Seaweed Res. Utiln., 36 (1&2) : 114 - 125, 2014

A review on resources, cultivation and utilisation of marine macroalgae in India

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Introduction

Marine macro algae, popularly known as seaweeds belong to non-flowering plants and inhabit the marine ecosystem. These autotrophic plants are commonly found in intertidal as well as in the subtidal regions of the sea. Based on morphology, cellwall and pigment composition, they are classified into green (Chlorophyceae), red (Rhodophyceae) and brown (Phaeophyceae) algae (Chapman, 1970). In India, certain coastal pockets of the peninsular coast comprising nine maritime states and Andaman-Nicobar as well as the Laccadive Archipelago harbour dense beds of these marine algae that can be exploited for commercial purposes. More than 10,000 species of marine algae have been reported from all over the world. According to the FAO data base during 2008, total world production of marine algae was estimated to 15.8 million tonnes (wet weight) equivalent to the value of 87.4 million US $ with 99.8 percent by weight and 99.5 percent by value contributed by Asian region alone (FAO., 2011). The information available on marine macro algal resources, their assessment, exploitation, post-harvest industry, cultivation and utilisation in India from various sources are reviewed in this paper.

Distribution and Resources

In India, luxuriant growth of several species of seaweeds occur along the south east coast of Tamilnadu, Gujarat, Lakshadweep and Andaman-Nicobar Islands. Fairly rich seaweed beds occur in the vicinity of Mumbai, Ratnagiri, Goa, Karwar, Bhatkal, Quilon, Varkala, Vizhinjam and Visakhapatnam as well as in coastal lakes such as Chilka and Pulicat (Umamaheswra Rao, 1969; Chennubhotla, 1996, 1999; Kaliaperumal, 1993). Indian coastline is endowed with 896 species of marine algae comprising 228 species of Chlorophyta, 210 species of Phaeophyta, 455 species of Rhodophyta and 3 species of Xanthophyta (Umamaheswra Rao, 2011).

Thivy (1951) estimated about 3,000 tonnes of fresh agarophytes per annum from Indian waters excluding the resources of Lakshadweep and Andaman Islands, while the estimate in 1960 (Thivy, 1960) indicated about 35 metric tonnes of dry agarophytes per annum from Indian waters. Chacko and Malu Pillai (1968) estimated 6,000 tonnes of agarophytes and 60,000 tonnes of alginophytes for the area between Point Calimere and Cape Comorin. Varma and Rao (1962) surveyed Pamban area of Mandapam coast during 1961-62 covering an area of 234.25 sq. km along the Hare Island on the west and Shingle Island on the east and estimated a standing crop of 70754 tonnes of agarophytes and 1,31,588 tonnes of alginophytes from which 341.35 tonnes wet weight of agarophytes and 657.94 tonnes

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wet weight of alginophytes can be harvested.

From the seaweed resources surveys carried out in the intertidal and shallow water areas of east and west coasts and also the archipelago of Laccadives and Andamans so far by the CMFRI Cochin, CSMCRI Bhavnagar and NIO Goa, it could be estimated that total standing crop of all the seaweeds in Indian waters is more than 1,00,000 tonnes (wet weight) consisting of 6,000 tonnes of agar yielding red seaweeds, 16,000 tonnes of algin yielding brown seaweeds and the remaining quantity of edible and other seaweeds(Devaraj *et al.*, 1999). According to Chennubhotla *et al.* (2013 a,b) the annual production of marine algae in India has been estimated to 3,01,646 tonnes. Marine algal resources of southern Kerala coast including Ashtamudi Lake, Quilon and Trivandrum coasts were assessed qualitatively by Balakrishnan Nair *et al.* (1982, 1986a, 1986b, 1990 and 1993).

