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Seaweed farming in India

Progress and Prospects

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Seaweeds are exploited commercially for their cell wall polysaccharides such as agar, algin, carrageenan and for manure, fodder and bioactive metabolites. Seaweed also represents an excellent source of fatty acids, vitamins and minerals. It is 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 the peninsular coastline, Andaman-Nicobar and Lakshadweep Archipelagos. India is bestowed with more than 0.26 million tonnes (potential yield) 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; i.e., 4,000 tonnes dry weight) of these resources are harvested annually from the wild in India.

Keywords: Agar, Bamboo raft, Cadalmin™ GAc, ICAR-CMFRI, Integrated Multi-Trophic Aquaculture, Livelihood, Seaweed

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 Farming: Current Status

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.

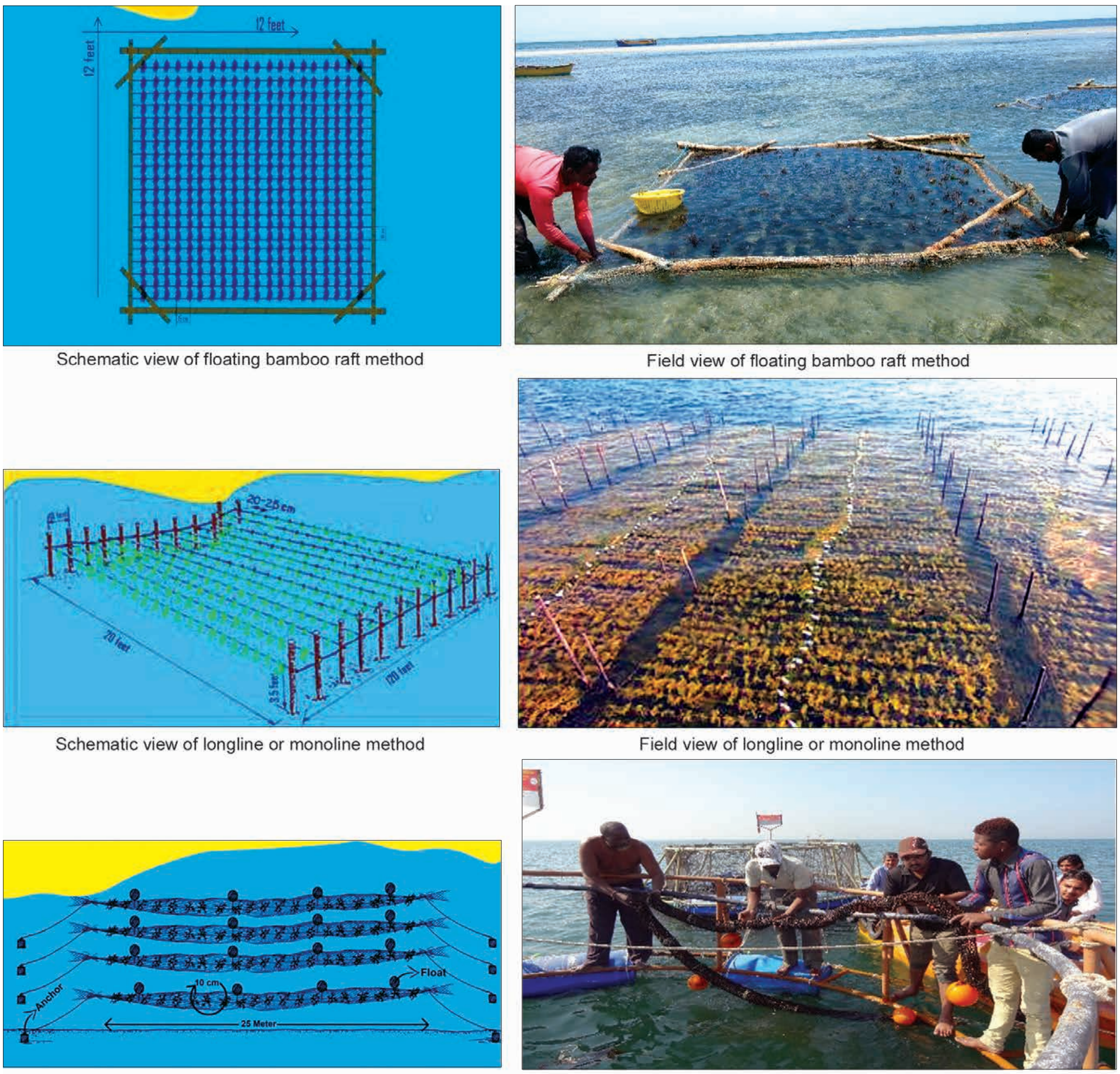
In places which are calm and shallow, raft method (12 × 12 feet bamboo poles) is ideal. Vegetative fragments inserted ropes are tied to the floating raft. In places characterized by moderate wave action, shallow depth and the presence of less herbivorous fishes, longline or monoline method is ideal. Seaweed inserted ropes are tied to the posts planted in the sandy and muddy bottom of the intertidal regions. First harvest can be made in 45-60 days depending on the species. The tube net method is being adopted in places with higher wave actions. It is a recent method in which long sleeves (10/25 m long and 6/10 cm dia.) made of nylon nets (1-1.5 cm mesh) are seeded with vegetative bits that appear like "net tubes". Both the ends are then tied and allowed to float in seawater. Anchors are used at each end to hold the tube nets steady in the water column. Harvesting is generally done after 60 days.

