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Seaweeds as Natural Resource for agar – agar Extraction in India– A Review

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ABSTRACT

Seaweeds are the marine macro algae and one of the most potential marine living resources in the World. It plays an important role in the sustainability of the marine ecosystems and carbon sequestration. Economically, seaweeds have high potentiality in the blue economy of the country. Among the various uses, seaweeds are the natural source of phycocolloids, which is a gelatinous substrate with high commercial potential. Agar-agar is one of the most important phycocolloids, and widely used in industries and biochemical laboratories. The commonly used red seaweeds (Rhodophyceae) as natural sources of agar-agar are the species of *Gracilaria, Gelidium, Gelidiella*. In India, these three genera are represented by 53 taxa, of which, about 14 taxa, consisting of ten taxa of *Gracilaria*, two taxa of *Gelidium* and two taxa of *Gelidiella* are recognised with agar-agar potentiality. The paper briefly highlights the taxonomic account and economic potentiality of these seaweeds as source of agar-agar in the Indian perspectives.

Keywords: Agar-agar, Phycocolloids, *Gracilaria, Gelidium, Gelidiella*, Cultivation, Seaweeds

The marine ecosystems cover more than 70% of the earth's surface and support more than one million marine species (Poiner, 2010). Marine macro algae (seaweeds) are one of the most potential marine natural living resources in the world and grow exclusively in the marine habitats, usually on rocks, pebbles, molluscs, coastal wastes, epiphytes etc. in the benthic, shallow, estuaries, intertidal and sub–tidal zones and even in deep waters of sea, up to a depth of 150 m or up to a depth that can receive more than 0.12% of the incident light (Markager and Sand–Jensen, 1992). It has been used by human beings in various forms such as food and fodder as early as 2500 years ago in Chinese literature (Tseng, 2004). Among the reported 45,000 taxa of algae (Guiry, 2012), seaweeds constitute about 11,000 taxa, comprising of *c.* 7,200 taxa of Rhodophyceae, *c.* 2,000 taxa of Phaeophyceae and *c.* 1,800 taxa of Chlorophyceae (https://www.seaweed.ie/). Globally, about 221 taxa of seaweeds are recognized for their economic importance and utilised in various forms by many maritime countries, particularly the south east Asian countries. Among these, about 145 taxa are recognised as suitable for food and 110 taxa for phycocolloid production (Chennubhotla *et al*. 2013; Nedumaran and Arulbalachandran, 2015). India has about 7500 km long coastline with variable coastal landscapes and harbours *c.* 865 taxa of seaweeds,

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which includes 442 taxa of Rhodophyceae, 212 taxa of Chlorophyceae and 211 taxa of Phaeophyceae (Rao and Gupta, 2015).

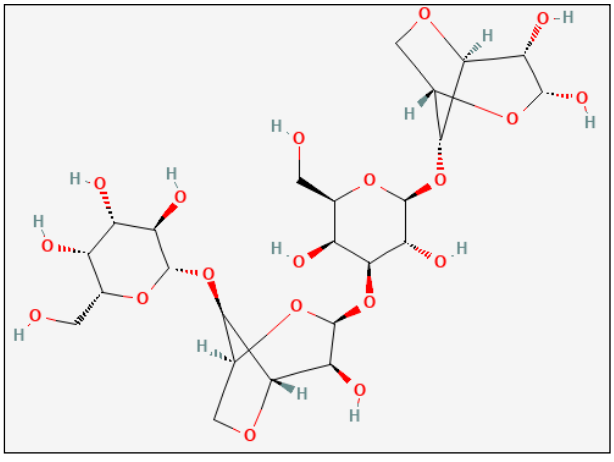
Seaweeds are one of the promising resources for blue economy (Ktari *et al*. 2022). Among the various economic and commercial potentials, the extraction of phycocolloids from seaweeds is a noteworthy and one of the globally most recognised commercial benefits from these marine resources. Phycocolloids are polysachharides and naturally derived from seaweeds. As they grow in very harsh saline environment, its cell wall develops many protective secondary metabolites including phycocolloids and many bioactive compounds such as proteins, peptides, fatty acids, antioxidants, vitamins, minerals, which exhibit a variety of therapeutic and economic potential potentials. Phycocolloids are polymers of chemically modified sugar molecules or organic acids, with gelatinous nature and have high commercial demands. The three major and widely used phycocolloids are *Agar agar*, *Alginates* and *Carrageenan*. Among these, agar- agar and Carrageenan are extracted from the red seaweeds (Rhodophyceae), while the *Alginates,* also known as *alginic acid,* are extracted primarily from the brown seaweeds (Phaeophyceae). Agars and Carrageenan are polymers of sugar molecules, such as galactose whereas alginates have organic acids, such as mannuronic acid and glucuronic acid.