Chennubhotla *et al.* (1987) reviewed the biological aspects of economically important Indian seaweeds including the taxonomy and ecological studies at different localities along the Indian coast, growth pattern, period of maximum growth, fruiting seasons for species such as *Cystoseira indica, Sargassum, Turbinaria, Gracilaria verrucosa* and *Gelidiella acerosa.* Chennubhotla *et al.* (1988) conducted an extensive resource assessment survey along the Kerala coast and brought out the details of availability of commercially important marine macro algae for the first time. Occurrence of *Porphyra kanyakumariensis* was reported from the southern Kerala coast by Chennubhotla *et al.* (1990). *Gracilariopsis lemaneiformis,* a long thalloid agar yielding red alga has been reported from certain backwaters of Dhalawapuram, (Quilon), Kadalundi (Kozhikode) and Mopla Bay (Kannur) along the Kerala coast (Kaladharan, 2005).

The agar yielding red alga *Gracilaria edulis* was introduced in the lagoon of Minicoy Atoll by transporting the wild stock from Kavarathi Isaland (Laccadives) and Rameswaram coast (Gulf of Mannar) in the year 1990. This species was not reported from Minicoy Atoll till then (Kaladharan and Chennubhotla, 1993). Kalimuthu and Kaliaperumal (1991) reported the unusual landing of *Gracilaria edulis* in Kottaipattinam area of Tamil Nadu coast which was drifted from Sri Lankan waters. Kaladharan (2001) reviewed the seaweed resource assessment surveys carried out by CMFRI, CSMCRI and NIO in the Lakshadweep Islands and indicated nearly 10,000- 19000 tonnes wet weight of standing crop of seaweeds in 12 atolls of Laccadive Archipelago comprising 114 species belonging to 62 genera. Seaweed distribution and resource assessment from 15 localities along the Kerala coast was studied by Kaliaperumal and Chennubhotla (1997) and reported 35 species belonging to 25 genera and 18 families.

Studies on the distribution and seasonal changes in the marine algal flora of Rameswaram coast was made for a period of one year from July 1983 to June 1984 by fortnightly collection of algae from intertidal and subtidal regions upto 1.0 m depth at seven localities namely Rameswaram, Pamban, Krusadi Island, Thonithurai, Seeniappa Darga, Pudumadam and Kilakkarai. Out of 104 algal species, Krusadi Island registered maximum number of 77 algal species and Rameswaram recorded minimum number of 35 species (Kalimuthu *et al.*,1992). Umamaheswara Rao *et al.* (2009) studied the morphological and anatomical characters of two varieties of *Gracilaria tenuistipitata* namely var. *tenuistipitata* Chang et Xia and var. *liui* Zhang et Xia and an unidentified *Gracilaria* species occurring in the Chilka Lake.

Nettar and Panikkar (2009a) described two new species *Hapalospongidion thirumullavaramensis* and *Pseudolithoderma thangasseriensis* of Family Ralfsiaceae, collected from the Quilon coast of Kerala. The taxonomy of four species of *Feldmannia* collected from different parts of Kerala namely *F. collumellaris, F. irregularis* and two new species *F. sahnienii* and *F. renienii* were also reported by Nettar and Panikkar (2009b). Nettar and Panikkar (2009c) reported five species of *Hincksia* collected from different parts of Kerala and these include *H. clavata* (Krishnamurthy and Baluswami) P.Silva, *H. rallsiae* (Vickers) P.Silva, *H. sandriana* (Zanardini) P.Silva, *H. mitchelliae* (Harvey) P.Silva and *H. turbinariae* (Jaasund) P.Silva. Among these, *H. rallsiae* is a new report to the Indian marine flora. Nettar (2009) described with illustrations on the occurrence of *Hecatonema sargassicola* Boergesen and *H. terminale* (Kuetzing) Kylin, collected from Kerala and Tamil Nadu.

