI, had been supporting training and demonstration of seaweed farming to fisherfolk and women self-help groups during 2007-08 to 2018-19. Accordingly, Rs.55.173 crores had been released by NFDB (DoF, 2022).

Source: Department of Fisheries, GoI

Hon'ble Finance Minister, Govt. of India, had announced establishing a multipurpose seaweed park in the state of Tamil Nadu, to promote seaweed cultivation; while presenting the Union Budget for the financial year 2021-2022. Hon'ble Minister had observed that the emerging sector of seaweed cultivation has the capacity to transform the lives of communities residing in the coastal areas, by generating large scale employment and by providing additional income.

Hub and spoke model integrating clusters/areas with end-to-end solutions is envisaged for the seaweed park, with special economic zone status. According to the Lok Sabha Secretariat (2021), the park would be harbouring infrastructure for pre-harvest and post-harvest, disease diagnostic laboratories, facilities for innovation, technology incubation, knowledge dissemination, recreation etc. Entrepreneurship would be promoted in the seaweed park in Public-Private Partnership (PPP) mode. In the seaweed park, 10,000 fisherfolk would be directly engaged in seaweed cultivation utilizing rafts and monolines. A quantity of 72,000 t of seaweed is estimated to be produced in the park. A total of 20,000 fisherfolk is envisaged to receive employment in the park.

For establishing the seaweed park, feasibility studies on seaweed farming were carried out in the districts of Ramanathapuram, Thoothukudi, Pudukkottai, Nagapattinam, Thanjavur and Tiruvarur (Krishna Chaitanya, 2021). The Govt. of Tamil Nadu has prepared a detailed project report (DPR) for the seaweed park and has submitted to Govt. of India. In the six districts of Tamil Nadu, one hundred thirty-six coastal villages were identified in the Palk Bay and the Gulf of Mannar for cultivating seaweed. Thirty-two coastal villages were identified for establishing seaweed seed bank. The districts identified for seaweed farming and seed bank are Nagapattinam (8 villages for farming), Tiruvarur (1 village for farming), Thanjavur (15 villages for farming & 8 villages for seed bank), Pudukkottai (20 villages for farming & 8 villages for seed bank), Ramanathapuram (85 villages for farming & 16 villages for seed bank), and Thoothukudi (7 villages for farming). A total budget of about Rs.127.7 crore was proposed for the seaweed park; which includes a contribution of Rs.75.15 crore from Govt. of India, Rs.48.94 crore from Govt. of Tamil Nadu and Rs.3.6 crores as beneficiary share (Krishna Chaitanya, 2022).

The draft 'National Fisheries Policy, 2020' of Govt. of India, which envisages holistic development of Indian fisheries sector for the next ten years, had recognized the untapped potential of seaweed aquaculture in India and identified various areas for immediate intervention. The major areas identified include encouraging aquaculture of seaweed, establishing seaweed seed banks, assisting women to undertake seaweed culture, promoting establishment of seaweed processing units, encouraging production of seaweed-based products, enabling marketing etc. (DoF, 2020).

The focus of Govt. of India on seaweeds can be perceived further by the thrust provided by the Hon'ble Prime Minister of India for this sector. Hon'ble Prime Minister had underlined the importance of seaweed on several occasions. While addressing the 86th Foundation Day of Indian Council of Agricultural Research (ICAR), on July 29, 2014, he called for superior research and encouragement to seaweed sector. While speaking at the birth centenary of cooperative leader Laxman Madhav Rao Inamdar, the Hon'ble Prime Minister on September 21, 2017 requested cooperatives to take up seaweed farming for doubling the income of farmers and to augment the rural economy. He also pointed out that there is enormous demand for seaweed in pharmaceutical industry and its extracts can be used to improve the health of the soil. Hon'ble Prime Minister, while addressing self-help groups (SHGs) at Ujire, Karnataka on October 29, 2017, urged the fishermen and SHGs in the coastal areas to take up farming of seaweeds, which has key pharmaceutical applications and nutrient value.

During a review meeting of the Islands Development Agency, on June 30, 2018, the Hon'ble Prime Minister requested exploring the possibility of seaweed farming in the Lakshadweep and Andaman and Nicobar Islands. While addressing a public meeting in Car Nicobar on December 30, 2018, the Hon'ble Prime Minister said that several projects such as cultivation of seaweeds are being encouraged by the government. While reviewing the progress of ICAR, on July 04, 2020, Hon'ble Prime Minister highlighted the need to study the impact of the use of seaweeds on soil health, apart from exploring its commercial applications in nutraceuticals. Hon'ble Prime Minister, while launching the submarine cable connectivity to Andaman & Nicobar Islands on August 10, 2020, said that the blue economy like fisheries, aquaculture and seaweed farming in Andaman and Nicobar will accelerate, in commensurate with the modern infrastructure being developed in the island.

Hon'ble Prime Minister on January 05, 2021, while dedicating the Kochi–Mangaluru Natural Gas Pipeline to the nation, observed that "The demand for seaweed is increasing in the world and India can play an important role in fulfilling it. The more incentives the farmers get for seaweed farming, the faster we will move forward in this area as well." Hon'ble Prime Minister, while inaugurating/ handing over/ laying of foundation stone of various projects of Chennai, informed that "We are optimistic about seaweed farming" and seaweed farming will improve the lives of coastal communities. While inaugurating the international cruise terminal in Kerala on February 14, 2021, Hon'ble Prime Minister has highlighted the popularity gained by seaweed farming. Hon'ble Prime Minister while addressing a webinar on implementation of Budget in Agriculture sector, on March 01, 2021, highlighted the potential of seaweed farming in India and its potential in enhancing the income of fisherfolk. While addressing the nation on the occasion of the 75th Independence Day**,** on August 15, 2021, the Hon'ble Prime Minister emphasized "to take full advantage of the new possibilities that are emerging in the cultivation of seaweed".

4.4 INITIATIVES FOR DEVELOPMENT OF SEAWEED SECTOR IN INDIA

The DoF, during August 2020, organized a National Consultation to discuss and work out an action plan for seaweed cultivation, processing and marketing and to achieve the production targets under PMMSY. A Technical Advisory Committee was constituted, under the Chairmanship of Joint Secretary (Marine Fisheries), DoF, for 'promotion and development of seaweed farming and value chain'.

NITI Aayog, the premier policy Think Tank of the Govt. of India, during September 2019, constituted a committee, under the Chairmanship of Member (Agriculture), NITI Aayog, to develop a comprehensive roadmap for promotion of seaweed cultivation in India. The terms of reference of the Committee include assessment of existing status of seaweed cultivation in India, development of a comprehensive roadmap for promoting seaweed cultivation in India, while addressing ecological concerns, and any other issues relevant to seaweed cultivation.

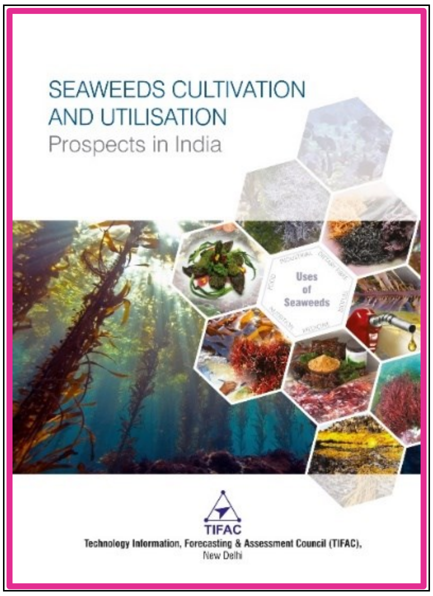
Source: NITI Aayog, GoI

The Science and Technology Vertical of NITI Aayog has been working with the Ministry of Environment, Forest and Climate Change (MoEFCC), GoI to foster seaweed farming and to resolve the outstanding issues in the sector. A joint study has also been taken up to comprehend the exact effect of seaweed farming on corals and sea grass.

The Blue Economy Working Group 3 on 'Fisheries, Aquaculture and Fish Processing', constituted by the Economic Advisory Council to the Prime Minister of India (EAC-PM), while developing a roadmap to harness the huge potential and opportunities of the sectors for the Blue Economy initiative of the Government of India have recommended farming of seaweeds in the integrated multi-trophic aquaculture (IMTA) systems for enhancing mariculture production. Accordingly, farming of seaweed has been suggested in the policy framework for India's blue economy (EAC-PM, 2020).

The Inter-ministerial Committee on Doubling Farmers' Income (DFI), constituted by GoI in 2016, has highlighted the enormous potential of seaweed aquaculture to generate livelihoods and to produce by-products with diverse applications. The twelfth volume of the Report of the DFI Committee, while addressing the scientific development and technological applications for doubling farmers' income, has identified seaweed culture as an area for long term research. The Report recommended focusing of R&D related to the constraints faced by seaweed farmers and popularization of seaweed aquaculture in India (DAC&FW, 2018).

Technology Information, Forecasting and Assessment Council (TIFAC), an autonomous organization of Department of Science and Technology (DST), GoI, had brought out a report on the prospects of seaweed cultivation and utilization in India. The report highlighted the potential for seaweed cultivation and downstream processing in India and further provided a roadmap for increasing the export base of seaweed-based products. A special emphasis was also made to create a 'Seaweed Development Board' for nurturing and boosting the Indian seaweed sector. Considering the immense potential of seaweeds to contribute towards the economy, employment and environment, the study proposed establishing a 'Seaweed Mission' to identify and prioritize potential areas of farming, to carry out research and skill development, to set up demonstration projects to provide inputs and impetus for forming a Seaweed Development Board (TIFAC, 2018). In February 2021, TIFAC has launched a 'Seaweed Programme' with the aim of promoting commercial scale seaweed aquaculture and its processing for production of value-added products. The programme is expected to contribute to the 'Aatmanirbhar Bharat Abhiyaan'.



The ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), a laboratory of Indian Council of Agriculture Research under Department of Agricultural Research and Education, GoI, in February 2016, had organized a 'National Consultation on mariculture, utilization and value addition of seaweeds for the livelihood security of coastal population' and recommended a plan of action (Kaladharan *et al*., 2016). ICAR-CMFRI also prepared a perspective plan for cultivation and utilization of seaweeds and listed various priorities (Kaladharan *et al*., 2019a).

Laxmanrao Inamdar National Academy for Cooperative Research and Development (LINAC) under the Ministry of Cooperation, GoI had convened an international workshop on "Entrepreneurship Development through Seaweed Business by Cooperatives" on January 28, 2021. The workshop aimed at promotion of entrepreneurship in seaweed sector through cooperatives. Various bottlenecks for entrepreneurship development in seaweed sector were identified in the workshop and accordingly actionable plans were delineated.

A Round Table on 'Seaweed cultivation and utilisation' was organized by National Academy of Agricultural Sciences (NAAS), during December 2003, and came up with a policy document (NAAS, 2003). CSIR- Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), a constituent laboratory of Council of Scientific and Industrial Research under the Department of Scientific and Industrial Research, GoI, is nurturing talent and manpower development in the area of seaweed farming and downstream processing by organizing skill development initiatives, primarily to create qualified skilled workforce for seaweed sector, to promote entrepreneurship and also to generate livelihood opportunities.

4.5 SEAWEED TRADE

The trade flows of seaweeds/ seaweed-based products were analyzed as per the Indian Trade Clarification based on Harmonized System (ITC-HS) codes. Only a few HS codes represented seaweeds/ seaweed-based products in entirety and the rest of the HS codes represented a mix of items. Hence, import and export data of commodities with HS codes exclusively representing seaweeds (**Table 4.3**) were only considered to apprehend the status/ trends in seaweed import and export from India.

Table 4.3: ITC-HS Codes Exclusively Representing Seaweeds

ITC- HS Code	Commodity
12122110	Seaweeds fit for human consumption
12122910	Other seaweeds
13021915	Agarose
13023100	Agar-Agar whether or not modified
13023240	Kappa Carrageenan
39131010	Sodium Alginate
39131090	Other alginic acid its salts and esters

The details of seaweed/ seaweed-based products imported to India between 2015-16 and 2021-22, in terms of quantity and value, are given in **Table 4.4** and **Table 4.5** respectively.

Table 4.4: Seaweed Import to India – Quantity (2015-16 to 2021-22)

ITC-HS Code	Quantity ('000 Kg)						
	2015-16	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
12122110	277.42	175.75	252.23	79.11	28.46	85.60	0.02
12122910	27.68	64.70	22.07	44.87	13.77	153.28	291.54
13021915	0.39	0.03	N. A.	N. A.	0.47	N. A.	N. A.
13023100	315.97	339.87	366.36	389.50	437.82	412.94	410.30
13023240	300.62	74.45	50.14	112.18	421.27	79.16	15.45
39131010	2,450.31	2,686.85	3,232.61	2,629.72	2,148.17	1,665.78	1,361.46
39131090	324.76	1247.17	884.51	1384.13	1051.82	893.25	836.41

N. A. - Not Available **Source:** Tradestat (2022)

Table 4.5: Seaweed Import to India – Value (2015-16 to 2021-22)

ITC-HS Code	Value (Rs. lakhs)						
	2015-16	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**
12122110	983.49	331.77	432.60	108.20	47.45	98.84	2.35
12122910	33.27	57.80	9.22	24.11	16.00	88.57	190.97
13021915	34.54	3.30	N. A.	N. A.	844.96	N. A.	N. A.
13023100	3,780.47	4,116.51	4,885.20	5,906.86	6,897.52	6,632.36	5,486.74
13023240	2,236.47	533.74	504.30	1,083.43	4,100.13	687.75	177.72
39131010	6,011.52	7,556.40	10,227.91	8,130.88	7,454.11	4,999.46	6,379.12
39131090	1,515.94	2,576.39	3,191.77	4,858.67	3,594.35	2,901.88	3,979.63

N. A. - Not Available **Source:** Tradestat (2022)

During 2015-16, a quantity of 277.42 tons (valued at Rs.983.49 lakhs) of seaweeds fit for human consumption was imported to India. Since then, the import declined sharply and during 2021-22 only a meager quantity of 0.02 tons (valued at Rs.2.35 lakhs) was imported. However, an increasing trend was observed in the quantity of seaweeds imported under the category other seaweeds. It increased from 27.68 tons (valued at Rs.33.27 lakhs) during 2015-16 to 291.54 tons (valued at Rs.190.97 lakhs) during 2021-22. However, the cost per kg of the commodity imported decreased from Rs.120/- (during 2015-16) to Rs.66/- (during 2021-22). The other seaweeds were imported from six countries during 2021-22. The import was mostly from Sri Lanka (117.57 tons valued at Rs.32.74 lakhs), followed by Indonesia (107.50 tons valued at Rs.120.54 lakhs) and Ireland (66.00 tons valued at Rs.30.37 lakhs).

The quantity of agarose imported to India was very meager and it ranged from 0.03 tons (valued at Rs.3.30 lakhs) during 2016-17 to 0.47 tons (valued at Rs.844.96 lakhs) during 2019-20. Import of agar-agar increased steadily from 315.97 tons during 2015-16 to 437.82 tons during 2019-2020. Subsequently, the imports decreased to 410.30 tons during 2021-22. The import value increased from Rs.3,780.47 lakhs during 2015-16 to Rs.5,486.74 lakhs during 2021-22. The cost per kg of the commodity imported during 2021-22 was Rs.1,337/-. Agar-agar was imported from more than ten countries during 2021-22. The import was mainly from China (about 50% of the quantity and 35% of value).

The quantity of kappa carrageenan imported to India decreased from 300.62 tons (valued at Rs.2,236.47 lakhs) during 2015-16 to 15.45 tons (valued at Rs.177.72 lakhs) during 2021-22. However, the cost per kg of the commodity imported increased from Rs.744/- (during 2015-16) to Rs.1,150/- (during 2021-22). Kappa carrageenan was imported from six countries during 2021-22. The import was mainly from China (48% of the quantity and 46% of value) followed by the Republic of Korea (26% of both quantity and value).

In terms of volume and value, sodium alginate was the major seaweed-based product imported to India. A declining trend was observed in the import of sodium alginate. It decreased from 2,450.31 tons during 2015-16 to 1,361.46 tons during 2021-22. Even though a declining trend was observed in the quantity imported, the value of imports increased from Rs.6,011.52 lakhs (during 2015-16) to Rs.6,379.12 lakhs (during 2021-22). The cost per kg of the commodity increased from Rs.245/- (during 2015-16) to Rs.469/- (during 2021-22). Sodium alginate was imported from fourteen countries, during 2021-22, and bulk of the imports was from China (1,249.77 tons valued at Rs.4,094.01). The imports from China contributed 92% to the quantity and 64% to the value.

The quantity of other alginic acid its salts and esters imported to India during 2021-22 was 836.41 tons, valued at Rs.3,979.63 lakhs. The cost per kg of the commodity during 2021-22 was Rs.476/-. Other alginic acid its salts and esters were imported to India from fourteen countries and China was the forerunner, in terms of volume (90%), and value (64%).

The major seaweed species exported from India include *Kappaphycus alvarezii*, *Gracilaria spp.*, *Gelidiella acerosa*, *Sargassum spp.*, *Turbinaria spp.* etc. The details of seaweed exported from India between 2015-16 and 2021-22, in terms of quantity and value, are given in **Table 4.6** and **Table 4.7** respectively.

