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Farming of agarophytes in India—a long-time sustainability for the industry and preserving wild stocks

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Abstract In India, food-grade agar is produced from *Gracilaria edulis* while bacteriological-grade agar is extracted from *Gelidiella acerosa*. Agarose is directly obtained from *Gracilaria dura*. Seaweeds for agar production mainly come from wild stocks located in reefs of the Gulf of Mannar, southeast coast. Landings of *Gr. edulis* were peak (982 dry t) during 1990 while landings of *Ge. acerosa* reached maximum (665 dry t) during 2002–2003. Overexploitation is leading to a decrease in biomass of these two algae at an alarming rate for the last decade. Commercial cultivation of agarophytes is yet to increase in India in spite of growing pressure on wild stocks triggered by increase in demand of raw material by the industry. Taking this into consideration, a number of efforts have been initiated to develop feasible cultivation methods for agarophytes. The present paper summarizes various methods developed for commercial cultivation of *Gr. edulis*, *Gr. dura*, *Gracilaria verrucosa* and *Ge. acerosa* in the open sea. We also discuss the challenges in the development of commercial farming of agarophytes in India.

Keywords Bamboo raft · Commercial cultivation · Farming · *Gracilaria dura* · *Gracilaria edulis* · *Gelidiella acerosa*

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Introduction

Agars are industrially important polysaccharides due to their excellent thickening or gelling abilities (Selby and Whistler 1993; Therkelsen 1993). The physical properties and texture of agar gel determine its application, especially in the food and pharmaceutical industries. *Gracilaria* and *Gelidium* are the principal seaweeds for commercial production of agar worldwide. *Gracilaria* is used for making food-grade agar while *Gelidium* is preferred for producing bacteriological- and pharmaceutical-grade agars. About 9600 t of agar was produced in the year 2009 worldwide (Bixler and Porse 2011). Of the total agar, 80% of agar was produced from *Gracilaria* and the remaining 20% from *Gelidium*. Commercial cultivation of *Gelidium* has not been reported from anywhere in the world. The entire quantity of *Gelidium* for agar production comes from wild stock. Harvesting of *Gelidium* is being done in Spain, Portugal, Morocco, South Korea, Japan and Mexico (Bixler and Porse 2011). On the other hand, *Gracilaria* is being cultivated commercially in a number of countries such as Spain, Portugal, Chile, Peru, Argentina, Indonesia, China, Vietnam and Taiwan and on pilot scale in Namibia, Venezuela and Malaysia (Bixler and Porse 2011).

In India, the population of *Gelidium* is very sparse and hence, *Gelidiella* is being used for commercial production of bacteriological-grade agar. The genus *Gelidiella* has six species (Oza and Zaidi 2001), and *Gelidiella acerosa* is the dominant species with abundant resources along the southeast coast. Agar from *Ge. acerosa* is reported to have gel strength of more than 1200 g cm^{-2} (Ganesan et al. 2015a, b). The genus *Gracilaria* has 32 species (Oza and Zaidi 2001), and *Gracilaria edulis* is the dominant species utilized for commercial production of food-grade agar with gel strength of 490 g cm^{-2} (Meena et al. 2008). Other species which complement the agar production are *Gr. salicornia*, *Gr. crassa*, *Gr.*

corticata, *Gr. debilis* and *Gracilaria verrucosa* (Ashok et al. 2015). Recently, agarose has been directly obtained from *Gracilaria dura* having gel strength of 2200 g cm^{-2} (Meena et al. 2007). This species has restricted distribution along the northwest coast of India.

The main objective of the present contribution is to summarize the present status of agarophyte farming in India. In addition, we review the statistics of agarophyte landings and agar production in the country to justify the need for commencement of commercial farming of agarophytes.

Landings of agarophytes

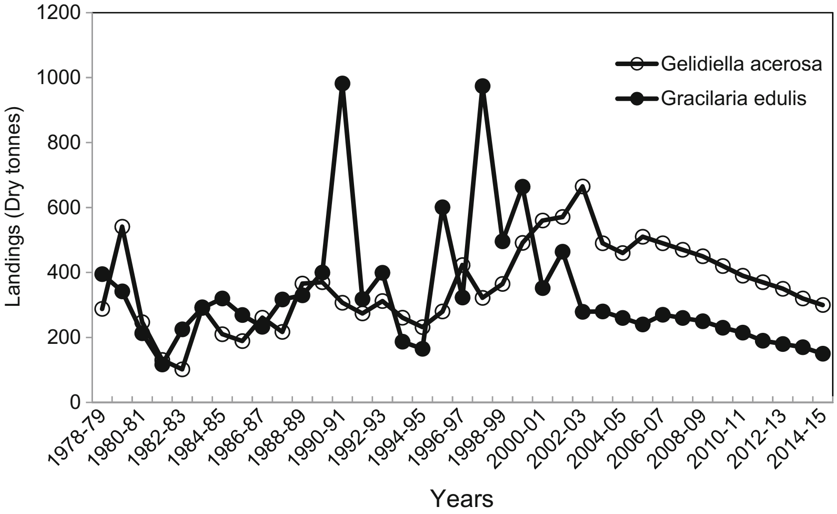
In India, *Ge. acerosa* and *Gr. edulis* have been commercially harvested since early 1950s (Krishnamurthy 1971). These two algae are harvested from 20 islands and mainland coast of the Gulf of Mannar, southeast coast of India. A broad (approximately 300 m wide) and long stretch (approximately 140 km long) of coral reef running parallel to the islands supports growth of *Ge. acerosa* and *Gr. edulis*. A similar stretch of reef runs parallel to the shore for about 70 km in the Gulf of Mannar coast. Commercial harvest of these two seaweeds from reef of the Gulf of Mannar islands and mainland coast is done mostly during spring tides of full moon and new moon days. About 5000 women in the age group of 18–35 with primary level education harvest the seaweeds. Seaweeds harvested from the Gulf of Mannar island reef and mainland reef are collected in boats and brought to the shore. Agents or middlemen procure the seaweeds from the harvesters on the shore and sell the seaweeds to the industry. Seasonal employment, middlemen exploitation, insufficient income, lack of recognition and insecure job are some of the problems encountered by the seaweed harvesters.