Palanisamy (2009) reported *Avrainvillea amadelpha* (Montagne) A.Gepp & E.Gepp for the first time from Mahatma Gandhi Marine National Park, Andamans. A general survey conducted for marine algae along the Gulf of Mannar region of southeast coast of India recorded agarophytes comprising three species of *Gracilaria, Gelidiella acerosa* and *Gelidium pusillum* (Balakrishnan *et al.*, 2009a), carrageenophytes of *Hypnea musciformis* and *H. valentiae* (Balakrishnan *et al.*, 2009b) and alginophytes comprising *Padina tetrastromatica*, three species of *Sargassum, Stoechospermum marginatum,* three species of *Turbinaria* and two species of *Dictyota* (Balakrishnan *et al.*, 2009c).

Seaweed exploitation

Effect of repeated harvesting on the growth of commercially important seaweeds such as agar yielding *Gelidiella acerosa* and *Gracilaria corticata* and algin yielding seaweeds *Sargassum cristaefolium, S. ilicifolium, S. myriocystum, S. wightii* and *Turbinaria conoides* growing in Krusadai Island, Pudumadam and Kilakkarai area was investigated by Kaliaperumal *et al.* (1990a, 1996) and Kalimuthu *et al.* (1993) for two years and from Kerala coast for one year period by Ushakiran and Kaladharan (2011). Ugarte *et al.* (2006) observed the changes in the morphology and biomass production in *Ascophyllum nodosum* due to harvesting by rake cutter from southern New Brunswick.

Data collected on the commercial exploitation of seaweeds from the natural seaweed beds of Tamil Nadu for 4 years period from 2000 to 2003 (Kaliaperumal *et al.*, 2004) showed that the quantity of agarophytes viz. *Gelidiella acerosa, Gracilaria edulis, G. crassa, G. foliifera* and *G. verrucosa* varied from 965 to 1518 tonnes (dry wt) and alginophytes *Sargassum* spp and *Turbinaria* spp from 1433 to 2285 tonnes (dry wt) per year. The commercial harvest of seaweeds in Gulf of Mannar and Palk Bay was recommended only during the peak growth period of the algae from August to January.

Seaweed biology and environment

Experiments were conducted with tetrasporophytes of *Gelidium pusillum, Pterocladia heteroplatos* and *Gelidiopsis variabilis* occurring at Visakhapatnam coast to determine the effects of various environmental factors on the liberation of spores (Umamaheswara Rao and Kaliaperumal, 1983). The ability to liberate spores and the quantity of spores shed by these three red algae varied with submerged condition of the plants, photoperiod, irradiance, salinity and temperature. Kaliaperumal (1989) investigated the effects of desiccation, salinity, light, dissolved oxygen and temperature on the diurnal periodicity in liberation of tetraspores of *Gelidium pusillum, Pterocladia heteroplatos* and *Gelidiopsis variabilis.*

Effect of light intensity, epiphytes and grazing on the growth of *Gracilaria edulis* cultivated in Palk Bay and Gulf of Mannar near Mandapam was studied by Kaliaperumal *et al.* (1993) and suggested that the suitable period of cultivation of *G. edulis* in Gulf of Mannar is during November to March. Kaladharan *et al.* (1996) have attempted to optimize certain physical and biological parameters associated with cultivation of *Gracilaria edulis* in island ecosystem such as effect of planting density, depth of water above substratum, periodic cleaning for removal of epiphytes, grazing pressure and regeneration after successive harvest from Minicoy Atoll of Laccadives.

Studies were conducted on the salinity tolerance of 13 economically important seaweeds of Mandapam coast (Kaliaperumal *et al.*, 2001). Effect of thermal stress (10 - 45 °C) on the liberation of tetraspore from *Gelidium pusillum, Pterocladia heteroplatos* and *Gelidiopsis variabilis* was monitored in response to various temperature

(Kaliaperumal and Umamaheswara Rao, 1987). Gulshad *et al.* (1999) studied the impact of domestic waste discharge on *Caulerpa racemosa* from lagoon of Minicoy Island. Rate of spore shedding and spore output in the tetrasporophytes of *Gelidium pusillum, Pterocladia heteroplatos* and *Gelidiopsis variabilis* were found to vary considerably with the salinity, temperature and photoperiod (Umamaheswara Rao and Kaliaperumal, 1983).