Table 4.6: Seaweed Export from India – Quantity (2015-16 to 2021-22)

ITC-HS Code	Quantity ('000 Kg)						
	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
12122110	N. A.	N. A.	0.64	14.09	N. A.	0.01	0.50
12122910	N. A.	0.13	0.20	N. A.	N. A.	0.73	52.47
13021915	0.05	0.19	0.13	0.18	0.06	0.17	0.03
13023100	141.45	143.14	131.82	129.46	136.15	96.46	131.33
13023240	2.65	1.65	0	4.03	1.58	1.99	103.47
39131010	84.60	92.84	96.70	152.06	58.77	37.90	112.81
39131090	52.69	43.96	91.72	64.10	20.26	20.14	31.52

N. A. - Not Available **Source:** Tradestat (2022)

Table 4.7: Seaweed Export from India – Value (2015-16 to 2021-22)

ITC-HS Code	Value (Rs. lakhs)						
	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
12122110	N. A.	N. A.	11.28	13.03	N. A.	0.08	1.08
12122910	N. A.	1.26	1.00	N. A.	0.03	2.04	63.59
13021915	0.43	0.97	1.56	1.28	1.77	2.60	6.20
13023100	1,681.32	1,742.87	1,470.62	1,580.09	1,749.49	1,342.56	1,860.83
13023240	16.82	7.24	0.01	25.86	11.46	16.89	115.62
39131010	352.15	578.64	709.63	997.20	304.32	271.17	849.57
39131090	205.04	181.95	338.28	306.33	219.62	181.26	342.03

N. A. - Not Available **Source:** Tradestat (2022)

The quantity of seaweeds fit for human consumption exported from India was negligible. During 2021-22, a quantity of 0.50 tons valued at Rs.1.08 lakhs was exported from India. The cost per kg of seaweeds fit for human consumption exported was Rs.216/-, during 2021-22. The quantity of seaweeds exported under the category other seaweeds, during 2021-22, was 52.47 tons, with a value of Rs.63.59 lakhs. The cost per kg of the commodity exported was Rs.121/-. During 2021-22, other seaweeds was exported to only three countries viz. the Netherlands (41.75 tons worth Rs.50.93 lakhs) Bangladesh (10.00 tons worth Rs.9.40 lakhs) and New Zealand (0.72 tons worth Rs.3.26 lakhs). Very little quantity of agarose was exported from India in the last few years. A quantity of only 0.03 tons of agarose valued at Rs.6.20 lakhs was exported from India during 2021-22. Agarose was mainly exported from India to Ethiopia.

Agar-agar was the major seaweed-based product exported from India. The volume of export declined from 141.45 tons (during 2015-16) to 131.33 tons (during 2021-22). Even though a declining trend was observed in the quantity exported, the value of exports increased from Rs.1,681.32 lakhs (during 2015-16) to Rs.1,860.83 lakhs (during 2021-22). The cost per kg of agar-agar exported from India varied from Rs.1,189/- (during 2015-16) to Rs.1,417/- (during 2021-22). This commodity was exported to more than eighty countries during 2021-22. In terms of both volume and value, the United Arab Emirates was the major country to which agar-agar was exported from India during 2021-22, followed by Iran.

The quantity of kappa carrageenan exported from India increased sharply from 2.65 tons (with a value of Rs.16.82 lakhs) during 2015-16 to 103.47 tons (with a value of Rs.115.62 lakhs) during 2021-22. In spite of the quantum jump in exports, price per kg of kappa carrageenan decreased from Rs.635/- (during 2015-16) to Rs.112/- (during 2021-22). Out of the nine countries exported, the major destination of kappa carrageenan during 2021-22 was China (100 tons valued at Rs.76.95 lakhs). China contributed 97% of volume and 67% of value of the commodity exported from India. A quantity of 112.81 tons of sodium alginate, with a value of Rs.849.57 lakhs was exported from India during 2021-22. The cost per kg of sodium alginate exported was Rs.753/-. During 2021-22, sodium alginate was exported from India to nearly forty countries. Algeria was the major export destination (36% of volume and 39% of value).

A decreasing trend was observed in the quantity of other alginic acid its salts and esters exported from India. A quantity of 52.69 tons was exported during 2015-16 and it was decreased to 31.52 tons during 2021-22. However, the value increased from Rs.205.04 lakhs (during 2015-16) to Rs.342.03 lakhs (during 2021-22). The cost per kg of other alginic acid its salts and esters exported from India increased exponentially from Rs.389/- to Rs.1,085/-. This commodity was exported to more than twenty countries, during 2021-22. Indonesia was the major export destination in terms of quantity (19%) and Republic of Korea was the major destination in terms of value (21%).

India exported 836 tons of dried seaweed during 2009-10 and a steady decline was observed in the exports, since then (**Table 4.8**). In the last six years, only meager amounts of dried seaweeds were exported. A list of Indian seaweed exporters is given in **Table 4.9**.

Table 4.8: Export of Dried Seaweed from India (2009-10 to 2019-20)

Year	Quantity (Tons)	Value	
		Rs. lakhs	USD million
2009-10	836	338.55	0.71
2010-11	794	472.32	1.05
2011-12	605	361.22	0.76
2012-13	719	447.58	0.84
2013-14	591	497.36	0.83
2014-15	19	61.09	0.10
2015-16	35	228.01	0.35
2016-17	0	0.00	0.00
2017-18	0	0.00	0.00
2018-19	0.4	2.50	0.004
2019-20	0	0.00	0.00

Source: MPEDA

Table 4.9: List of Indian Seaweed Exporters

Sl No.	Seaweed Exporters
1.	Marinex, Chennai, Tamil Nadu
2.	P S S Ganesan & Sons, Tuticorin Tamil Nadu
3.	G. R. Pulses and Grains Private Limited, Tuticorin Tamil Nadu
4.	Aquagri Processing Pvt. Ltd., New Delhi
5.	Ashwathy Green Enterprise Pvt. Limited, Chennai, Tamil Nadu
6.	Crescent Marine Traders
7.	Marine Lixirs
8.	Pepsico India Holdings Pvt. Ltd.
9.	Pekon Electronics
	Agar-Agar Exporters
10.	Marine Mercantile Company, Chennai, Tamil Nadu
11.	Marine Chemicals, Cochin, Kerala
12.	Ocean Chemicals
13.	Goodway Marine Export
14.	Seven Hills Chem Products, Undrajavaram Mandal, Andhra Pradesh
15.	Premier Seafoods Exim P. Ltd., Alappuzha, Kerala

Source: MPEDA

5.0 SEAWEED VALUE-ADDITION INDUSTRIES/ PRODUCTS IN INDIA

5.1 INTRODUCTION

Majority of seaweed processing industries in India are micro-enterprises producing phycocolloids, mostly from wild harvested seaweeds (Ganesan *et al*., 2017; Ganesan *et al*., 2019b). The main seaweed-based value-added products manufactured commercially in India include agar, alginate, carrageenan and biofertilizer/ plant biostimulant. A few industries are also producing nutraceuticals from seaweeds. The capacity utilization of seaweed-based industries in India are abysmal due to shortage in raw material supply. In India, the cost of raw materials used for hydrocolloid production (*Gracilaria* and *Gelidiella*) range from USD 0.65/ kg to USD 1.7/ kg, on dry weight basis (GFI, n.d.).

Indian traditional seaweed processing industry is primarily a cottage industry and fully dependent on red seaweeds *Gelidiella acerosa* and *Gracillaria edulis* and the brown seaweeds *Sargassum* and *Turbinaria*, harvested from the wild (Kaladharan & Kaliaperumal, 1999). These industries use traditional technologies and have comparatively much lesser yields. Hence, there is a need to modernize the traditional industries and equip them with the latest technologies. Some of the major seaweed-based companies in India and their products are given in **Table 5.1**.

Table 5.1: Major Seaweed-Based Companies in India and their Value-Added Products

Sl. No.	Name of Company	Value-Added Products
1	SNAP Natural and Alginate Products Pvt. Ltd., Ranipet, Tamil Nadu	Alginates, carrageenan, plant growth stimulant, aquaculture inputs etc.
2	AquAgri Processing Private Ltd., New Delhi	Carrageenan, plant growth stimulant, animal feed ingredient etc.
3	Marine Hydrocolloids, Cochin, Kerala	Agar, agarose, carrageenan, sodium alginate, pulverized seaweed
4	Biostadt India Limited, Mumbai	Plant growth stimulant, fish growth stimulant
5	HiMedia Laboratories, Mumbai	Agar, alginic acid
6	Acadian Seaplants India Private Limited, Mumbai	Plant growth stimulant
7	Dhanuka Agritech Limited, Gurgaon	Plant growth regulator
8	PI Industries Ltd., Gurgaon	Plant growth stimulant, biofertilizer
9	AquaRev, Una, Gujarat	Carrageenan, stabilizer for ice cream, khoya & paneer
10	Sathyam Kissan Care, Madurai, Tamil Nadu	Plant growth stimulant
11	Agri Life - SOM Phytopharma (India) Limited, IDA Bollaram, Telangana	Biopesticides, biofertilizers, biostimulants

Sl. No.	Name of Company	Value-Added Products
12	Vikas Crop Care, Bhavnagar, Gujarat	Biofertilizers, biostimulants
13	Pushpa J. Shah, Ankleshwar, Gujarat	Biostimulants
14	Karma Chemicals, Vadodara, Gujarat	Biofertilizers, biostimulants
15	Wellspring Bio-Organics, Chennai	Biofertilizers
16	Srinivasa Marine Chemicals, Madurai, Tamil Nadu	Agar-agar
17	Jumat Agar-Agar Industries, Tirupur, Tamil Nadu	Agar-agar
18	East Coast Seaweed Inc, Madurai, Tamil Nadu	Biofertilizers, biostimulants
19	Prathibha Biotech, Hyderabad	Biofertilizers, biostimulants
20	Nitesh Agro Industries, Ahmedabad, Gujarat	Biostimulants
21	Saosis Biotech Private Limited, Kolkata	Biofertilizers
22	Humates and Seaweeds Pvt. Ltd, Aurangabad, Maharashtra	Biofertilizers
23	Sujay Biotech Pvt. Ltd., Vijayawada, Andhra Pradesh	Biofertilizers
24	Indorama India Private Limited, Kolkata	Plant growth promoter
25	Dew Speciality Chemicals (P) Ltd, Greater Noida, Uttar Pradesh	Plant growth promoter
26	Hifield - Ag Chem. India Private Limited, Aurangabad, Maharashtra	Seaweed powder, flakes, plant growth promoter
27	Sarda Biopolymers Pvt. Ltd., Mumbai	Carrageenan
28	Altrafine Gums, Ahmedabad, Gujarat	Food grade kappa carrageenan
29	Prasmo Agri, Kumbakonam, Tamil Nadu	Biostimulants
30	Pioneer Pharmaceuticals, Kochi, Kerala	Seaweed-based nutraceuticals
31	Ideal Biosciences, Tiruchirappalli, Tamil Nadu	Seaweed-based shrimp & fish feed supplements
32	Maziq Farm Technologies (P) Ltd., Mumbai	Biostimulants

Sl. No.	Name of Company	Value-Added Products
33	VLCC, Gurgaon	Nutraceuticals
34	Tata Chemicals, Mumbai	Plant growth regulator
35	Lucid Colloids Ltd., Mumbai	Carrageenan (Carraluc ™)
36	Exotic Biosolutions Private Limited, Mumbai	Seaweed-based poultry & cattle feed supplements
37	SUBONEYO Chemicals Pharmaceuticals (P) Limited, Jalgaon, Maharashtra	Seaweed extract-based organic fertilizer
38	Pinnacle Biosciences, Agasteeswaram, Tamil Nadu	Seaweed- based fertilizer, animal feed supplement, nutraceuticals, cosmetics etc.
39	Gayatri Herbals Pvt. Ltd. Thane, Maharashtra	Seaweed-based biostimulants
40	Parshv Chem Industries, Bhavnagar, Gujarat	Seaweed granules
41	Redox Industries Limited, Ahmedabad, Gujarat	Seaweed extract flake
42	Aushadh Limited, Ahmedabad, Gujarat	Seaweed extract flake, liquid seaweed fertilizer etc.
43	Sikko Industries Ltd., Ahmedabad, Gujarat	Seaweed plant growth promoter
44	Manidharma Biotech Private Limited, Chennai	Liquid fertilizer (biostimulant) (Organic Six)
45	Aquatic Chemicals, Mumbai	Biostimulant
46	VNET, Anand, Gujarat	Biostimulant
47	Agrocare India Private Limited, Bengaluru	Seaweed-based enzymes, seaweed granules etc.
48	Seaweed Fertilizer Co. Bhavnagar, Gujarat	Semi refined carrageenan, seaweed fertilizer, etc.
49	AK Seaweeds Company, Ramanathapuram District, Tamil Nadu	Alginate, seaweed fertilizers etc.
50	Purvraj Agro Industries Private Limited, Anand, Gujarat	Seaweed fertilizer, soil conditioner etc.
51	Agrocart, Madurai, Tamil Nadu	Seaweed fertilizer
52	Laford Agrotech Limited, Lucknow, Uttar Pradesh	Seaweed extract flakes, granules, gel etc.
53	AB Agritech Private Limited, Kolkata	Seaweed extract
54	Scarlet Marine Chemicals, Hyderabad	Seaweed extract, fertilizer etc.

55	Excel Crop Care Limited, Mumbai	Foliar Plant Nutritional Supplement (Excel AeROS)
56	AURA Biotechnologies Private Limited, Chennai	Agar-agar, seaweed fertilizer etc.

5.2 AGAR INDUSTRY/ PRODUCTS

In India, food grade agar is manufactured from seaweed *Gracilaria edulis*, bacteriological grade agar from *Gelidiella acerosa*, and agarose from *Gracilaria dura* (Ramalingam *et al*., 2002; Veeragurunathan *et al*., 2015a, 2015b; Ganesan *et al*., 2019b). Many efforts were made, and various techniques were explored for extracting agar from seaweeds in India, since Second World War (Kalimuthu & Ramalingam, 1996; Kaladharan & Kaliaperumal, 1999; Khan *et al*., 2003). Thivy (1960) established a method, at cottage industry level, for extraction of agar from *Gracilaria edulis*. Subsequently, a process was developed by Kappanna & Rao (1963) for manufacturing agar from *Gelidium acerosa*. With abundant availability of *Gelidiella acerosa* and *G. edulis* from the wild harvest and development of processes for commercial scale extraction, a few industries took up production of agar and these industries flourished during the 1960s and 1970s (Ganesan *et al.,* 2019b). As mentioned by Ganesan *et al.* (2019b), twenty-five agar processing plants are operating in India and food grade agar constitutes 67% of the total production. The requirement for agar in India is 400 t per annum, whereas only 30% is being produced indigenously (Johnson & Ignatius, 2020). Marine Hydrocolloids, Cochin (**Box-1**) is the principal manufacturer of bacteriological-grade agar in India and contributes more than 70% of the total production (Ganesan *et al*., 2019b).

Box-1: Marine Hydrocolloids, Cochin, Kerala

Marine Hydrocolloids is manufacturing agar for more than thirty years and offers food grade, bacteriological grade and pharmaceutical grade agar. The company has an annual production capacity of over 350 tons.

Manufacturing Facility: The state-of-the-art manufacturing facility located at Cochin, Kerala complies with all major environment and Good Manufacturing Practices (GMP) protocols. The company possess license for drug manufacturing. The plant is having ISO 22000:2005, ISO 9001:2008, HACCP, KOSHER, Halal and Food Safety and Standards Authority of India (FSSAI) certifications.

Products: Agar, agarose, carrageenan etc.

Market: Both domestic and international. Products are exported to countries like Europe, USA, South America, Russia etc.

5.3 ALGINATE INDUSTRY/ PRODUCTS

In India, alginate is produced from seaweeds such as *Sargassum spp.* and *Turbinaria spp.* collected from the natural stocks along the Gulf of Mannar coast of Tamil Nadu. Thivy (1964) estimated, based on the algin-yielding seaweed resources in the wild, that the production potential of refined alginates in India is 500 t. A steady increase had been observed in the production of alginate in India. It grew from 98 t in 2003 to 200 t in 2016 and 262 t during 2018-

19 (Rao & Mantri, 2006; Ganesan *et al*., 2019b; Mantri *et al*., 2020). According to Rao & Mantri (2006), twenty-five factories are producing alginate in India. Various alginate products manufactured in India include sodium alginate, potassium alginate, calcium alginate, ammonium alginate, alginic acid etc. India is having an annual alginate requirement of 1,000 t, whereas only less than 40% is being produced indigenously (Johnson & Ignatius, 2020). SNAP Natural Products and Alginate (P) Ltd., Ranipet, Tamil Nadu (**Box-2**) is the main manufacturer of alginate in India, with a market share of about 90% (Mantri *et al*., 2020).

Box-2: SNAP Natural Products and Alginate (P) Ltd., Ranipet, Tamil Nadu

Established in 1979, SNAP Natural Products and Alginate (P) Ltd. is the oldest and chief manufacturer of alginate in India.

Manufacturing Facility: Two units are currently operational at Tamil Nadu. The unit at Thirupallani is used for post-harvest processing of seaweed and the facility at Ranipet is utilized for manufacturing seaweed-based products. The production processes are developed in-house with high degree of automation.

Products:
Salts of alginic acid are manufactured from brown seaweed *Sargassum wightii* collected from natural beds at Ramanathapuram. Annually about 15,000 t of wet seaweed is used as raw material. Various alginate products manufactured include sodium alginate, calcium alginate, potassium alginate, ammonium alginate and alginic acid. Industrial grade, food grade, and pharmaceutical grade alginates are being manufactured by SNAP.

