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PROSPECTS OF SEAWEED FARMING IN INDIA

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ABSTRACT

Seaweeds constitute one of the commercially important marine living renewable resources. They are used as human food, feed for animals, fertilizer for land crops, source of chemicals and drugs. The estimated total standing crop of seaweeds from intertidal and shallow waters of all maritime states, Lakshadweep and Andaman was 91,339 tons (wet wt.). The quantity of seaweeds estimated in deep waters of Tamilnadu was 75,373 tons (wet wt.) in an area of 1863 sq.km. from Dhanushkodi to Kanyakumari. Annually about 5000 tons (dry wt.) of alginophytes *Sargassum* spp, *Turbinaria* spp and *Cystoseira trinodis* and 1000 tons (dry wt.) of agarophytes *Gelidiella acerosa, Gracilaria edulis, G.crassa, G.folifera* and *G.verrucosa* are exploited from the natural seaweed beds of Tamil Nadu and used as raw materials for the production of agar, alginates and liquid seaweed fertilizer. In India, experimental / pilot scale culture of agarophytes *Gelidiella acerosa, Gracilaria edulis* and *Gracilaria* spp and carrageenophytes *Hypnea* spp and *Kappaphycus alvarezii* is going on. The need for taking up large scale cultivation of these seaweeds to meet the raw material requirement of Indian seaweed industry is emphasized. The prospects of seaweed research and utilization in our country are discussed in this paper.

INTRODUCTION

Seaweeds or marine algae are primitive non-flowering plants without true root, stem and leaves. They constitute one of the commercially important marine living renewable resources. They are the only source for the production of phytochemicals such as agar, carrageenan and algin. Seaweeds are divided into green, brown, red and bluegreen algae based on the type of pigments and external and internal structures.

Seaweeds contain many trace elements, minerals, protein, iodine, bromine, vitamins and many bioactive substances. Seaweeds are used for the production of phytochemicals such as agar, carrageenan and alginate which are widely employed as gelling, stabilizing and thickening agents in many industries like food, confectionary, pharmaceutical, dairy, textile, paper, paint and varnish etc. Agar (China grass) is manufactured from some red algae like *Gelidiella, Gracilaria, Gelidium* and *Pterocladia,* while carrageenam from red algae viz. *Eucheuma, Kappaphycus, Chondrus, Hypnea* and *Gigartina.* The brown algae such as *Sargassum, Turbinaria, Laminaria, Undaria, Macrocystis* and *Ascophyllum* yield alginates. Other chemical products namely mannitol, iodine, laminarin and furcellarin are also obtained from seaweeds.

Many protein rich edible seaweeds such as *Ulva, Enteromorpha, Codium* and *Monostroma* (green algae), *Sargassum, Hydroclathrus, Laminaria, Undaria, Macrocystis* (brown algae); *Porphyra, Gracilaria, Eucheuma, Laurencia* and *Acanthophora* (red algae) are consumed in the form of soup, salad, vegetable and porridge. The food products like jelly, jam, chocolate, pickle and wafer can also be manufactured from certain marine algae. Seaweeds are cheap source of minerls and trace elements. Hence, meal could be prepared by grinding the cleaned and washed seaweeds. It can be also mixed with fishmeal.

Seaweeds are used in different parts of the world as fertilizer for various land crops. In India, freshly collected and cast ashore seaweeds are used as manure for coconut plantation either directly or in the form of compost in coastal areas of Tamil Nadu and Kerala. Seaweed manure has been found superior to farm yard manure. The high amount of water soluable potash, other minerals and trace elements present in seaweeds are readily absorbed by plants and control mineral deficiency diseases. The carbohydrates and other organic matter present in the marine algae alter the nature of soil and improve the moisture retaining capacity. The liquid seaweed fertilizer obtained from seaweed extract is used as foliar spray for inducing faster growth and yield in leafy and fleshy vegetables, fruits, orchards and horticultural plants. There are several medicinal properties of seaweeds. Algae rich in iodine such as *Asparagopsis taxiformis, Sarconema* spp. can be used for controlling goiter disease caused by enlargement of thyroid glands. Many bioactive compounds can be obtained from seaweeds. In India, marine algae are used as raw material for manufacture of agar, alginates and liquid seaweed fertilizer. (Chennubhotla *et al.*, 1981; 1987a, 1987 b, Kaliaperumal *et al.*, 1987, 1995; Chennubhotla and Kaliaperumal, 1998).