Seaweed culture

Kaliaperumal *et al.* (1986) conducted experimental field cultivation of *Acanthophora spicifera* in the Gulf of Mannar following vegetative propagation method. Grazing incidence of cultured seaweed *Gracilaria edulis* in Minicoy lagoon is well documented (Chennubhotla *et al.*,1994). The experimental culture of *Gracilaria edulis* by spore shedding method was carried out at Mandapam on cement blocks from November 1988 to April 1989 and the spores grew to adult plants reaching a maximum length of 16 cm after four months of their output (Reeta and Kaliaperumal,1991). Reeta and Ramamoorthy (1999) reported the seasonal variation in the growth of *Gracilaria edulis* cultured from spores through an year long experiment conducted in the Gulf of Mannar and Palk Bay near Mandapam.

With a view to find out the feasibility of Lakshadweep lagoons for cultivation of *Gracilaria edulis*, experimemal culture was carried out at four sites in Minicoy lagoon (Chennubhotla *et al.*, 1992a, b) and encouraging results were obtained indicating high potential of about 15 fold increase in yield. Kaladharan *et al.* (1996) conducted mariculture of the agar-yielding red seaweed *Gracilaria edulis* in Minicoy lagoon during 1990–1992. Experiments were conducted on dry matter accumulation, effects of planting density, depth of water above culture nets, periodic cleaning for removal of epiphytes, grazing and the yield as well as regeneration of *G. edulis* after successive harvests to understand the optimum requirements of this seaweed. Artificial seawater prepared with simplified recipes was found suitable for maintaining seaweeds of commercial importance under laboratory conditions (Kaladharan, 2000). In India, cultivation of carragennophyte *Kappaphycus alvarezii* started in Diu of Sourashtra coast and in Mandapam, southeast coast of Tamil Nadu, during 1995–1997 for carrageenan production (Mairh *et al.*, 1995; Johnson and Gopakumar, 2011). The current status of *Kappaphycus* farming and the constraints are reviewed by Johnson and Gopakumar (2011).

Seaweed utilization

The red algae such as *Gracilaria, Gelidiella, Gelidium* and *Pterocladia* yield agar. Some other red algae viz., *Kappaphycus, Hypnea, Gigartina* and *Chondrus* are the major sources for the production of carrageenan. Algin is obtained from brown algae like *Sargassum, Hormophysa, Laminaria, Turbinaria, Undaria, Cystoseria* and *Macrocystis* (Anon, 1987). These phycocolloids are used as gelling, stabilizing and thickening agents in food, confectionery, pharmaceuticals, dairy, textile, paper and paint industries etc. Apart from these products, Mannitol, Iodine, Laminarin and Fucoidin are also obtained from seaweeds (Kaliaperumal 1993; Kalipaerumal *et al.*, 2004). Many protein rich marine algae such as *Ulva, Enteromorpha, Caulerpa, Codium, Monostroma, Sargassum, Hydroclathrus, Laminaria* and *Acanthphora* are used as human food (Anon, 1987). In Japan, Korea, China, Malaysia, Philippines and other Southeast Asian countries seaweeds are used in the form of soup, salad and vegetables. The food value of seaweeds depends on the protein, minerals and vitamins present in them (SEAFDEC., 2000).

Seaweeds such as *Enteromorpha linza, Enteromorpha prolifera, Ulva fasciata, Caulerpa taxifolia* and *Sargassum johnstonii* from natural and cultivated populations were evaluated for food safety and nutritional quality (Naidu *et al.*, 1993). The acute oral feeding of *E. linza, U. fasciata, C. taxifolia* and *S. johnstonii* and subacute oral feeding of *E. linza* for 12 weeks did not produce any toxic effects on male and female rats. Secondary metabolites of seaweed *Ulva fasciata* and *Hypnea musciformis* collected form southeast and southwest coast of India were tested for biotoxicity potential and both these species showed potential antibacterial activity, brine shrimp cytotoxicity, larvicidal, antifouling activities (Selvin and Lipton, 2004). Nutritional value of six species of seaweeds (*Sargassum wightii, Ulva lactuca, Kappaphycus alvarezii, Hypnea musciformis, Acanthophora spicifera* and *Gracilaria corticata*) as complementary source of dietary proteins for animal nutrition was evaluated based on their amino acid profile (Vinojkumar and Kaladharan, 2007).