Carrageenan is manufactured from farmed red seaweed *Kappaphycus alvarezii* and is being offered for industries such as dairy and processed meat. Seaweed extract is produced in granular, gel and liquid form for agriculture application. Seaweed extract is also produced as aquaculture input and is offered in the form of gel, which must be mixed with water and broadcasted over the pond for optimal plankton production. Specialized stabilizer and emulsifier blends are manufactured for use in ice creams, frozen desserts, kulfi and ice candy/ ice lollies.

Certifications:
The facility at Ranipet is the first alginate plant in India with ISO 9001, ISO 14001 and GMP certifications. The seaweed extract produced is organic certified as per the National Programme for Organic Production (NPOP) standards prescribed by Agricultural and Processed Food Products Export Development Authority (APEDA), GoI.

5.4 CARRAGEENAN INDUSTRY/ PRODUCTS

In India, manufacturing of carrageenan commenced with the arrival of private enterprises such as Pepsi Foods and AquAgri Processing. The manufacturing unit was established in 2009 and commercial production of carrageenan, for the first time in India, was started in 2010 (Seth & Shanmugam, 2016). In India, carrageenan is mostly manufactured from cultured *Kappaphycus alvarezii*. However, a small number of cottage level processing units are extracting kappa carrageenan from seaweed species such as *Hypnea musciformis* and *Hypnea valentiae* (Veeragurunathan *et al*., 2022). Even though the estimated annual requirement of carrageenan in India is 1,500-2,000 tons (Johnson & Ignatius, 2020), only 100-132 tons per annum is produced indigenously (Veeragurunathan *et al*., 2022).

5.5 PLANT BIOSTIMULANT INDUSTRY/ PRODUCTS

The extracts from seaweeds contain several compounds that can activate plant defences and promote plant growth. Hence, seaweed extracts have been used as a biostimulant during crop cultivation. The use of seaweed extracts as plant growth stimulant is gaining momentum, due to adoption of sustainable agricultural production practices. Majority of seaweed-based biostimulants present in the Indian market are produced from brown seaweeds. However, red seaweed *Kappaphycus alvarezii* is reckoned as an excellent raw material for producing low-cost biostimulants in India.

CSIR-CSMCRI had perfected the technology to extract sap from *Kappaphycus* and the technology was licensed to AquAgri Processing Pvt. Ltd. Seaweed sap, extracted using CSIR-CSMCRI technology, is being marketed in both liquid and granule forms by Indian Farmers Fertiliser Cooperative Limited (IFFCO), under the brand name 'Sagarika'. Seaweed sap technology developed by CSIR-CSMCRI was later on transferred to Prasmo Agri, Kumbakonam, Tamil Nadu (2013); Pushpa J Shah, Ankleswar, Gujarat (2019); and Vikas Crop Care, Bhavnagar, Gujarat (2019). The plant biostimulant/ biofertilizer market in India is valued between Rs.1,500 and Rs.1,700 crore (Ranjan, 2020).

Plant biostimulant is also produced from naturally harvested *Sargassum* by SNAP Natural and Alginate Products Pvt. Ltd. CSIR-CSMCRI had also developed *Sargassum* based liquid seaweed plant biostimulant (LSPB) technology, and the same was transferred to more than nine industries. Even though several players are present in the Indian biostimulant market currently, the biostimulants are mostly imported and marketed subsequently. Extracts of seaweeds such as *Ascophyllum*, *Kappaphycus*, etc., valued at Rs.150-160 crores are imported annually from Canada, Indonesia, Norway, the Philippines, and China (TIFAC, 2018). Some of the major seaweed-based plant biostimulant manufacturers in India include AquAgri Processing Private Limited (**Box-3**), Prasmo Agri (**Box-4**) etc.

Box-3: AquAgri Processing Private Limited, New Delhi

AquAgri Processing Private Limited, incorporated in December 2007, took over seaweed business from Pepsi Foods and commenced its operations in April 2008. AquAgri is engaged in production of seaweed-based value-added products having use in an array of industries like food processing, agriculture and animal husbandry.

Manufacturing Facility: The manufacturing facility is located in Manamadurai, Tamil Nadu. The raw material is obtained from seaweed farming operations of rural self-help groups in Tamil Nadu. The technology used for producing seaweed extract was sourced from CSIR-CSMCRI.

Products: Carrageenan (with application in dairy, meat, beer, pet food, air fresheners, toothpaste), plant biostimulant, animal feed supplement etc.

Certifications: ISO 22000: 2005 Food Safety Certificate, FSSAI, NPOP, Halal etc.

Box-4: Prasmo Agri, Kumbakonam, Tamil Nadu

Prasmo Agri started its operations in 2013 and had acquired the patent licence of *Kappaphycus* sap extraction technology for production of biostimulants from CSIR-CSMCRI.

Manufacturing Facility: Two manufacturing units are located in Tamil Nadu. One unit is used for manufacturing micronutrients, pesticides, mixer fertilizers and other seaweed related products. The second unit is utilized for production of carrageenan, biostimulants and other organic agricultural inputs from seaweed.

Products: The company produces more than 30 different products and are marketed in five states across India.

Certifications: The company had obtained organic certification and ISO certification.

Department of Fisheries, Govt. of Tamil Nadu has established a seaweed sap extraction unit at a cost of Rs.3.96 crores through the Fisheries Management for Sustainable Livelihoods Project (FIMSUL-2); a collaborative initiative between the Govt. of India, the Govt. of Tamil Nadu and the Food and Agriculture Organization of the United Nations (FAO) (GoT, 2020). The technical know-how for the unit was provided by CSIR-CSMCRI. The unit is having a capacity to process one-ton fresh seaweeds per day. Fisherwomen groups were created for operating the manufacturing facility and about 1,500 women are being involved. Another five units are also envisaged to be established with the support of Govt. of Tamil Nadu.

5.6 ANIMAL FEED SUPPLEMENT INDUSTRY/ PRODUCTS

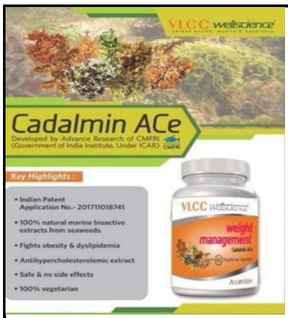
CSIR-CSMCRI, under the New Millennium Indian Technology Leadership Initiative (NMITLI) of CSIR, had developed formulations of seaweed-based feed supplements for enhancing health and productivity of broilers, layers, growing calf and milch cows. The raw material for the feed supplement comprises of a combination of both cultured and naturally collected seaweeds. The supplement exhibits higher bioactivity and extended shelf life due to the novel process adopted for cleaning and processing of raw material and stringent quality control. The feed supplement boosts immunity of cattle and poultry and can result in reduced antibiotics use. The formulation was validated by ICAR-Indian Veterinary Research Institute (ICAR-IVRI), ICAR-Central Avian Research Institute (ICAR-CARI), and ICAR-National Dairy Research Institute (ICAR-NDRI), and the toxicity trials were carried out at CSIR-Indian Institute of Toxicology Research (CSIR-IITR). The industrial partner was AquAgri Processing Private Limited, New Delhi.

Exotic Biosolutions Private Limited, Mumbai, under "Nutrimark" brand is producing and marketing seaweed-based poultry and cattle feed supplements. The product boosts immunity, maintains gut integrity and improves mineral absorption capacity, thereby enhancing the overall health condition of the birds. Supplementation of the product also leads to improved weight gain, improved food conversion ratio, better meat quality, better dressing percentage, increased hatchability and laying percentage. The product controls harmful bacteria population in rumen, increase milk yield, improve solids not fat (SNF) and fat percentage in milk, increase nutrient absorption, and reduce susceptibility to infections in cattle.

5.7 NUTRACEUTICAL INDUSTRY/ PRODUCTS

Seaweeds are receiving enormous interest from the nutraceuticals industry, due to their protective capabilities against a variety of diseases. ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI) has extracted a spectrum of bioactive compounds from seaweeds. Utilizing these molecules, wide-ranging nutraceutical products/ formulations have been developed for treating ailments like arthritis, type-2 diabetes, hypothyroidism, dyslipidemia, hypertension, osteoporosis etc. A probiotic nutraceutical and an antibacterial ointment have also been developed by ICAR-CMFRI (Gopalakrishnan *et al.*, 2020). Various seaweed-based nutraceuticals developed by ICAR-CMFRI are as follows:

	**Cadalmin™Anti-diabetic extract (Cadalmin™ADe)** ▪ Green alternative to synthetic drugs to fight against type-2 diabetes ▪ Hinders occurrence of diabetes by inhibiting dipeptidyl peptidase-4 and tyrosine phosphatase 1B ▪ Technology licensed to Pioneer Pharmaceuticals, Kochi, Kerala ▪ Sold under the brand name Algamin-Diabet-Ease



Cadalmin^{TM} Anti-hypercholesterolemic extract (Cadalmin^{TM}ACe)

- Natural remedy for dyslipidemia and obesity (By inhibiting HMG-CoA reductase)
- Contains extracts from seaweed *Sargassum wightii*
- Technology licensed to Gurgaon based VLCC Personal Care Limited

Cadalmin^{TM} Anti-hypothyroidism extract (Cadalmin^{TM}ATe)

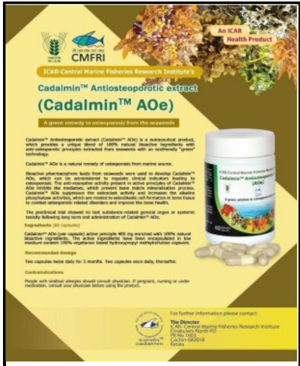
- Combats hypothyroid disorders
- Contains extracts from seaweeds such as *Sargassum*, *Turbinaria* and *Kappaphycus*
- Stimulates thyroid releasing hormone and increases activity of selenodeiodinase to produce metabolically active T4 and T3
- Technology licensed to VLCC Personal Care Limited, Gurgaon

Cadalmin^{TM} Green Algal extract (Cadalmin^{TM}GAe)

- Combats rheumatic arthritic pains
- Hinders occurrence of inflammatory pain and arthritis by inhibiting pro-inflammatory cyclooxygenase-2 and lipooxygenase
- Technology licensed to Pioneer Pharmaceuticals, Kochi, Kerala
- Sold under the brand name Algamin-Arthrit-Ease

Cadalmin^{TM}Anti-hypertensive extract (Cadalmin^{TM}AHe)

- Combats pathophysiologies associated with hypertension
- Lowers blood pressure by ACE inhibition
- Contains extracts from seaweed *Sargassum wightii*
- Technology licensed to Pioneer Pharmaceuticals, Kochi, Kerala
- Sold under the brand name Algamin-Tension-Ease



Cadalmin™ Anti-osteoporotic extract (Cadalmin™AOe)

- Natural remedy for osteoporosis
- Efficiently suppress the osteoclast activity and increases alkaline phosphatase activities
- Contains extracts from seaweeds like *Gracilaria salicornia* and *Sargassum wightii*
- Commercialized with Chazah Pharmaceuticals Limited, Kochi, Kerala

Cadalmin™ Immunoboost extract (Cadalmin™IBe)

- Contains natural immune boosting agent
- Helps to improve innate immune system
- Usage could lead to reduced inflammatory response
- Contains extracts from seaweeds *Turbinaria conoides* and *Sargassum wightii*
- Commercialized with Chazah Pharmaceuticals Limited, Kochi, Kerala

Cadalmin™Antibacterial extract (Cadalmin™ABe)

- Antimicrobial skin and wound care ointment
- Comprises of unique blend of 100% natural bioactives from seaweed and seaweed-associated Firmicutes
- Helps in cleansing wounds, promotes a moisture balanced environment and protects wounds from becoming dry
- Has anti-infective properties against Methicillin resistant *Staphylococcus aureus*
- Technology scheduled for licensing

Cadalmin™Maribac (Cadalmin™MBc)

- Antimicrobial therapeutic composition
- Developed from seaweed-associated Firmicute along with seaweed extract to improve gut microflora
- An excellent probiotic
- Technology scheduled for licensing

Cadalmin™ LivCure extract (Cadalmin™ LCe) for use against non-alcoholic fatty liver disease (NAFLD)

- Improves liver health, reduce disposition of fatty substances, and maintain other liver/ lipid parameters within clinically acceptable limits
- Inhibits different enzymes and various target receptors associated with dyslipidemia/ nonalcoholic steatohepatitis and pathophysiology leading to NAFLD
- Technology is ready for commercialization

Pioneer Pharmaceuticals Limited, Kochi is one of the pioneering companies in India producing seaweed-based nutraceuticals. A brief description of the company is given at **Box-5**.

Box-5: Pioneer Pharmaceuticals Limited, Kochi, Kerala

Pioneer Pharmaceuticals Limited is a wellness and pharmaceutical company based at Kochi, involved in manufacturing of seaweed-based nutraceuticals.

Products: The product range comprises of three patented products developed by ICAR-CMFRI, as a natural therapy for diseases like joint pain/arthritis (Cadalmin™ GAe), type-2 diabetes (Cadalmin™ ADe) and hypertensive disorders (Cadalmin™ AHe).

Production capacity: 400 million capsules/ year.

Annual turnover: About Rs.10 crores.

ICAR-Central Institute of Fisheries Technology (ICAR-CIFT) has developed and commercialized different fucoidan-based products from seaweeds (Gopalakrishnan *et al*., 2020). The details of various seaweed-based nutraceuticals developed by ICAR-CIFT are as follows:

CIFTEQ® FucoidanEx

CIFTEQ® FucoidanEx is a freeze dried product comprising of fucoidan and micronutrients. It finds application in a range of nutraceuticals as well as cosmetic products. Fucoidan is extracted from seaweed *Sargassum wightii* through an enzymatic technique involving green chemistry. The extraction process does not involve use of any harmful organic solvents. Pre-clinical study of the product exhibited exceptional in vivo antioxidant activity. The product was licensed to Amalgam Foods Pvt. Ltd., Kochi and the company is selling the product in the European Union.

CIFTEQ® FucoTeaEx

It is a food supplement prepared by blending fucoidan and green tea phenolics, to manage cardiac health. The product acts a source of antioxidants, vitamins and minerals. FucoTeaEx is prepared by microencapsulation technology, for augmenting bioavailability. Each capsule contains at least 90 mg of fucoidan. The preclinical study had demonstrated that FucoTeaEx can reduce the effect of drug-induced myocardial infarction. FucoTeaEx was licensed to Bodinanaturals Pvt. Ltd., Kerala. Product manufacturing has been commenced and will be marketed in the trade name 'Seavina'.

5.8 FUNCTIONAL FOOD INDUSTRY/ PRODUCTS

ICAR-CIFT has also developed and commercialized different seaweed-based products such as nutritional drink, cookie, and yoghurt (Gopalakrishnan *et al*., 2020). The details of various seaweed-based functional foods developed by ICAR-CIFT are as follows:

CIFTEQ® Seaweed Nutridrink

It is a blend of grape juice and extract of seaweed *Sargassum wightii*. Seaweed extract is blended with grape juice and microencapsulated to form a reconstitutable powder. The powder can be solubilized instantly in water to produce the drink. The Nutridrink contains considerable amounts of fucoidan, riboflavin, pantothenic acid, and taurine. Each 100 ml of the Nutridrink contains 500 mg of fucoidan (Geethalakshmi *et al*., 2021). Incorporation of seaweed extract in fruit juice also resulted in enhanced iron and calcium contents. The product was licensed to Kerala Nutraceuticals Pvt. Ltd., Kochi, Kerala.

CIFTEQ® Seaweed Cookies

The cookies are prepared with seaweed *Caulerpa racemosa* as an ingredient. The product has high content of protein, dietary fibre, and phenolics and also possesses antioxidative potential. The product was licensed to ZCorp. Organic Pvt. Ltd., Palakkad, Kerala, and Zaara Biotech, Thrissur, Kerala. The product is being marketed as organic cookies, to boost digestive health, with a price of Rs.240/- for a packet of 140 g (Geethalakshmi *et al*., 2021).

CIFTEQ® Seaweed Yoghurt

The product is fucoidan supplemented yoghurt. Following an ultrasonication assisted extraction process, fucoidan is isolated from seaweed *Sargassum wightii* and added to yoghurt. The yoghurt displays superior phenolic content and antioxidative potential. The uniqueness of the product is that it can act as an efficient delivery system of physiological benefits offered by seaweeds. The product was licensed to Kerala Co-operative Milk Marketing Federation (MILMA), Kerala.

ICAR-CMFRI had developed recipes of various seaweed-based products such as seaweed cookies, seaweed jelly, seaweed cocktail, seaweed chutney, seaweed pickle, seaweed chapathi etc. (Jayasankar *et al*., 2005).

5.9 COSMETICS INDUSTRY/ PRODUCTS

Seaweeds are extensively used as ingredients in the production of cosmetics. The cosmetic properties are attributed by the bioactive compounds present in seaweeds. In India, production of seaweed-based cosmetics is in its nascent stage and only very few categories of cosmetics are currently being produced. Some of the major seaweed-based cosmetics companies in India and their products are presented in **Table 5.2**.