MATERIALS AND METHODS

The present study is mainly based on the study of relevant literature and collection of fresh seaweeds by field exploration. In the present paper, it has been attempted to briefly highlight the importance of seaweeds as natural resources for the extraction of agar-agar, protocol for its extraction, with updated taxonomic highlights on the agar yielding seaweeds in the Indian scenario.

Agar-agar

Agar - Agar is one of the widely used phycocolloids in the industries, particularly in food confectionery and bio-chemical laboratories because of its gelatinous nature. The name *agar-agar* has derived from the Malay name of red seaweed *Gracilaria*, where it is used in the double form, '*agar-agar*' to describe jelly (FAO, 1990; Imeson, 2010). Presently, it is extracted mainly from the members of Rhodophyceae such as species of *Gracilaria, Gelidium, Gelidiella* etc. Chemically, agar consists of two compounds *i.e.* the linear polysaccharide (up to about 70%) *Agarose* ($C_{24}H_{38}O_{19}$, Fig. 1), and a heterogeneous mixture of smaller molecules called *Agaropectin* (up to about 30%).



Source: *https://pubchem.ncbi.nlm.nih.gov/compound/11966311.*

Fig. 1: Chemical structure of an *Agarose* polymer ($C_{24}H_{38}O_{19}$)

The first report on the uses of Agar from seaweed came in light in Japan (where it is known as *Kanten*, meaning *cold weather*) during the 17th century, probably in 1658, where it was extracted accidently, before it was introduced to the Western Countries (FAO, 1987; Gioele *et al*. 2017). Presently, there are many protocols for agar extraction. However, all of these are derived from a common base and include various stops like harvesting of selected raw material, drying seaweeds, pre-treatment (alkali process), extraction, filtration, gelation, bleaching, washing, freezing, thawing, washing, thawing, drying, grinding and obtainment of final product in the form of strip or powder. Therefore, a common and standard protocol, as develop as per FAO (1987) for the extraction of agar from the agarophytes is depicted in Fig. 2.

Agar extraction in India

In India, the extraction of agars came in existence in 1940 using *Gracilaria edulis* as raw material on a cottage industry-scale and the methodology was developed by Thivy (Thivy, 1960; Rao and Mantri,

2006). Presently, the extraction is done mainly from the species of *Gracilaria, Gelidium* and *Gelidiella*. The food grade agar is extracted from *Gracilaria* while the bacteriological grade of agar is extracted from *Gelidium* (Ganesan *et al*. 2017). The Indian coastlines exhibit about 865 taxa of seaweeds, comprising of 442 taxa of Rhodophyceae. Among which, the agarophytic genus *Gracilaria* is represented by 37 taxa, while *Gelidium* by 9 taxa and *Gelidiella* by 7 taxa (Table 1). Presently, there are many seaweed-based industries for the production of Agars in India, particularly in the southern coastal parts of the country (Rao and Mantri, 2006).

