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Effect of Thallus spacing on growth and biomass production of *Gracilaria edulis* under floating bamboo raft culture method

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Abstract

Field cultivation of *Gracilaria edulis* (S. G. Gmelin) P. C. Silva, 1952 was carried out using the floating bamboo raft method to evaluate suitable spacing intervals for improved growth and biomass production along the Ratnagiri coast of Maharashtra, India. The experiment was conducted during the pre-monsoon season for 60 days at Mirya Bandar (17.039542° N, 73.269939° E). Five spacing intervals were evaluated: 5 cm (T₁), 10 cm (T₂), 15 cm (T₃), 20 cm (T₄) and 25 cm (T₅). The highest daily growth rate (DGR) of $3.84 \pm 0.01\%$ day⁻¹ and maximum plant yield of 204.20 ± 3.99 g line⁻¹ were recorded in T₃ (15 cm spacing), whereas the lowest values were observed in T₁ (5 cm spacing). Statistical analysis revealed significant differences among the treatments ($p < 0.05$). The results indicate that a 15 cm spacing interval provided favourable growth and biomass production of *Gracilaria edulis* under floating bamboo raft culture method. The study demonstrates the potential of floating bamboo raft cultivation for *Gracilaria edulis* production along the Ratnagiri coast and provides useful suggestion for optimizing planting spacing under similar environmental conditions.

Keywords: *Gracilaria edulis*, floating bamboo raft culture, spacing interval, daily growth rate, plant yield, seaweed cultivation

Introduction

Seaweeds constitute an important component of marine ecosystems and represent a versatile biological resource with considerable nutritional and commercial value. Their biomass is widely utilized as food and as a source of hydrocolloids, particularly agar, carrageenan, and alginates, which have extensive applications in food processing, pharmaceuticals, cosmetics, and several other industries. In addition to these industrial applications, seaweeds contain proteins, essential amino acids, vitamins, minerals, and diverse bioactive compounds that contribute to their nutritional and functional properties (Dhargalkar and Pereira, 2005; Rajapakse and Kim, 2011) [4, 19]. The increasing demand for seaweed-derived products has consequently stimulated interest in the sustainable utilization and cultivation of commercially important seaweed species. Commercial exploitation of seaweeds in India expanded during the Second World War, particularly with the development of agar production from *Gracilaria* species (Rao and Mantri, 2006) [20]. Subsequent surveys documented the rich seaweed diversity of India, comprising 271 genera and 1, 153 species, including 442 red, 211 brown, and 212 green algae (Rao and Gupta, 2015) [21]. The Maharashtra coast also supports considerable seaweed resources, with approximately 240 species reported along the coast and 46 species recorded from Ratnagiri waters (Redekar *et al.*, 2007) [22]. Despite this diversity, the availability of natural seaweed biomass remains insufficient to meet the requirements of agar, alginate, and other seaweed-based industries (NFDB, 2015) [16]. Increasing dependence on natural resources has consequently emphasized the need for systematic cultivation of commercially important seaweeds.

Among commercially important red seaweeds, *Gracilaria edulis* (S. G. Gmelin) P. C. Silva, 1952 is an economically valuable agarophyte with good potential for coastal cultivation. Its adaptability to different culture environments has been demonstrated through earlier cultivation trials. Bharathan (1987) [2] reported higher specific growth of *G. edulis* in open-water culture (5.2% day⁻¹) than in pond culture (2.5% day⁻¹), highlighting the suitability of open-water systems.

Further studies using rope and raft culture recorded yields of 6-22 kg per raft over a 60-day period (Kaliaperumal *et al.*, 1990) [12]. These studies establish the cultivation potential of *G. edulis* in coastal waters and provide a basis for further optimization of culture practices, particularly planting and spacing arrangements, to improve biomass production.

The Konkan coast of Maharashtra supports diverse seaweed resources, including several economically important Rhodophyta (Redekar *et al.*, 2007) [22]. Ratnagiri district, in particular, harbours diverse seaweed flora, including *Gracilaria edulis* (Valanju and Jamdhade, 2014) [27]. Despite this potential, information on standardized field cultivation practices for *G. edulis* along the Maharashtra coast remains limited. Planting density and spacing are important factors influencing seaweed growth and biomass production by affecting light penetration, water movement, nutrient availability, and competition among thalli. Appropriate spacing is therefore essential for efficient use of culture area and optimization of biomass production. Accordingly, the present study was undertaken at Mirya Bandar, Ratnagiri, Maharashtra, to evaluate the effect of different spacing intervals on the field cultivation of *G. edulis* using a floating bamboo raft system. The study assessed daily growth rate (DGR), plant yield, and associated environmental parameters to identify a suitable spacing interval for efficient cultivation of *G. edulis* under the prevailing coastal conditions.