Table 5.2: Major Indian Seaweed-Based Cosmetics Companies and Products

Sl. No.	Name of Company	Seaweed-Based Products
1	Blossom Kochhar Beauty Products Pvt. Ltd., Roorkee, Uttarakhand	Hydrating face pack
2	Myra Veda Organics Pvt. Ltd., Mumbai	Seaweed scrubs
3	Bio Veda Action Research Company, Sirmaur, Himachal Pradesh	Seaweed revitalizing anti -fatigue eye gel
4	Shahnaz Ayurvedics, Roorkee, Uttarakhand	Seaweed under-eye mask
5	Kaya Limited, Mumbai	Skin hydrating night mask face gel
6	Kulsum's Kaya Kalp Herbals Pvt Ltd, Jaipur	Under eye dark circle seaweed gel
7	Good Vibes, Palghar, Maharashtra	Hydrating and age defying night gel
8	AM Enterprises, Solan, Himachal Pradesh	Anti tan face mask
9	O3+ Skin Solution, Noida	Face emulsion, skin cleansing gel, face mask, face cream, acne control serum etc.
10	Cosmic Nutracos Solutions Private Limited, New Delhi	Insta glow face mask

Sl. No.	Name of Company	Seaweed-Based Products
11	Indus Cosmeceuticals, Shimla, Himachal Pradesh	Acne gel
12	Indrani Cosmetics, Pune, Maharashtra	Face/ skin gel
13	VLCC, Gurgaon	Skin bleach

VLCC Wellness is offering 'Seaweed Therapy', promoted as a unique, safe and natural solution for cellulite reduction and detoxification. The products used in the therapy include seaweed cream (anti-ageing, reduce cellulite and retain moisture), seaweed pack (nourish skin, augment firmness, reduces subcutaneous fat), seaweed serum (anti-ageing), detox oil (revitalize skin, remove body toxins) etc. The therapy is expected to result in weight reduction, body shaping, body detoxification, cellulite reduction, skin moisturization, skin tightening etc.

5.10 STARTUPS AND PRODUCTS

Very limited number of seaweed startups are currently operating in India. Some of the major Indian startups in the realm of seaweed value-addition and their product details are as follows:

Sea6 Energy Pvt. Ltd.

Sea6 Energy Pvt. Ltd., Bangalore is built on the vision of sustainably and ethically harnessing the oceans to build a future for mankind independent of traditional energy sources. The manufacturing facilities are designed to operate on minimal freshwater and chemical use, while the manufacturing processes are certified organic as per India and EU equivalent standard. The products include agriculture products (plant biostimulant & liquid fertilizer), animal feed (immunity booster for aquatic animals and poultry), food ingredient (food gelling agent), bio-polymers (biofilms & bioplastics), biofuels etc.

The skill base of Sea6 Energy comprises of marine biotechnology (screening and discovering novel salt-tolerant microbes), fermentation technology (developing a salt tolerant microbial platform to convert sugars into industrial chemicals), analytical chemistry (analyze, characterize and quantify individual components of seaweed biomass enabling a library of active ingredients), synthetic chemistry (engineer novel molecules through chemical modification of components of seaweed biomass), product development (biorefinery approach to extract specific molecules and customize for multiple industrial applications), molecular biology (expertise to establish a mode of action of products at a cellular level in plants and animals using pre-existing and novel model systems), prototyping (design and execute pilot tests to establish critical control points and process parameters for ensuring consistent product quality), process engineering (develop and design processes imbibing quality by design principles for scaling manufacturing from pilot to industrial scale), engineering and sustainable design.

Zaara Biotech

Zaara Biotech, established in 2016 and based at Thrissur, Kerala, is a biotechnology startup nurtured by the Innovation and Entrepreneurship Development Center scheme of Kerala Startup Mission instituted by the Govt. of Kerala, at Sahrdaya Technology Business Incubator sponsored by Kerala State Industrial Development Corporation Ltd. The objective of the startup is to create a brand comprising of nutritionally superior, high quality and affordable products to improve the lifestyle of the common people.

The startup, with the technical knowhow from ICAR- CIFT, is producing seaweed-based cookie under the brand name 'B-lite Cookies'. This cookie is considered superior to other biscuit products due to its instant energy boosting capacity, and higher protein and dietary fibre content. The cookie is also enriched with minerals such as iron and calcium and is devoid of preservatives, trans fat and cholesterol. The superoxide dismutase present in the cookie is expected to aid in slowing the aging process in humans. In addition to seaweed cookie, Zaara Biotech also produces cookie from spirulina, under the 'B-lite Cookies' brand.

Seaweed-based cookies was showcased at GITEX 2020, the global tech and startup event held at Dubai during December 2020. Recently, Zaara Biotech received an investment of USD 10 million from UAE-based TCN International Commerce LLC for R&D, manufacturing, and marketing of B-lite Cookies.

Oceanic Organics

Oceanic Organics, a startup incorporated in 2019 in Mumbai, aspires to innovate and deliver sustainable business models integrating the blue and green economies. The objectives of the startup include development of non-chemically processed products and generation of alternative income for the coastal as well as rural community in India. Oceanic Organics produces a natural growth promoter from seaweeds for all types of plants under the brand name 'O-Plants'. The product consists of plant growth hormones and multiple beneficial microbes which support wholesome growth of plants. The benefits of the product include increased shoot length, root length, leaf area and enhanced seed germination, fruiting and flowering. The product also helps in boosting plant immunity.

Agastya Marine Pvt. Ltd.

Agastya Marine is a startup company established in 2020 at Bhavnagar with the objective of seaweed farming and its downstream processing. The startup intends to culture seaweed for manufacturing various value-added products like agar-agar, agarose, bio-stimulants, organic fertilizer etc.

Zerocircle Alternatives Pvt. Ltd.

Zerocircle Alternatives Private Limited, incorporated in the year 2020, is a startup with registered office at Gurgaon, Haryana. The company aims at developing bio-alternatives to products used in the daily lives using renewable resource such as seaweeds, to achieve circular economy. The areas into which Zerocircle are foraying include food packaging (films, cups, bottles and laminates), shoe soles (fully compostable soles for high performance shoes), medical (materials to replace synthetic gloves, masks, and medical sutures), future food (vegan protein formulation with plant-based B-12 omega 3 fatty acids, minerals and vitamins), textile (bioyarn-based fabrics) courier packaging (materials with durability for E-tailers to sustain long distance transport). The biodegradable products are prepared from both edible and non-edible seaweeds sourced from Tamil Nadu, Gujarat, and Maharashtra.

The clients of Zerocircle encompass companies in the area of FMCG, food, personal care, homecare etc. Zerocircle has been a winner in the 'India Plastic Challenge – Hackathon 2021', organized by the Ministry of Environment, Forest and Climate Change (MoEFCC), Govt. of India in partnership with German Agency for International Cooperation (GIZ) and Climate Collective Foundation to develop alternatives to single-use plastics, for the transformation to a circular economy. Zerocircle has been shortlisted for the USD 1.2 million Tom Ford Plastic Innovation Prize, powered by Lonely Whale.

ClimaCrew Private Limited

ClimaCrew Private Limited was established in 2022. Kamaljyot Investments Limited, the wholly owned subsidiary of Excel Industries Limited, holds major stake in the company. ClimaCrew aims to harness the benefits bestowed by seaweeds through development of enabling platforms, creating and fostering strategic business partnerships, and seeking national and international scientific collaborations.

6.0 SEAWEED VALUE-ADDITION TECHNOLOGIES DEVELOPED IN INDIA

Based on the readiness level, seaweed value-addition technologies are classified as technologies already commercialized, ready for commercialization, pilot scale and lab scale. The details of various seaweed value-addition technologies developed in India are given below:

6.1 TECHNOLOGIES ALREADY COMMERCIALIZED

Sl. No.	Name of Technology	Licensee Company	Year of License	Patent Details
ICAR- Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi				
1	Cadalmin™ Green Algal extract (Cadalmin™ GAe) for joint pain/arthritis	Celestial Biolabs Limited, Hyderabad & Pioneer Pharmaceuticals Limited, Kochi	2013 & 2020	Indian Patent No. 294451 Indian Patent No. 333392 Indian Patent Application No. 5199/CHE/2012
2	Cadalmin™ Antidiabetic extract (Cadalmin™ ADe) for type-2 diabetes from seaweeds	Celestial Biolabs Limited, Hyderabad & Pioneer Pharmaceuticals Limited, Kochi	2016 & 2020	Indian Patent No.346531
3	Cadalmin™ Antihypercholesterolemic extract (Cadalmin™ ACe) for dyslipidemia from seaweeds	VLCC Personal Care Limited, Gurgaon	2017	Indian Patent Application No. 201711018741
4	Cadalmin™ Anti-hypothyroidism extract (Cadalmin™ ATe) from seaweeds	VLCC Personal Care Limited, Gurgaon	2018	Indian Patent Application No. 201911036205 Indian Patent ApplicationNo.201911017798
5	Cadalmin™ Antihypertensive extract (Cadalmin™ AHe) from seaweeds	Pioneer Pharmaceuticals Limited, Kochi	2020	Indian Patent Application No. 201911038055
6	Cadalmin™ Antiosteoporetic extract (Cadalmin™ AOe) from seaweeds	Chazah Pharmaceuticals Limited, Kochi	2021	Indian Patent Application No. 202011009121
7	Cadalmin™ Immunoboost extract (Cadalmin™ IBe) from seaweeds	Chazah Pharmaceuticals Limited, Kochi	2021	Indian Patent Application No. 202011054632

Sl. No.	Name of Technology	Licensee Company	Year of License	Patent Details
CSIR- Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar				
8	Integrated process for the simultaneous recovery of liquid fertilizer (sap) and carrageenan (semi-refined & refined) from fresh *Kappaphycus alvarezii*	2 companies	2008 & 2013	Indian Patent No. 224938 US Patent No. US 6,893,479B2 European Patent No. EP 1,534,757 B1 PCT Patent Publication No. WO2004/016656A1 Denmark Patent Publication No.DK1534757T3 Korean Patent Publication No. KR100689982B1; Chinese Patent Publication No. CN1324052C; Japan Patent Publication No. JP2006504605A
9	Process for recovery of sap (liquid seaweed bio-stimulant) from *Kappaphycus alvarezii* seaweed as basic raw material and its application	2 companies	2019	Indian Patent No. 224938 US Patent No. US 6,893,479B2
10	Preparation of refined kappa-carrageenan from *Kappaphycus alvarezii* granules via semi-refined kappa-carrageenan	1 company	2014	---
11	An integrated process for the simultaneous preparation of biostimulant, cellulose and biochar from brown seaweed *Sargassum* species	9 companies	2016, 2017, 2018, 2019, 2020	Indian Patent Application No. 201811029622
12	Improved process for the preparation of agarose polymer from seaweed extractive	1 company	2013	Indian Patent Application No. 0567/DEL/2009; Japanese Patent No. JP5642152B2 Canada Patent No. CA 2756520C Australia Patent Application No. AU 2010227247 B2 European Patent No. EP 2,411,418 B1 PCT Patent Publication No. WO2010/109289 A1; China Patent Publication No. CN 102439047B; Russian Patent Publication No. RU2,541,635C2

Sl. No.	Name of Technology	Licensee Company	Year of License	Patent Details
13	A zero liquid discharge process for the production of alginic acid and its derivatives from alginophytes	1 company	2020	Indian Patent Application no. 201711025753
14	*Kappaphycus alvarezii* and red seaweed based formulations for improving productivity and health of dairy and poultry animals	1 company	2020	---
15	Preparation of food grade agar from *Gracilaria edulis*	NGO, Port Blair	2008	---
16	Process for recovery of sap (liquid seaweed biostimulant) from *Kappaphycus alvarezii*	Director of Fisheries, Govt. of Tamil Nadu	2018	Indian Patent No. 224938 US Patent No. US 6,893,479B2
17	Sodium alginate	Belur Enterprises, Mumbai	1978	---
18	Agar	Director of Fisheries, Govt. of Madras	1963	---
19	Macro-algal bio refinery for CO2 sequestration and production of biofuel and value added compounds	Aquagri processing Pvt. Ltd., New Delhi & NRDC, New Delhi	2014-15	---
ICAR- Central Institute of Fisheries Technology (ICAR-CIFT), Kochi				
20	Development of a seaweed NutriDrink (CIFTEQ® Seaweed Nutridrink)	Amalgam Foods Limited, Kochi & Kerala Nutraceuticals Pvt. Ltd., Kochi	2019	---
21	Freeze-dried ingredient rich in high-value nutraceutical Fucoidan and micronutrients (CIFTEQ® FucoidanEx)	Amalgam Foods Limited, Kochi	2019	---
22	Seaweed-incorporated biscuits (CIFTEQ® Seaweed Cookies)	ZCorp. Organic Pvt. Ltd., Palakkad & Zaara Biotech, Thrissur	2018	---
23	Seaweed based ice cream	Kerala Cooperative Milk Marketing Federation, Thiruvananthapuram	2019	---
24	Fucoidan-enriched yoghurt (CIFTEQ® Seaweed Yoghurt)	Kerala Cooperative Milk Marketing Federation, Thiruvananthapuram	2019	---
25	Microencapsulated dietary supplement formulation of Fucoidan and green tea extract (CIFTEQ® FucoTeaEx)	Bodina Naturals Pvt. Ltd., Kochi	2020	---

Sl. No.	Name of Technology	Licensee Company	Year of License	Patent Details
26	Carrageenan based hand sanitizer (CIFTEQ® Seaweed-based Hand Sanitizer)	Kerala Nutraceuticals Pvt. Ltd., Kochi& Bodina Naturals Pvt. Ltd., Kochi	2020	---
27	Fucoidan based gargle	Bodina Naturals Pvt. Ltd., Kochi	2020	---
28	Fucoidan capsule	Bodina Naturals Pvt. Ltd., Kochi	2020	---
29	Production of high gel strength agar	Marine Chemicals, Kochi	---	---
Fisheries Research Station, Junagadh Agricultural University, Port-Okha				
30	Seaweed liquid fertilizer (SLF) using *Sargassum* sp.	Propagated among farmers & coastal communities, as a part of regular extension activity	---	---

6.2 TECHNOLOGIES READY FOR COMMERCIALIZATION

Sl. No.	Technology	Patent Details
ICAR- Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi		
1	Cadalmin™ Antibacterial extract (Cadalmin™ ABe) as topical skin care ointment from seaweeds	Indian Patent Application No. 201911018958
2	Cadalmin™ probiotic nutraceutical to improve intestinal gut microflora (Cadalmin™ MBc) from seaweeds	Indian Patent Application No. 201911032735
3	Cadalmin™ LivCure extract (Cadalmin™ LCe) from seaweeds	---
CSIR- Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar		
4	An integrated process to valorize seaweed biomass for a spectrum of bioproducts	Indian Patent Application No. 3811/DEL/2013; US Patent No. US10,000,579B2 European Patent No. EP 3,089,999 B1 Australia Patent No. AU2014/374908B2 PCT Patent Publication No. WO 2015/102021 A1
5	Biodegradable films and capsule shells based on semi refined kappa carrageenan	Indian Patent No. 280260; US Patent No. US7,067,568B1 PCT Publication No. WO2006/059180A2
6	Zero-effluent process for the recovery of high purity 5-hydroxymethyl furfural (HMF) from aqueous agar solution	Indian Patent Application No. 201711018189
7	Seaweed polysaccharides-based foot care gel	Indian Patent Application No. 202011036009

Sl. No.	Technology	Patent Details
	ICAR- Central Institute of Fisheries Technology (ICAR-CIFT), Kochi	
8	Dietary fibre(CIFTEQ® Seaweed Dietary Fibre)	---
9	Seaweed incorporated extruded snacks(CIFTEQ® Seaweed Kure)	---
10	Fish feed supplement (CIFTEQ® Seaweed Aqua Booster)	---
11	Edible sachet (CIFTEQ® Seaweed Edible Sachet)	---
12	Seaweed-based bioplastics (CIFTEQ® Seaweed-based Packaging Materials)	---
13	Fucoxanthin rich SFE (supercritical fluid extraction) extract	---
	National Institute of Food Technology Entrepreneurship and Management (NIFTEM), Sonipat	
14	Seaweed tea infusion/Seaweed tea	---
	Sathyabama Institute of Science and Technology, Chennai	
15	*Kappaphycus alvarezii* sap extractor	Indian Patent No. 353906
16	Value addition of Seaweed SAP – Paste	---
	V.O. Chidambaram College, Tuticorin	
17	Healthy and cost effective seaweed fish feed	---
18	Potential fish feed with high antimicrobial property with the help of sea weeds as an influential component	---

6.3 PILOT SCALE TECHNOLOGIES

Sl. No.	Technology	Patent Details
	Gandhigram Rural Institute, Gandhigram	
1	Seaweed incorporated chocolate	Indian Patent No.346611
	Central University of Kerala, Kasaragod	
2	Extraction of Phycobiliproteins for food applications	---
3	Polysaccharides(Agar/alginate) extracted spent seaweed biomass for bioethanol production using marine yeast	---
	Vels Institute of Science, Technology and Advanced Studies, Chennai	
4	A potent immunostimulant chemically separated from a marine macroalga (sea weed) for prophylactic (preventive) health management in finfish aquaculture	Indian Patent Application No. 2271/CHE/2012

Sl. No.	Technology	Patent Details
5	An efficacious marine plant - derived immunostimulant for preventing diseases in carps and other fishes in aquaculture	Indian Patent Application No. 524/CHE/2015
6	Sea weed–derived immunostimulant for protecting striped murrels (Snake heads) and other culture fishes from diseases	Indian Patent Application No. 4022/CHE/2015
7	A polysaccharide immunostimulant for preventing diseases in finfish aquaculture	Indian Patent Application No. 201641027311
8	*Caulerpa scalpelliformis* polysaccharide fraction as an immunostimulant for Nile tilapia and other fin fishes	---
Alagappa University, Karaikudi		
9	Anti-malarial drug from seaweed	---
10	Seaweed as a tool for mosquito larval control	---
Centre of Advanced Study in Marine Biology, Annamalai University, Parangipettai		
11	Seaweed recipe products (Seaweed coffee, biryani, beer, noodles, chocolate etc.)	---