SEAWEED DISTRIBUTION AND RESOURCES

Seaweeds grow in the interdial, shallow and deepwaters of the sea upto 180m depth and also in estuaries and backwaters. They occur on rocks, dead corals, stones, pebbles, solid substrata and on other plants. Seaweeds grow abundantly in the southern coast of Tamil Nadu, Gujarat coast, Lakshadweep and Andaman Nicobar Islands. Luxuriant growth of seaweeds is also found at Mumbai, Ratnagiri, Goa, Karwar, Varkala, Vizhinjam, Visakhapatnam, Pulicat lake and Chilka lake. About 271 genera and 1153 species of marine algae belonging to four groups of algae namely Chlorophyceae, Phaeophyceae, Rhodophyceae and Cyanophyceae have been recorded so far from Indian waters. The total standing crop of seaweeds from intertidal and shallow waters of all maritime states and Lakshadweep was estimated as 91,333 tons (wet wt.). The quantity of seaweeds estimated in deep waters of Tamilnadu was 75,373 tons (wet wt.) in an area of 1863 sq. km from Rameswaram (Dhanushkodi) to Kanyakumari (Kaliaperumal, 1994; Kaliaperumal *et al.*, 1998).

SEAWEED CULTURE

Seaweeds are cultivated for supply of raw materials to the seaweed industries and for their use as human food. In India, seaweeds collected from the wild are used as raw material for the production of agar and alginate. Nearly 25 agar and 10 algin industries are functioning at different places in maritime states such as Tamilnadu, Kerala and Karnataka. Annually about 5000 tons (dry wt.) of alginophytes, *Sargassum* spp, *Turbinaria* spp and *Cystoseira trinodis* and 1000 tons (dry wt.) of agarophytes *Gelidiella acerosa, Gracilaria edulis, G. crassa, G. foliifera* and *G. verrucosa* exploited from the natural seaweed beds mostly from south Tamil Nadu coast are used as raw materials by these industries. These quantities, particularly agar yielding seaweeds, are inadequate to meet the raw material requirements of Indian seaweed industries. As a number of seaweed industries are coming up every year, there is an increasing demand for the raw materials, which the existing resource cannot meet (Kalimuthu and Kaliaperumal, 1996). Hence commercial scale cultivation of seaweeds is necessary for uninterrupted supply of raw material to the industries. There are several advantages in the culture of seaweeds. In addition to continuous supply of alga, crop of single species could be maintained continuously. By adopting scientific breeding and other modern techniques of crop improvement, the yield and quality of seaweeds could be improved. Further, if seaweed culture is carried out on large scale, natural beds could be conserved purely for obtaining seed materials.

There are two methods for cultivation of seaweeds, one by vegetative propagation method and the other by reproductive method. In the vegetative propagation method, the fragments are inserted in the twists of ropes, tied to nylon twine or polypropylene straw and cultured in the near shore area of the sea. The fragments are also cultured by broadcasting them in outdoor ponds and onshore tanks. The fragment culture method is a simple one and gives quick results. Different culture techniques such as fixed off bottom culture, floating raft/cage culture, bottom culture, greenhouse culture, spray culture, raceways culture and tissue culture are adopted for cultivation of various economically important seaweeds in different countries by vegetative propagation method. (Thivy, 1964, Chennubhotla *et al.,* 1987 c; 1990; Kaliaperumal, 1993, 2000; Anonymous, 1996).

In the reproductive method, healthy reproductive plants collected from wild are transported to the laboratory/nursery and different types of spores such as swarmers, zoospores, tetraspores, carpospores and monospores are collected on various substrata like nylon rope, synthetic rope, coir rope, plastic strips (polypropylene straw/raffia), bamboo splint ladder, cement blocks, coral stones, etc. The spores on the substrata are cultured into sporelings in the culture room / hatchery by manipulation of temperature, light and providing nutrient culture media. Then the substrates containing sporelings/germlings are transferred to the suitable culture areas in the sea for their further growth to harvestable size plants. This method is followed for the commercial scale cultivation of edible red alga *Porphyra* and green algae *Enteromorpha* and *Monostroma*; agar yielding red alga *Gracilaria cylindrica* and algin yielding brown algae *Laminaria, Undaria* and *Macrocystis* in foreign countries such as Japan, China, Korea, Taiwan, Malaysia and U.S.A. (Chennubhotla *et al.*, 1987c; Santelices and Doty, 1980; Kaliaperumal, 1993). In this method the spores take more period for their development to harvestable size plants when compared with the growth of fragments in the vegetative propagation method.