Dry biomass of *Sargassum wightii* exhibited maximum metal uptake at pH 4–5 and the value ranged from 18% to 29% of dry biomass and the kinetics of metal adsorption was fast with 70–80% taking place within 30 min. Based on these results, a biobattery involving perforated columns packed with pulverized dry biomass of *S. wightii* was designed, which could remove metals in the range of 50–97% from a multi-metal ion solution within two and a half hours (Vinojkumar and Kaladharan, 2006). Net primary production (NPP) of 10 commonly available seaweeds of Minicoy Atoll varied from 2 to 10 g C/m^3/day. The mean of NPP of these 10 seaweeds when measured individually was 5.68 g C/m^3/d and that of all seaweeds incubated collectively registered 5.32 g C/m^3/d. Hence it is presumed that the probable rate of NPP of seaweed community contributing to Minicoy lagoon to be approximately 5g/C/m^3/d (Kaladharan and Kandan, 1997). Polyculture practice of *Gracilaria* and shrimp improve water quality to great extent and prevent bacterial diseases of shrimp (Liu *et al.*, 1997). Cultivation of *Gracilaria parvispora* in shrimp farm effluents enhanced the growth of the algae (Nelson *et al.*, 2001).

Seaweeds are utilised in different parts of the world in diversified fields such as animal feed, fertilizer for crops etc (Dave *et al.*, 1977). The high amount of water soluble potash, other minerals and trace elements present in seaweeds are readily absorbed by plants and they check deficiency diseases in crops. Liquid seaweed products were introduced in 1950 and now enjoy a world-wide reputation. The manurial value of these products is not related to their N P K content and they show unusual properties such as enhanced germination of seeds, increased frost resistance and induce resistance to fungal and insect pests (Booth, 1969).

Cytokinin - like substances were extracted from green seaweed *Caulerpa racemosa* and purified using an ion exchange column of CM-cellulose. Bioassay of these extracts with dark-germinated cotyledons of cucumber for chlorophyll biosynthesis proved the presence of cytokinin, a plant growth promoter in the extract of *C. racemosa*. The efficiency of it is comparable to that of commercially available kinetin (Kaladharan and Sridhar, 1999). Cost effective and organic medium for the laboratory culture of microalgae has been developed from the extracts of some selected green seaweeds (Kaladharan *et al.*, 2002). Agar factory waste was tried as fuel for cooking and manure for seedlings of cowpea (*Vigna ungiculata*) which registered improved seedling vigour. The fuel cakes prepared out of agar factory waste registered high energy content, high ash content and high rate of combustibility over fire wood (Kunda and Kaladharan, 2003).

Jothinayagi and Anbazhagan (2009) studied the effect of different concentrations (20%, 40% 60%, 80% and 100%) of seaweed liquid fertilizer (SLF) of *Sargassum wightii* on the growth and biochemical characteristics of *Abelmoschus esculentus*. Sridhar and Rengasamy (2010) tested the efficiency of different concentrations of seaweed liquid fertilizers (SLFs) obtained from the brown seaweed *Sargassum wightii* and green seaweed *Ulva lactuca* on groundnut *Arachis hypogaea* under field trial. Thirumaran *et al.* (2009) investigated the effect of seaweed liquid fertilizer of *Rosenvigea intricata* with or without chemical fertilizer on seed germination, growth, yield, pigment content and soil profile of *Abelmoschus esculentus*. Erulan *et al.* (2009) studied the effect of seaweed liquid fertilizer of *Sargassum polycystum* on the seed germination, growth, yield, biochemical and pigment characteristics of pigeon pea *Cajanus cajan.* The effect of different concentrations of liquid seaweed fertilizer of *Ulva lactuca* on morphological and biochemical changes of *Vigna unguiculata* was assessed by Lakshmi and Sundaramoorthy (2010). The seaweed liquid fertilizer derived from the green seaweed *Ulva lactuca* was used to study its effect on physical and biochemical parameters and yield of *Capsicumannum*(Sridhar and Rengasamy, 2012).