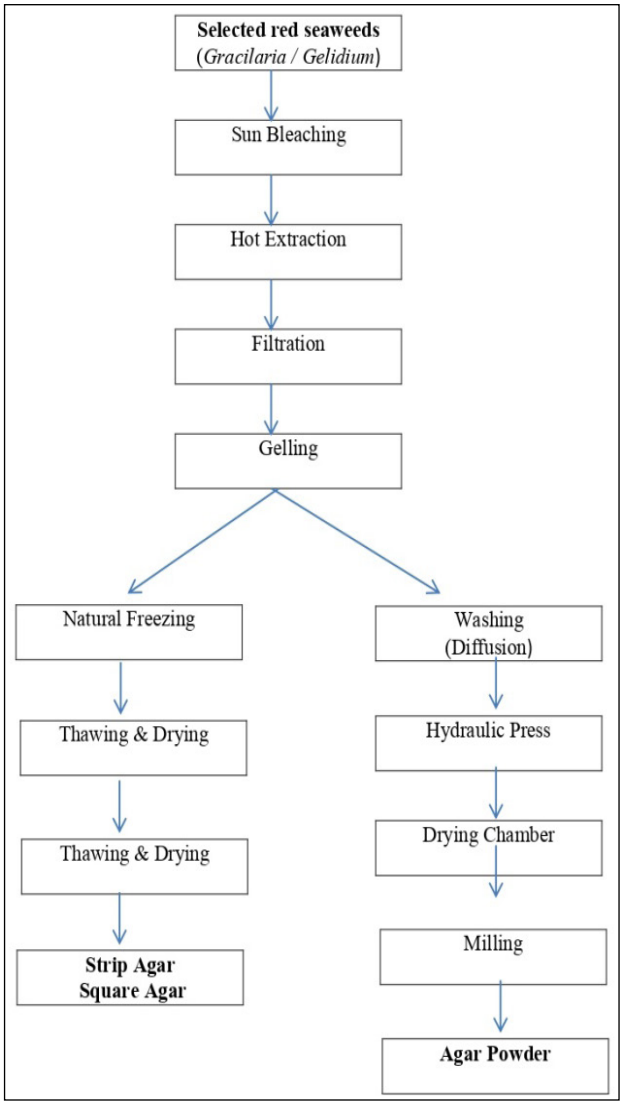


Fig. 2: Flow chart showing extraction of agar-agar from seaweeds (FAO, 1987)

RESULTS AND DISCUSSION

The present study revealed that the Indian coastline supports about 865 taxa of seaweeds, with significant diversity of agarophytic taxa. The three major genera of agarophytes represent about 53 taxa, consisting of 37 taxa of *Gracilaria*, 9 taxa of *Gelidium* and 7 taxa of *Gelidiella.* Of which, 14 taxa are used for agar-agar extraction. These agarophytic seaweeds include ten taxa of *Gracilaria* namely *G. arcuata, G. canaliculata, G. corticata* var. *corticata, G. corticata* var. *cylindrica, G. debilis, G. edulis, G. foliifera, G. gracilis, G. salicornia* and *G. verrucosa*; two taxa of *Gelidium* namely *Gelidium micropterum* and *G. pusillum* and two taxa of *Gelidiella* namely *Gelidiella acerosa* and *G. indica* (Table 1). The brief taxonomic account of these agarophytic seaweed genera are presented below:

Order: GRACILARIALES

Family: GRACILARIACEAE

Genus: *Gracilaria* Grev.

Taxonomically, this genus was established by Greville in 1830. Its type species is *Gracilaria bursa-pastoris* (S. G. Gmel.) P.C. Silva. Presently, this genus is represented by 231 taxa in the world (Guiry and Guiry, 2023) and 37 in India (Rao & Gupta, 2015). Morphologically, its thallus is usually light – dark pinkish red in colour, cylindrical-terete or flattened, up to 60 cm long, erect to prostrate, cartilaginous and lithophilic in nature. Fronds are irregularly or dichotomously branched, occasionally alternate or lateral, with entire to proliferated margins. Anatomically, its thallus is multilayered, consisting of cortex and medullary cells.

The perusal of literature during the present study revealed that out of 35 taxa in India, 10 taxa are recognised with potential for agar extraction (Table 1). These are *Gracilaria arcuata, G. canaliculata, G. corticata* var. *corticata, G. corticata* var. *cylindrica, G. debilis, G. edulis, G. foliifera, G.gracilis, G. salicornia* and *G. verrucosa*. Among these, the most common species is *Gracilaria corticata* (J. Agardh) J. Agardh (Fig. 3), which has been recorded from the many maritime coastal state like Andaman & Nicobar Islands, Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Maharashtra and Tamil Nadu (Palanisamy *et al.* 2020; Palanisamy & Yadav, 2022).

