

ROLE OF CMFRI IN SEAWEED MARICULTURE IN INDIA AND DEVELOPMENT OF HIGH-VALUE COMPOUNDS AND BIOMASS UTILIZATION FOR ATMANIRBHAR SWASTH BHARAT

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SEAWEED RESEARCH AND DEVELOPMENT BY CMFRI: PROGRESS AND PROSPECTS

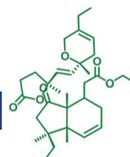
Seaweeds are exploited commercially for their cell wall polysaccharides such as agar, algin, carrageenan etc and for manure, fodder and bioactive metabolites. Seaweed also represents an excellent source of fatty acids, vitamins and minerals. They are marine macrophytic thallophytes consisting of taxonomically distinguished groups of green (Chlorophyta), brown (Phaeophyta) and red (Rhodophyta) seaweeds. These seaweed resources grow best in the tidal and inter-tidal waters along our peninsular coastline and the Andaman-Nicobar and Lakshadweep Archipelagos. India is bestowed with more than 0.26 million tonnes wet harvestable biomass of seaweeds belonging to 700 species. Of these, nearly 60 species are economically important for their polysaccharides and secondary metabolites. Approximately 20,000 tonnes (wet weight) of these resources are harvested annually from the wild in India. The commercial exploitation of seaweeds in India has started in 1966. Seaweeds such as *Gelidiella*, *Gracilaria* and *Sargassum* were being exported from India until 1975. But, the Government of India, considering the need of local agar and algin industries, later banned the export. However, the seaweed industries in India do not produce as yet the required quantities of sodium alginate and agar. As a result, India imports agar and algin every year, spending a considerable amount of foreign exchange. At present, seaweeds from Gujarat coast and many localities in Tamil Nadu are harvested by small- and large-scale industries. The ICAR-Central Marine Fisheries Research Institute (CMFRI) has been working on seaweed mariculture and seaweed utilization in India since 1972. Mandapam Regional Station of CMFRI has developed the technology for commercial scale cultivation of *Gracilaria edulis*, an agar yielding red algae, using raft, coir-rope nets/spore method. This Station has also developed a cottage industry method for the manufacture of agar from *Gracilaria* spp. and alginic acid from *Sargassum* spp. during 1980s and demonstrated the agar and algin production to many farmers and entrepreneurs. These demonstrations have paved ways for development of many small-scale agar industries at Madurai, Tamil Nadu.



Seaweed-based nutraceuticals developed by ICAR-Central Marine Fisheries Research Institute for use against lifestyle- and metabolic disorders

NUTRACEUTICAL INDUSTRIES

The seaweeds are gaining enormous attention in the nutraceutical industries due to their protective capabilities against various chronic diseases. The nutraceuticals market in India has been growing at the compound annual growth rate of 20% for the past three years, especially in the functional food products, antioxidants, and immunity booster segments. With increasing health awareness and the shift towards preventative health care, India has a promising future in this segment. Recent efforts by the government to bring clarity in regulatory protocols related to nutraceutical products have also resulted in the rapid growth of this segment. The continued research efforts at ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI) have resulted in developing a library of bioactive molecules from seaweeds. The research work in ICAR-CMFRI developed pharmacophore leads and commercialized nutraceuticals for use as immune-boost agent, antimicrobial therapeutic product against multi-resistant pathogens, for human health and mariculture, and those against hypercholesterolemia, hypertension, osteoporosis, cardioprotection, diabetes, inflammation, hypothyroidism, steatohepatitis, and metabolic/lifestyle disorders. These efforts raised technology transfer agreements, which developed business relations of ICAR institute with different public and private organizations. An increasing interest in seaweed-based bioactive compounds and functional food ingredients have appropriately demonstrated the possibilities of bioactive compounds from seaweeds to maintain and improve human health and well-being. Seaweeds constitute a large congregation of species that preponderate the coastal shelf areas of India, and are often termed as the “wonder herbs of the ocean” on account of their potential pharmaceutical properties. In view of this, the research work at ICAR-CMFRI has developed a systematic approach involving chemical profiling of Indian seaweeds coupled with evaluation of target biological activities against different lifestyle and metabolic disease models, and a library of molecules with bioactive potential as promising therapeutic candidates. Commercialization of these products



is significant to the coastal fishermen as this has enhanced the demand to produce seaweeds along the Indian coastline contributing to seaweed-based value chain.

