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POLICY, REGULATORY FRAMEWORK, AND SERVICE DELIVERY FOR SEAWEED CULTIVATION AND UTILIZATION OF SEAWEED-BASED PRODUCTS FOR VALUE ADDITION

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ABSTRACT

Seaweed is proving to be an extremely promising resource for mariculture due to its remarkable adaptability, short growth period, and sustainable nature. The seaweed industry in India has emerged as a prominent sector due to its various advantages, such as its nutritional value, contribution to the conservation of coastal ecosystems, and potential as a renewable resource. The demand for seaweeds has been on the rise, due to the recent advancements in their utilization for producing nutraceuticals, plant growth promoters, fertilizers, and other industrial applications. However, the progress towards establishing a profitable business focusedon value-added products is still in its nascent stages. Hence, by strengthening the involvement of the government and stakeholders in seaweed farming can facilitate itssustainable development and growth. Additionally, the implementation of strategic and coordinated policy interventions is also essential to create market opportunities and promote the development of value-added seaweed products to further propel the growth of this sector.

Keywords: Seaweed farming, Policy and regulatory framework, Service delivery, Value addition

INTRODUCTION

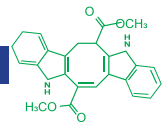
Mariculture plays a crucial role in fisheries development by providing a sustainable solution to meet the increasing demand for seafood. This practice involves the cultivation of marine organisms, such as fish, shellfish, and seaweed, in controlled environments like ponds, tanks, or cages. The significance of mariculture lies in its ability to alleviate pressure on wild fish populations, reduce overfishing, and contribute to food security. Seaweed has emerged as one of the most promising resources for mariculture due to its remarkable adaptability, short development period, and resource sustainability. It is an effective breakthrough to alleviate future resource crises, poverty and unemployment (Zhang et al. (2022); Mantri et al. (2022a,b)). Seaweed farming has been identified as one of the diversified-livelihood options for coastal

fishers in India. With a rich marine biodiversity and favourable coastal conditions, India holds significant potential for seaweed cultivation, contributing to both economic prosperity and environmental sustainability.

Seaweed farming involves the cultivation of various species of marine macroalgae for diverse purposes, ranging from food and pharmaceuticals to biofuels and environmental remediation. In India, this industry has gained traction due to the recognition of seaweed's multifaceted benefits, including its nutritional value, role in coastal ecosystem conservation, and potential as a renewable resource. The coastal states of Tamil Nadu, Gujarat, Maharashtra, and Kerala have witnessed significant strides in seaweed farming initiatives, leveraging the country's extensive shoreline. The cultivation process typically takes place in shallow coastal waters, where seaweeds thrive in the nutrient-rich marine environment. Several commercially important seaweed species were identified which include red algae species such as *Gracilaria edulis, Gelidiella acerosa,* and *Kappaphycus alvarezii* and brown algae species such as *Sargassum wightii, Turbinaria conoides,* and *Cystoseira* spp (Kaladharan et al. (1996); Kaliaperumal and Kalimuthu (1997); Rao and Mantri (2006)). A number of farming techniques using floating rafts, net-tubes, long-lines, and fin fish-stocked cage-based IMTA systems have been standardized for seaweed culture. Farming of seaweedspecies including K. alvarezii and *G. acerosa,* and *Gracilaria spp*. is economically profitable as well as livelihood enhancing, thereby suitable for commercial scale-up (Mantri et al. (2022a,b)).

The demand for seaweeds has been on the rise due to recent innovations involving their use in the production of secondary bioactive metabolite-based nutraceuticals, plant growth promoters, and fertilizers, besides their traditional industrial applications (Chakraborty et al. (2018); Cotaset al. (2020); Gopalakrishnan et al. (2020)). Seaweeds offer a wide range of value-added products that have gained significant popularity in various industries. These products, derived from seaweed extracts, are known for their numerous benefits and applications. From the food and beverage industry to cosmetics and pharmaceuticals, seaweed-based products have become a sought-after choice due to their rich nutritional content, unique flavors, and potential health benefits. Additionally, seaweed extracts are used in agriculture as bio-stimulants and soil conditioners, contributing to sustainable farming practices.