Table 1: List showing Agarophytic taxa of *Gracilaria, Gelidium* and *Gelidiella* reported from India

Sl. No.	Genus	Name of the species (including varieties, forma etc.	Agar extraction recorded (based on references)
1	Gracilaria	*Gracilaria arcuata* Zanardini	+ (Kaliaperumal *et al.* 1995)
2		*Gracilaria arcuata* var. *attenuata* Umam. Rao	–
3		*Gracilaria arcuata* f. *rhizophora* Boergesen	_
4		*Gracilaria armata* (C. Agardh) Grey.	–
5		*Gracilaria blodgettii* Harv.	–
6		*Gracilaria bursa-pastoris* (S.G. Gmel.) P.C. Silva	–
7		*Gracilaria canaliculata* Sund. (=*Gracilaria crassa* Harv. ex J. Agardh)	+ (Kaliaperumal *et al.* 1995; Rao and Mantri, 2006)
8		*Gracilaria corticata* (J. Agardh) J. Agardh var. *corticata* J. Agardh	+ (Kaliaperumal *et al.* 1992, 1995; Rao and Mantri, 2006)
9		*Gracilaria corticata* var. *cylindrica* Umam. Rao	+ (Kaliaperumal *et al.* 1992, 1995)
10		*Gracilaria corticata* var. *linearis* J. Agardh	–
11		*Gracilaria corticata* var. *ramalinoides* J. Agardh	_
12		*Gracilaria debilis* (Forssk.) Boergesen (=*Gracilaria fergusonii* J. Agardh)	+ (Krishnamurthy, 1991; Veeragurunathan *et al.* 2015)
13		*Gracilaria disticha* (J. Agardh) J. Agardh	–
14		*Gracilaria dura* (C. Agardh) J. Agardh	–
15		*Gracilaria edulis* (S.G. Gmel.) P.C. Silva	+ (Kaliaperumal *et al.* 1995; Rao and Mantri, 2006)
16		*Gracilaria eucheumatoides* Harv.	–
17		*Gracilaria foliifera* (Forssk.) Boergesen	+ (Kaliaperumal *et al.* 1995; Rao and Mantri, 2006)
18		*Gracilaria foliifera* f. *aeruginosa* (Turner) Boergesen	_
19		*Gracilaria foliifera* f. *granatea* (J.V. Lamour.) Boergesen	–
20		*Gracilaria gracilis* (Stack.) Steentoft, L.M. Irvine & W.F. Farnham	+ Gioele *et al.* 2017)
21		*Gracilaria incrustata* J. Agardh	–
22		*Gracilaria indica* Umam. Rao	–
23		*Gracilaria kanyakumariensis* Umam. Rao	–
24		*Gracilaria kilakkaraiensis* V. Krishnam. & N.R. Rajendran	_
25		*Gracilaria mannarensis* Umam. Rao	–
26		*Gracilaria millardetii* (Mont.) J. Agardh	–
27		*Gracilaria opuntia* Durair.	_
28		*Gracilaria pudumadamensis* V. Krishnam. & N.R. Rajendran	–
29		*Gracilaria pygmaea* Boergesen	–
30		*Gracilaria salicornia* (C. Agardh) Dawson	+ (Said, 2022)
31		*Gracilaria spinuligera* Boergesen	_
32		*Gracilaria textorii* (Suringar) De Toni	–
33		*Gracilaria tuticorinensis* V. Krishnam. & N.R. Rajendran	–