Seaweed Industry

The seaweed industry in India is mainly a cottage industry and is based only on natural stock of agar yielding red seaweeds such as *Gelidiella acerosa* and *Gracilaria edulis* and algin yielding brown seaweeds such as *Sargassum* and *Turbinaria* (Coppen, 1991; Kaladharan and Kaliaperumal, 1999). Kaladharan and Kaliaperumal (1999) reported that India produces 110-132 t of agar annually utilizing about 880-1100 t of dry agarophytes and 360-540 t of algin from 3600-5400 t of dry alginophytes from nearly 40 seaweed processing units of which 22 produce agar. Carrageenan production in India started very recently with the beginning of large scale cultivation of *Kappaphycus alvarezii* in the PalkBay (Johnson and Gopakumar, 2011).

Agar producers in India follow a simple method of agar extraction (Armisen and Galatas, 1987). In this method the dry weed is boiled, hot extract is filtered, cooled, freeze thawed, bleached and dried in the sun. The agar is marketed either in strips or as powder. *Gelidiella acerosa* yields bacteriological/ pharmaceutical grade agar, whereas species of *Gracilaria* yield food grade agar (Coppen, 1991; Kaladharan and Kaliaperumal, 1999). *Sargassum* and *Turbinaria* are the two major raw materials used by the algin industry in India. *Sargassum* is preferred over *Turbinaria* as the quality and quantity of algin yield are better (Coppen, 1991). Most of the algin producing units in India are capable of producing 20-30 tonnes /year and total algin production in India is 360-540 tonnes/ year (Kaladharan and Kaliaperumal,1999). The global production of carrageenan has shown a 4% annual growth from 1978 to 1993 and the five leading international market for carrageenan are Europe-36%, North America-26%, Latin America-17%, Australia 13% and Japan-8% (Hurtado-Ponce, 1996).

Kaliaperumal *et al.* (2004) analysed the data on commercial exploitation of seaweeds from the natural seaweed beds of Tamil Nadu coast for four years from 2000- 2003 and recommended the harvest of seaweeds from the natural beds during the peak growth period from July to January. It is estimated that 90% of dry biomass of raw material used for the extraction of agar is considered as waste as the available method can extract only 10-12 % agar from the raw material. The agar factory discharge has been utilized as fuel for cooking and manure for field crops effectively (Kunda and Kaladharan, 2003).

Phycocolloids from marine algae

Phycocolloids refer to those polysaccharides extracted from both fresh water and marine algae (Armisen and Galatas, 1987). Polysaccharides derived from marine red and brown algae such as agar, carrageenan and algin are economically important and have commercial significance, since these polysaccharides exhibit high molecular weight, high viscosity and excellent gelling, stabilizing and emulsifying properties (Ji Minghou, 1990). These colloids have many applications in food, pharmaceutical, cosmetic, biotechnologic industries etc as gelling agents, thickeners or stabilizing and emulsifying agents (Yaphe, 1984; Kaladharan *et al.*, 1998).

The basic structure of agar is a regularly alternating sequence of 3 - linked-β D galactopyranose and 4 - linked 3-6 anhydro -α- L-galactopyranose. Carrageenan which is also derived from different genera of Rhodophyta (red seaweeds) is a linear polysaccharide with a repeating structure of alternating 1, 3-linked- β- D galactopyranose and 1-4 linked α- D-galactopyranose units. The 3 linked units occur as the 2 and 4-sulphate or unsulfated, while the 4-linked units occur as the 2-sulphate, 2,6-disulphate, the 3,6 anhydridand the 3,6 anhydrid 2-

sulphate (Stanley, 1987). Algin (also known as alginate or alginicacid) extracted from genera of Phaeophyta (brown seaweeds) is a linear polymer based on two monomeric units, β- D mannuronic acid and α- L- guluronic acid (Wilma, 1990).