Materials and Methods

Site Selection: The experimental site was selected at Mirya Bandar, Ratnagiri coast, Maharashtra, India (17.039542° N, 73.269939° E), based on the site-selection criteria recommended by Prema (2013) [17]. The site was considered suitable for field cultivation of *Gracilaria edulis* under coastal conditions.

Floating Bamboo Raft Construction: A floating bamboo raft measuring 1.0 × 1.0 m was constructed using locally available bamboo poles (3.0-4.0 inch diameter). Commercial fishnet with a 10 mm mesh size was securely fixed to both the upper and lower surfaces of the raft to provide protection to the cultured seaweed. The raft was anchored at the culture site using 6 mm polypropylene rope attached to natural stones, following the method of Veeragunathan *et al.* (2015) [28].

Seedlings Material and Acclimatization: Healthy vegetative planting material of *Gracilaria edulis* (S. G. Gmelin) P. C. Silva, 1952 was procured from Mandapam, Tamil Nadu. The material was packed in wet jute sacks and transported to the experimental site to minimize moisture loss and desiccation. On arrival, the seaweed was acclimatized in natural seawater at the culture site for 2-3 days before planting.

Experimental Design: To evaluate the influence of planting spacing on growth and biomass production, a uniform initial biomass of 187.5 g line⁻¹ of *G. edulis* was used. The seaweed was attached to four 1-m monolines (n = 4) at five spacing intervals: 5 cm (T₁), 10 cm (T₂), 15 cm (T₃), 20 cm (T₄), and 25 cm (T₅). Each monoline was treated as an experimental replicate. The culture experiment was conducted for 60 days, from 18 December 2017 to 16 February 2018.

Growth and Biomass Assessment: Growth performance was evaluated at 15-day intervals throughout the culture period. Representative thalli were randomly sampled from each experimental line, cleaned of adhering organisms and debris, and weighed using a commercial weighing balance with an accuracy of 0.5 g. Changes in biomass were recorded to determine growth performance and plant yield under each spacing treatment.

The daily growth rate (%) was calculated using the formula given by Dawes *et al.* (1994) [3]:

$$\text{DGR (\%)} = \frac{\ln(W_t - W_0)}{t} \times 100$$

The plant yield (Y) was calculated using the formula of Doty (1986) [5]:

$$Y (\text{g m}^{-1} \text{ line}^{-1}) = \frac{(W_t - W_0)}{L_t}$$

Environmental Parameters: Environmental parameters were monitored at weekly intervals throughout the 60-day culture period. Water temperature was measured using a GH Zeal Ltd. thermometer (London, England; precision ± 1 °C), while pH was recorded using an Eutech EcoTestr pH pen (precision ± 0.1). Water transparency was determined using a 20-cm diameter Secchi disc. Water samples were collected weekly for analysis of nitrite (NO₂⁻), nitrate (NO₃⁻), phosphate (PO₄³⁻), silicate (SiO₄), dissolved oxygen (DO), and salinity following standard analytical methods. The observed environmental conditions were subsequently related to the growth and biomass production of *Gracilaria edulis* under the different spacing treatments.

Statistical Analysis: Statistical analysis of the data was carried out as per Snedecor and Cochran (1967) [24] and Zar (1999) [30] as well as statistical software SPSS (version 16).

Results and Discussion

Field Observations and Biomass Losses

Initially, *Gracilaria edulis* was cultured on seven monolines, of which four successfully supported growth until harvest. The loss of biomass from some monolines during the culture period was associated with several field-related factors. Grazing by pelagic fishes caused damage to the tips and thalli of the cultured seaweed. *Gracilaria* species are consumed by herbivorous fishes such as siganids (Lundberg and Lipkin, 1979) [14], rabbitfishes (Kaladharan *et al.*, 1996) [11], and other pelagic fishes, which can adversely affect biomass production. Similar constraints associated with grazing and field conditions have been reported in earlier seaweed cultivation studies (Doty, 1973 [6]; Trono and Azanza-Corales, 1981 [25]; Nelson and Tsutsui, 1981 [15]; Smith *et al.*, 1984 [23]; Hurtado-Ponce, 1990) [10]. In addition, epiphytic and competing seaweeds, including *Enteromorpha intestinalis*, *Chaetomorpha antennina*, *Ceramium diaphanum*, and *Padina tetrastromatica*, developed on the bamboo rafts and protective nets, potentially restricting water circulation and available space. Periodic cleaning of the rafts and nets was therefore undertaken to maintain suitable conditions for *G. edulis*. The attachment of molluscan eggs, presence of juvenile crabs,

wave action, and water currents also contributed to physical loss and biomass loss during the culture period.