34		*Gracilaria veleroae* Dawson.	–
35		*Gracilaria verrucosa* (Huds.) Papenf.	+ (Kaliaperumal *et al.* 1995; Rao and Mantri, 2006)
36		*Gracilariopsis lemaneiformis* (Bory) Dawson & al	–
37		*Graciliaropsis megaspora* Dawson	–
38	Gelidium	*Gelidium amansii* (J.V. Lamour.) J.V. Lamour.	_
39		*Gelidium corneum* (Huds.) J.V. Lamour.	–
40		*Gelidium crinale* (Turner) Gaillon	–
41		*Gelidium micropterum* Kuetz.	+ (Thivy, 1958; Kappanna and Rao, 1963)
42		*Gelidium proliferum* Kuetz.	–
43		*Gelidium pusillum* (Stackh.) Le Jolis	+ (Kaliaperumal *et al.* 1995)
44		*Gelidium pusillum* var. *pulvinatum* (C. Agardh) Feldmann	_
45		*Gelidium pulvinatum* f. *parvissimum* Boergesen	–
46		*Gelidium rigidum* (C. Agardh) Grev.	–
47	Gelidiella	*Gelidiella acerosa* (Forssk.) Feldamann & Hamel	+ (Rao and Mantri, 2006; Ganesan *et al.* 2015)
48		*Gelidiella diuens* P.S. Rao & Trivedi	–
49		*Gelidiella indica* P.S. Rao	+ (Kaliaperumal *et al.* 1995)
50		*Gelidiella lubrica* (Kuetz.) Feldmann & Hamel	_
51		*Gelidiella bornetii* (Weber Bosse) Feldmann & Hamel	–
52		*Gelidiella myrioclada* (Boergesen) Feldmann & Hamel	_
53		*Gelidiella pannosa* (Feldmann) Feldmann & Hamel	_

Legends: + *(Present);* – *(Absent);* = *Synonym.*

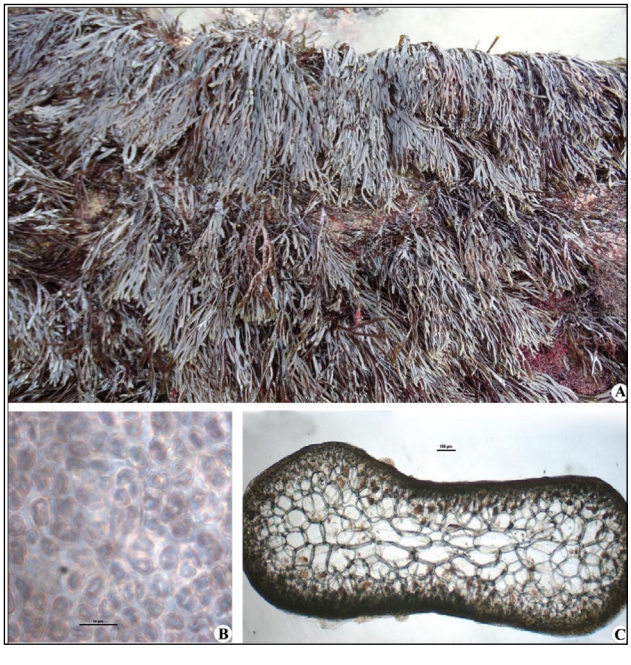


Fig. 3: *Gracilaria corticata* (J. Agardh) J. Agardh: **(A)** Habit, **(B)** Microscopic image of surface cells; **(C)** Cross section through the middle portion of frond

Order: GELIDIALES

Family: GELIDIACEAE

Genus: *Gelidium* J.V. Lamour.

Taxonomically, this genus was established by Lamouroux in 1813. Its type species is *Gelidium corneum* (Huds.) J.V. Lamour. Presently, this genus is represented by 171 taxa in the world (Guiry and Guiry, 2023) and 9 in India (Rao & Gupta, 2015). Morphologically, its thallus is usually dark-purple red in colour, erect, up to 20 cm long, cartilaginous and lithophilic in nature. Fronds are compressed or flattened, pinnately or irregularly branched with several branchlets and irregularly proliferated margins. Anatomically, thallus is uniaxial, consisting of compactly arranged cortex and large medullary cells.

The study revealed that out of 9 taxa in India, only 2 taxa are recognised with potential for agar extraction (Table 1), which are *Gelidium micropterum* and *G. pusillum*. Of which, *G. micropterum* (Fig. 4) is the

most common species and has been recorded from the coastal states of Goa, Gujarat, Karnataka, Kerala, Maharashtra and Tamil Nadu (Palanisamy *et al*. 2020, Palanisamy and Yadav, 2022).