The range and possibilities of seaweed products with added value are constantly growing, positioning them as a promising and groundbreaking solution across various industries. Moreover, the potential of seaweed in carbon sequestration and its role in mitigating climate change effects further underscore its significance. However, the progress toward the development of a profitable business focused on added-value products are still at early stages (Henriquez and Carcamo (2019)). As India seeks to address challenges related to food security,



environmental sustainability, and economic diversification, seaweed farming emerges as a strategic solution, aligning with global efforts towards a more sustainable and resilient future.

PRESENT STATUS

Global seaweed production has reached 35 million tonnes in 2022 with the market value estimated around 16.5 billion USD as reported by the FAO state of world fisheries and aquaculture report (FAO (2022)). In India, the production of seaweed is estimated at about 34000 tonnes in 2021 which is only 0.01 per cent of the world production and 2.5 per cent of the actual production potential of our country (Reddy et al. (2023)). Moreover, India has a potential area of 23,970 ha suitable for cultivation along India's shallow coastal waters using a combination of a primary survey approach as well as a GIS-based site suitability model (Johnson et al. (2020); Divu et al. (2020); Parappurathu et al. (2023)). Presently, seaweed farming is practiced on a limited scale by several hundreds of farmers' groups along the Palk Bay areas of Tamil Nadu supported by the carrageenan, agar, and seaweed-based fertilizer industries located in neighbouring areas. Earlier, the farming of *K. alvarezii* experienced a boom during 2000–2013 when the local fishers along the coasts of Tamil Nadu, Gujarat, and Odisha entered into a contractual farming arrangement with PepsiCo India Holdings Ltd. followed by Aqua Agri Processing Pvt. Ltd. for carrageenan production. However, this was short-lived due to many biophysical and economic constraints (Krishnan and Narayanakumar(2013); Johnson and Ignatius (2020)). Nevertheless, the sector is re-entering into a phase of renewed development owing to considerable policy thrust and technological and logistical advancements in recent times (Parappurathu et al. (2023)).

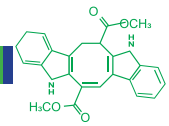
Integrated Multi-trophic Aquaculture (IMTA) is another novel mariculture practice that has been gaining momentum in recent years with its bio-mitigation potential, complementarity functions in the ecosystem, besides economic potential (Chopin et al. (2008); Barrington et al. (2009)). In India, recent integrated trials carried out by ICAR-CMFRI in the Palk Bay area of Tamil Nadu involving cobia in marine cages with K. alvarezii in floating rafts set around the cage have shown encouraging results (Johnson et al. (2021)). Similar trials involving different combinations of mullets (*M. cephalus* and *Liza parsia*), milkfish (*Chanoschanos*), pearl spot (*E. suratensis*), and shrimp (*Penaeus monodon, P. indicus*) as fed species, together with oyster (*Crassostrea cuttackensis, C. madrasensis*) and seaweed (*Enteromorpha spp.*) as extractive species were evaluated as viable aquaculture options in brackish water ecosystems of the Indian Sundarban areas of West Bengal and Sindhudurg district of Maharashtra (Balasubramanian et al. (2018); Biswas et al. (2019)). Recognizing the potential, fishers from Palk Bay and other parts of the southwest coast of India have started practicing IMTA-based farming operations in recent times (Johnson et al.(2021)).

GLOBAL BEST PRACTICES FOR SEAWEED CULTIVATION

Seaweed cultivation is currently being practiced commercially in large or small scale in different parts of the world. It can be performed offshore, onshore and even in aquaculture integrated systems. Based on the essential factors such as the type of species, place of the farm and cultivation facilities, seaweed is farmed using a variety of techniques which can range from intensive systems like tanks or ponds to a comprehensive open sea farming system that utilize long lines or rafts. Various methods such as fixed off-bottom, raft methods, net methods etc., are in practice to cultivate various seaweeds throughout the world. All these methods have a few advantages as well as a few disadvantages or limitations. For instance, off-bottom method, single raft method and hanging longline method are better only in shallow waters (Behera et al., 2022). Main techniques of seaweed cultivation adapted globally outlined by Radulovich et al.,2015, and Sudhakar et al., 2018 are presented in Table 1.