6.4 LAB SCALE TECHNOLOGIES

Sl. No.	Technology	Patent Details
CSIR- Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar		
1	Process for the preparation of graded agarose from seaweed extract	Indian Patent Application No. 201611002824
2	Process for the production of graphene sheets with tunable functionalities from seaweed promoted by deep eutectic solvents	US Patent No. US 10,549,997 B2
3	Process for improved seaweed biomass conversion for fuel intermediates and fertilizer	Indian Patent Application No. 1789/DEL/2012 Australian Patent No. AU2013303760 Japan Patent Publication No. JP2015533777A PCT Patent Publication No. WO 2014/027368 A2 Israel Patent Publication No. IL237157D0
4	Process for the preparation of sprayable Aqueous Chitin formulations fortified with Plant Macronutrients	Indian patent application No. 201911026412
5	A method for the preparation of refreshing drink and use thereof	PCT Patent No. WO2008020457A1
ICAR- Central Institute of Fisheries Technology (ICAR-CIFT), Kochi		
6	Preparation of suture using seaweed extracts	---

Sl. No.	Technology	Patent Details
7	Seaweed noodles	---
8	A bioactive compound from seaweed - Phlorotannin	---
9	Dried *Ulva* powder as an ingredient in Pasta	---
10	Extraction of sulphated polysaccharide from seaweed	---
11	Extraction of bioactive compounds, ulvan polysaccharide	---
12	Conjugated alginate for biomedical applications	---
13	Carrageenan based ointment	---
14	Seaweed based composite scaffolds	---
15	Seaweed Jerky	---
VIT University, Vellore		
16	Seaweed polysaccharide nanoparticle and a method of preparing the same	Indian Patent Application No. 201741003682
17	Antibacterial composition effective against *Aeromonas salmonicida* infection in aquaculture	Indian Patent Application No.201741002439
18	A novel anticoagulant peptide from the Nori (*Porphyra yezoensis*) hydrolyzate	Indian Patent No. 338414
National Institute of Food Technology Entrepreneurship and Management (NIFTEM), Sonipat		
19	Seaweed nutraceutical capsule rich in polyphenols	---
Madurai Kamaraj University, Madurai		
20	Marine seaweed *Sargassum wightii* extract as a low-cost sensitizer for ZnO photoanode based dye-sensitized solar cell	---
Chettinad Academy of Research and Education, Kelambakkam		
21	Extraction and purification of polyphenolic compounds from green, red and brown seaweeds collected from South East Coast of India	---
22	Extraction and formulation of agar from brown seaweed and use of their anticancer properties	Indian Patent Application No.201941026209A
Gandhigram Rural Institute, Gandhigram		
23	Seaweed incorporated tea	---

Sl. No.	Technology	Patent Details
24	Seaweed incorporated biscuit	---
25	Seaweed incorporated yoghurt	---
26	Extending shelf life of tomatoes by coating seaweed gel	---
Sathyabama Institute of Science and Technology, Chennai		
27	Immobilization of beneficial microorganisms from spent biomass	---
Central University of Kerala, Kasaragod		
28	Synthesis of silver nanoparticles (AgNPs) from aqueous extracts of red seaweeds for nanopesticide formulation	---
Manonmaniam Sundaranar University, Kanyakumari		
29	Extraction of carrageenan from *Kappaphycus alvarezii* and its use as a therapeutic agent	---
30	Extraction of fucoidan, sodium alginate, and calcium alginate from brown seaweed *Sargassum polycystum* and its use as a therapeutic agent	---
31	Extraction of fucoidan, sodium alginate, and calcium alginate from brown seaweed *Sargassum wightii* and its use in shrimp disease management	---
32	Extraction of ulvan from green seaweed *Ulva fasciata* and its use as a therapeutic agent	---

7.0 TRENDS IN DEVELOPMENT OF SEAWEED VALUE-ADDITION TECHNOLOGIES

The technology development trends in the area of seaweed value-addition, at national level and international level, have been analyzed by mapping the patents filed in India and by tracking the technology development projects being implemented across the globe respectively.

7.1 INDIAN PATENTS

The patents related to seaweed, published in India during the last two decades (2001-2020), were retrieved from the official Indian patent database namely Indian Patent Advanced Search System (inPASS). Eighty-nine records of published patent applications related to seaweeds were observed, of which sixty-five were associated with seaweed value-addition or related product development. Among the patent applications published, in the last twenty years, only sixteen patents were granted in the area of seaweed value-addition (**Table 7.1**).

Table 7.1: Seaweed Value-Addition Patents Granted in India (2001-2020)

Sl No	Patent No	Title of Invention	Applicant
1.	213513	Production of carrageenan and carrageenan products	FMC Corporation, USA
2.	224938	A process for production of phycocolloid containing solid residue and liquid fertilizer from fresh seaweeds	CSIR-CSMCRI
3.	280260	Biodegradable films based on semi refined kappa carrageenan	CSIR-CSMCRI
4.	281677	Integrated process for the production of biofuels from different types of starting materials and related products	Nazzareno de Angelis, Italy
5.	294451	A process to prepare antioxidant and anti-inflammatory concentrates from brown and red seaweeds and a product thereof	ICAR-CMFRI
6.	331632	Cosmetic composition containing gulfweed extract sea staghorn extract and brown seaweed extract	Amorepacific Corporation, Korea
7.	333392	Anti-inflammatory principles in a preparation of brown seaweeds	ICAR-CMFRI
8.	338414	Anticoagulant peptide isolated from seaweed *Porphyra* hydrolyzate	VIT University, Vellore
9.	342498	Method of preparing anti-oxidative edible film from carp gelatin and fucoidan	Fisheries College and Research Institute, Tamil Nadu Fisheries University, Tuticorin
10.	343913	Upgrading process streams	Xyleco Inc., USA

Sl No	Patent No	Title of Invention	Applicant
11.	346611	A nutritional rich chocolate composition	Ms. Thahira Banu A., Gandhigram Rural Institute, Gandhigram Dr. Sumayaa, Thassim Beevi Abdul Kader College for Women, Kilakarai Dr. S. Umamageswari, Avinashilingam University Coimbatore
12.	350065	Preparation of seaweed polysaccharide-based hydrophobic biocompatible ropes	CSIR-CSMCRI
13.	353906	*Kappaphycus alvarezii* sap extractor	Sathyabama University, Chennai
14.	355406	A method of reducing the pyrogenicity of a seaweed extract	Marinova Pty. Ltd., Australia
15.	358929	*Kappaphycus alvarezii* sap free of gibberellic acid (GA3) and its method of preparation	CSIR-CSMCRI
16.	360393	A biostimulant formulation for improving plant growth and uses thereof	Sea6 Energy Pvt. Ltd., Bengaluru

Source: inPASS (2021)

Out of the sixteen seaweed value-addition patents granted in India, five patents were granted to foreign entities and the rest of the eleven patents were awarded to Indian institutions/ organizations. The fields of invention of awarded patents include biochemistry (3 patents), chemical (3 patents), pharmaceuticals (3 patents), biotechnology (2 patents), food (1 patent), mechanical engineering (1 patent), polymer technology (1 patent), traditional knowledge biotechnology (1 patent), and traditional knowledge chemical (1 patent).

Six applications were found to be in order for granting the patent but are awaiting the approval of the National Biodiversity Authority (NBA). The details of these patent applications are given in **Table 7.2**.

Table 7.2: Seaweed Value-Addition Patents found to be in Order for Granting, but Awaiting Approval of National Biodiversity Authority (2001-2020)

Sl No	Title of Invention	Applicant
1.	A facile synthesis of seaweed polysaccharides based hydrophobic biocompatible crosslinked composite porous materials for energy-efficient separation	CSIR- CSMCRI
2.	A fertilizer composition for enhancing or inducing the growth or development in a plant growth	Ocimum Herbals, Pune
3.	Process for improved seaweed biomass conversion for fuel intermediates and fertilizer	CSIR- CSMCRI
4.	A process for integrated production of ethanol and seaweed sap from *Kappaphycus alvarezii*	CSIR- CSMCRI

Sl No	Title of Invention	Applicant
5.	Improved process for the preparation of agarose polymer from seaweed extractive	CSIR- CSMCRI
6.	A biodegradable plastic like material	Steer Engineering Pvt. Ltd., Bangalore

Source: inPASS (2021)

Twenty-five patent applications have been published and are being considered for approval in India. The details of these patent applications are given in **Table 7.3**.

Table 7.3: Seaweed Value-Addition Patent Applications Published and Under Consideration for Approval in India (2001-2020)

Sl No	Title of Invention	Field of Invention	Applicant
1.	Novel PI3K & AKT inhibitor that can control different types of cancer	Pharmaceuticals	B. S. Abdur Rahman Crescent Institute of Science and Technology, Chennai
2.	Method of identifying and isolating bioactive compounds from seaweed extracts	Biotechnology	Laboratoires Goëmar, France
3.	A biodegradable and antibacterial alpha seaweed cellulose sheet	Polymer Technology	Gujarat Energy Research and Management Institute, Gandhinagar
4.	Bio nano composite degradable plastic	Polymer Technology	Vels Institute of Science Technology & Advanced Studies (VISTAS), Chennai
5.	Extraction and formulation of agar from brown seaweed & use of their anticancer properties	Bio-chemistry	Chettinad Academy of Research and Education, Kanchipuram
6.	An oral drug delivery system and an anti bacterial topical applicant from seaweed based hydrogel and a process thereof	Food	ICAR-CMFRI
7.	A process to prepare anti-hypothyroidism concentrates from seaweeds and a product thereof	Polymer Technology	ICAR-CMFRI
8.	A process to prepare anti-dyslipidemic concentrate marine macroalgae and coastal sea crustacean	Biotechnology	ICAR-CMFRI
9.	Preparation of superabsorbent antimicrobial gel sheet (SAGS) and application thereof	Electrical	Jai Prakash Chaudhary & Preeti Singh
10.	An integrated process for the simultaneous preparation of biostimulant, cellulose and biochar from brown seaweed Sargassum species	Chemical	CSIR- CSMCRI
11.	Novel molecule with anti-cancer activity	Chemical	Oceans Ltd., Canada

Sl No	Title of Invention	Field of Invention	Applicant
12.	Use of Ulvan as activator of shrimp immune system against white spot syndrome virus	Food	Pondicherry University, Pondicherry
13.	A process for preparation of seaweed nanoparticles and its application for DNA isolation	Pharmaceuticals	CSIR- CSMCRI
14.	A zero liquid discharge process for the production of alginic acid and its derivatives from alginophytes	Chemical	CSIR- CSMCRI
15.	A process to prepare anti-dyslipidemic concentrate from seaweed and a product thereof	Pharmaceuticals	ICAR-CMFRI
16.	Zero-effluent process for the recovery of high purity 5-hydroxymethyl furfural (HMF) from aqueous agar solution	Bio-chemistry	CSIR- CSMCRI
17.	Seaweed mixture inducing growth or development and stress tolerance in plants	Chemical	Dr. P. Anantharaman & Dr. C. Periyasamy
18.	Seaweed polysaccharide nanoparticle and a method of preparing the same	Pharmaceuticals	VIT University, Vellore
19.	A polysaccharide immunostimulant for preventing diseases in finfish aquaculture	Traditional Knowledge Chemical	Vels University, Chennai
20.	Process for the preparation of graded agarose from seaweed extract	Bio-chemistry	CSIR- CSMCRI
21.	Processing materials	Physics	Xyleco Inc., USA
22.	Seaweed botanical formulation for crop pest and phytopathogens management	Bio-chemistry	St. Xavier's College
23.	An integrated process to valorize seaweed biomass for a spectrum of bioproducts	Chemical	CSIR- CSMCRI
24.	Antibacterial property of green seaweed *Chaetomorphasp*. against *Helicobacterpylori*	Pharmaceuticals	Amity University, Noida
25.	A product containing anti-inflammatory principles from brown seaweeds and a process thereof	Pharmaceuticals	ICAR-CMFRI

Source: inPASS (2021)

Eighteen patent applications related to seaweed value-addition have been withdrawn, abandoned or refused in India and the details are given in T**able 7.4**.

Table 7.4: Seaweed Value-Addition Patent Applications Withdrawn, Abandoned or Refused in India (2001-2020)

Sl No	Title of Invention
1.	Seaweed based organic flocculent for clarification of dairy wastewater and the process thereof

Sl No	Title of Invention
2.	Seaweed liquid fertilizer composition and method for manufacturing thereof
3.	Liquid seaweed for plant
4.	Highly soluble N-P-K fertilizer with seaweed extract and spirulina for use in agriculture
5.	An efficacious marine plant - derived immunostimulant for preventing diseases in carps and other fishes in aquaculture
6.	Method for cultivating seaweed and method for producing alginic acid containing composition
7.	Microbial consortia enabled fermented marine single cell detritus (FMSCD) feed preparation process for shrimp larvae rearing
8.	Process of production of renewable chemicals and biofuels from seaweeds
9.	Composition comprising a glucan or a glucan derivative and a pesticide and methods for improving plant health
10.	Carbonized biopolymers
11.	A method for the preparation of refreshing drink and use thereof
12.	A cost-effective process for preparing agarose from *Gracilaria spp*.
13.	An antiviral activity in the extract prepared from the Indian seaweeds
14.	Process design and fabrication of sodium alginate from *Sargassum wightii* as a coating roof of proteinated grape fruits using agricultural waste proteins
15.	Processing materials
16.	Filtration
17.	Processing biomass
18.	Solid fuel

Source: inPASS (2021)

7.2 GLOBAL TECHNOLOGY DEVELOPMENT PROJECTS

Many projects and collaborations/ networks have been formed worldwide to develop a range of innovative technologies and novel products from seaweed and its commercialization. Some of the major projects are given below:

Novel Bioactive Seaweed Based Ingredients and Products (2012-2015)
Implemented by Nordic Innovation, the objective of the project was to evolve technologies to extricate novel bioactive compounds from Bladderwrack seaweed *Fucus vesiculosus* and prepare innovative products like food supplements, cosmetics and food antioxidants with active consumer collaboration. The project culminated in production of Marinox™ extracts, which can be used as an ingredient for food supplement production and as a food antioxidant. Marinox™ extracts is also used to produce UNA skincare™ (a line of high-class bioactive skincare products). The project had demonstrated the market demand for products with bioactive seaweed ingredients.

SeaGas Project (2015-2018)
The project aimed at creation of a feasible supply chain for culturing and storing seaweed in the UK, initially to produce biomethane through anaerobic digestion, but finally for manufacturing high-value products. The project focused on aspects such as storage of seaweed for perennial supply, potential for manufacturing biomethane and anaerobic digestion operational factors, and environmental and socio-economic effects. The project partners included Centre of Process Innovation (CPI), Scottish Association for Marine Science (SAMS), The Crown Estate, Centre for Environment, Fisheries and Aquaculture Science (CEFAS) etc. The £2.78 million project was funded by Innovate U.K., and the Biotechnology and Biosciences Research Council. The project was innovative in its provision of a scalable, industrial anaerobic digestion process for seaweed.

SeaRefinery (2015-2018)
The SeaRefinery project envisaged development and testing of a novel biorefinery approach for utilization of seaweed in the Northern Europe. The project also envisioned use of seaweed bioactive molecules for manufacturing value-added products such as pharmaceuticals, nutraceuticals, functional foods, cosmetics, and bio-based materials for industrial uses. The project aimed at demonstrating sustainable cultivation of brown seaweed *Saccharina latissima* focusing on seasonal variations of natural chemical biomolecules of industrial interest, developing chemical and enzymatic processes for extraction of bioactive molecules for industrial utilization, evaluating bioactive compounds for value-added products and bio-based materials, and disseminating relevant results to investors and policymakers to inform about Blue Growth perspectives for seaweed. The project was carried out by a consortium comprising of institutions from Denmark (Danish Technological Institute, ViVoX ApS), Belgium (Centexbel, Sioen Industries NV), Ireland (Cork Institute of Technology, CyberColloids Ltd), Iceland (Marinox ehf), and The Netherlands (Hortimare AS).

Seaweed Production Systems with High-Value Applications (2015-2020)
The project involved production and cultivation of novel strains of seaweeds *Porphyra sp.* and *Ulva lactuca* in Sweden and to evolve sustainable processes for isolation of high-value compounds from algal biomass. A biorefinery approach was envisaged for extraction of

seaweed bioactive compounds. Three types of products namely food ingredients, fine chemicals and new bio-based materials were envisaged to be produced from the biorefinery. This was a collaborative project comprising of Swedish universities/ institute namely Chalmers University of Technology, University of Gothenburg, and KTH Royal Institute of Technology. The Swedish Foundation for Strategic Research provided financial assistance for the project.

