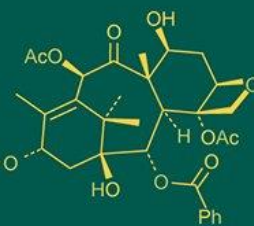
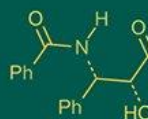


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Field cultivation of *Gracilaria edulis* under different stocking densities at Mirya Bandar, Ratnagiri, Maharashtra

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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 the effect of different stocking densities on 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 stocking densities were evaluated: 125 g line⁻¹ (T₁), 187.5 g line⁻¹ (T₂), 250 g line⁻¹ (T₃), 312.5 g line⁻¹ (T₄), and 375 g line⁻¹ (T₅). Among the treatments, T₂ recorded the highest daily growth rate (DGR) of 3.75±0.04% and the highest plant yield of 179.70±9.47 g line⁻¹. The differences in growth and yield among the treatments were statistically significant (ANOVA, $p < 0.05$). The results indicate that stocking density significantly influences the growth and biomass production of *G. edulis*, with 187.5 g line⁻¹ showing the most favourable performance under the prevailing environmental conditions. The study demonstrates the suitability of floating bamboo raft culture for *G. edulis* cultivation and highlights its potential for improving seaweed productivity along the Ratnagiri coast of Maharashtra.

Keywords: *Gracilaria edulis*, floating bamboo raft, stocking density, daily growth rate, plant yield, seaweed cultivation

Introduction

Seaweeds are important marine resources with considerable nutritional, industrial, pharmaceutical, and economic value. They are consumed as food and serve as raw materials for phycocolloids such as agar, carrageenan, and alginates. They also contain vitamins, minerals, essential amino acids, and bioactive compounds with applications in functional foods and pharmaceutical products (Dhargalkar and Pereira, 2005; Rajapakse and Kim, 2011) [9, 23]. Their derivatives are widely used in food processing, cosmetics, toothpaste, paints, and other industries, contributing to livelihood generation and the growing blue economy.

India possesses a rich diversity of marine macroalgae, including several economically important red, brown, and green seaweeds. Commercial utilization of seaweeds in India expanded during the Second World War, particularly with the development of agar production from *Gracilaria* species (Rao and Mantri, 2006) [24]. The Maharashtra coast, particularly Ratnagiri, supports diverse seaweed resources, including several species of Rhodophyta and *Gracilaria* (Redekar *et al.*, 2007; Valanju and Jamdhade, 2014) [26, 32].

Among commercially important red seaweeds, *Gracilaria edulis* (S. G. Gmelin) P. C. Silva, 1952 is an important agarophyte with considerable potential for cultivation. Earlier studies have demonstrated its suitability for open-water, rope, and raft-based cultivation, with favourable growth and biomass production. Cultivation of *G. edulis* can therefore provide an alternative source of agarophyte biomass while reducing dependence on natural stocks.

Stocking density is a critical factor influencing seaweed growth and biomass production through its effects on nutrient availability, light penetration, water movement, and competition among plants. Determining an appropriate stocking density is therefore essential for maximizing productivity under specific environmental conditions. Although the Ratnagiri coast offers considerable potential for seaweed cultivation, information on the optimum stocking density of *G. edulis* under floating raft culture remains limited.

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Hence, the present study was undertaken at Mirya Bandar, Ratnagiri, Maharashtra, to evaluate different stocking densities of *G. edulis* and their effects on daily growth rate, plant yield, and associated environmental parameters under floating bamboo raft cultivation.

In this context, the present study was undertaken at Mirya Bandar, Ratnagiri, Maharashtra, to evaluate the effect of different stocking densities on the field cultivation of *Gracilaria edulis* using a floating bamboo raft method. The study aimed to determine the optimum stocking density based on daily growth rate (DGR) and plant yield and to assess the prevailing environmental parameters during the culture period. The findings are expected to contribute to the development of suitable cultivation practices for *G. edulis* and support its potential for sustainable seaweed production along the Maharashtra coast.