Agarophyte landings from 1978 to 2015 showed lot of fluctuation (Fig. 1). Landings of *Gr. edulis* attained peak (982 dry t) during 1990–1991 and again during 1997–1998 (974 dry t) and drastically reduced thereafter up to 2015. Landings of *Ge. acerosa* reached maximum (665 dry t) during 2002–2003 and gradually decreased during the next 12 years due to overexploitation. The price of *Ge. acerosa* is US$ 2000 per dry tonne while the price of *Ge. edulis* is US$ 700 per dry tonne at the sea shore.

Agar production

Agar production in India for the last 13 years (2002 to 2015) is shown in Fig. 2. Food-grade agar production increased steadily and attained a significant increase from 2011 to 2012 onwards with maximum production (300 t) during 2014–2015 despite landings of *Gr. edulis* from natural harvests decreasing substantially during these periods. Agar industries imported *Gr. edulis* from Sri Lanka and Indonesia. In addition, *Gr. salicornia*, an another important alga yielding food-grade agar with gel strength of 510 g cm^{-2} (Mehta et al. 2010), complement *Gr. edulis*. An average of 400 dry t per annum of *Gr. salicornia* was harvested from wild stocks of Palk Bay, southeast coast of India, during 2012 to 2015 (A Bose Personal communication). On the other hand, bacteriological-grade agar production decreased sharply from 2011 to 2012 onwards with lowest production (80 t) during 2012–2013 (Fig. 2). M/S Marine Chemicals, Cochin, is the major agar producer contributing more than 70% of bacteriological-grade agar produced from India. This industry imports the entire quantity of raw material from other countries and produces agar. Increase in custom duty and changes in import policy affect the import of dry seaweed. In addition, this industry buys crude agar from small-scale industries, refines the agar and

Fig. 1 Total agarophyte landings in India (source: Bose, Sivas Chemicals, Madurai, personal communication; Nehemiah, SNAP, Ranipet, personal communication)



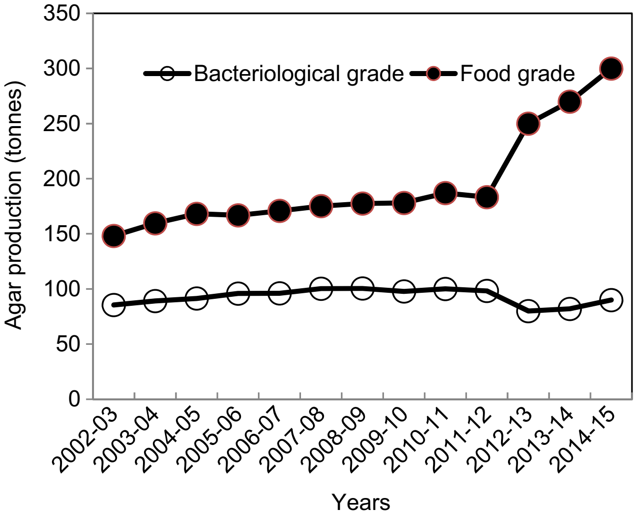


Fig. 2 Agar production in India (source: Bose, Sivas Chemicals, Madurai, personal communication; Nehemiah, SNAP, Ranipet, personal communication)

exports the product. A number of small cottage industries produce agar for local need using agarophytes harvested from wild stocks. Many of these industries face raw material shortage. Some of them switched over to alginate production, and others were able to produce only 50% of the total capacity of the plant during the last 10 years. Studies conducted on the biomass of *Ge. acerosa* and *Gr. edulis* using 1-m^2 quadrats on the reef of the Gulf of Mannar at different periods (Anon 2001, 2005, 2008,2010) revealed a rapid decline of their resources (Fig. 3). Biomass of *Ge. acerosa* (1.4 kg fresh wt m^{-2}) recorded during 1996–1998 drastically declined to 0.50 kg fresh wt m^{-2} during 2004–2005 and then to 0.45 kg fresh wt m^{-2} during 2009–2010 (Fig. 3a). Similarly, biomass of *Gr. edulis* (5.10 kg fresh wt m^{-2}) observed during 1996–1998 steadily decreased to 3.15 kg fresh wt m^{-2} during 2002–2003 and 0.50 kg fresh wt m^{-2} during 2009–2010 (Fig. 3b).