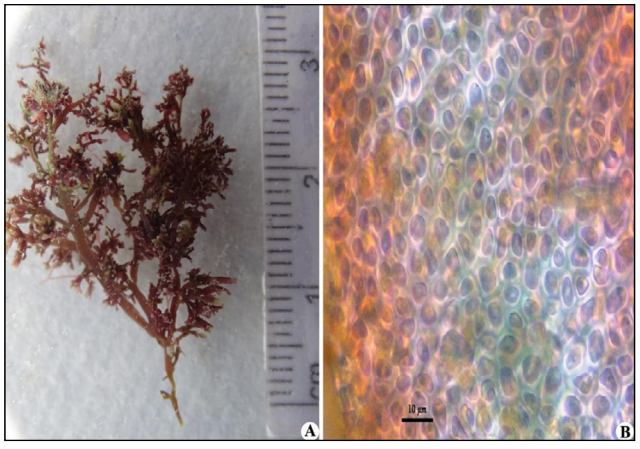


Fig. 4: *Gelidium micropterum* Kuetz.: **(A)** Habit; **(B)** Microscopic image of surface cells

Order: GELIDIALES

Family: GELIDIELLACEAE

Genus: *Gelidiella* Feldmann & Hamel

Taxonomically, this genus was established by Feldmann and Hamel in 1934. Its type species is *Echinocaulon spinellum* Kuetz. which is now a synonym of *Gelidiella acerosa* (Forssk.) Feldmann & Hamel. Presently, this genus is represented by 15 taxa in the world (Guiry and Guiry, 2023) and 7 in India (Rao and Gupta, 2015). Morphologically, its thallus is usually light - dark red in colour, erect, up to 12 cm long, cartilaginous, erect and epilithic in nature with rhizomatous or discoid holdfast. Fronds cylindrical-terete or flattened, erect, tufted, irregularly or pinnately divided into several branchlets. Anatomically, thallus consists of cortex and medulla cells. In India, it is a monogeneric family.

The study revealed that out of 7 taxa in India, only 2 taxa are recognised with potential for agar extraction (Table 1), which are *G. acerosa* and *G. indica*. Of which, *Gelidiella acerosa* (Fig. 5) is the most common species and has been recorded from the coastal states of Andaman Islands, Gujarat, Karnataka, Kerala, Lakshadweep Islands, Maharashtra and Tamil Nadu (Palanisamy *et al.* 2020, Palanisamy and Yadav, 2022).

Fig. 5: Habit of *Gelidiella acerosa* (Forssk.) Feldamann and Hamel

CONCLUSION

Seaweeds are one of the potential marine natural resources and can play an important role in the blue economy of the country. The Indian coastline supports a considerable diversity of seaweeds. The agar-agar is one of the most important phycocolloids and has high economic potential in many industries. Among the 53 taxa, 14 taxa under three agarophytic genera, consisting of ten taxa of *Gracilaria*, two taxa of *Gelidium* and two taxa of *Gelidiella* are recognised with agar-agar potentiality. Presently, the agar extraction industries in India is very limited as compared to many south east Asian countries like Philippines, Indonesia, Malaysia, Japan, Chile, Tanzania and Zanzibar. To overcome the problem in supply of raw materials up to industrial scale, proper awareness and cultivation need to be promoted (Bixler and Porse, 2011). Therefore, seaweed cultivation is one of the important aspects to maintain the supply of targeted species of seaweeds as raw materials on large scale industrial requirements. Further,

seaweed farming can also play an important role as carbon sink and in mitigating the impact of climate change, reducing eutrophication by removing excess quantity of nutrients from the water bodies (Behera *et al*. 2022). In India, presently several methods of seaweed cultivation are in practice such as Coral stone method, Concrete block method, Bamboo raft method, Suspended stone method for these agarophytes (Subbaramaiah *et al.* 1975; Patel *et al*. 1986; Reeta *et al*. 2006; Ganesan *et al*. 2009; Ganesan *et al*. 2017). However, some of the common challenges identified in cultivation of these agarophytes are development of fast growing algae, epiphytic algae, invasive algae, disease caused by various microbes, thallus ageing, seasonal variation etc. (Buschmann *et al*. 1999; Ganesan *et al*. 2017). There has been an estimate that seaweed resources in India can provide employment to more than 20,000 fishers in harvesting and an equal number of jobs in post-harvesting activities, provided stocks are managed rationally (Krishnan and Kumar, 2010). Therefore, seaweeds in general and agarophytes in proper, have great economic potential, which need to be explored and promoted for cultivation for its sustainable utilization for the welfare of the people.

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