Varma and Rao (1962) estimated that 11.84 tonnes of dry algin can be extracted from 98.69 tonnes of dry alginophytes and 5.59 tonnes of dry agar from 36.38 tonnes of dry agarophytes from the Pamban area of Mandapam coast. Studies were made on the yield and physical properties of agar from *Gelidiella acerosa, Gracilaria arcuata* and *G. edulis* and algin and mannitol from *Padina boergesenii, Chnoospora implexa, Sargassum duplicatum, Turbinaria conoides* and *T. ornata* growing in eight islands of Lakshadweep (Kaliaperumal *et al.*, 1989). Kaliaperumal *et al.* (1990b) investigated the agar content from 8 red algae and algin from 10 brown algae collected along south Tamil Nadu Coast.

Agar

During the second World War, due to the shortage of agar, the Board of Scientific and Industrial Research started manufacture of agar in India at the Research Department of Kerala University. Since then, much stride has been made in these lines on the economic utilization of algae and the Central Marine Fisheries Research Institute developed a cottage industry method for the manufacture of agar from *Gracilaria* spp. and *Gelidium micropterum* (Thivy, 1960). The agar obtained from *Gracilaria verrucosa* growing in Chilka Lake, Odisha was studied qualitatively and quantitatively and recommended using different agarophytes like *Gelidlella acerosa* and *Gracilaria edulis* in three different proportions to obtain desired quality of gel by Chennubhotla *et al.* (1977a). Optimum levels of alkali/ acid treatment and thermal manipulations during extraction of agar were determined to increase the yield and quality of agar from *Gracilaria edulis* (Rao and Kaladharan, 2003).

Results obtained on seasonal growth, yield and physical properties of agar in *Gelidiella acerosa* and *Gracilaria edulis* from Rameswaram coast for one year was reported by Chennubhotla *et al.* (1986). Seventeen agar samples were extracted from *Gelidiella acerosa* collected from 9 sites on the Indian coast (5 from southeast coast and 4 from the west coast) for stability characteristic of their gels (Prasad *et al.*, 2007). Balakrishnan *et al.* (2009a) reported three species of *Gracilaria, Gelidiella acerosa* and *Gelidium pusillum* in the Gulf of Mannar and among these agarophytes *Gracilaria edulis, Gelidiella acerosa* and *Gelidium pusillum* showed agar yield of above 60% from many of the study sites which exceeded the values reported earlier.

Alginic acid

Kaliaperumal and Kalimuthu (1976) studied the seasonal changes in growth, reproduction, alginic acid and mannitol contents in *Turbinaria deccurens* from Rameswaram coast. Chennubhotla *et al.* (1982) found that alginic acid yield varied with the seasonal growth behaviour of *Sargassum ilicifolium* and *S. myriocystum* showing maximum yield in July or August and recommended the suitable harvesting period from July to September for getting the maximum yield of alginic acid. Variation in growth and mannitol content in *Padina gymnospora* conducted during 1975-1976 was reported by Chennubhotla *et al.* (1977b). Studies were made from September 1985 to August 1986 on the standing crop, algin and mannitol contents of three brown algae *Colpomenia sinuosa, Hydroclathrus clathratus* and *Rosenvingea intricata* growing at Shingle Island and Kilakkarai near Mandapam and there was no marked seasonal variation in the yield of algin and mannitol in these algae (Kalimuthu *et al.*, 1991). Kalimuthu *et al.* (1980) investigated the yield of alginic acid and mannitol content of *Stoechospermum marginatum* and *Sargassum marginatum* for one year during 1976 and found that the yield of alginic acid varied from 14.5 to 23.8% and mannitol from 1.2 to 2.7% and these values were lower than in *Sargassum* and *Turbinaria* spp.