Cultivation methods

Agar production in India is very small when compared with the world production of agar (9600 t) (Bixler and Porse 2011). Scarcity of agarophytic seaweeds in wild stock due to overexploitation and supply of impure raw material to the agar industries are some of the reasons for the low agar production. While in countries like the Philippines, Indonesia, Malaysia, Japan, Chile, Tanzania and Zanzibar, seaweed farming contributes 90% of seaweed biomass for phycocolloid extraction (Bixler and Porse 2011); in India, the entire quantity of biomass for phycocolloid production is from natural harvest. Therefore, it is imperative to establish commercial farming of agarophytes.

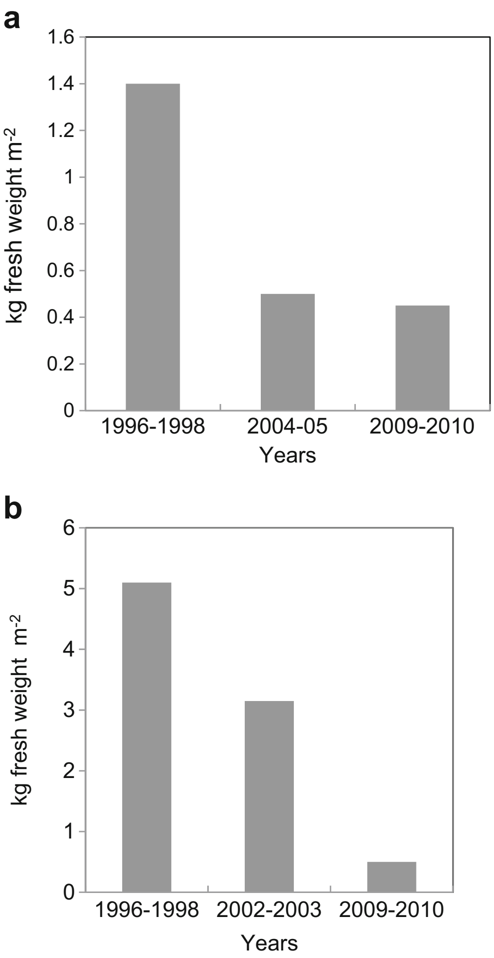


Fig. 3 Impact of overexploitation of **a** *Gelidiella acerosa* and **b** *Gracilaria edulis* from wild stocks of southeast coast

Gelidiella acerosa

Efforts to cultivate *Ge. acerosa* in India were initiated several decades ago. A number of techniques were tested for fastening *Ge. acerosa* to the substratum. Subbaramaiah et al. (1975) first started with the long-line rope culture method at Krusadai Island lagoon (9° 15′ N and 79° 12′ E), southeast coast of India. About 2-cm apical segments fastened to nylon strings were wound around the main horizontal support rope. The seeded ropes were placed between the support poles and submerged to a depth of 0.5–1.0 m. A maximum growth of 6.6 cm with production of 1.05 g dry wt m^{-1} month^{-1} was reported. Due to poor biomass obtained from the rope method, Subbaramaiah and Banumathi (1992) modified the rope method into single-rope floating raft technique (SRFT) in which *Ge. acerosa* seedlings were attached to both on vertical (1 m long) and horizontal ropes (10 m long). Vertical ropes gave higher biomass (42 g dry wt m^{-1}) than horizontal ropes (40 g dry wt m^{-1}). Later, pilot-scale farming (0.25-ha area) on the dead coral stone was established (Patel et al. 1986). Here, fragments of *Ge. acerosa* were tied to nylon threads and the seeded