MACRO CASCADE (2016-2021)

The project aimed at evaluating the viability and bio-economic impact of processing farmed seaweeds to produce an array of products with high value. The project envisaged establishing and evaluating the viability of a seaweed biorefinery on lab scale, pilot scale, and conceptual scale. Some of the major project deliverables include conversion of seaweed into nutritious feed additives with increased digestibility; production of algae enriched rapeseed-based feed for pigs; biorefinery approach based on sample composition; production of mannitol, laminarin, polyphenol; conversion of laminarin polysaccharides into branched immunomodulating β-glucan oligosaccharides; evolving biocatalytic procedures for transforming alginate into unsaturated uronic acids for the chemical industry; evolving biocatalytic procedures for conversion of fucoidan into bioactive fucoidan oligosaccharides etc. The overall budget of the project was €4316425,88 of which €4156356,25 was contributed by the European Union.

Extraction and characterization of BIOactives and CARBohydrates from seaweeds and seagrasses FOR FOOD-related applications (BIOCARB-4-FOOD) (2018-2021)

The project aimed at exploring new, sustainable and coherent extraction processes and utilization of residual biomass to consecutively obtain unique carbohydrate-based extracts and fibers (nano-cellulose) from macro algae and seagrasses. The project resulted in extraction and characterization of agar, alginates and laminaran from various seaweed species utilizing novel extraction techniques such as ultrasound-assisted extraction, enzyme-assisted extraction etc. Use of unique extraction techniques resulted in increased yield of agar and decreased extraction time. The project established development of unique processing technologies for enhanced yield of seaweed carbohydrates. The project was carried out by a consortium of scientific institutions from Spain (IATA-CSIC), Norway (Nofima AS), Ireland (Teagasc Food Research Centre), Germany (University of Hohenheim), and Sweden (RISE Research Institutes). The project had a budget of one million Euro.

ZCORE Project: Seaweed Residues for Superior Bio-Coatings (2019-2022)

The project aims at producing bio-coatings (paint) with superior properties from seaweed processing residue. Conversion of non-edible sugars to bio-based aromatics is being explored in the project and the resulting aromatics would be tested in coating applications. For aromatic production, novel chemical processes are envisaged to be developed in the project. The expected outcome of the project is production of sustainable, cost-effective and durable 100% bio-based alkyd resin coatings. The bio-aromatics are also expected to exhibit superior properties such as better abrasion resistance, gloss, UV resistance etc. The project is being operated by Biorizon in partnership with SMEs such as Sea Harvest Holland and Engineering Chemicals, and another five major coating manufacturers. The knowledge partners of the project comprise of TNO, Avans and Maastricht University. The total fund awarded for the project is € 2 million. The project is anticipated to contribute positively to greenhouse gas reduction, strengthen the chemical industry and open innovation network in the southern Netherlands.

Seaweeds for Novel Applications and Products (SNAP) (2020-2023)

The project aims at evolving unique products and applications by improving and altering the polysaccharides from farmed brown and wild collected red seaweeds. The project sub-goals include characterization of seaweed biomass; extraction, chemo-enzymatic upgradation and functional characterization of polysaccharides; production and characterization of unique biomaterials etc. Targeted applications include food and feed supplements, nutraceuticals, prebiotics, cosmetics, biomedical, regenerative medicine, 3D printing etc. The project is being carried out by a consortium comprising of SES, DuPont, Tallinn University, The Royal Institute of Technology etc.

8.0 R&D TRENDS IN SEAWEED VALUE-ADDITION IN INDIA

Research papers published by researchers from Indian institutions/ organizations on seaweed value-addition, in the previous decade (2011-2020), were analyzed to understand the trends in R&D. Based on applications, the research papers published by Indian researchers on seaweed value-addition are broadly classified into four categories namely applications for human health and nutrition, agriculture applications, animal husbandry applications, and industrial applications. The list of major institutions/ organizations involved in seaweed related R&D in India is provided in **Annexure - 2**.

8.1 HUMAN HEALTH AND NUTRITION

Evaluation of potential health benefits of bioactive compounds extracted from seaweeds is an emerging area of research. The protective properties of these bioactive compounds and their capacity to combat various diseases/ medical conditions have been widely researched and the details are described below:

Antimicrobial Activity

In majority of the studies, metal nanoparticles were synthesized using seaweed and its potential as an antibacterial agent was examined. Among the nanoparticles, silver was the most frequently studied metal and others include zinc, gold, zirconia, platinum, copper, selenium etc. Various species of seaweed used for synthesizing nanoparticles include *Caulerpa racemosa*, *Sargassum wightii, S. polyphyllum*, S. *myriocystum*, *S. swartzii*, *S. ilicifolium*, *Padina tetrastromatica*, *P. gymnospora*, *Halymenia dilatata*, *Stoechospermum marginatum*, *Gracilaria corticata, Cladophora fascicularis* etc. Extracts of *Grateloupia lithophila*, *Ulva reticulata*, *Laurencia papillosa* etc. were screened for their antibacterial activity. Studies also demonstrated the biological activity of compounds such as sulfated polysaccharides (fucoidan etc.), terpenes (guaiane sesquiterpene, alpha-bisabolol etc.), and sterols (24-Branched Delta 5 sterol etc.), against human bacterial pathogens. The antifungal activity of silver nanoparticles synthesized from *Gracilaria corticata,* against *Candida albicans* and *C. glabrata*, had been investigated. The potential of Callophycin A, a red seaweed derived metabolite, to treat vaginal candidiasis caused by the yeast *C. albicans* had also been explored.

Anti-Cancer Activity

The bioactive secondary metabolites present in seaweeds are reckoned to be active against different cancer cell lines. The anti-cancer activities of polysaccharides isolated from seaweeds, against various cell lines, were studied and the details are given in **Table 8.1**.

Table 8.1: Anti-cancer Activities of Seaweed Polysaccharides Against Various Cell Lines

Seaweed Species	Cell Line	Type of Cancer
Sargassum plagiophyllum	HepG2	Liver cancer
Sargassum plagiophyllum, Turbinaria conoides, Acanthophora spicifera	A549	Lung cancer
Sargassum polycystum, S. wightii	MCF-7; MDA-MB-231	Breast cancer
Sargassum cinereum, S. *longifolium*	HCT-15; HCT 116; Caco-2	Colon cancer
Sargassum wightii, Enteromorpha compressa, Acanthophora spicifera	HT-29	Colorectal cancer

Different nanoparticles, synthesized using seaweed extracts, were examined for their cytotoxicity against various forms of cancer as in **Table 8.2**.

Table 8.2: Cytotoxic Activity of Seaweed Nanoparticles on Various Cancer Cell Lines

Nanoparticles	Seaweed Species	Cell Line & Type of Cancer
Silver and zinc oxide	*Gracilaria edulis*	PC3 (Prostate cancer)
Silver and platinum	*Padina gymnospora*	A549 (Lung cancer)
Silver	*Padina tetrastromatica, Gracilaria corticata*	MCF-7 (Breast cancer)
Silver	*Sargassum longifolium*	Hep-2 (Cervical cancer)
Silver	*Turbinaria ornata*	Y79 (Retinoblastoma)

Extracts of various seaweed species were investigated for their antiproliferative activity on different cancerous cell lines and the details are provided in **Table 8.3**.

Table 8.3: Antiproliferative Activity of Seaweed Extracts on Various Cancer Cell Lines

Seaweed Species	Cell Line	Type of Cancer
Caulerpa peltata, Padina gymnospora, Gelidiella acerosa, Sargassum wightii	A549, HCT-15, MG-63, and PC-3	Lung cancer, Colon cancer, Bone cancer, Prostate cancer
Turbinaria ornata, Acanthophora spicifera, Kappaphycus alvarezii, Gracilaria corticata	A549, HCT-15, MG-63, and PC-3	Lung cancer, Colon cancer, Bone cancer, Prostate cancer
Ulva fasciata	HT-29, Hep-G2, and MCF-7	Colon cancer, Liver cancer, Breast cancer
Sargassum sp.	MCF-7 and Hep-2	Breast cancer, Liver cancer

Various bioactive compounds such as polyphenols and terpenes, extracted from macro algae, were evaluated for their anti-tumorigenic potential as follows:

Bioactive Compound	Cell Line
Polyphenols	Human pancreatic cancer cell lines (MiaPaCa-2, BXPC-3,Panc-1, and Panc-3.27); Lung cancer cell line (A549)
Terpenes	Triple-negative breast cancer (TNBC) cell line (MDA MB-231); Lung cancer cell line (A549)

Anti-Diabetic Activity

Crude extracts of seaweed *Turbinaria ornata* were examined for their anti-diabetic properties using enzyme inhibitory assays. Several extracts (petroleum ether, ethyl acetate, methanol, acetone etc.) of seaweeds *Sargassum polycystum* and *S. wightii* were studied for their anti-diabetic properties using in vitro enzyme inhibitory assays. The tyrosine phosphatase-1B inhibitory activity of fridooleanene triterpenoids and labdane diterpenoids derived from seaweed *S. wightii* was investigated.

Anti-Hypertensive Activity

Ethyl acetate extract and ethyl acetate: methanol extract of seaweed *S. wightii* were examined for their angiotensin converting enzyme inhibition potential, for use as anti-hypertensive therapeutic and found that the biological properties of the extracts were due to existence of phlorotannin compounds and O-heterocyclic analogues.

Anti-Inflammatory Activity

Crude extracts of *Gracilaria opuntia*, *Turbinaria ornata*, *T. conoides*, *Kappaphycus alvarezii, Sargassum wightii* etc. were evaluated for their anti-inflammatory potential. The studies pointed out that anti-inflammatory property of seaweeds was attributed by the presence of bioactive compounds such as azocinyl morpholinone, fucoidan, oxocine carboxylate cyclic ether, 2H-chromen derivative, Aryl polyketide lactones, furanyl compounds etc.

Neuroprotective Activity

The anti-amyloidogenic potential of marine seaweed *Padina gymnospora* was evaluated and found that the bioactive compound alpha bisabolol present in seaweed might be responsible for the cholinesterase inhibition. The neuroprotective potential of fucoidan, isolated from brown seaweed *Turbinaria decurrens* was investigated. The anti-Alzheimer potential of *Sargassum wightii* was examined and it was concluded that the promising cholinesterase inhibitory activity was most likely due to the existence of large quantities of terpenoids. The neuroprotective potential of seaweed *Gelidiella acerosa* against Aβ 25–35 peptide mediated toxicity was evaluated under in vivo conditions.

Hepatoprotective Activity

The hepatoprotective property of fucoidan isolated from *Turbinaria decurrens* was evaluated. The effects of crude extract of *Ulva lactuca* on d-galactosamine (d-Gal)-induced DNA damage, hepatic oxidative stress, and necrosis in rats were investigated. The acetone extract of *Turbinaria ornata*, *Gracilaria crassa* and *Laurencia papillosa* were evaluated for hepatoprotective activities and for use in pharmaceutical applications. The hepatoprotective activity of ethanol extract of *Hypnea musciformis* against liver damage induced by carbon tetrachloride in rats was studied.

Antioxidant Activity

Crude extracts from about forty seaweed species were evaluated for antioxidant activity. Some of the seaweed species studied include *Halimeda tuna, Turbinaria conoides, Gracilaria foliifera, Enteromorpha compressa, Caulerpa veravelensis, Hypnea musciformis, Jania rubens, Chaetomorpha linum, Gelidiella acerosa, Kappaphycus* alvarezii, *Portieria hornemannii, Spyridia hypnoides, Asparagopsis taxiformis, Centroceras clavulatum*, *Padina pavonica* etc. Sulfated polysaccharide purified from seaweeds like *Sargassum swartzii*, *S. tenerrimum*, *Turbinaria* *conoides* etc. were evaluated for antioxidant potential. Various polysaccharides investigated include fucoidan, alginate, laminaran etc.

Globally, numerous studies have established the presence of phenolic compounds in seaweeds and have demonstrated their antioxidant properties. Methanolic extracts of green seaweeds *Caulerpa racemosa, C. peltata, C. taxifolia, Codium elongatum, and Chlorodesmis fastigiata w*ere investigated for antioxidant properties using various in vitro assays. The aryl meroterpenoids derived from *Hypnea musciformis* were examined for their potential antioxidative properties.

Anticoagulant Activity

The anticoagulant activity of polysaccharides and peptides derived from seaweeds like *Porphyra yezoensis*, *Spyridia hypnoides*, *Gracilaria filiforms, Turbinaria conoides, Enteromorpha compressa etc.* were examined by various studies.

Biomedical/ Bioengineering Applications

The potential of collagen-fucoidan blend films, synthesized from seaweed *Laminaria japonica* was examined for tissue regenerative properties. Phloroglucinol, a phenolic derivative extracted from *Sargassum wightii, S. tenerrimum* and *Turbinaria conoides* was examined for biomedical properties. Seaweed polysaccharide-based copolymers were synthesized and the self-assembly, degradation, and in vitro hydrophobic/hydrophilic drug release behaviour were studied to ascertain their use as biomaterials. The efficacy of silver nanoparticles synthesized using seaweed *Acanthophora spicifera*, against biofilm forming pathogens was evaluated using microtiter plate assay and antimicrobial assay for use as a disinfectant for biomedical devices.

Disease Control

Green synthesized nanoparticles have been suggested as extremely effective and eco-friendly larvicidal against mosquito vectors. Nanoparticles prepared using various seaweed species were assessed for their larvicidal property against several mosquito vectors as in **Table 8.4**.

Table 8.4: Seaweed Nanoparticles Larvicidal Property Against Mosquito Vectors

Seaweed Species	Vector
Caulerpa scalpelliformis	*Culex quinquefasciatus* (Filariasis)
Hypnea musciformis	*Aedes aegypti* (Dengue)
Sargassum muticum	*Aedes aegypti (Dengue), Anopheles stephensi (Malaria), and Culex quinquefasciatus (Filariasis)*
Sargassum polycystum	*Anopheles stephensi* (Malaria), *Aedes aegypti* (Dengue), *Culex tritaeniorhynchus* (Japanese encephalitis)
Ulva lactuca	*Anopheles stephensi* (Malaria)
Turbinaria ornata	*Aedes aegypti* (Dengue), *Anopheles stephensi* (Malaria), and *Culex quinquefasciatus* (Filariasis)
Gracilaria edulis	*Culex quinquefasciatus* (Filariasis)

Different plant-based natural products were used as insecticides to control various insect pests and vectors. The crude extract of seaweed *Halymenia palmate* was assessed for larvicidal activity against dengue vector *Aedes aegypti*. The effectiveness of combinations of different solvent extracts of *Gracilaria firma* to control *Aedes aegypti* were studied. The effectiveness of crude extract of seaweed *Sargassum wightii*, in combination with *Bacillus thuringiensis* var. *israelensis*, in controlling malaria vector *Anopheles sundaicus* Liston was also determined.

The anti-plasmodial activity of the extracts of *Caulerpa toxifolia, C. peltata, Chaetomorpha antennina, Gracilaria verrucosa, Hypnea espera* etc. was investigated. The anti-plasmodial property of fucosterol and polyherbal preparations from the methanolic extracts of mangrove plants and seaweeds was also investigated.

Food and Nutrition

The effectiveness of seaweed supplementation in enhancing the nutritional quality of various food products were examined as follows:

Food Products	Seaweed Species/ Products
Spice adjunct	*Kappaphycus alvarezii*
Fish jerky	*Sargassum wightii*
Chicken sausages	Semi-refined carrageenan
Biscuits	*Caulerpa racemosa*

Numerous studies have examined the ability of seaweed extracts to improve food preservation and storage, thereby ensuring quality of foods. To explore the potential of seaweed as a biopreservative in seafood industry, methanolic extract of *Gracilaria verrucosa* was incorporated into ice and the quality and safety of Indian mackerel during storage was tested. The capability of seaweeds to enhance the storage stability of C20-22n-3 fatty acid methyl ester was examined by analyzing the combined effect of ethyl acetate fractions *of Kappaphycus alvarezii, Hypnea musciformis and Jania rubens*.

Films prepared from seaweeds acts as a potential food packaging material. Seaweed polysaccharides have exhibited film forming properties. Studies have explored developing edible films from the polysaccharides extracted from seaweeds like *Kappaphycus alvarezii*, *Ulva fasciata*, *Acanthophora spicifera* etc. Development of cellulose sheet, extracted from *Ulva fasciata*, deposited with zinc oxide nanorod clusters was attempted to explore the application in food packaging.

The potential use of seaweed species such as *Sargassum wightii*, *S. myriocystum*, *S. plagiophyllum*, *Caulerpa spp.*, *Anthophycus longifolius*, *Spatoglossum asperum*, *Stoechospermum polypodioides*, *Gracilaria corticata*, *Grateloupia indica* etc., as functional food supplements, have been investigated. The sulfated polygalactans isolated from *Kappaphycus alvarezii* and *Gracilaria opuntia* were evaluated for their potential as functional food ingredient in nutraceutical products. The prebiotic activity of polysaccharide extracted from seaweeds such as *Sargassum wightii*, *Enteromorpha compressa*, *Acanthophora spicifera* etc. was evaluated for formulating functional food ingredients

8.2 AGRICULTURE APPLICATIONS

Numerous studies assessed the effects of application of sap extracted from different seaweed species on various crops/ plants. Seaweed species investigated extensively include *Kappaphycus alvarezii*, *Gracilaria edulis*, and *Sargassum wightii* and the details of the major studies are given in **Table 8.5**.