Table 1. Main techniques of seaweed cultivation adapted globally

Techniques	Summary	Type of cultivation
1. Line cultivation	Seaweeds are attached to ropes of varying lengthsthat are placed in a parallel arrangement	Onshore & Offshore
i. Off-bottom	Planting close to the bottom near shore.	
ii. Submerged hanging line	Planting is in midwater near shore, submerged several meters at high tides and at the surface or even exposed during low tides	
iii. Floating line (long-line)	Planting at or close to the surface with seaweeds slightly submerged	
II. Net cultivation	Seaweed propagules are attached to nets placed at a given water depth	Onshore & Offshore



III. Floating raft cultivation	Planting occurs at the surface, attaching seaweeds to lines or nets with the shape given by a floating rigid frame made of bamboo or other material.	Onshore & Offshore
IV. Tank or pond cultivation	Culture in tanks under controlled conditions	Onshore
V. Other methods (i) Direct planting on the ocean bottom (ii) Free-floating rafts	Placing seaweeds attached to artificial substrate on the sea floor Equivalent to line or net cultivation	Offshore Offshore

Source: Radulovich et al. (2015), and Sudhakar et al. (2018)

The Integrated Multitrophic Aquaculture (IMTA) and Macroalgal cultivation rig are the recent innovative techniques which are gaining significant recognition worldwide due to their ability to improve the sustainability and efficiency of seaweed cultivation (Jagtap and Meena (2022)). These techniques play a vital role in meeting the increasing demand for seaweed products with its bio-mitigation potential, complementarity functions in the ecosystem, besides economic potential.

SERVICE DELIVERY OF SEAWEED CULTIVATION

The service delivery mechanism for seaweed cultivation includes a range of economic activities aimed at supporting and enhancing this emerging sector. There is a need for accessible and comprehensive training programs for seaweed farmers. These programs should cover various aspects, including seaweed species identification, cultivation techniques, harvesting methods, and sustainable practices. Extension services also play a vital role in disseminating knowledge and best practices to seaweed farmers, ensuring they have the necessary skills to manage their cultivation effectively. Government agencies, agricultural departments, and various NGOs also play a pivotal role in the service delivery mechanism (Johnson et.al. (2023)). They can provide financial support, subsidies, and incentives to encourage seaweed cultivation (Johnson et.al. (2020)). Research and development institutions contribute significantly to the service delivery mechanism by conducting studies on optimal seaweed cultivation practices, disease management, and innovation in farming techniques (Ajith et al. (2019)). Infrastructure development is another critical aspect of seaweed cultivation. This includes the provision of

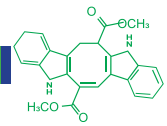
quality seeds, rafts, other equipment, and processing facilities. Ensuring a smooth supply chain from cultivation to market is essential for the success of seaweed farming. Adequate transportation and storage facilities are necessary to prevent post-harvest losses and maintain the quality of the seaweed. Market linkages and value addition also form integral parts of the service delivery mechanism. Connecting seaweed farmers to markets, both domestic and international, ensures a steady income for cultivators. Encouraging the development of seaweed-based products and facilitating their entry into diverse markets enhances the economic viability of seaweed cultivation. Monitoring and regulatory frameworks contribute to a sustainable service delivery mechanism. Regular checks on water quality, adherence to environmental regulations, and quality control measures ensure the overall health of the seaweed cultivation industry. It is also very essential to bring seaweed cultivation under insurance coverage to compensate the crop loss during natural calamities (Johnson et al. (2017)).

VALUE ADDED PRODUCTS

Value addition in seaweed farming is essential for maximizing the economic, environmental, and social benefits of seaweed cultivation. Seaweeds possess significant commercial value due to their cell wall polysaccharides, including agar, algin, carrageenan, and more, as well as their bioactive metabolites, manure, and fodder. These seaweeds find diverse applications in the food, pharmaceutical, cosmetic, and mining industries. Additionally, certain seaweeds are gaining recognition as health foods for human consumption, apart from their role as raw materials for extracting bioactive compounds and marine chemicals. Edible seaweed also holds the potential to serve as a sustainable and nutrient-rich source of macronutrients and micronutrients in the human diet.