Though started in 1972, seaweed mariculture (agarophytes *Gracilaria edulis* and *Gelidiella acerosa*) in India remained in low key until the year 2000. Seaweed cultivation with native species has been shown to be beset with problems such as grazing of seed material and grown up plants by fishes, longer culture duration and slow growth rate of species like *Gelidiella acerosa*. Large scale, commercial sea-farming of *Kappaphycus alvarezii*, a *kappa* carrageenan yielding seaweed started in 2000 with a backup by PepsiCo India Holdings Ltd. in the coastal waters of Tamil Nadu, Odisha, Gujarat and Daman and Diu with technical support from CSIR - Central Salt and Marine Chemicals Research Institute (CSIR-CSMCRI), Bhavnagar. It is reported that with the contract farming of *Kappaphycus alvarezii* by the fisher folks of east coast of India, more than 46,600 tonnes wet biomass of *Kappaphycus* was produced in a decade during 2005 to 2015. The market price during this period found to increase from less than ₹ 4.5 to 35/kg (dry weight). The present market price is about ₹ 50/kg (dry weight). However, the production sharply declined after 2013 due to mass mortality as a result of "ice-ice" disease and the average production of cultured *Kappaphycus alvarezii* in recent years is only to the tune of 200 t (dry weight)/year. At present, commercial farming is carried out following three techniques, namely floating bamboo raft, tube net (net sleeves), and long lines; of which the former two are widely practiced (Fig. 1).

The economics of *Kappaphycus alvarezii* farming as analysed by ICAR-CMFRI is as follows:

- Seaweed production: 1,000 kg/raft/yr- 240 kg as seed material for 4 crops/yr = 760 kg
- Price of seaweed: ₹ 8/kg (wet weight)/raft or ₹ 50/kg/dry weight (Dry weight = 10%)
- Total revenue generated: ₹ 6080/year/ raft @ ₹ 8/kg/wet weight
- Total cost of production (including capital cost): ₹ 1500/raft/yr
- Net profit: ₹ 4580/raft/year (₹ 6080 minus 1500)
- One family (2 person) can handle average 30 rafts (12 × 12 ft)
- Total Net profit (30 rafts) in fresh weight = 30 × ₹ 4580 = ₹ 1,37,400/yr
- One hectare can accommodate 400 rafts (12 ft × 12 ft) of seaweeds
- Total production per ha = 760 kg × 400 rafts = 304 tonnes (wet weight)
- Net profit per hectare= 4580 × 400 = ₹ 18,32,000/-

Considerable research has been carried out on various aspects of Indian seaweeds by ICAR-CMFRI.