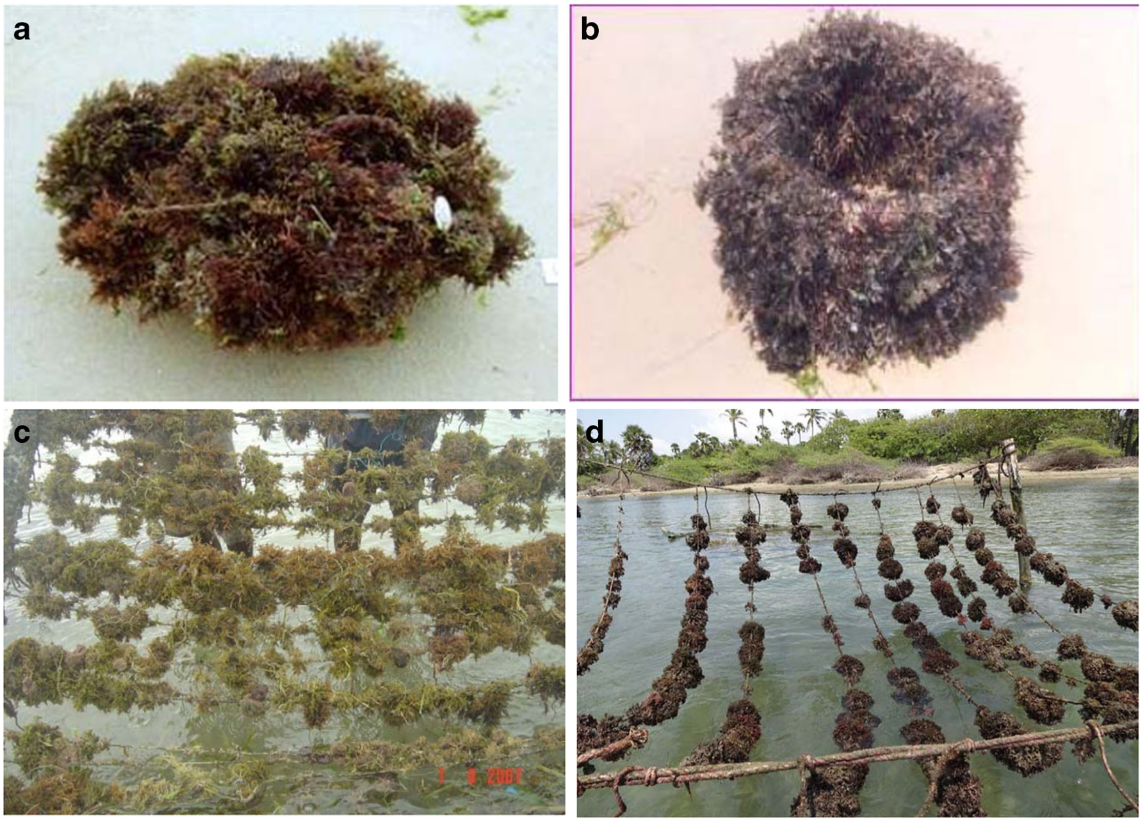


Fig. 4 Various methods of *Gelidiella acerosa* cultivation. **a** Coral stone method. **b** Concrete block method. **c** Bamboo raft method. **d** Suspended stone method

threads were then wound around nails fixed on the coral stones (Fig. 4a). The seeded stones were then kept in the lower intertidal and subtidal regions. Two harvests were made in a year, and a total yield of 4.5 t dry wt ha^{-1} year^{-1} was obtained. Later, the farm was expanded to 0.5-ha area (Subba Rao et al. 2004), and a crop yield of 4.0 t dry wt ha^{-1} year^{-1} was achieved.

Due to the constrains in getting the coral stones, artificial concrete blocks were designed for cultivation (Ganesan et al. 2009). In this method, fragments of *Ge. acerosa* were directly inserted between the layers of 3-mm-diameter polypropylene ropes and the ropes were wound around the concrete blocks having 0.5-m^2 surface area (Fig. 4b). A 2-ha farm was established with these concrete blocks. Two harvests were done, and biomass harvested was similar to those obtained from the coral stone method (3.8 t dry wt ha^{-1} year^{-1}) (Ganesan et al. 2009). However, both methods were discontinued due to high labour involvement. Currently, the floating bamboo raft method and suspended stone method are being practiced for *Ge. acerosa* farming. In floating bamboo raft, square frames (1.5 m × 1.5 m size), constructed from bamboo poles (7.5–10.0-cm diameter), form the cultivation structure. Each raft held 20 parallel lines of polypropylene rope (3-mm diameter), which were spaced at a 5-cm distance to which vegetative fragments of thalli (0.8 ± 0.25 g fresh wt and 3.0 ± 0.1 cm long) were attached. Each rope had 25 propagules with a total fresh weight of 25 g rope^{-1}. A raft with 20 ropes had an initial mass of propagules of 400 g fresh wt raft^{-1}, which was equivalent to 178 g fresh wt m^{-2} (Fig. 4c). The raft was anchored securely by using stones (approximately 25 kg wt). The plants were harvested at 90- to 120-day interval. Three harvests in a year were made, and an average biomass yield of 12.4 t dry wt ha^{-1} year^{-1} (Ganesan et al. 2009) was achieved.

The suspended stone method is a combination of both raft and stone methods (Ganesan et al. 2011a). Here, seedlings of approximately 2 g fresh wt were tied onto the nylon thread and they were wound around to the small calcareous stones ranging from 1.5- to 7.0-cm^2 size with a 100- to 200-g weight and hung 5 cm below from the polypropylene ropes (3-mm diameter), which were tied across the bamboo frame (Fig. 4d). Harvesting of *Ge. acerosa* was carried out by cutting the erect portions of thalli and leaving the basal portions on stones for further growth. It was ensured that leftover biomass on the stone was approximately similar to that of initial seedling density (2 g fresh wt). The total biomass of each raft was arrived at by adding the biomass of alga harvested from individual stone. Three harvests were done in a year with a total crop yield of 18 t dry wt ha^{-1} year^{-1} (Ganesan et al. 2011a).