SEAWEEDS AS PROSPECTIVE RESOURCES OF PHARMACOLOGICALLY ACTIVE METABOLITES, NUTRACEUTICAL PRODUCTS AND FUNCTIONAL FOODS

Seaweeds constitute a major share of marine flora, and they were reported to possess structurally diverse compounds of various bioactivities endowed with antihypertensive, anti-inflammatory, and anticarcinogenic activities. These marine floras are considered as valuable sources of bioactive compounds with potential pharmacological significance. Novel secondary bioactive metabolites from the seaweeds are attracting attention because of the growing demand for new compounds of 'marine natural' origin, having potential applications in pharmaceutical fields, and concerns about the toxic effects by synthetic drugs. Considering the group's importance, ICAR-CMFRI developed a research programme to systematically search these candidate seaweed species to develop promising bioactive molecules for human health and medication. The active ingredients in the nutraceutical products are in the concentrated form of the purified compounds, and not the crude extract (350 mg active principle capped in the hydroxypropyl methyl cellulose capsules). Optimized methods were developed to prepare the concentrated form of the active ingredients from the crude seaweed extract, and the active principles were stabilized with the natural additives and stabilizing agents. The nutraceutical products were found to have no side effects ($LD^{50} > 5000$ mg/kg BW) as proved from the preclinical and acute/long term chronic toxicity studies on experimental subjects (animal models) in the DSIR recognized hospitals/institutes.



The seaweeds contain a large assemblage of species that predominate in the coastal shelf areas of Indian subcontinent

The research works at ICAR-CMFRI developed a database of seaweeds with small molecular weight bioactive molecules responsible to combat various life-threatening diseases and developed seven nutraceutical products after conducting successful preclinical trials in recognized hospitals/DSIR recognized centres. The research work carried out in the institute developed natural anti-inflammatory supplements enriched with lead molecules as nutraceutical Cadal-



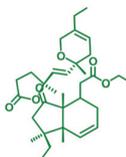
minTM Green Algal extract (CadalmiTM GAe) from seaweeds to combat rheumatic arthritic pains. This product has been out-licensed to the biopharmaceutical company for commercial production and marketing in India and abroad. The research efforts to isolate the lead molecules with action against type-2 diabetes led to the development of a nutraceutical product CadalmiTM Antidiabetic extract (CadalmiTM ADe) from marine algae that has been out-licensed to a leading Biopharma Company. CadalmiTM Antihypercholesterolemic extract (CadalmiTM ACe) and CadalmiTM Antihypothyroidism extract (CadalmiTM ATe) developed from seaweeds to combat dyslipidemia and hypothyroid disorders, respectively, and these products were also out-licensed to a pharmaceutical company. CadalmiTM Antihypertensive extract (CadalmiTM AHe), CadalmiTM Antiosteoporotic extract (CadalmiTM AOe), CadalmiTM Livcure extract (CadalmiTM LCe), and CadalmiTM Immunoboost extract (CadalmiTM IBe) from seaweeds were commercialized. CadalmiTM Immunalgin extract (CadalmiTM IMe) was also commercialized to a pharmaceutical company.

Seaweed-derived bioactive components with potential health benefits are an emerging area of research. Considering their underutilization, exploring bioactive compounds and development of any biologically useful products has dual benefits-as health products and their commercial farming of mollusks and seaweeds in coastal habitats, resulting in C-sequestration and C-budgeting in a scenario where climate change may pose a serious threat in future. Development of value-added products from these underutilized species will also promote their farming in coastal habitats, which has not been seriously explored earlier due to the lack of knowledge about their commercial importance.



SEAWEED FARMING

Seaweed farmers in India are generally small-scale farmers, produce crops of (mostly) red algae in small patches of intertidal sand flats. The main culture methods involve either vegetative propagation using fragments from mother plants or by different kinds of spores. Kelps (brown algae) cannot be grown from fragments as there is a high level of specialization and fragments of sporophytes do not normally regenerate whereas the agarophyte (red algae) cultivation can be done by vegetable propagation starting from fragments. The propagation of seaweeds through reproductive method was also carried out by ICAR-CMFRI by using the reproductive units like zoospores, monospores, tetraspores and carpospores in different species. Reproductive propagation was successful in *Gracilaria edulis* liberating the carpospores on different substrata like nylon twine, cement block and HDP rope. These spores liberated on the substrata were allowed to grow to germling stage in nursery for 15-17 days and then transplanted to natural environment during favourable period of growth. At Mandapam Regional Centre of CMFRI, more than 50 hands on training had been conducted on farming of *Kappaphycus* and native



species during 2011-2019 to 619 trainers (fishers and government officials) from Andaman & Nicobar, Andhra Pradesh, Gujarat, Maharashtra, Kerala, Tamil Nadu and West Bengal. Under SCSP programme, the centre is also involved in *Kappaphycus* farming of 92 fishers along the Palk Bay since 2018.