Schematic view of floating bamboo raft method

Field view of floating bamboo raft method

Schematic view of longline or monoline method

Field view of longline or monoline method

Schematic view of tube net method

Field view of tube net method

Fig. 1. Seaweed cultivation

Fig. 2. View of harvested farmed Kappaphycus alvarezii

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 (Fig. 2). 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.

Integrated Multi-Trophic Aquaculture (IMTA)

The bio-mitigation along with increased biomass production in mariculture activity can be achieved through Integrated Multi-Trophic Aquaculture (IMTA) by integrating different groups of commercially important aquatic species, which are having varied feeding habits (Fig. 3). 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) by integrating seaweed *Kappaphycus alvarezii* farming with cage farming of Cobia (*Rachycentron canadum*). 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 1,000 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

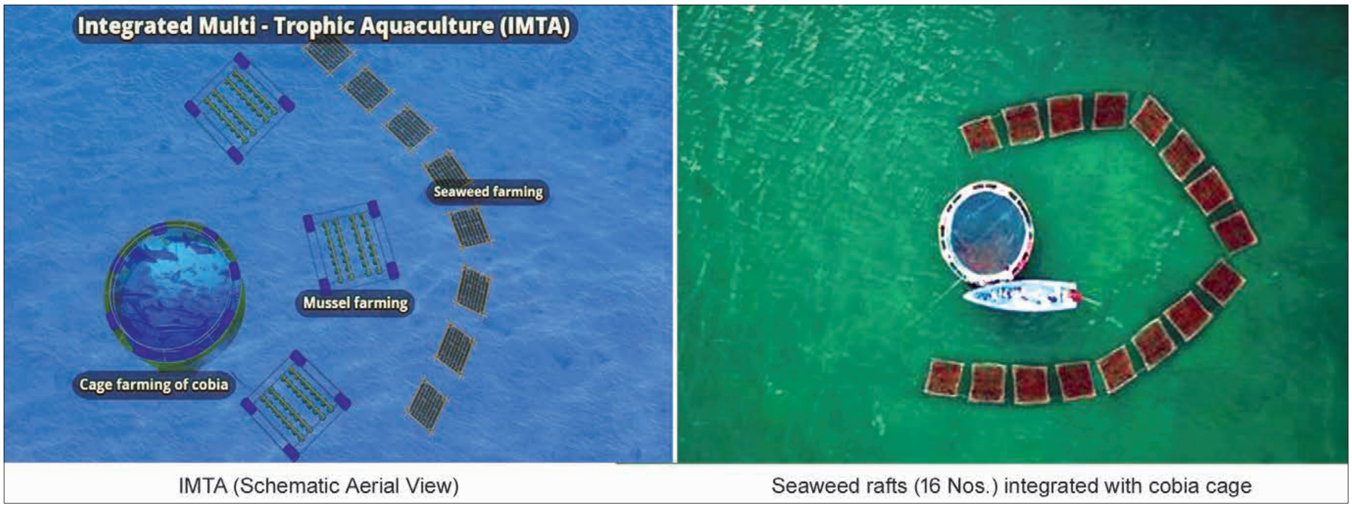


Fig. 3. Integrated Multi-Trophic Aquaculture (IMTA)

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.

Seaweed mariculture for combating climate change impacts

It is estimated quantitatively that seaweeds are capable of sequestering dissolved CO_2 at the rate 80.5 mg/g wet weight/day while their rate of emission through respiration is only 10 mg/g wet weight/day. Large scale seaweed mariculture has been recognized as one of the climate resilient aquaculture techniques to mitigate ocean acidification. Being highly autotrophic, seaweed vegetation can utilize the carbon dioxide for photosynthesis which can remove the dissolved CO_2 from the seawater. Seaweed beds and seaweed farms are considered significant CO_2 sink and can play active role in mitigation and adaptation of climate change. It is estimated that the seaweed biomass alone along the Indian coast is capable of utilizing 3017 t CO_2/day against emission of 122 t CO_2/day indicating a net carbon credit of 2,895 t/day.