Daily Growth Rate and Plant Yield

The mean daily growth rate (DGR) of *G. edulis* cultured at five spacing intervals for 60 days is presented in Figure 1. The highest DGR was recorded in T₃ (15 cm spacing), with a value of $3.84 \pm 0.01\% \text{ day}^{-1}$, whereas the lowest was observed in T₁ (5 cm spacing), at $3.59 \pm 0.02\% \text{ day}^{-1}$. One-way ANOVA revealed a significant difference in DGR among the spacing treatments ($p < 0.05$). The Student-Newman-Keuls (SNK) test further showed that the DGR in T₃ was significantly higher than those of the other treatments ($p < 0.05$). The superior growth at 15 cm spacing may be attributed to improved water movement, light penetration, and nutrient availability around the thalli, while closer spacing may have increased competition and reduced effective water circulation.

The mean plant yield (g line⁻¹) under the different spacing treatments is presented in Figure 2. The highest plant yield was recorded in T₃ (15 cm spacing), at $204.20 \pm 3.99 \text{ g line}^{-1}$, whereas the lowest yield was observed in T₁ (5 cm spacing), at $143.50 \pm 4.57 \text{ g line}^{-1}$. One-way ANOVA indicated a significant difference in plant yield among the treatments ($p < 0.05$), and the SNK test confirmed that T₃ produced significantly higher plant yield than the other spacing treatments. The higher biomass production at 15 cm spacing suggests that this spacing provided more favourable conditions for thallus development and resource utilization. Overall, the results demonstrate that an intermediate spacing of 15 cm was most favourable for both growth rate and biomass production of *G. edulis* under the floating bamboo raft conditions of the present study.

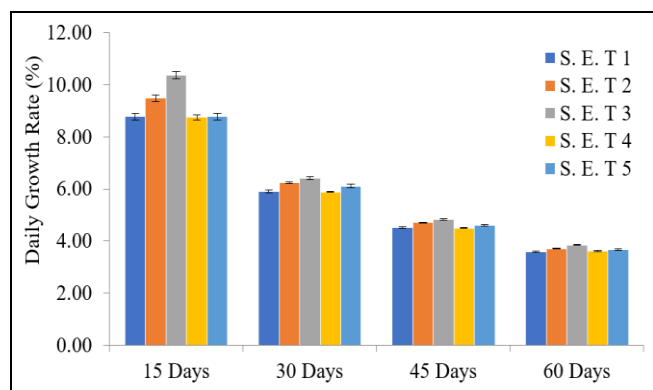


Fig 1: Mean DGR (%) of *Gracilaria edulis* during the culture period.

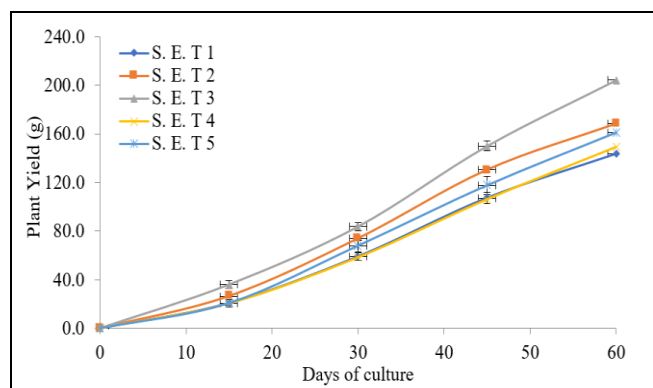


Fig 2: Mean plant yield (g) of *Gracilaria edulis* during the culture period.