Materials and Methods

A suitable site for the cultivation of *Gracilaria edulis* was selected based on the site-selection criteria suggested by Prema (2013) [22], and accordingly, Mirya Bandar, Ratnagiri coast, Maharashtra, India (17.039542° N, 73.269939° E) was selected for the present study. A floating raft measuring 1.0 × 1.0 m was constructed using locally available bamboo poles of 3.0-4.0 inch diameter and covered with commercial fishnet of 10 mm mesh size on both the upper and lower surfaces for protection. The raft was anchored at the culture site using 6 mm polypropylene rope attached to natural stones following the method described by Veeragunanathan *et al.* (2015) [33]. Healthy planting material of *Gracilaria edulis* (S. G. Gmelin) P. C. Silva, 1952 was procured from Mandapam, Tamil Nadu, packed in wet jute sacks to minimize desiccation during transportation, and acclimatized in natural seawater at the culture site for 2-3 days before stocking. The experiment was conducted for 60 days from December to February, and *G. edulis* was stocked at five different densities, namely 125 g line⁻¹ (T₁), 187.5 g line⁻¹ (T₂), 250 g line⁻¹ (T₃), 312.5 g line⁻¹ (T₄), and 375 g line⁻¹ (T₅). Each treatment consisted of seven 1 m monolines (n = 7), with each line considered an experimental replicate, and a spacing of 15 cm was maintained between adjacent culture lines (Image 1). The respective quantities of seaweed were uniformly attached to the culture lines according to the assigned stocking density. Growth assessment was carried out at 15 day intervals throughout the culture period by randomly collecting representative samples from each experimental line and recording their biomass using a commercial weighing balance with an accuracy of 0.5 g. The recorded biomass values were used to evaluate the growth performance of *G. edulis* under different stocking-density treatments. The daily growth rate (%) was calculated using the formula given by Dawes *et al.* (1994) [7]:

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

Where:

The plant yield (Y) was calculated using the formula of Doty (1986) [10]:

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

Environmental parameters were monitored at weekly intervals throughout the experimental period. Water temperature was measured using a GH Zeal Ltd. thermometer (London, England) with a precision of ±1 °C, while pH was recorded using an Eutech EcoTestr pH pen with a precision of ±0.1. Water transparency was measured using a Secchi disc of 20 cm diameter. Water samples were collected weekly for the estimation of nitrite (NO₂⁻), nitrate (NO₃⁻), phosphate (PO₄³⁻), silicate (SiO₄), dissolved oxygen (DO), and salinity following standard analytical methods. The experimental data were statistically analysed following the methods described by Snedecor and Cochran (1967) [29] and Zar (1999) [35], using SPSS statistical software (Version 16.0).



Image 1: Monolines of *G. edulis* showing different stocking density for pre-monsoon culture studies

Results and Discussion

Harvest and Field Observations

Harvesting of *Gracilaria edulis* was carried out after 60 days of culture, following the harvesting period recommended by Kaliaperumal *et al.* (1990) [17] and Ganesan *et al.* (2011) [12]. Wenno *et al.* (2015) [34] reported that plant density influences nutrient uptake and growth, with higher growth generally observed during the early stages of cultivation followed by a decline with prolonged culture duration. In the present study, *G. edulis* was initially cultured on seven monolines; however, only four lines successfully supported the growth of the seaweed until harvest. Losses in some monolines were associated with several field-related factors, including grazing by pelagic fishes. Species of *Gracilaria* are consumed by several herbivorous and pelagic fishes, including siganids and rabbitfishes, which can damage the tips, thalli and consequently reduce biomass production (Lundberg and Lipkin, 1979; Kaladharan *et al.*, 1996) [18, 16]. Similar losses due to grazing and other environmental factors have been reported in earlier seaweed cultivation studies (Doty, 1973 [11]; Trono and Azanza-Corrales, 1981 [30]; Smith *et al.*, 1984 [28]; Hurtado-Ponce, 1990) [13]. In addition, the growth of epiphytic and competing seaweeds, including *Enteromorpha intestinalis*, *Chaetomorpha antennina*, *Ceramium diaphanum* and *Padina tetrastromatica*, on the bamboo rafts and protective nets adversely affected the cultured biomass. Periodic cleaning of the rafts and nets was therefore carried out to maintain water circulation and provide adequate space for *G. edulis*. Attachment of molluscan eggs, occurrence of juvenile crabs, wave action, and water currents also contributed to physical damage and biomass loss during the culture period.