In experiments involving the culture of seaweed (*Kappaphycus alvarezii*) in ICAR-CMFRI it was estimated that specific rate of sequestration of carbon dioxide (CO_2) 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.

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 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 importance of the group, ICAR-CMFRI and ICAR Central Institute of Fisheries Technology (ICAR-CIFT) developed research programme to systematically search these candidate seaweed species for the development of 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} > 5,000 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 research work carried out at ICAR-CMFRI developed natural anti-inflammatory supplements enriched with lead molecules as nutraceutical Cadalmin™ Green Algal extract (Cadalmin™ 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 Cadalmin™ Antidiabetic extract (Cadalmin™ ADe) from marine algae that has been out-licensed to a leading Biopharma Company. Cadalmin™ Antihypercholesterolemic extract (Cadalmin™ ACe) and Cadalmin™ Antihypothyroidism extract (Cadalmin™ ATe) developed from seaweeds to combat dyslipidemia and hypothyroid disorders, respectively. These products were also out-licensed to a pharmaceutical company. Cadalmin™ Antihypertensive extract (Cadalmin™ AHe), Cadalmin™ Antiosteoporotic extract (Cadalmin™ AOe), and Cadalmin™ Immunoboost extract (Cadalmin™ IBe) from seaweeds are under commercialization (Fig. 4).

The ICAR-CIFT has developed and commercialized many aqua-nutraceuticals in line with the regulatory compliances to address the felt demand of the consumers keeping eye on their healthcare and nutritional requirement and established its prominence in the aqua- nutraceuticals domain. The products like *FucoidanExt*, *FucoTeaExt, FucoxanthinExt, Seaweed NutriDrink*, *Seaweed Cookies*, *Seaweed Yoghurt*, *Seaweed Sanitizer* are some of the promising seaweed based products developed by the institute.

The Way forward

Seaweed for livelihood: Seaweed mariculture is an economically viable livelihood option for the coastal fishing community especially for the fisherwomen. The seaweed cultivation requires no land, no fresh water and no fertilizer or pesticide. The large-scale cultivation will enhance rural employment

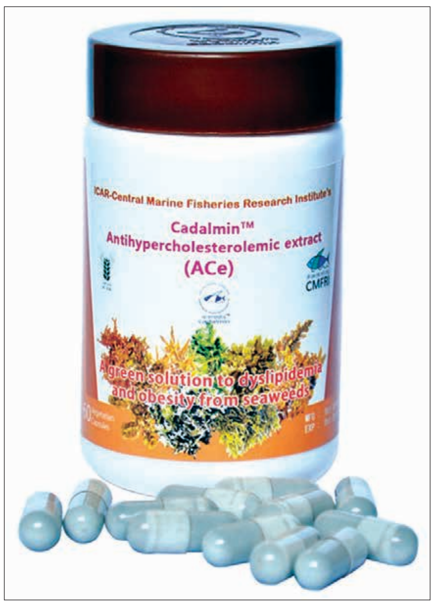


Fig. 4. Cadalmin™ Antihypercholesterolemic extract (Cadalmin™ ACe)

opportunities and improve rural economy. It was found that the Benefit Cost Ratio (BCR) is above 2.0, which signifies the profitability of the activity and it can double the fisher's income.

Need for marine spatial plans and leasing policies: Currently, the growth of seaweed farming is constrained primarily by lack of proper marine spatial plans. Areas suitable for seaweed farming in three coastal states (Tamil Nadu, Gujarat and Andhra Pradesh) have been identified by ICAR-CMFRI. Large-scale expansion of the seaweed cultivation will necessitate a more complete understanding of the changes that the farming activity may bring in the ecosystem. Most Indian seaweed cultivation is located in near-shore waters, and to overcome inshore challenges an alternative farming strategy including expanding to offshore culture systems is recommended.