Considerable research has been carried out on various aspects of Indian seaweeds by ICAR-CMFRI. Survey of the seaweed resources on the coasts of Tamil Nadu, Goa, Maharashtra, Gujarat, Andhra Pradesh, Odisha, Kerala and Lakshadweep has been completed and the estimates of total standing crop of these areas and, in particular, the harvestable quantities of agarophytes and alginophytes had been made. Annual seaweed harvest estimation (wild collection) from Indian Coast as well as production through farming in the sea along the east coast of India is being enumerated periodically by this Institute with which potential yield was estimated. Taxonomy of commercially important seaweeds has been studied by the institute. All these had led to publishing a comprehensive bulletin on Seaweed Research & Utilisation in 1987. The ICAR-CMFRI has been providing technical inputs for the meetings and discussions on seaweed culture and commercialization of seaweed products to the Ministry of Agriculture and Farmers Welfare and Ministry of Fisheries, Animal Husbandry & Dairying, Government of India. The ICAR-CMFRI has played a key role in bringing out a policy document on 'Seaweed Cultivation and Utilisation' and an 'Action Plan on Seaweed Research and Utilization' following a National Consultation organised in ICAR-CMFRI jointly with the Department of Biotechnology, Government of India in 2016.

INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA)

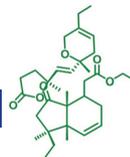
The bio-mitigation along with increased biomass production in mariculture activity can be achieved by integrating different groups of commercially important aquatic species, which are having varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA) which is gaining importance at global level. Seaweeds are excellent bio-remediating agents and capable of improving water quality by uptake of dissolved minerals, nitrates, ammonia and phosphates. In this context, the ICAR-CMFRI has successfully conducted demonstration of Integrated Multi-Trophic Aquaculture (IMTA) under participatory mode with a fishermen group at Palk Bay, Tamil Nadu by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*) during 2016-19. A total of 16 bamboo rafts (12× 12 feet) with 60 kg of seaweed per raft were integrated for a span of 4 cycles along with one cobia stocked cage (6 m diameter and 3.5 m depth with 1000 cobia fingerlings). Seaweed rafts integrated with cobia stocked cage had a better average yield of 320 kg per raft while in the non-integrated raft, the yield was 144 kg per raft. An addition of 176 kg of seaweed per raft was achieved due to the integration with the cobia cage farming. The total amount of carbon sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 357 kg and 161 kg, respectively. Hence there is



an addition of 196 kg carbon credit due to integration of 16 seaweed rafts (4 cycles) with one cobia stocked cage (one crop). The presence of inorganic extractive components contributes to the periphyton to the aquaculture area as well as offer habitat for planktons to settle. Seaweeds are known to release 30-39% of their gross primary production as dissolved organic carbon (DOC) to the ambient water. In experiments involving the culture of seaweed (*Kappaphycus alvarezii*) in three bamboo rafts to estimate its carbon sequestration potential was conducted by the ICAR-CMFRI at Munaikadu, Tamil Nadu. In each of the rafts (12 ft × 12 ft), 3 pre-weighed bunches of seaweed were tagged and their weights were periodically (once in 15 days) measured. The average carbon content was 19.92% and specific rate of sequestration of carbon dioxide (CO₂) by the *Kappaphycus* is estimated as 19 kg/day/tonnes of dry wt. of seaweed. Hence, large scale mariculture of seaweeds preferably red seaweeds would definitely be helpful to check ocean acidification, which indeed is a green technology without the involvement of energy, fertilizers and chemical inputs and is not a labour-intensive avocation.

CONCLUSIONS AND THE WAY FORWARD

The diverse range of seaweed-derived products includes high-value, low-volume items like hydrocolloids, pharmaceuticals, nutraceuticals, cosmetics, pigments, functional foods, and aromatics. Additionally, there are low-value, high-volume products such as plant biostimulants, animal feed supplements, biomaterials, and bioenergy. The global seaweed processing industry primarily focuses on hydrocolloid production, followed by food supplements and cosmetics. However, a growing trend is observed in the use of seaweed extracts as biostimulants, additives in cattle feed for methane reduction, and nutraceuticals. The rise of startups specializing in eco-friendly seaweed products, including bioplastics and functional foods, reflects the expanding horizons in this field. Seaweed culture and utilization offer a sustainable and multifaceted solution to environmental challenges, food security enhancement, and economic development. With thoughtful planning, research, and policy support, seaweed cultivation and utilization can contribute to a greener and more sustainable future. Embracing this opportunity and implementing effective policies will unlock the vast potential of seaweed culture and utilization for the benefit of present and future generations.



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