Recently, tissue cultured progenies regenerated from callus of *Ge. acerosa* in the laboratory were transferred and cultivated in the exposed sea (Ganesan et al. 2015a). Four tissue cultured progenies (approximately 0.04 ± 0.01 g fresh wt and 2–3 cm long) were initially cultured in closed net bags to avoid drifting and multiplied to produce 73 plantlets each with an average biomass of 70 ± 20 g fresh wt plant^{-1}. These plantlets were later shifted to the exposed sea and cultivated using the suspended stone method along with wild harvested plantlets. Biomass harvested from tissue cultured farm plants (1.86 ± 1.0 to 2.97 ± 0.7 kg fresh wt m^{-2}) was higher than that harvested from wild farm plants (0.44 ± 0.12 to 0.62 ± 0.31 kg fresh wt m^{-2}). The gel strength of agar extracted from tissue cultured farm plants was higher (2400 ± 250 g cm^{-2}) than that of wild farm plants (1900 ± 135 g cm^{-2}).

Gracilaria edulis

The first experiment on *Gr. edulis* cultivation was conducted during late 1960s at shallow lagoon of Krusadai island (9° 15′ N and 79° 12′ E) in the Gulf of Mannar by adopting the long-line rope method (Raju and Thomas 1971) (Fig. 5a). Vegetative apical fragments of 3–4 cm long were inserted between the braids of coir rope. The crop yield from this long-line rope method was 20 t dry wt ha^{-1} year^{-1} (Krishnamurthy et al. 1975). Based on the success achieved in the long-line rope method, large-scale cultivation trails of *Gr. edulis* were initiated in 1986 at Vedalai (9.26′ N and 79.11′ E), southeast coast of India, by Bay of Bengal Program (BOBP) jointly supported by the Food and Agricultural Organization (FAO) of the United Nations and Swedish International Development Agency. However, commercial cultivation did not take off fully. Later, Subbaramaiah and Thomas (1995) obtained more crop yield (30 t dry wt ha^{-1} year^{-1}) from single-rope floating raft technique (SRFT) (Fig. 5b). In this method, *Gr. edulis* fragments were seeded on several vertical lines of 1-m-long polypropylene ropes (3-mm diameter) tied to 20-m-long horizontal polypropylene rope (6-mm diameter). The floating bamboo raft method and the tube net method are being implemented currently. The floating bamboo raft method is the same adopted for *Ge. acerosa*; however, the initial mass of propagules of 500 g fresh wt raft^{-1}, equivalent to 222 g fresh wt m^{-2}, was used for *Gr. edulis* (Fig. 5c) (Ganesan et al. 2011a).

Fig. 5 Different methods adopted for *Gracilaria edulis* cultivation. **a** Long-line rope method. **b** Single-rope floating technique (SRFT) method. **c** Bamboo raft method. **d** Tube net method

The tube net method, which is being adopted for *Kappaphycus alvarezii* along the west coast of India (Mantri et al. 2017), has been recently introduced for *Gr. edulis* (Fig. 5d). Two-metre-long tube nets (2.0-cm mesh size) are seeded with *Gr. edulis* with the help of a 1.5-m-long plastic pipe. The diameter of the pipe is little less than that of the tube net for efficient seeding. The plastic pipe is inserted into the tube, and the entire tube is pulled down, so that the mouth of plastic pipe stands out of the tube. *Gr. edulis* seed material is passed onto the tube through the plastic pipe. The tube net is pulled down from the bottom of the plastic pipe carefully in such a way that the seedling material is loaded into the tube, sequentially leaving no gap between the seedlings. This process is continued till the entire tube net is seeded with algal biomass. The tubes are closed at both ends with a rope to prevent the material from being lost. About 2 kg fresh wt of *Gr. edulis* is seeded into the tube. The seeded tube nets are then tied to bamboo rafts on both sides. In both methods, the plants are harvested at 45-day intervals. Seven harvests in a year are being done with an average biomass yield of 35 t dry wt ha^{-1} year^{-1}.

Gracilaria dura

Gr. dura assumes significance as agarose can be directly extracted from this alga. The agarose extracted from *Gr. dura* has gel strength of 2200 g cm^{-2}, gelling temperature 30 °C and sulphate content 0.15% (Meena et al. 2007). This alga is grown along the west coast of India (Oza and Zaidi 2001). Recently, the alga was brought to the southeast coast, acclimatized to the sea condition and several methods have been tested as given in the following to develop feasible commercial cultivation method (Veeragurunathan et al. 2015).