Seasonal variation in biochemical constituents of *Sargassum wightii* in relation to alginic acid content has been reported by Reeta

(1993) The lipid content showed a reciprocal relation, while carbohydrate a positive correlation with alginic acid content. Seasonal variations in growth, alginic acid and mannitol contents of *Sargassum wightii* and *Turbinaria conoides* growing in the Gulf of Mannar near Mandapam were investigated for a period of two and a half years from August 1965 (Umamaheswara Rao, 1969). The yield of alginic acid was found high during the peak growth and fruiting periods and mannitol content was at its maximum in the early stages of the growth cycle from May to August and minimum after the initiation of the reproductive receptacles. Reeta (1993) studied the yield and quality sodium alginate on the of pretreatment of *Sargassum wightii* with chemicals such as HCl, NaOH and formalin. Istini *et al.* (1994) compard the yield and physical properties of algin obtained from *Laminaria japonica, Eklonia cava* and *Sargassum duplicatum* collected from Japan. Balakrishnan *et al.* (2009c) reported that among the alginophytes in the Gulf of Mannar area, *Stoechospermum marginatum* registered the richest source of alginic acid closely followed by the species of *Sargassum* and *Turbinaria*.

Carrageenan

With a view to find out a suitable method for carrageenan extraction from *Kappaphycus alvarezii*, a detailed investigation was made on quantitative and qualitative estimation of carrageenan subjected to different physical and chemical treatments (Mishra *et al.*, 2006). Seasonal variation in growth and carrageenan content in *Hypnea valentiae, Acanthophora spicifera, Laurencia papillosa* were observed for one year from April 1995 to March 1996 (Kaliaperumal *et al.*, 2002) and the carrageenan content recorded 11.3%, 6.0% and 8.1% in *H. valentiae, A. spicifera* and *L. papillosa* respectively. Balakrishnan *et al.* (2009b) found that among the eight species of carragenophytes from Gulf of Mannar, *Sarconema filiforme, Laurencia papillosa* and the two species of *Hypnea* yielded carrageenan above 60% from most of the study sites and the carrageenan content recorded in *Hypnea* and *Laurencia* exceeded the values reported earlier from other coasts of India.

Biochemicals

Biochemical composition of some marine algae from Mandapam coast, Tamil Nadu was assessed by Chennubhotla *et al.* (1977). Protein, lipid and carbohydrate content of the red alga *Porphyra kanyakumariensis* from the southern Kerala coast was studied by Chennubhotla *et al.* (1990). Christabel *et al.* (2011) screened aqueous extracts of seven species of marine macroalgae for their antimicrobial activity against ten pathogenic bacterial strains. Seasonal variation in growth and biochemical constituents such as protein, carbohydrate and lipid in *Hypnea valentiae, Acanthophora spicifera, Laurencia papillosa, Enteromorpha compressa, Ulva lactuca* and *Caulerpa recemosa* from Mandapam coast were observed for one year from April, 1995 to March, 1996 (Kaliaperumal *et al.*, 2002). Kaladharan and Velayudhan (2005) tested the crude GABA (γ- amino butyric acid) extracted from *Hypnea valentiae* collected from Vizhinjam coast and compared its activity of favouring settlement of pediveliger larvae of green mussel *Perna viridis* to the standard commercial grade GABA. Algin yielding brown alga *Turbinaria ornata* is known to exhibit antioxidant and anti-inflammatory properties (Ananthi *et al.*, 2010).

From the above account, it is evident that several studies have been made in India on seaweed distribution, resources, taxonomy, culture, harvest, industry, utilization, post-harvest technology and utilization. Intensive studies should be made on different aspects of seaweeds occurring in Kerala coast. The present review will be much useful to the researchers and the entrepreneurs to establish seaweed industries in Kerala during the years to come.

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