Table 8.5: Effects of Seaweed Sap Application on Various Crops/ Plants

Sl. No.	Seaweed Species	Effects on Crops/ Plants	
		Crops/ Plants	Effects
1	*Ascophyllum nodosum*	Soybean	Growth & development
2	*Enteromorpha intestinalis*	Soybean	Seed germination, yield, biochemical parameters & pigment characteristics
3	*Gelidiella acerosa*	Brinjal (*Solanum melongena*)	Germination
4	*Gracilaria dura*	Wheat	Drought tolerance
5	*Gracilaria edulis*	Wheat	Yield & quality improvement
		Rice	Growth, productivity & quality enhancement
		Sugarcane	Productivity, sugar content
		Sesame and soybean	Productivity
		Maize	Growth, yield, nutrient uptake, productivity & quality
		Finger millet	Somatic embryogenesis & plant regeneration
		Tomato (*Lycopersicon esculentum*)	Production of transgenics with high frequency and survivability
		Ashwagandha (*Withania somnifera)*	Growth characteristics and major withanolides production in hairy root culture
6	*Gracilaria foliifera*	*Alternanthera sessilis*	Plant regeneration
7	*Gracilaria salicornia*	Brinjal (*Solanum melongena*)	Germination
		Bacopa monnieri	In vitro regeneration
8	*Kappaphycus alvarezii*	Wheat	Growth & yield
		Rice	Growth, productivity, quality enhancement & yield
		Sugarcane	Productivity, sugar content
		Sesame and soybean	Productivity
		Aromatic plants	Productivity and essential oils
		Maize	Productivity, quality, growth & nutrient uptake

		Tomato (*Lycopersicon esculentum*)	Growth, yield, quality & nutrient uptake, defence-related genes
		Potato	Growth, yield & quality improvement
		Green gram (*Phaseolus radiata*)	Yield & seed quality
		Bacopa monnieri	In vitro regeneration
		Picrorhiza kurroa	Mass propagation
9	*Padina boergesenii*	Finger millet	Somatic embryogenesis & plant regeneration
		Foxtail millet	Growth, development, biochemical characteristics and yield
		Brinjal (*Solanum melongena*)	Germination
10	*Padina gymnospora*	Brinjal (*Solanum melongena*)	Germination
11	*Sargassum johnstonii*	Tomato (*Lycopersicon esculentum*)	Growth, yield, quality & biochemical constituents
12	*Sargassum myriocystum*	Black gram (*Vigna mungo*)	Germination, growth & biochemical constituents
13	*Sargassum wightii*	Wheat	Growth & yield
		Tomato (*Lycopersicon esculentum*)	Production of transgenics with high frequency and survivability
		Ashwagandha (*Withania somnifera)*	Growth characteristics and major withanolides production in hairy root culture
14	*Ulva flexuosa*	Tomato	Yield & nutritional quality

8.3 ANIMAL HUSBANDRY APPLICATIONS

Seaweeds are having the potential to manage diseases in aquaculture. The polysaccharide fucoidan, extracted from seaweed *Sargassum wightii*, was supplemented with the diets of post larvae and juvenile *Penaeus monodon* and was examined for immunity/ resistance against shrimp pathogens such as White Spot Syndrome Virus (WSSV) and *Vibrio parahaemolyticus*. The immunomodulatory response of dietary fucoidan, extracted from seaweed *S. wightii*, on the fingerlings of shark catfish *Pangasianodon hypophthalmus* and Indian carp *Labeo rohita*, against the bacteria *Aeromonas hydrophila* was studied. Immunostimulation by polysaccharides extracted from seaweed *Padina gymnospora* in the common carp *Cyprinus carpio* against bacterial pathogens *Aeromonas hydrophila* and *Edwardsiella tarda* was also observed.

Antibacterial and antiviral activities of extracts from seaweeds *Sargassum duplicatum, S. wightii, Asparagopsis sp., Hypnea musciformis, Gracilaria edulis, Cystoseira trinodis, Gelidium pusillum, Caulerpa racemosa, Enteromorpha flexuosa* etc. against shrimp pathogens were evaluated. The antibacterial properties of petroleum ether, dichloromethane, chloroform, ethanol and aqueous extracts of seaweeds *Gracilaria folifera*, *Sargassum longifolium*, *S. cinereum*, *Padina gymnospora* etc. on tilapia *Oreochromis mossambicus* were assessed against fish pathogens such as *Aeromonas salmonicida*, *Pseudomonas aeruginosa* etc.

8.4 INDUSTRIAL APPLICATIONS

Biofuels

Many studies have attempted sequential production of biofuel and a stream of other economically important products from seaweeds, mostly adopting a biorefinery approach. The fresh and spent biomass of various seaweed species were investigated and among them *Ulva spp.* was most extensively studied, followed by *Gracilaria* spp. and *Kappaphycus alvarezii*. Various seaweed species utilized for biofuel production and the resultant products in the major studies are given in **Table 8.6**.

Table 8.6: Seaweed Species Utilized for Biofuel Production and Products Obtained

Sl. No.	Seaweed Species	Biofuel & Other Products
1	*Caulerpa racemosa*	Biodiesel
2	*Codium tomentosum*	Bioethanol
3	*Enteromorpha compressa*	Biodiesel
4	*Gelidium pusillum*	Liquid fertilizer, pigments, lipids, agar, cellulose, bioethanol
5	*Gelidiella acerosa*	Liquid fertilizer, pigments, lipids, agar, cellulose, bioethanol
6	*Gracilaria corticata*	Pigments, crude lipid, agar, soil conditioner, liquid fertilizer, bioethanol
7	*Gracilaria dura*	Liquid fertilizer, pigments, lipids, agar, cellulose, bioethanol
8	*Gracilaria edulis*	Biodiesel
9	*Gracilaria verrucosa*	Agar, bioethanol, biodiesel
10	*Kappaphycus alvarezii*	Biofertilizer, bioethanol
11	*Padina tetrastromatica*	Bioethanol
12	*Rhizoclonium sp.*	Bioethanol
13	*Sargassum ilicifolium*	Bioethanol
14	*Sargassum tenerrimum*	Bio-oil
15	*Sargassum wightii*	Bioethanol
16	*Stoechospermum marginatum*	Biodiesel
17	*Turbinaria ornata*	Bioethanol
18	*Ulva fasciata*	Liquid fertilizer, lipid, ulvan, cellulose, bio-oil, bioethanol, biodiesel
19	*Ulva lactuca*	Crude protein, liquid fertilizer, lipid, ulvan, cellulose bioethanol, biodiesel, biomethane
20	*Ulva linza*	Biodiesel
21	*Ulva reticulate*	Biodiesel
22	*Ulva rigida*	Biodiesel
23	*Ulva tubulosa*	Biodiesel

Wastewater Treatment
The major seaweeds species investigated for their potential to treat wastewater are *Ulva spp*., *Gracilaria spp*., *Sargassum spp*., *Padina spp*. and *Kappaphycus alvarezii*. The details of various wastewater treatment studies utilizing different seaweed species/ products are presented in **Table 8.7**.

Table 8.7: Wastewater Treatment Potential of Different Seaweed Species/ Products

Sl. No.	Seaweed Species	Product	Potential Use
1	*Caulerpa racemosa*	Seaweed biomass	Biosorption of toxic heavy metals Cr(III), Cr (VI), Pb(II) and Cd(II)
2	*Caulerpa scalpelliformis*	Seaweed biochar	Remediation of Remazol dyes Removal of Reactive Yellow 81 dye
3	*Enteromorpha sp.*	Activated carbon from seaweed	Adsorption of Malachite Green dye
		Seaweed biomass	Biosorption of hexavalent chromium
4	*Gracilaria corticata*	Seaweed biomass	Biosorption of Methylene Blue dye
		Activated carbon from seaweed	Removal of Crystal Violet dye
5	*Gracilaria edulis*	Seaweed biomass	Removal of Reactive Blue 19 dye
		Native and ethanol modified seaweed biomass	Biosorption of Rhodamine B dye
6	*Gracilaria salicornia*	Native and ethanol modified seaweed biomass	Biosorption of Rhodamine B dye
7	*Hypnea valentiae*	Seaweed biomass	Biosorption of cadmium
8	*Kappaphycus alvarezii*	Native and ethanol modified seaweed biomass	Biosorption of Rhodamine B dye
		Seaweed biomass	Removal of phosphate
		Seaweed biomass	Removal of Cu (II), Cd(II), Ni(II) & Pb(II)
		Seaweed biomass	Biosorption of Methylene Blue dye
9	*Lobophora variegata*	Seaweed biomass chemically modified by $CaCl_2$	Biosorption of Ni(II)
10	*Padina gymnospora*	CdO- ZnO nanoparticles using seaweed	Photocatalytic degradation of industrial effluents
		Ag-ZnO nanoparticles using seaweed	Photocatalytic degradation and decolorization of Methylene Blue and Reactive Blue 198 dyes

Sl. No.	Seaweed Species	Product	Potential Use
11	*Padina tetrastromatica*	ZnO nanoparticles using seaweed	Photodegradation of Drimarene Turquoise Blue and Methylene Blue dyes
		Au nanoparticles using seaweed	Degradation of hazardous organic dyes like Eosin Yellow and Congo Red
12	*Sargassum myriocystum*	Seaweed biomass	Removal of Cr (VI)
13	*Sargassum swartzii*	Seaweed biomass	Removal of Malachite Green dye
14	*Sargassum tenerrimum*	Functionalized graphene nanosheets from seaweed	Removal of F^- from fluoride contaminated ground water
15	*Sargassum wightii*	Seaweed biomass	Biosorption of toxic heavy metals Cr(III), Cr(VI), Cd(II) and Pb(II)
		Seaweed biomass	Removal of praseodymium ions
		Seaweed biomass	Removal of Brilliant Green dye
16	*Turbinaria conoides*	Seaweed biomass	Removal of praseodymium ions
17	*Ulva fasciata*	FeS/Fe (0) functionalized graphene nanocomposite from seaweed	Filtration of complex wastewater feeds
18	*Ulva flexuosa*	Ag nanoparticles using seaweed	Antibacterial agents for *in vitro* water disinfection
19	*Ulva lactuca*	Algal biochar	Remediation of remazol dyes
		Ag nanoparticles using seaweed	Photocatalytic degradation of Methyl Orange dye
		Crystalline nanocellulose synthesized from seaweed	Biosorption of tetracycline hydrochloride
20	*Ulva reticulata*	Algal biochar	Remediation of remazol dyes

8.5 OTHER APPLICATIONS

The production of bioplastic from seaweed *Kappaphycus alvarezii* was explored. Cotton fabrics coated with seaweed (*Padina gymnospora*) based silver nanoparticles were investigated for antibacterial activity and UV-protection property. The potential of Fe_3O_4/Fe doped graphene nanosheets from *Sargassum tenerrimum* was investigated as a sustainable replacement for existing precious metal-based oxygen reduction reaction catalysts in an alkaline fuel cell. Graphene, prepared from seaweed *Ulva fasciata*, coated with polyaniline nanofiber was investigated for energy storage applications. The extract of seaweed *Sargassum wightii* was evaluated for its potential as a cost effective and environment friendly sensitizer for ZnO photoanode-based solar cell.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 DISCUSSION AND CONCLUSIONS

Seaweeds are often reckoned as the '*wonder plants of the sea*' as well as the '*unsung hero of the ocean*'. They are unique regenerative marine resource with varied economic applications, ecological significance, nutritional benefits and biological properties. In the wake of the copious benefits offered by seaweeds, it is inappropriate to term them as weeds. Hence, the term 'seaweed' is in fact a misnomer.

Seaweeds are a good source of nutrients and bioactive primary and secondary molecules. The macronutrients and micronutrients present in seaweeds have the potential to meet the dietary requirements of humankind. Globally, availability of freshwater and arable land is some of the critical factors limiting food production, thus posing a serious challenge for meeting the dietary requirements of growing population. Production of seaweeds does not rely on scarce resources such as freshwater and arable land and have lesser carbon footprint, in comparison with terrestrial plants. Hence, seaweeds could be utilized as a sustainable nutritional source to fulfill the ever-increasing dietary requirements of the global population. However, considering the current production levels of seaweeds, in order to cater to the global nutritional requirements, seaweed aquaculture should be expanded by leaps and bounds; for which the prevailing technological and economic barriers should be duly contemplated. While utilizing as an alternative nutrient source, the food safety issues related to seaweed need to be addressed. It is of paramount importance to ensure that seaweed is devoid of toxic contaminants like heavy metals and pathogens.

The versatile health beneficial bioactive molecules present in seaweeds exhibits interesting biological activities. Due to diverse therapeutic activities like antioxidant, antibacterial, antiviral, anti-tumor, anti-diabetic, anti-hypertensive, anti-inflammatory, neuroprotective, hepatoprotective, anticoagulant etc., the bioactive compounds derived from seaweeds offers a plethora of possibilities for manufacturing wide range of novel high-value products such as nutraceuticals, functional foods, cosmeceuticals, pharmaceuticals, specialty chemicals etc. Seaweed bioactive compounds could be ideal alternative drug candidates, due to the growing dilemma of drug resistance. However, aspects such as efficacy, safety, mode of action etc. need to be established before commencing the commercial production of seaweed-based pharmaceuticals.

Seaweeds are highly ecologically relevant due to the multiple ecosystem services offered by them. Among the valuable ecosystem services provided by seaweeds, climate mitigation and nutrient bioremediation are the two major services. Climate change mitigation and adaptation by seaweeds are achieved through sequestration of carbon. Reducing methane emission in ruminants by seaweed supplementation in cattle feed, replacing fossil fuels by seaweed-based biofuel, replacing polluting plastics with biodegradable bioplastics etc. have the potential to combat climate change and limit environmental pollution. Typically, seaweeds are valued for their biomass and food trading values only. The value of several ecosystem services offered by seaweeds, including biomitigation is, however, not recognized. The value of ecosystem services provided by seaweeds is quite significant and should be considered to provide financial incentives to the farmers/ entrepreneurs to promote seaweed aquaculture. Seaweed farming may also be included in the Nationally Determined Contributions (NDCs), under the Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC).

Seaweeds also have the potential to contribute towards sustainable futures. Seaweeds could be used to address many of the 'Development Challenges' directly linked to the United Nations Sustainable Development Goals (SDGs). The macronutrients and micronutrients present in seaweeds have the potential to meet the dietary needs of the population and thus could help to achieve SDG 2, which involves ending hunger, attaining food security and enhancing nutrition. The nutraceuticals and pharmaceuticals manufactured from the bioactive compounds of seaweeds could play a vital role in promoting human wellbeing and thus could support achieving SDG 3, which envisage ensuring a healthy life. With their active participation in seaweed farming and processing, the women from coastal communities could be empowered and this could help to achieve SDG 5, which envisages achieving gender equality and empowering women and girls. The carbon offsetting capability of seaweeds, reduction of methane from cattle and biofuel has a role to play in achieving SDG 13, which involves actions to combat climate change.

The natural stock of seaweeds in India have been depleting fast, due to overharvesting coupled with habitat destruction. This decline in natural stock entails ecosystem-based sustainable management and restoration of seaweed resources. Thus, seaweed harvesting need to be regulated adequately and best practices should be established. The fisherfolk involved in seaweed collection should be educated/ trained accordingly. Guidelines, protocols and programmes need to be designed for seaweed habitat restoration. Private industries/ corporates should be encouraged to invest in restoration of natural stock of seaweed. The creation of 'Restore Fund' by Apple Inc., with an investment of USD 200 million, for accelerating natural solutions to climate change is a notable example. Investing in habitat restoration can provide jobs to the coastal population and other benefits to the society. All the stakeholders, including the fisherfolk involved in seaweed collection, should be taken into confidence while carrying out the restoration activities.

In India, seaweed farming activities are mostly carried out by the coastal population and are dominated by fisherwomen. Expansion of seaweed aquaculture could help in generation of rural employment and empowerment of women. As per estimates, the farming of seaweeds could provide jobs to about 15 individuals per hectare. Since India has a vast coastline of 8118 km and an exclusive economic zone (EEZ) of 2.02 million sq km, even farming of seaweeds in a fraction of the available area could provide huge employment opportunities. Seaweed farming also has the potential to significantly increase the income of coastal population and could contribute considerably towards achieving the target of the Government of India of doubling farmer's income. Thus, seaweed could act as an engine of employment generation in the coastal areas and also as a tool to achieve gender mainstreaming in India.

Even though India is blessed with a vast coastline, the quantity of seaweeds currently produced in India is very low. The contribution of India to global farmed aquatic algae production is also insignificant (approximately 0.02%). At present, very limited number of seaweed species are commercially farmed in India, predominantly at the near-shore areas of Tamil Nadu and Gujarat and to a smaller extent in Maharashtra and Odisha. To augment seaweed production, diversification in terms of area, species and culture techniques should be carried out. Strain development is also very critical for developing a sustainable seaweed aquaculture.

Seaweed production in India should be expanded by initiating large-scale seaweed aquaculture in the coastal waters along the islands of Andaman and Nicobar and Lakshadweep. For sustainable production and optimal utilization of resources, seaweeds should be integrated in aquaculture approaches like Integrated Multi-Trophic Aquaculture (IMTA). Apart from near-shore farming, seaweed cultivation in open ocean and land-based systems should also be explored. Viable upstream production technologies need to be developed for taking up open ocean seaweed aquaculture. Currently, high infrastructure and management costs are limiting the land-based intensive seaweed cultivation in ponds, tanks and raceways. In order to achieve viability, biomass produced through land-based production systems should be utilized for production of high-value low-volume products. However, it is worthwhile to note that recently the PMMSY scheme of Govt. of India has provided necessary impetus for promoting aquaculture of seaweeds in India.