SEAWEED CULTURE IN INDIA

With a view to develop suitable technology on commercial scale cultivation of agarophytes for augmenting supply of raw material to agar industries, since 1964 CMFRI, CSMCRI and other research organizations have attempted experimental cultivation of agar yielding seaweeds *Gelidiella* and *Gracilaria* and also carrageenophytes and edible seaweeds such as *Hypnea,* *Sargassum, Turbinaria, Cystoseira, Hormophysa, Caulerpa, Ulva, Enteromorpha* and *Acanthophora* in different field environments using various culture techniques. These experiments revealed that *Gelidiella acerosa* can be successfully cultivated on coral stones and *Gracilaria edulis, Hypnea musciformis, Acanthophora spicifera* and *Enteromorpha flexuosa* on long line ropes and nets. The techniques developed, areas tested and proved and results obtained for these five species are given below:

Gelidiella acerosa

This agar yielding red alga was cultured successfully on coir rope frames, nylon ropes nets and coral stones in the inshore water of Gulf of Mannar and Palk Bay near Mandapam. Small fragments obtained from mother plants were inserted in the twist of the coir ropes, tied at the mesh intersections of nylon rope nets using nylon twine and seeded twines were wound on the nails fixed to coral stones. Two fold increase over the quantity of seed material after 60 days of culture period was obtained from coir rope frames and nylon rope nets and 33 fold increase on coral stones (Subbaramaiah *et al.*, 1975; Patel *et al.*, 1986). The CSMCRI has developed technology for commercial scale cultivation of *Gelidiella acerosa* by coral stone method.

Gracilaria edulis

Cultivation of this agarophyte was carried out in the lagoon of Gulf of Mannar islands and in the shallow waters of Gulf of Mannar and Palk Bay at Mandapam using coir rope and nets, nylon rope nets and nylon monolines. The fragments of the plants were directly inserted in the twists of coir ropes and nets, tied at mesh intersections of nylon rope nets with nylon twine. In these experiments, an yield of 3.5 kg/m/year was obtained on long line ropes. Maximum yield of 14 fold increase after 80 days and an average yield of 3 fold increase after 60 days were obtained on coir ropes and nylon ropes nets. From the experiments conducted in 0.1 ha area of nets, it is estimated that a total quantity of 120 tons (wet wt.) crop could be harvested from 1 ha area of nets in a year. These experiments also showed that *Gracilaria edulis* could be successfully cultivated on commercial scale throughout the year in the Gulf of Mannar side and during June to September in Palk Bay side of Mandapam area (Raju and Thomas, 1971; Umamaheswara Rao, 1974; Krishnamurthy *et al.*, 1975, 1977; Chennubhotla *et al.*, 1978; Kaliaperumal *et al.*, 1996). Attempts were made to culture the agarophytes *Gracilaria edulis, G. corticata* and *G. follifera* in Kerala coast by reproductive and vegetative propagation methods.

Based on the results obtained in the field cultivation of *Gracilaria edulis* at Gulf of Mannar and Palk Bay near Mandapam, the Central Marine Fisheries Research Institute has evolved a viable technology in 1983 for commercial scale cultivation of this agar yielding seaweed using coir rope nets (Chennubhotla and Kaliaperumal, 1983; Kaliaperumal and Ramalingam, 2000). According to this method, one kg of seed material would yield on an average 3 kg/m^2 of net after 60 days.

Attempt was made for the first time in 1990 to transport *Gracilaria edulis* from Krusadai Island (Mandapam) and Karvaratti Island (Lakshadweep) to Minicoy and cultivate them in the lagoon on long line coir ropes and nets by vegetative propagation method. Very encouraging results showing maximum of 30 fold increase in yield was obtained after 60 days growth. These experiments proved that *Gracilaria edulis* could be very successfully cultivated on commercial scale in the lagoon of Lakshadeweep island during the premonsoon (March to June) and post monsoon (October to February) seasons (Chennubhotla *et al.*, 1992; Kaliaperumal *et al.*, 1992).

Gracilaria edulis was cultured successfully in fiberglass tanks at outdoor environment with continuous running seawater and aeration. Maximum of 4.75 fold increase in biomass was obtained after 70 days. This method can be also be adopted for commercial scale cultivation of *Gracilaria edulis* after perfection of technology. *Gracilaria edulis* was cultivated successfully also by reproductive method from tetraspores and carpospores. These spores from mature plants were liberated and settled on cement blocks and other substrates and cultured to germlings in the laboratory. Thereafter, they were transferred to the sea. The young plants grew from the germlings after one month of transplantation and they took another 4 to 5 months to reach harvestable size plants. This technology has been perfected at CMFRI for commercial scale cultivation (Reeta Jayasankar and Kaliaperumal, 1991).