Effect of Spacing on Growth and Yield

The maximum DGR and plant yield recorded at 15 cm spacing in the present study were comparable with the yields of 200 and 250 g m⁻² and DGRs of 1.9 and 2.4% day⁻¹ reported at spacing intervals of 10-15 cm by Guanzon and Castro (1992)^[8]. Spacing between thalli is an important technical factor influencing seaweed growth because it affects nutrient uptake, light availability, water movement, and competition for space. Prihaningrum *et al.* (2001)^[18] reported that spacing influences nutrient absorption, while Alifatri (2012)^[1] suggested that appropriate spacing can reduce competition among thalli for space and nutrients required for photosynthesis and growth. Adequate spacing also facilitates the movement of nutrient-rich water through the culture unit, thereby improving resource utilization and potentially enhancing production efficiency.

In the present study, five spacing intervals were evaluated to identify a suitable planting arrangement for vegetative fragments of *G. edulis* cultivated on suspended monolines attached to a floating raft. The significantly higher DGR and plant yield observed at 15 cm spacing indicate that this intermediate spacing provided favourable conditions for thallus development and biomass accumulation. Closer spacing may have increased competition and restricted water movement, whereas wider spacing may have resulted in underutilization of the available culture area. Thus, the present findings support 15 cm as a suitable spacing interval for *G. edulis* under the experimental conditions.

Harvesting Period

Harvesting of *Gracilaria edulis* was carried out after 60 days of cultivation. The selection of a 60-day culture period was based on previous reports on the cultivation and harvesting of *G. edulis*. Umamheswara Rao (1974)^[26], Kaliaperumal *et al.* (1993)^[13] and Ganesan *et al.* (2011)^[7] reported successful cultivation and harvesting of *G. edulis* within comparable culture durations, indicating that a 60-day period is suitable for obtaining substantial biomass under favourable environmental conditions. The duration of cultivation is an important factor in seaweed farming because growth and biomass accumulation are not necessarily constant throughout the culture cycle.

During the initial phase of cultivation, newly planted vegetative fragments generally undergo acclimatization followed by active thallus development and biomass accumulation. As the culture progresses, increasing biomass can alter the conditions within the culture unit by increasing competition among thalli for light, nutrients, and available space. Dense growth may also reduce water movement and the exchange of nutrients around the thalli. Wenno *et al.* (2015)^[29] reported that plant density influences nutrient uptake and growth, with relatively higher growth and biomass accumulation during the early stages of cultivation followed by a decline with prolonged culture duration. Therefore, extending the culture period beyond the optimum stage may not always result in a proportional increase in biomass productivity.

In the present study, the 60-day culture period provided sufficient time for *G. edulis* to establish and accumulate harvestable biomass while maintaining satisfactory growth performance. The observed variation in growth among the different spacing treatments further indicates that the interaction between culture duration and planting arrangement is important for achieving efficient biomass

production. Appropriate spacing can facilitate water circulation, light penetration, and nutrient availability, thereby supporting sustained thallus growth during the culture period. A practical cultivation perspective, harvesting at 60 days may also provide a balance between biomass accumulation and the maintenance of healthy, actively growing thalli. Timely harvesting can prevent excessive biomass accumulation and associated crowding effects, while also allowing the harvested material to be utilized for commercial purposes or as planting material for subsequent culture cycles. Thus, the 60-day cultivation period adopted in the present study was considered appropriate for evaluating the effect of spacing intervals on the growth and biomass production of *G. edulis* under floating bamboo raft conditions at Mirya Bandar, Ratnagiri.

Environmental Parameters

Water quality parameters, including temperature ($^{\circ}\text{C}$), pH, dissolved oxygen (mg L^{-1}), salinity (psu), transparency (cm), nitrite (mg L^{-1}), nitrate (mg L^{-1}), phosphate (mg L^{-1}), and silicate (mg L^{-1}), were monitored weekly throughout the 60-day culture period and are presented in Figures 3-5. Figure 3 presents the variations in temperature, pH, and dissolved oxygen; Figure 4 shows the variations in salinity and transparency; and Figure 5 illustrates the variations in nitrite, nitrate, phosphate and silicate concentrations during the culture period. These parameters were evaluated to characterize the prevailing environmental conditions and assess their association with the growth and biomass production of *G. edulis* under different spacing treatments.