Enhancing availability of planting materials/seeds: Traditional seaweed farming techniques involving vegetative propagation require a large amount of seed stock biomass. An average of 10-20% of harvested material needs to be recycled during seeding procedures. To improve production of *Kappaphycus* in India, developing *in vitro* cell culture techniques is crucial as it facilitates year-round mass supply of seed materials maintained under controlled conditions. Development of new and improved strains of *Kappaphycus* through strain development and hybridization and through protoplast fusion techniques are envisaged for production of fast growing, productive, high-temperature-tolerant and fouling- and disease-resistant strains. Challenges faced by seaweed farming include difficulty in obtaining quality seed materials of native species such as *Gracilaria dura*, *G. debilis* especially after monsoon rains, natural calamities such as cyclonic weather and grazing by herbivores fishes. Import of high-yielding species/varieties and establishment of seed banks for improving the availability of quality seed material to support farming activities may be given top priority.

Meeting the requirement of seaweed products and augmenting self-sufficiency in production: The Indian requirement of agar and alginate is about 400 tonnes per annum and 1,000 tonnes per annum, whereas only 30% and less than 40% respectively of it has been produced indigenously. The Indian requirement of carrageenan is 1,500-2,000 tonnes per annum. The food sector accounts for nearly 70% of the world market for carrageenan. Taking the demand on agar, alginate and carrageenan, the total annual seaweed requirement in dry weight basis is 4,000 tonnes of agar yielding algae; 5,000 tonnes of alginate yielding algae and 4,500-6,000 tonnes of carrageenan yielding algae. Hence to improve self sufficiency in seaweed-based products, large scale farming needs to be promoted.

Policies and institutional support: Seaweed cultivation can be taken up by fishermen/fisherwomen co-operatives and self-help groups (SHGs) of the coastal areas. A minimum price for the farmed seaweeds and opening of marketing channels for seaweeds also should be considered before taking up large scale farming of seaweeds in the country. Promotion of seaweeds as healthy food for human consumption apart from its use as raw materials for the extraction of bioactive compounds and phyco-chemicals may also be attempted. National fisheries development agencies like NFDB can promote seaweed consumption through awareness campaigns and seaweed food festivals organised throughout the country. Hence, large scale mariculture of seaweeds which is a green technology for their nutraceuticals and other secondary metabolites is a dire necessity which can help mitigate major greenhouse gas and can check ocean acidification, while the seaweed farmers can make a living out of the harvest. Appropriate financing and insurance cover against crop losses due to natural calamities are also the need of the hour to further promote seaweed farming in Indian waters.

More nutraceuticals and bio-active molecules from seaweeds: Considering the diversity of chemical constituents present in seaweeds that are capable of exerting wide range of bioactivities, a growing trend is developing across globe to include seaweeds in nutritional and biomedical applications. The future programmes envisages in developing high value pigments and omega-3-fatty acids from seaweeds as cardioprotective and antidiabetic supplements. It is also proposed to develop novel seaweed liquefaction technology to produce seaweed products, which can be used as animal feed, soil conditioners, bio-pesticides, and plant growth promoting foliar spray. Work on seaweed-enriched extruded snack foods, soup powder, protein powder, pasta, seaweed tuna jerky, noodles, seaweed based composite scaffolds and membranes for medical application, seaweed based edible and biodegradable packaging materials, carrageenan-based ointment, seaweed incorporated fish feed, are underway and are in different stages of development.

SUMMARY

Seaweed farming offers immense scope as a livelihood opportunity and for developing a large number of by-products with several applications. Seaweed farming has the advantage of low capital input, as it is a primary producer requiring no inputs. Expansion of seaweed farming in the country will improve the socio-economic status of coastal fishermen/farmers and will be helpful in mitigating the negative effects of climate change while protecting the marine ecosystems from ocean acidification and ocean de-oxygenation. Establishment of seed banks, processing and marketing units, marine spatial planning, policies and institutional support are essential for sustaining seaweed farming.

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