Hypnea musciformis

This carrageenan yielding red alga was cultivated by the CSMCRI in the lagoon of Krusadai Island. Vegetative fragments of the plants were used as seed material and they were cultured on long line ropes. Fourfold increase in biomass was obtained after 25 days growth (Rama Rao *et al.*, 1985; Rama Rao and Subbaramaiah, 1986).

Acanthophora spicifera

This carrageenan yielding and edible red alga was cultivated by CMFRI in the nearshore areas of Hare Island near Mandapam by vegetative propagation method. Seed materials tied with polypropylene straw (plastic strip) were fastened to nylon monolines. Two fold increase in yield was realised after 25 days of growth. This seaweed was also successfully cultivated on nylon rope nets in Mandapam CMFRI fish farm ponds, which is connected to the sea through a feeder canal. An yield of 3.6 fold increase after 45 days in the first harvest and more than 2 fold increase after another one month in the second harvest were obtained (Kaliaperumal *et al.*, 1986).

Kappaphycus alvarezii

Experimental culture of the carrageenam yielding seaweed *Kappaphycus alvarezii* was carried out successfully by vegetative propagation method at Saurashtra and Mandapam region (Mairh *et al.*, 1995; Eswaran *et al.*, 2002). The same species was cultured in the nearshore area of Narakkal (Kochi) and Calicut. Pilot scale culture of *Kappaphycus alvarezii* by Pepsi Co. is going on in the nearshore area of Mandapam.

Enteromorpha flexuosa

This edible green alga was cultivated on nets in the intertidal belt at Okha (Gujarat) by reproductive propagation method using swarmers. Maximum biomass of 681.24 g fresh and 82.78g. dry alga per square meter of nets was obtained with in six weeks. The favourable period of cultivation was found to be from December to January (Ohno *et al.*, 1981; Oza *et al.*, 1985).

Transfer of technology of seaweed culture for rural development

The technology of cultivation of *Gracilaria edulis* on coir rope nets was transferred to the fisherfolk of Mandapam and nearby coastal villages by the Central Marine Fisheries Research Institute under the Lab-to-land programme of the Institute during 1978-1981 and under the Department of Biotechnology sponsored project during 2000-2002. They were also given training in the post-harvest technology of seaweeds and production of agar by industrial method. The Central Marine Fisheries Research Institute is also conducting every year short-term training course on "Seaweed culture, processing and utilization" to the interested fish farmers, seaweed utilisers, entrepreneurs, State and Central Government officials.

WORLD STATUS OF SEAWEED RESOURCES

Seaweeds grow abundantly in South Australia, Japan, South Africa, North-east Pacific and Mediterranean regions. Among the tropical areas, rich algal flora occur in the farwest Central Pacific, Carribean and South India. Australia has about 1/3 of world's benthic algae. The United States has the northern hemisphere's most diversified algal vegetation. More than 10,000 species of marine algae have been reported all over the world.

The aquaculture production of brown seaweeds is 5 million tonnes, red seaweeds is 2 million tonnes and green seaweeds is 15,000 tonnes. Farmed seaweed production has been increasing in the last decade (7 million metric tonnes in 1999) and now it is 88% of total seaweed supplies. Most of the quantities is utilized domestically for food. But there is growing international trade. China the major producer has started exporting seaweed as food to Korean Republic and Japan. The Republic of Korea exports some quantities of *Porphyra* (red seaweed) and *Undaria* (brown seaweed) to Japan. The total exports of Korea Republic in 1999 is 14,000 metric tons. Chile produces over 100,000 tonnes of seaweeds and is responsible for about 75% of global production of *Gracilaria* sp which is used for agar manufacture. Significant quantities of *Eucheuma* (red seaweed) are exported by the Philippines, Tanzania and Indonesia to USA, Denmark and Japan. The total European Countries import of seaweeds in 2000 is 61,000 tonnes with the Philippines, Chile, Indonesia and Australia as major suppliers. Chile is an important exporter, processor and exporter of agar and carrageenan.

Seaweed culture is at present almost entirely confined to the Orient, reaching its peak of sophistication in Japan and China. The seaweeds under commercial scale cultivation in the Indo-Pacific region are *Porphyra, Kappaphycus* and *Eucheuma* (red algae), *Undaria* and *Laminaria* (brown algae); *Caulerpa, Enteromorpha* and *Monostroma* (green algae). The important seaweeds for which commercial scale cultivation has been developed are *Gracilaria, Hypnea* and *Chondrus* (red algae) and *Macrocystis* (brown alga). The Japanese and Korean *Porphyra* industry, the Chinese *Laminaria* industry and the Philippines *Eucheuma* industry are now mainly based on cultured seaweeds.