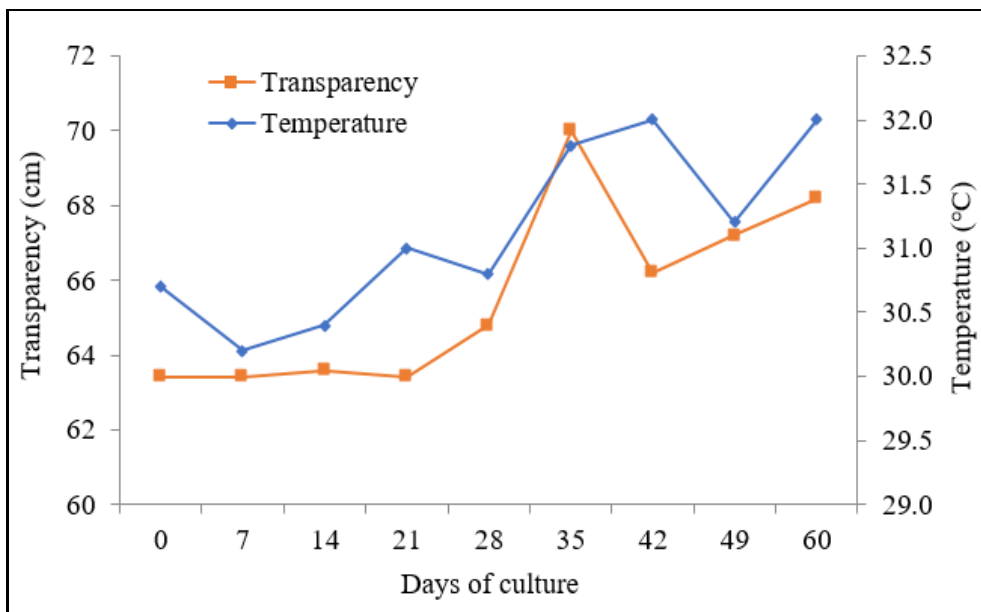


Fig 3: Variations in physical parameters during the culture period.

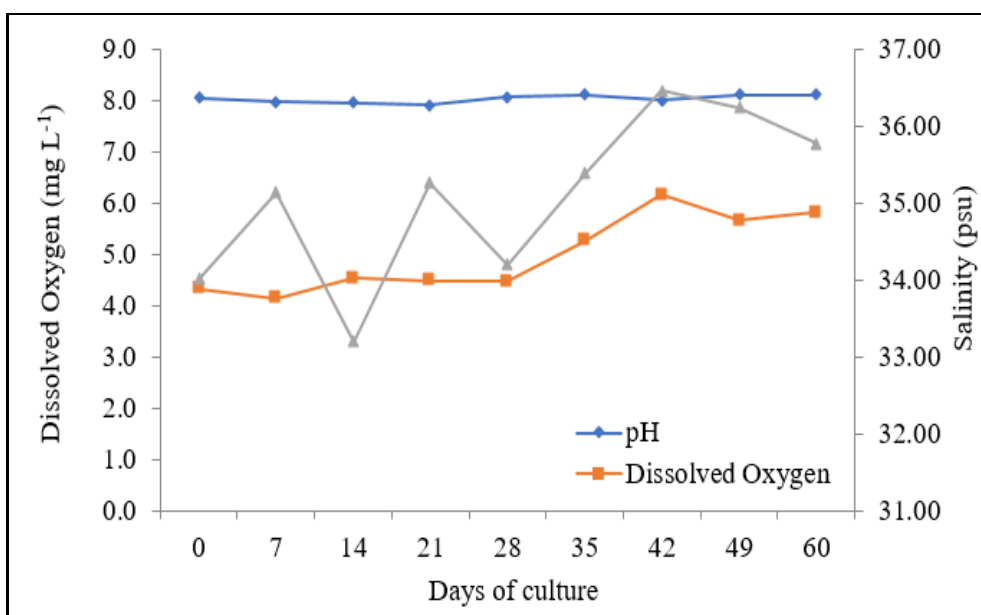


Fig 4: Variations in chemical parameters during the culture period.