Cultivation of seaweeds is increasingly threatened by a variety of stressors including climate change. These stressors directly affect the physiology, growth, reproduction, and survival of seaweeds. Seaweeds are also vulnerable to diseases caused by biotic as well as abiotic factors. Hence, development of appropriate breeding strategies and crop selection to safeguard seaweed from temperature induced stress and diseases are crucial. The superior strains, thus developed, will be able to enhance and sustain production of seaweed biomass.

The traditional seaweed processing units in India mostly utilizes seaweed biomass harvested from the wild as the raw material. Reduction in seaweed resources in the wild has resulted in raw material shortage in the processing units. Moreover, the traditional seaweed processing units are operating at cottage level utilizing redundant technologies. Hence, there is an urgent need to reinvigorate the processing units by ensuring raw material availability, technological up-gradation, capital infusion and skill development. Such actions could lead to enhanced productivity, product quality and profitability in the traditional seaweed processing units in India.

Hydrocolloids and plant biostimulants, produced from seaweed genus such as *Kappaphycus, Gracilaria*, and *Gelidium*, are the principal commercial seaweed-based value-added products currently manufactured in India. Nutraceuticals/ functional foods are also being produced, but at a very lesser scale. Commercial scale production of seaweed supplemented animal feed in India is in a nascent stage. In India, only few industries are processing seaweeds; that too for producing very limited value-added products. Also, only a handful of seaweed-based startups are currently operating in India. Thus, serious efforts are required to support entrepreneurship and nurture innovation in the Indian seaweed sector. Product diversification should also be targeted to make the industry more vibrant.

Use of seaweed-based biostimulants in crop cultivation has enormous opportunity in India. Seaweed-based biostimulants and biofertilizer have the potential to increase crop yield by about 20% and reduce the requirement of chemical fertilizer by about 25%, thus improving the economics of crop cultivation. Also, the process of plant biostimulant production is found to have a low carbon footprint. Since seaweeds have the potential to decrease enteric methane emissions by ruminants, incorporation of seaweeds in cattle feed could help to combat climate change and additionally provides health benefits to the cattle. Thus, supplementation of seaweed in cattle feed should be promoted in India, after considering the consumer and animal safety issues.

Currently, downstream processing of seaweed biomass for production of value-added products in India focuses mostly on a single product or at most a couple of products, leaving the residual biomass as waste. This linear approach is resulting in sub-optimal utilization and wastage of the valuable bioresource. It is estimated that, about 70-85% of biomass is wasted in this process. It is imperative to develop and adopt new sustainable processes for complete utilization of seaweeds and to achieve a circular economy. Shifting towards a biorefinery approach, which aims at maximizing the utilization of seaweed biomass through cascading valorization, would be a move in the right direction. The seaweed biorefinery should target production of biofuel (biomethane and bioethanol through anaerobic digestion and fermentation respectively) and high value chemicals/ extracts. Unlike seaweed biorefinery, since the microalgae possess high lipid content, the focus of microalgal biorefinery should be production of biodiesel. As per an estimate, the seaweed requirement to produce 1 kg of bioethanol is 8.48 kg dry biomass and the raw material requirement to produce 1 kg of biodiesel is 6.56 kg dry microalgal biomass. The biorefinery not only improves the economic viability of the products but also reduces the pressure on the environment due to minimal/ nearly zero waste production.

At present, commercial production of seaweed-based value-added products in India is limited to non-fuel products. However, commercial biofuel production from seaweeds offers huge opportunities in the years to come. In order to take up commercial scale biofuel production, farming of seaweed species with high carbohydrate content should be attempted. But, cultivation of seaweed solely for production of biofuel will not be cost-effective. Hence, co-production of biofuel and high-value low-volume products like pharmaceuticals, nutraceuticals, cosmetics, chemicals etc. will have to be explored. However, the sustainability of seaweed-based products should be ascertained by performing life cycle assessment (LCA).

The extraction techniques are having a direct bearing on the structure, composition and properties of the bioactive compounds. In India, extraction of bioactive compounds from seaweeds is currently carried out mainly by conventional technique like solvent extraction. This technique often uses organic solvents, which is detrimental to environment as well as functionality of extracted compounds. In order to overcome this constraint, use of greener natural deep eutectic solvents might be considered. The traditional extraction techniques are constrained with prolonged extraction periods, necessity of high purity solvents, huge solvent evaporation, low extraction yield, high energy consumption etc. The lacuna in the traditional techniques can be overcome by adopting innovative extraction techniques like supercritical fluid extraction, enzyme assisted extraction, microwave and ultrasound assisted extraction, etc. Nearly all of these techniques, often considered as green methods, are characterized with better extraction efficiency, better selectivity for isolation of desired compounds, absence of unwanted reactions during the extraction, superior quality of end product etc.

India depends heavily on the imports of seaweeds/ seaweed-based products. Only about 30% of annual domestic agar requirement and 40% of alginate requirement in India is met by indigenous production. This highlights the urgency to augment domestic production of seaweed/ seaweed-based products to achieve self-sufficiency. For attaining self-sufficiency in agar production in India, about 2380 tons of dry agarophytes such as *Gelidiella acerosa*, *Gracilaria edulis*, *G. crassa*, etc. need to be additionally produced annually. In order to completely meet the annual alginate requirement in India, additional production of more than 6000 tons of dry alginophytes such as *Sargassum spp., Turbinaria spp. and Cystoseira spp.*, etc. need to targeted. The unit value of seaweed-based products imported to India is higher than that of the products exported from India. This indicates a lesser degree of seaweed value-addition in India. Hence, enhancing the extent of value-addition of indigenously produced seaweed products should be targeted.

In India, seaweed value-addition R&D is mainly concentrated at very few public funded R&D laboratories and educational institutions and the research by rest of the organizations/ institutions have been sporadic. It is quite disappointing that in India, even though a large number of research articles are published on seaweed value-addition, few lab-scale technologies are reaching the commercialization stage. There is virtually very little or no support for advancing lab scale technology to pilot scale and further to make it ready for commercial use. The rate at which Indian seaweed value-addition technologies are patented is also very abysmal. Thus, there is a strong need to support seaweed value-addition technology development, and commercialization. It is also necessary to create appropriate collaborations and networks to address the knowledge gaps and for R&D and commercialization of seaweed value-added products. Collaboration among various stakeholders is highly imperative for creating a successful ecosystem for technology development and transfer in the country.

Even though, numerous bioactive compounds have already been extracted and characterized from seaweeds, very few of them have reached the market. The commercial production is mostly hampered by factors such as non-availability of sustainable raw material, structural complexity, lack of efficacy etc. However, the reduction in time to commercialize bioactive compounds, observed in the past decades is a positive change. Dissemination of information pertaining to various bioactive compounds isolated from seaweeds, through free and publicly-accessible databases can play a prominent role in reducing the time for drug discovery. Currently, the 'Seaweed Metabolite Database' (SWMD) created by Department of Bioinformatics, Sri Ramachandra Institute of Higher Education and Research, Chennai provides information about seaweed-based bioactive compounds and their biological activity.

Finally, to boost seaweed production and to effectively create a sustainable seaweed industry in India, formulation of policies, programmes and proactive management plans are of utmost importance. Relevant legislations and programmes in the areas of commercial farming, biosecurity, value-addition, marketing, R&D, innovation etc. need to be enacted and implemented on priority basis. Necessary guidelines, regulations, standards, code of best practices, certification etc. also need to be formulated for creating a sustainable seaweed industry.

9.2 RECOMMENDATIONS

Seaweed is a sunrise sector and offers an ocean of opportunities. Value-addition of seaweed is inextricably intertwined with aspects such as seaweed farming and raw material availability, research and technology development, policy etc. Hence, holistic recommendations are formulated for establishing sustainable seaweed value chains and eventually for Indian seaweed industry to become 'Atmanirbhar' or self-reliant. The recommendations are envisaged for implementation in three different time frames i.e., short-term (< 3 years), medium-term (4-7 years) and long-term (> 7 years).

SHORT-TERM
Raw Material • Promote adoption of seaweed in integrated multi-trophic aquaculture (IMTA) • Organize the fisherfolk/coastal population to form Self-Help Groups (SHGs) and further create a Producer Company for large scale seaweed farming • Demarcate suitable areas across the coastline for seaweed aquaculture • Prepare an action plan for expanding commercial scale seaweed aquaculture to the Islands of Lakshadweep and Andaman and Nicobar
Value-Addition • Enhance production of hydrocolloids (agar, alginate & carrageenan) and plant biostimulants to reduce the dependence on imports and to achieve self-reliance • Encourage supplementation of seaweed in cattle feed to reduce enteric methane emissions • Support traditional seaweed processing units/ industries by capital infusion and technology upgradation
Policy • Prepare and adopt a 'National Seaweed Policy' for creating a sustainable and resilient seaweed industry in India • Formulate guidelines for leasing of natural water bodies for seaweed aquaculture • Provide crop insurance to seaweed farmers/ entrepreneurs against disease outbreak, predation, natural calamities etc. • Provide a minimum assured price from time to time for seaweeds • Support/compensate seaweed farmers for the ecosystem services provided by seaweeds and for the role in combating climate change

- Support technology demonstration projects to establish the feasibility of technologies developed by Indian R&D/ academic institutions and to instill confidence in the entrepreneurs
- Create a 'Technology Adoption Fund' for supporting entrepreneurs to adopt indigenously developed seaweed-based technologies and to mitigate technology risks
- Support seaweed-based startups by mentoring, providing seed fund, market access etc.
- Create a digital platform "India Seaweed Network" for the exchange of ideas and to promote cooperation and synergy between all the stakeholders
- Launch a 'Seaweed Grand Challenge Programme' to attain solutions for important problems in the sector
- Include seaweed in the approaches to attain the goals/ targets of Sustainable Development Goals
- Encourage private industries/ corporates to invest in restoring/ replenishing natural stock of seaweed

MEDIUM-TERM

Raw Material

- Establish seed banks for seaweeds in Public-Private Partnership (PPP) mode
- Form a Section 8 company (non-profit company) for production and distribution of quality seed materials to seaweed farmers
- Promote large scale industrial seaweed cultivation, especially in the Islands of Andaman and Nicobar and Lakshadweep
- Explore land-based farming of seaweeds for production of high-value products
- Develop robust, cost-effective, upstream production technologies for open ocean seaweed aquaculture
- Promote farming of seaweeds with high carbohydrate content, such as *Ulva*, for biofuel production along with production of other value-added products

- Promote cultivation of indigenous seaweed species like *Monostroma*, *Caulerpa lentillifera*, *Porphyra* etc. for food/ feed application, *Gracilaria dura*, *G. edulis*, *Gelidiella acerosa*, *Sargassum wightii* etc. for hydrocolloid production and *Asparagopsis taxiformis* for cattle feed supplement production
- Develop seaweed strains that are resilient to climate change, disease resistant and with higher growth rates
- Develop new strains of seaweeds with high concentration of desired bioactive molecules

Value-Addition

- Provide necessary support for commercial production of seaweed-based functional foods, nutraceuticals and cosmetics
- Establish a consortium of government, industry and R&D institutions to work in a mission mode for developing large scale seaweed farming and processing technologies
- Adopt a sequential biorefinery approach for manufacturing seaweed value-added products
- Enhance biofuel production efficiency by developing effective enzymes for seaweed hydrolysis and bacterial strains for fermentation process
- Adopt innovative extraction techniques like supercritical fluid extraction, enzyme assisted extraction, subcritical water extraction, microwave assisted extraction, ultrasound assisted extraction, pressurized liquid extraction, etc. for extracting bioactive compounds
- Adopt green chemistry in the production of seaweed value-added products
- Develop unique sustainable protocols for downstream processing of seaweeds to produce products with high yield and purity

Research and Technology Development

- Conduct priority research on bioprospecting for novel bioactive compounds from seaweeds
- Encourage complete isolation and characterization of polyphenols, peptides, polysaccharides, amino acids, and materials with probiotic or prebiotic properties
- Conduct multi-disciplinary dietary intervention studies on the characterized seaweed bioactive compounds

- Establish incubation centers and accelerators for providing necessary support for validation and up-scaling of seaweed value-addition technologies developed by startups
- Create 'Centre of Excellence in Seaweed Bioproducts Development' at R&D institutions and academic institutions
- Support R&D for producing innovative products such as biomaterials from seaweeds
- Provide financial support for upscaling of lab scale technologies to pilot scale and pilot scale technologies to ready for commercialization stage
- Create a knowledge platform for technology development and commercialization comprising national and international collaborations/ partners

Policy

- Establish 'Seaweed Parks' at Gujarat and in the Islands of Andaman and Nicobar and Lakshadweep, in addition to Tamil Nadu, by integrating various activities such as seaweed farming, downstream processing, R&D etc. and create a startup hub
- Create a 'Technology Development Fund' to foster technology development and innovation
- Popularize consumption of seaweed by developing seaweed-based products suitable for the Indian palate and by community outreach
- Create necessary market linkages for the products manufactured indigenously from seaweeds
- Integrate seaweed into national biofuel policy/ programme
- Attract foreign investments in seaweed sector

LONG-TERM

- Support clinical trials and commercial production of seaweed-based pharmaceuticals
- Provide necessary support for large scale commercial production of seaweed-based biomaterials such as films, fibers etc.
- Support large scale industrial production of seaweed-based bio-energy

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ANNEXURE - 1

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4.	Dr. Arup Ghosh, Sr. Principal Scientist, CSIR-Central Salt and Marine Chemicals Research Institute, (CSIR-CSMCRI), Bhavnagar, Gujarat
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9.	Prof. Alka Mehta, Professor, School of Biosciences and Technology, VIT, Vellore, Tamil Nadu
10.	Dr. A. Thahira Banu, Assistant Professor, Department of Home Science, The Gandhigram Rural Institute, Gandhigram, Dindigul District, Tamil Nadu
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16.	Prof. R. Dinakaran Michael, Former Dean-Life Sciences, Vels Institute of Science, Technology and Advanced Studies, Chennai, Tamil Nadu
17.	Dr. G. Immanuel, Associate Professor, Marine Natural Products Laboratory, Centre for Marine Science and Technology, Manonmaniam Sundaranar University, Kanyakumari District, Tamil Nadu
18.	Dr. P. Senthilkumar, Assistant Professor, PG and Research Department of Biotechnology, Kongunadu Arts and Science College, Coimbatore, Tamil Nadu

19.	Dr. D. Radhika, Head, Department of Zoology, V.O. Chidambaram College, Tuticorin, Tamil Nadu
20.	Dr. V. Ganesh Kumar, Associate Professor, Centre for Ocean Research, Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu
21.	Dr. Sundaram Ravikumar, Professor & Head, Department of Biomedical Sciences, Alagappa University, Karaikudi, Tamil Nadu
22.	Dr. P. Anantharaman, Professor & Dean, Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai, Tamil Nadu
23.	Dr. Putan Singh, Principal Scientist, ICAR-Indian Veterinary Research Institute (ICAR-IVRI), Izatnagar, Uttar Pradesh

ANNEXURE - 2

Major Institutions Involved in Seaweed-Based R&D in India

Sl. No.	Name of Institution
1.	CSIR-Central Salt and Marine Chemicals Research Institute, (CSIR-CSMCRI), Bhavnagar, Gujarat
2.	ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi, Kerala
3.	ICAR-Central Institute of Fisheries Technology (ICAR-CIFT), Kochi, Kerala
4.	Annamalai University, Chidambaram, Tamil Nadu
5.	University of Delhi, Delhi
6.	CSIR-National Institute of Oceanography, (CSIR-NIO), Dona Paula, Goa
7.	MoES-National Institute of Ocean Technology (NIOT), Chennai, Tamil Nadu
8.	Alagappa University, Karaikudi, Tamil Nadu
9.	Bharathidasan University, Tiruchirappalli, Tamil Nadu
10.	Vellore Institute of Technology (VIT), Vellore, Tamil Nadu
11.	Sathyabama Institute of Science and Technology, Chennai, Tamil Nadu
12.	Manonmaniam Sundaranar University, Tirunelveli, Tamil Nadu
13.	Madurai Kamaraj University, Madurai, Tamil Nadu
14.	University of Madras, Chennai, Tamil Nadu
15.	Pondicherry University, Kalapet, Pondicherry
16.	CSIR-Central Food Technological Research Institute (CSIR-CFTRI), Mysuru, Karnataka
17.	Bharathiar University, Coimbatore, Tamil Nadu
18.	ICAR-Central Institute of Fisheries Education (ICAR-CIFE), Mumbai, Maharashtra
19.	ICAR-Central Institute of Brakishwater Aquaculture (ICAR-CIBA), Chennai, Tamil Nadu
20.	Periyar University, Salem, Tamil Nadu
21.	Tamil Nadu Dr. J. Jayalalithaa Fisheries University, Nagapattinam, Tamil Nadu
22.	Indian Institute of Technology (IIT) Madras, Chennai, Tamil Nadu
23.	Institute of Chemical Technology, Mumbai
24.	Indian Institute of Science, Bengaluru
25.	Syed Ammal Engineering College, Ramanathapuram, Tamil Nadu
26.	National Institute of Technology (NIT), Rourkela, Odisha
27.	Gandhigram Rural Institute, Gandhigram, Dindigul District, Tamil Nadu
28.	Central University of Kerala, Periye, Kasaragod, Kerala
29.	St Xaviers College, Palayankottai, Tamil Nadu
30.	PSG College of Technology, Coimbatore, Tamil Nadu
31.	Berhampur University, Berhampur, Odisha
32.	V.O.Chidambaram College, Tuticorin, Tamil Nadu
33.	Scott Christian College, Nagercoil, Tamil Nadu

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