Bottom net method

A square net (2 m × 2 m size) made of polypropylene rope (3-mm diameter) was seeded with an initial seedling weight of 1.5 kg fresh wt net^{-1}(Fig 6a). The seeded nets were tied at all four corners to vertical bamboo poles erected in the sea at 1.5-depth. Stone sinkers were used to anchor the seeded nets at

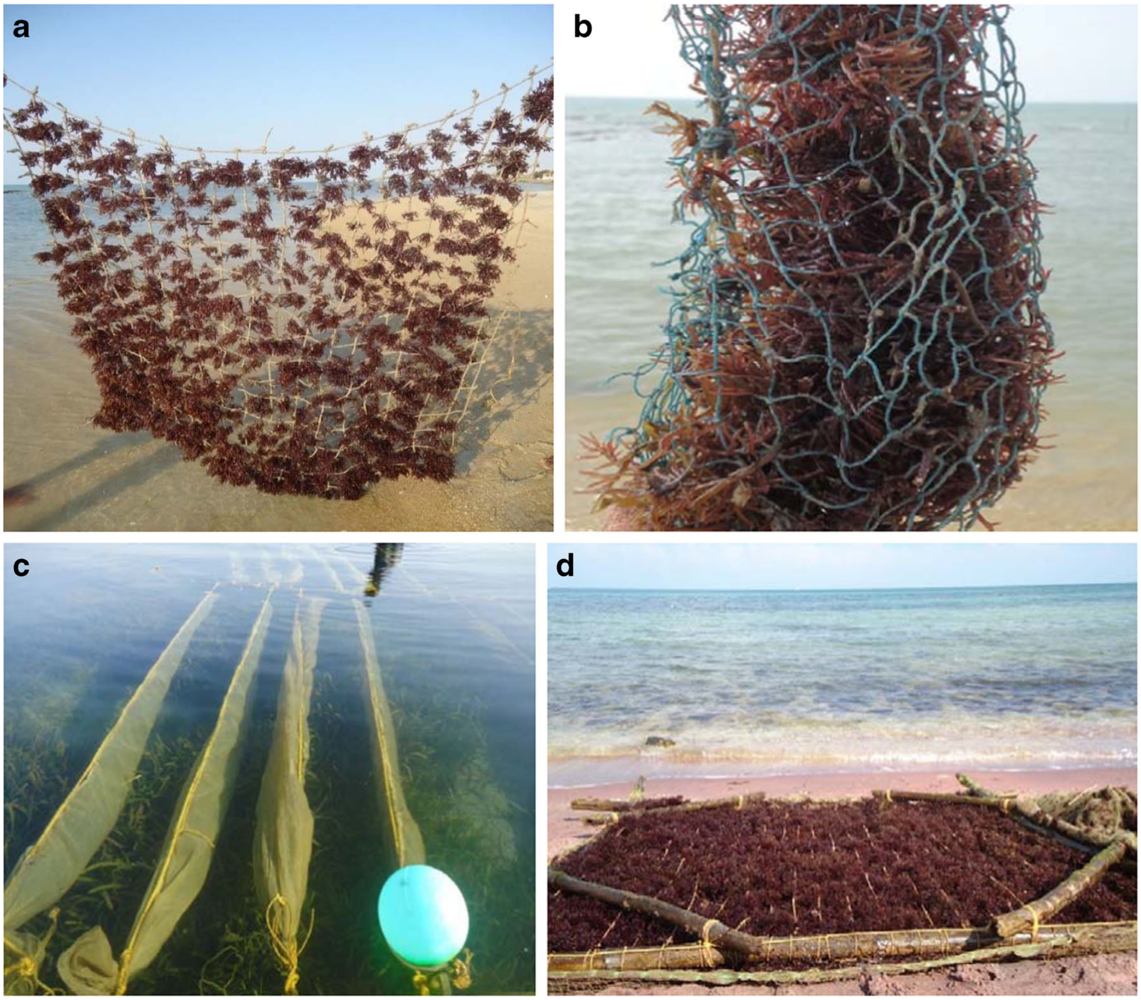


Fig. 6 Various methods of cultivation of *Gracilaria dura*. **a** Bottom net method. **b** Net bag method. **c** Net pouch method. **d** Bamboo raft method

25 cm above the bottom. A biomass of 7 kg fresh wt net^{-1} was obtained at the end of 45-day growth.

Net bag method

A 75-cm-long bag prepared from commercial fishnet was seeded with 200–300-g seedlings (Fig. 6b). The entire length of the net bag was covered with agro net (1.0 ± 0.2-mm mesh size and 90-μm thickness) in order to minimize grazing. The bag was tied onto an 8-mm polypropylene rope, and the rope was tied on both sides to the bamboo poles erected vertically. The final biomass of 900 g fresh wt was harvested at 45 days.

Net pouch method

Net pouch was made with similar way of net bag method, but with a 3-m-long tube. The bag was then made in to five equal compartments by a hand stitch up to the nylon thread. Each compartment is seeded with 300 g of *G. dura* fragments (Fig. 6c). The entire pouch has seed material of 1.5 kg fresh material. The biomass yield obtained from this method was 2.0 kg fresh wt after 45 days of growth.

Floating bamboo raft method

This method (Fig. 6d) is similar to those adopted for both *Ge. acerosa* and *Gr. edulis.* The seed material used here was 730 g fresh wt raft^{-1}. Biomass of 4192 g fresh wt raft^{-1} was obtained after about 8 weeks of cultivation. This method is more suitable than other methods described earlier as the biomass yield from this method is much higher than the other methods (Saminathan et al. 2015).