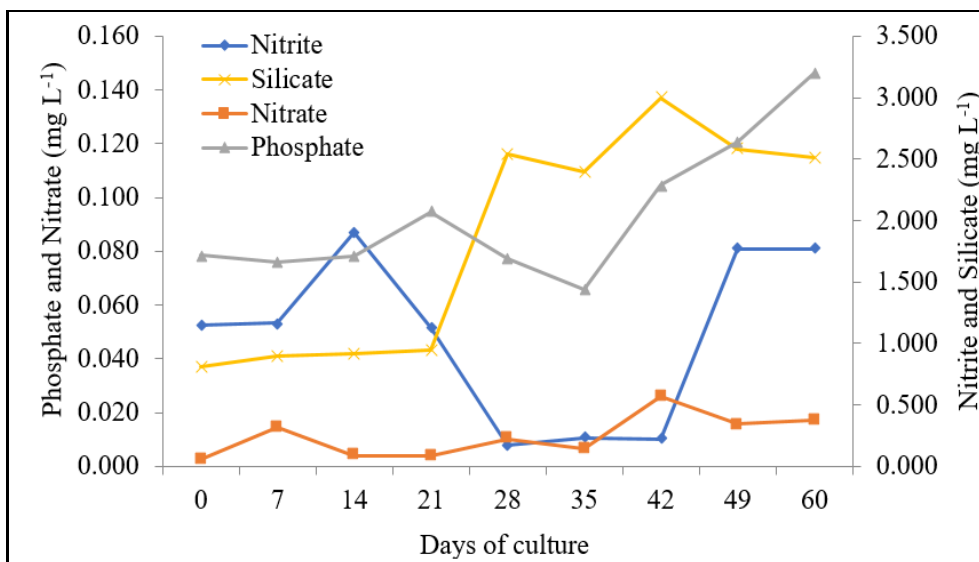


Fig 5: Variations in nutrient contents during the culture period.

Conclusion

The present study demonstrated that planting spacing significantly affected the growth and biomass production of *Gracilaria edulis* cultivated using a floating bamboo raft system at Mirya Bandar, Ratnagiri, Maharashtra. Among the five spacing intervals evaluated, 15 cm spacing resulted in the highest daily growth rate ($3.84 \pm 0.01\%$ day⁻¹) and plant yield (204.20 ± 3.99 g line⁻¹), whereas the lowest growth rate and yield were recorded at 5 cm spacing ($3.59 \pm 0.02\%$ day⁻¹ and 143.50 ± 4.57 g line⁻¹, respectively). The superior performance at 15 cm spacing suggests that an intermediate planting interval provides favourable conditions for thallus development and efficient utilization of light, nutrients, and water movement. Therefore, a 15 cm spacing interval may be considered suitable for *G. edulis* cultivation under floating raft conditions during the study season. The findings provide a useful basis for developing standardized cultivation practices and improving biomass production of *G. edulis* along the Ratnagiri coast of Maharashtra.

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References

- Alifatri LO. Laju pertumbuhan dan kandungan agar *Gracilaria verrucosa* dengan perlakuan bobot bibit terhadap jarak tanam di tambak Balai Layanan Usaha Produksi Perikanan Budidaya Karawang Jawa Barat [thesis]. Bogor: Institut Pertanian Bogor; 2012.
- Bharathan G. Experimental culture of *Gracilaria* at the mariculture centre, Muttukadu, Tamil Nadu. Journal of Marine Biological Association. 1987;29:54-59.
- Dawes CJ, Lluisma AO, Trono GC. Laboratory and field growth studies of commercial strains of *Eucheuma denticulatum* and *Kappaphycus alvarezii* in the Philippines. Journal of Applied Phycology. 1994;6:21-24.
- Dhargalkar VK, Pereira N. Seaweed: promising plant of the millennium. Science and Culture. 2005 Mar-Apr;60-61.
- Doty MS. Estimating returns from producing *Gracilaria* and *Eucheuma* on line farms. Monographs in Biology. 1986;4:45-62.
- Doty MS. Farming the red seaweed *Eucheuma* for carrageenans. Micronesica. 1973;9:59-73.
- Ganesan M, Sahu N, Eswaran K. Raft culture of *Gracilaria edulis* in open sea along the south-eastern coast of India. Aquaculture. 2011;321(1-2):145-151.
- Guanzon NG, Castro TRD. The effects of different stocking densities and some abiotic factors on cage culture of *Gracilaria* sp. (Rhodophyta, Gigartinales). Botanica Marina. 1992;35:239-243.
- Herliany NE, Zamdial Z, Meylia R. Cultivation of seaweed *Gracilaria* sp. using longline methods under different space of planting: budidaya rumput laut *Gracilaria* sp. menggunakan metode longline dengan jarak tanam berbeda. Journal of Aquatropica Asia. 2016;2(2):2704-3601.
- Hurtado-Ponce AQ. Vertical rope cultivation of *Gracilaria* (Rhodophyta) using vegetative fragments. Botanica Marina. 1990;33:477-481.
- Kaladharan P, Vijayakumaran K, Chennubhotla VSK. Optimization of certain physical parameters for the mariculture of *Gracilaria edulis* (Gmelin) Silva in Minicoy lagoon (Laccadive Archipelago). Aquaculture. 1996;139:265-270.
- Kaliaperumal N, Chennubhotla VS, Kalimuthu S, Ramalingam JR, Muniyandi K. Environmental factors influencing the growth of *Gracilaria edulis* in culture. Marine Fisheries Information Service. 1990;105:10-11.
- Kaliaperumal N, Chennubhotla VSK, Kalimuthu S, Ramalingam JR, Muniyandi K. Growth of *Gracilaria edulis* in relation to environmental factors in field cultivation. Seaweed Research and Utilization. 1993;16(1-2):167-176.
- Lundberg B, Lipkin Y. Natural food of the herbivorous rabbitfish (*Siganus* spp.) in Northern Red Sea. Botanica Marina. 1979;22:173-181.