Central Marine Fisheries Research Institute (CMFRI) has developed and commercialized a number of products for use as nutraceuticals from seaweed such Cadalmin™ Green Algal extract (Cadalmin™ GAe) as agreen solution to join disorder and arthritis, Cadalmin™ Antidiabetic extract (Cadalmin™ ADe) as a remdy for tpe II diabetes, Cadalmin™ Anti-hypertensive extract for reducing hypertension, Cadalmin™ Anti-hypothyrodism extract combats hypothyroidism and Cadamin™ Anti-hypercholesterolemic extract for dyslipidemia and obesity.

The Central Marine Fisheries Research Institute (CMFRI) has successfully developed and brought to market several nutraceutical products derived from seaweed. One of these products is Cadalmin™ Green Algal extract (Cadalmin™ GAe), which offers a green solution for treating joint disorders and arthritis. Additionally, CMFRI has also introduced CadalminTm Antidiabetic extract (Cadalmin™ ADe) as a remedy for type II diabetes, Cadalmin™ Anti-



hypertensive extract for reducing hypertension, CadalminTm Anti-hypothyroidism extract to combat hypothyroidism, and Cadalmin™ Anti-hypercholesterolemic extract for addressing dyslipidemia and obesity. These innovative products serve as effective solutions for various health conditions, uplifting the exploration of natural remedies in medical science.

Hence, the expanding versatility and potential of value-added seaweed products make them a promising and innovative solution across various sectors. Furthermore, value addition encourages innovation and research, leading to the development of sustainable practices and efficient processing methods. The environmental benefits of seaweed farming, such as carbon sequestration and nutrient remediation, can be enhanced through value addition, aligning with the growing global demand for seaweed products. Therefore, emphasizing the promotion of value addition can effectively meet the growing demand for seaweed in the future. Through these endeavours, seaweed farmers can not only reap economic benefits but also contribute to the development of sustainable and environmentally friendly industries.

ENVIRONMENTAL SUSTAINABILITY

Seaweed farming is an environmentally friendly alternative to traditional agriculture, as it does not require fertilizers, pesticides, energy, or chemical inputs. This sustainable practice is considered as a green technology (Johnson et al. (2020a) and has numerous benefits. Seaweeds also act as natural filters, absorbing excess nutrients and pollutants from the water, thereby improving water quality and reducing the risk of harmful algal blooms. Additionally, seaweed farms provide a habitat for various marine organisms, promoting biodiversity and supporting the overall health of coastal ecosystems. Large scale mariculture of seaweeds is one of the climate resilient aquaculture techniques and very much essential to mitigate ocean acidification. This sustainable practice not only helps combat climate change by sequestering carbon dioxide but also provides a renewable source of food, fuel, and various biodegradable products. As a result, seaweed farming is a significant mitigating measure for the adverse impacts of climate change and can earn carbon credits for our country (Johnson et al. (2020b)).

IMPORTANT POLICIES AND REGULATIONS

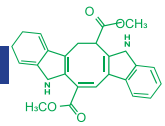
The seaweed sector in India is presently in its initial phase of progress. The Government of India recognizes that although it is relatively easier to cultivate compared to other aquaculture sectors, the seaweed production potentialof the country and utilization of biomass have not been thoroughly explored (Mantri et al. (2022)). Government of India has initiated significant steps to effectively tap into this unexplored potential by encouraging research and development activities through public institutions and agencies functioning under the state and Union governments of India. To ensure its sustainability, it is imperative to take into account strategic

and coordinated policy interventions. The initial stages of research were guided by isolated attempts on project mode limited to individual research institutes and Universities. Recently, coordinated research focus was brought about through network projects such as the "All India Network Project on Mariculture" of the Indian Council of Agricultural Research (ICAR) and other inter-institutional collaborative research efforts involving NCSCM, CSIR-CSMCRI, and State Universities. Additionally, development efforts in the form of training, funding as well as logistical support by Government organizations such as the National Fisheries Development Board (NFDB), Hyderabad, and the Marine Products Export Development Authority (MPEDA), Kochi have also contributed significantly to popularizing mariculture among the fisher folk and fish farmers.