Gracilaria verrrucosa

Experimental *Gr. verrucosa* cultivation has been done in ponds in Narakkal coast along the southwest coast of India (Reeta et al. 2006). Three rafts (1.5 m × 1.5 m size) made of PVC tube and attached with plastic nets at the bottom were filled with an initial seed material of 920 g fresh wt of *Gr. verrucosa* and kept at the surface of the pond water. *Gr. verrucosa* was established in the bottom of the pond for 60 days, and a total 1015 kg fresh wt of *Gr. verrucosa* was harvested from the pond after 90 days (Reeta et al. 2006).

Economics of cultivation

The floating bamboo raft method has been adopted for pilot-scale cultivation of all these three agarophytes, as this method has several advantages over the other methods. Being at the sub-surface level of the seawater column, the algae have better exposure to sunlight. The rafts can be easily handled and relocated to suitable locations free from epiphytes and grazing for sustainable crop production. The bottom net will minimize the grazing of algae by herbivores. Further, it allows wider choice of farming, circumventing site selection issues including bottom profile, water depth, underwater terrain, etc., encountered with other culture methods. Infrastructure for making raft such as bamboo, anchor stone, polypropylene rope, etc. (Table 1) are available in nearby areas. The raft method is being successfully employed for large-scale cultivation of the carrageenophyte *K. alvarezii* along this coast. The crop production values given for *Gr. edulis*, *Gr. dura* and *Ge. acerosa* are lower than the yield reported earlier (Ganesan et al., 2011a, b, 2015a, b; Saminathan et al. 2015) to give a guarantee for profit (Table 2). The Government of Tamil Nadu has several schemes to provide a subsidy to the seaweed farmers for procuring infrastructure.

Table 1 Costing of a bamboo raft (2 m X 2 m) for agarophyte cultivation

Sr. no.	Particulars/specifications	Quantity	Rate (US$)	Cost/raft (US$)
1	3–4″ dia bamboos of 6.5 ft. × 4 for main frame + 1.25 ft. × 4 for diagonals	35 ft	0.06 ft.$^{-1}$	2.09
2	Anchor stone of 45 kg unit^{-1}, two anchors can hold a cluster of 10 rafts	90 kg	2.68 unit^{-1}	0.53
3	3-mm PP twisted rope for plantation—20 bits of 3 m each	0.30 kg	3.43 kg^{-1}	1.02
4	Fishing net to protect the raft bottom (3 m × 3 m size)	0.75 kg	0.97 kg^{-1}	0.72
5	Nylon thread	0.25 kg	2.68 kg^{-1}	0.67
6	3-mm rope to tie the HDPE net (28 m)	0.09 kg	3.43 kg^{-1}	0.30
7	Anchoring rope of 10-mm thickness (17 m per cluster of 10 rafts)	0.25 kg	3.43 kg^{-1}	0.85
8	Rafts linking ropes per cluster 10 rafts—6 mm thick—2 ties × 3 m × 9 pairs = 54 m length	0.1 kg	3.43 kg^{-1}	0.34
9	Local transport infrastructure	–	–	1.79
	Total raft cost	–	–	8.31
	Total cost per raft 2 m × 2 m (rounded off)	–	–	8.4

Table 2 Economics of agarophyte farming for 2000 bamboo rafts occupying 1 ha area

Item	Specifications	Seaweed		
		Gracilaria edulis	*Gelidiella acerosa*	*Gracilaria dura*
Investments				
A	Infrastructure cost (US$) (@ US$8.4 per raft)	16,800	16,800	16,800
B	50% subsidy for infrastructure from Government ($)	8400	8400	8400
C	Actual investment (US$) (A–B)	8400	8400	8400
D	No. of beneficiaries ha^{-1} farm	10	10	10
Biomass produced				
E	Biomass produced/cycle/raft (kg dry wt)	2.5	3.0	1.0
F	No. of cycle $year^{-1}$	07	03	05
G	Biomass produced $year^{-1}$ ha^{-1} (kg dry wt)	35,000	18,000	10,000
Income				
H	Cost of dry weed kg^{-1} (US$)	0.67	1.80	3.73
I	Gross income from biomass produced $year^{-1}$ (US$)	23,450	32,400	37,300
J	Net income from biomass produced $year^{-1}$ (US$) (I–C)	15,050	24,000	28,900
K	Net income $person^{-1}$ $month^{-1}$ (US$)	125.41	200.00	240.83