15. Nelson SG, Tsutsui RN. Browsing by herbivorous reef fishes on the agarophyte *Gracilaria edulis* (Rhodophyta) at Guam, Mariana Islands. Proceedings of the International Coral Reef Symposium. 1981;4:503-506.
16. National Fisheries Development Board. Guidelines for seaweed cultivation. Hyderabad: National Fisheries Development Board; 2015. Available from: NFDB Guidelines for Seaweed Cultivation. Accessed 2022 Jan 1.
17. Prema D. Site selection and water quality in mariculture. Cochin: Central Marine Fisheries Research Institute; 2013. p. 35-43.
18. Prihanigrum A, Meiyana M, Tahun DE. Biologi rumput laut: teknologi budidaya rumput laut (*Kappaphycus alvarezii*). Petunjuk teknis. Lampung: Departemen Kelautan dan Perikanan, Direktorat Jenderal Perikanan Budidaya, Balai Budidaya Laut; 2001.
19. Rajapakse N, Kim SK. Nutritional and digestive health benefits of seaweed. Advances in Food and Nutrition Research. 2011;64:17-28.
20. Rao PS, Mantri VA. Indian seaweed resources and sustainable utilization: scenario at the dawn of a new century. Current Science. 2006;91:164-174.
21. Rao PSN, Gupta RK. Algae of India: a checklist of Indian marine algae (excluding diatoms and dinoflagellates). Kolkata: Botanical Survey of India; 2015. p. 93.
22. Redekar PD, Sadawarte RK, Kovale SR. Composition and seasonal occurrence of marine algae (seaweeds) along Ratnagiri coast. Shirgaon, Ratnagiri, Maharashtra: College of Fisheries; 2007. p. 1-3.
23. Smith AH, Nichols McLachlan J. Cultivation of seamoss (*Gracilaria*) in St. Lucia, West Indies: a preliminary report. Hydrobiologia. 1984;116/117:249-251.
24. Snedecor GW, Cochran WG. Statistical methods. 6th ed. New Delhi: Oxford and IBH Publishing Co.; 1967. p. 593.
25. Trono GC, Azanza-Corrales. The seasonal variation in the biomass and reproductive states of *Gracilaria* in Manila Bay. International Seaweed Symposium. 1981;10:743-748.
26. Umamaheswara RM. On the cultivation of *Gracilaria edulis* in the near shore areas around Mandapam. Current Science. 1974;43:660-661.
27. Valanju NM, Jamdhade VM. Study of marine macro-algal biodiversity at Kurli-Kasop beach, Ratnagiri district of Maharashtra. Bionano Frontier. 2014;7(1):172-175.
28. Veeragurunathan V, Eswaran Malarvizhi J, Gopalkrishnan M. Cultivation of *Gracilaria dura* in the open sea along the southeast coast of India. Journal of Applied Phycology. 2015:1-14.
29. Wenno PA, Syamsuddin R, Zainuddin EN, Ambo-Rappe R. Cultivation of red seaweed *Kappaphycus alvarezii* (Doty) at different depths in South Sulawesi, Indonesia. Aquaculture, Aquarium, Conservation and Legislation: International Journal of the Bioflux Society. 2015;8(3):468-473.
30. Zar JH. Biostatistical analysis. New Delhi: Pearson Education India; 1999. p. 228-232.