The spore culture technique is adopted for cultivation of *Porphyra, Gracilaria, Undaria, Laminaria, Macrocystis, Monostroma* and *Enteromorpha* using various substrates such as synthetic rope nets, plastic frames, plastic strips, bamboo splint ladders, polythene film and fibreglass cloth. Vegetative propagation method is followed for cultivation of *Eucheuma, Gracilaria, Caulerpa, Hypnea* and *Chondrus*. *Eucheuma* is cultured in calm sea, *Gracilaria* and *Caulerpa* in ponds and *Hypnea* and *Chondrus* in outdoor tanks.

PROSPECTS

In India, the seaweeds *Gelidiella acerosa,Gracilaria edulis, G. crassa, G. foliifera, G. verrucosa, Sargassum* spp, *Turbinaria* spp and *Cystoseira trinodis* collected from wild are used as raw materials for the production of agar, alginates and liquid seaweed fertilizer. The unexploited other species of *Gracilaria, Hypnea, Acanthophora, Laurencia, Hormophysa, Ulva, Enteromorpha* and *Caulerpa* may be harvested from their natural beds at different parts of the Indian coast and used for the production of agar, carrageenan, alginates and edible products. The phytochemical especially carrageenan can be manufactured by exploiting the huge natural resource of *Hypnea* spp occurring in shallow and deepwaters and also by cultivating *Kappaphycus* on large scale. The edible seaweed products like jelly, jam, pickle, wafer etc. should be manufactured from seaweeds and marketed in our country.

The brown algae *Laminaria* and *Macrocystis* are used for production of methanol in some developed countries. Species of *Sargassum* and *Turbinaria* available in large quantities at different parts of the Indian coast could be used for this purpose. The large quantity of cast ashore seaweeds may be utilised as a source of energy for producing methanol, hydrogen and biogas and as fodder, manure and liquid fertilizer. The seaweed resource may also be used for extraction of bioactive agents and producing many pharmaceutical products.

There is good demand from some foreign countries like Japan for certain seaweeds, which are underexploited or unexploited. Hence, they may be collected from the wild or cultivated and exported to earn foreign exchange to our country. The seaweed industries in India are not producing the required quantity of agar and alginates to the local demand, particularly agar, due to paucity of raw material. Some quantity of agar and alginates are exported from our country. The required seaweeds in dried form may be imported from other countries to increase the production of phytochemicals in order to meet the local requirement and to promote the export of finished seaweed products.

In India, only experimental scale cultivation of commercially important seaweeds such as *Gelidiella acerosa, Gracilaria edulis, Hypnea musciform, Acanthophora spicifera* and *Sargassum* spp at different field environments using various culture techniques of vegetative propagation method and *Sargassum plagiophyllum, Enteromorpha flexuosa, Ulva fasciata* and *Gracilaria edulis* by reproductive method using spores have been carried out successfully. But in recent years pilot scale culture of *Kappaphycus alvarezii* is being carried out by Pepsi Co. in Mandapam area. The various biotechnological aspects being applied for large scale cultivation of *Porphyra* (Japan, Korea, Taiwan), *Undaria* (Japan, Korea), *Laminaria* (China, Japan), by reproductive propagation method and *Eucheuma* and *Kappaphycus* (Philippines), *Gracilaria* (Taiwan), *Hypnea* (Philippines), *Chondrus* and *Gigartina* (Florida) and *Caulerpa* (Philippines) by vegetative propagation method can be adopted for the production of commercially important seaweeds on large scale to meet the raw material need of Indian seaweed industries and to conserve the natural seaweed resources for using as seed material for commercial cultivation.

The bays and creeks present in the open shore along the east and west coast, lagoons of coral reefs in the south-east coast of Tamil Nadu, Andaman-Nicobar islands and atolls of Lakshadweep are suitable localities for cultivation of seaweeds. Commercial cultivation of seaweeds may be undertaken in these areas by the seaweed utilisers and private entrepreneurs availing financial assistance from banks and other funding agencies connected with rural development programmes. Seaweed cultivation on large scale could not only augment supply of raw material to the seaweed based industries, but it would also provide employment to the people living in the coastal areas of the mainland, Lakshadweep and Andaman-Nicobar islands. This would help in improving their economic status and thus help in rural upliftment.

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