Challenges in development of commercial farming

Epiphytism is a major threat to agarophyte cultivation in India

Many seasonal and fast-growing algae such as *Ulva* and *Cladophora* (green algae); *Ectocarpus*, *Padina* and *Dictyota* (brown algae); *Centroceras*, *Jania*, *Amphiroa*, *Acanthophora* and *Champia* (red algae); and *Lyngbya* and *Phormidium* (blue green algae) attached to the cultivated algae and caused severe damage to the crop yield (Ganesan et al. 2015b). These epiphytic algae compete with cultured plants for sunlight and also for nutrients and dissolved CO_2 in the seawater. Epiphytes add weight to the cultured algae and cause detachment of plants from culture ropes (Enright 1979; Friedlander et al. 1996; Kushel and Buschmann 1991). A *Gr. edulis* cultivation farm along the southeast coast of India has been infested with 20 species of epiphytic algae (Ganesan et al. 2011b). High temperature during summer induces more epiphytic algae. *Ge. acerosa* attracted more epiphytes because of its wiry thallus structure. Twenty-five species of epiphytic algae have been reported in *Ge. acerosa* cultivation (Ganesan et al. 2011a). Manipulation of salinity, pH nutrient contents, increasing water circulation and applying chemicals have been suggested to control the growth of epiphytic algae (Buschmann et al. 2001). However, these methods will be successful only in tank cultivation and cannot be applied to the open sea. Maintenance of seaweed farming by manually removing epiphytes is the best practice to achieve higher crop yield.

A *Ge. acerosa* farm has been infected by the sponge *Sigmadocia pumila* (Porifera) during summer (April to June) every year (Sahu et al. 2007). *Ge. acerosa* infected with *S. pumila* showed stunted growth and pale brown colour, lost weight and slowly detached from the cultivated rope. Infestation of *Gr. Salicornia*, another important agarophyte in India, with 48 species of herbivores comprising 20 polychaete, 11 gastropod, 8 isopod species and 2 amphipod and bivalve species and 1 arthropod and amphipod species, has been observed (Gobalakrishnan et al. unpublished).

Thallus ageing and loss of vigour are important factors affecting the crop yield

Persistent use of the same culture site triggers the development of pests that affect the production of *Gracilaria* (Buschmann et al. 1995, 1999, Ganesan et al. 2011b). Drop in production after 2 to 3 years of high yield has been observed in commercial farming of *K. alvarezii* (Mantri et al. 2017). Harvesting method is the main reason affecting vigour. Pruning method of harvest where the fronds grown above the substratum are pruned and leaving basal portion on the substratum for further growth is more ideal for *Ge. acerosa* where the holdfast is firmly attached to the hard substratum (Ganesan et al. 2009). However, the pruning method of harvest is not suitable for *Gr. edulis* and *Gr. dura*. Recently, Ashok et al. (2015) examined two methods of harvest—complete harvest and pruning method of harvest—in *Gr. edulis* along the southeast coast and found that the former resulted in the highest biomass yield (7.21 ± 0.83 kg fresh wt m^{-2}) and DGR (5.93 ± 0.11% day^{-1}).

Seasonal changes and the growth of agarophytes

Cultivation is possible for 8 months in a year during August to March next year. During April to July, the seawater temperature is always high and sometimes reaches 32°C (Ganesan et al. 2011a). High temperature resulted in mass mortality of *K. alvarezii* in a commercial farm along the southeast coast of India during 2013 (Mantri et al. 2017). High temperature during summer (April to July) caused stunted growth of *Ge. acerosa* (Ganesan et al. 2011a) and *Gr. edulis* (Ganesan et al. 2011b) in farming.

Seaweed cultivators getting lower price for the raw material produced

This is because of limited market options for agar in India due to the export of red algae being banned after the Second World War. Therefore, most of the Indian agar industries are medium- and small-scale producing agar for domestic use only. The agar fetches a very low price and this results in a lower price for the seaweeds. If the ban is lifted, the price of seaweeds will be increased and commercial cultivation will be more profitable.

Seaweed entrepreneurs are reluctant to invest in seaweed cultivation. Since the agar industries are located far from the sea coast, they feel that the management of seaweed farming is an additional burden besides operating the industries. Currently, the seaweeds harvested from the wild stock are delivered at their industry premises by agents who procure the material from the seaweed collectors. When natural harvested materials are inadequate to run their plant, the industries opt for importing seaweeds from Morocco, Sri Lanka, Indonesia and other countries rather than starting cultivation in India.

Conclusion

The cultivation of agarophytes in the open sea has been shown to be technically and economically feasible in the southeast coast of India. Sedimentation, pests and unpredicted stormy winds affect the growth of cultured seaweeds. The southeast Indian coast is more ideal for launching commercial larger-area seaweed farms. The intertidal region is flat, wide and shallow with moderate wave action. The ambient seawater has rich nutrient contents with optimum temperature and salinity suitable for cultivation of agarophytes. Commercial farming of *K. alvarezii* has a high profile along this coast with an annual production of 1480 dry t in 2013 (Mantri et al. 2017). Hence, the commercial cultivation of agarophytes also has to be started immediately. Industries should consider to pay higher price for the cultivated seaweeds considering the purity of material. Although the seaweed farmers are exempted from fees for using the area in the sea, financial assistance should also be provided to them for procuring infrastructure for farming activities. The algal research group of the Central Salt & Marine Chemicals Research Institute is continuing its efforts to improve the techno-economic feasibility of cultivation.

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