Most of the developmental programs are presently being supported by budgetary allocations under the Pradhan Mantri Matsya Sampada Yojana (PMMSY), a flagship scheme of the Union Government for fisheries development. A draft National Mariculture Policy was prepared in 2019 consequent to the constitution of an expert committee by the NFDB. The draft policy, which identified thrust areas for development and underlying policy imperatives, was subsequently incorporated as a part of the "National Fisheries Policy 2020," which is due to be notified by the Government of India and will eventually supersede all other existing policy documents in fisheries and allied sectors. Apart from this, various maritime state governments are in the process of firming-up separate state-level policies to expedite mariculture development at the grassroots level. The Government of Goa notified "Goa State Mariculture Policy 2020" in June 2022, which is the first of its kind in the country (Parappurath et al. (2023)).

ROLE OF GOVERNMENT AND STAKEHOLDERS

The role of the government and stakeholders in seaweed farming is decisive for the sustainable development and growth of the sector. The government plays a significant role in providing regulations and policies that promote responsible and ecofriendly cultivation and harvesting of seaweed. They can also provide financial support and incentives to encourage farmers to engage in seaweed farming. Additionally, the government can invest in research and development to improve farming techniques and ensure the quality and safety of seaweed products. On the other hand, stakeholders such as farmers, industry associations, and research institutions play a vital role in collaborating with the government to develop best practices, share knowledge, and address challenges in seaweed farming. They can contribute to the development of standards, certifications, and marketing strategies to promote the growth of the sector.



CHALLENGES AND OPPORTUNITIES

Seaweed cultivation in India has been a considerable success economically and ecologically. Nevertheless, there are certain obstacles that require meticulous attention and resolution. These challenges include inadequate availability of high quality seed, yield loss due to high temperature/disease/grazing, damage of bamboo rafts, insufficient leasing policy of coastal areas, lack of technical expertise in offshore seaweed culture, poorly organised markets for seaweeds and its products, the necessity for diversification in the value chain and processing facilities, need for insurance to cover risks, lack of domestic acceptance of seaweed as food and need for commercial micro-propagation hubs in different parts of the nation (Johnson et al. (2023)). Additionally, the potential environmental impact of seaweed farming poses another challenge. It is crucial to carefully manage the cultivation process to minimize any adverse effects on marine ecosystems. This involves monitoring water quality, preventing the spread of invasive species, and ensuring responsible harvesting practices. Despite these challenges, the opportunities for seaweed farming in India are immense. By tapping into its potential market opportunities for seaweed-based products, India can not only meet domestic demand but also establish their significance on a global scale. Promoting initiatives in education, infrastructure development, and environmental management, India can effectively overcome these challenges and leverage the advantages of seaweed farming for both its economy and the environment.

CONCLUSION

Seaweed cultivation in India has significant implications due to its economic potential, nutritional value, environmental benefits, and sustainable aquaculture practices. The expansion of seaweed farming in the country can greatly contribute to the overall well-being of fishermen/farmers and the nation as a whole. The involvement of the government and stakeholders in seaweed farming plays a crucial role in ensuring its sustainable development and growth. It is essential to consider strategic and coordinated policy interventions to guarantee its long-term viability. Additionally, establishing market linkages and value-added seaweed products can further enhance the development of the sector. By encouraging the development of seaweed-based products and facilitating their entry into diverse markets, the economic viability of seaweed cultivation can be strengthened. Implementing effective monitoring and regulatory frameworks can also contribute to its successful development in the country. By addressing these challenges through education, infrastructure development, and environmental management India can fully harness the potential of seaweed farming and reap its economic and environmental benefits.

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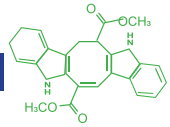

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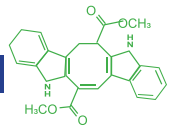

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