Daily Growth Rate

The mean daily growth rate (DGR) of *G. edulis* cultured under five stocking densities for 60 days is presented in Figure 1. The highest DGR was recorded in T₂ (187.5 g line⁻¹), with a value of $3.75 \pm 0.04\%$ day⁻¹, whereas the lowest was observed in T₁ (125 g line⁻¹), at $3.48 \pm 0.03\%$ day⁻¹. One-way ANOVA indicated a significant difference in DGR among the stocking-density treatments ($p < 0.05$). The DGR recorded in T₂ was significantly higher than those of T₁ and T₄, whereas it was statistically comparable with T₃ and T₅. The variation in growth among stocking densities may be related to differences in nutrient availability, light penetration, water movement and competition among thalli. Similar variations in stocking density and growth performance have been reported for *Gracilaria* species by Kaliaperumal *et al.* (1990) [17] and Chennubhotla *et al.* (1992) [6]. The DGR values obtained in the present study were greater than 2% day⁻¹ in all treatments, indicating satisfactory growth performance for cultivation. Similar growth rates above 2% day⁻¹ have been reported for *Gracilaria* species by Atmadja and Sulistijo (1980) [4], Hurtado-Ponce (1990) [15], Gerung (2000) [13], and Ganesan *et al.* (2011) [12]. According to the criteria reported by Ask and Azanza (2002) [3], Anggadiredja *et al.* (2008) [2] and Hendri *et al.* (2018) [14], a DGR exceeding 2% day⁻¹ is considered suitable for commercial seaweed cultivation. The DGR recorded in the present study (3.48 – 3.75% day⁻¹) was comparable with previously reported values, including 2.61% day⁻¹ in *Gracilaria* (Veeragurunathan *et al.*, 2015) [33], 3.5% day⁻¹ in *Gracilaria* spp. (Dawes, 1995) [8], 5.0% day⁻¹ in *G. gracilis* (Anderson *et al.*, 1996) [1], 3.48% day⁻¹ in *G. edulis* (Siraimetan and Selvaraj, 1999) [27], and 4.67% day⁻¹ in *G. dura* (Mantri *et al.*, 2009) [19]. Higher values of 4.4% , 7.4% , and 8.96% day⁻¹ have also been reported for *G. birdie* (Bezzera and Morinho-Soriano, 2010) [5], *G. edulis* (Ganesan *et al.*, 2011) [12] and *G. verrucosa* (Padhi *et al.*, 2011) [21], respectively. The growth rates observed in the present study therefore fall within the range reported for cultivated *Gracilaria* species.

Plant Yield

The mean plant yield of *G. edulis* under different stocking densities, recorded at 15-day intervals over the 60-day culture period, is presented in Figure 2. The highest final plant yield was recorded in T₂ (187.5 g line⁻¹), with 179.70 ± 9.47 g line⁻¹, while the lowest yield was recorded in T₁ (125 g line⁻¹), with 124.20 ± 4.52 g line⁻¹. One-way ANOVA revealed a significant difference in plant yield among the treatments ($p < 0.05$). The yield obtained in T₂ was significantly higher than those recorded in T₁ and T₄, while it was statistically comparable with T₃ and T₅. The Student Newman Keuls (SNK) test further confirmed significant differences in plant yield among the treatments. The superior performance of T₂ suggests that 187.5 g line⁻¹ provided favourable conditions for biomass accumulation under the environmental conditions prevailing at the study site. At lower stocking density, the available culture space may not have been fully utilized, whereas higher densities may have increased competition for nutrients, light, and water movement, thereby limiting biomass accumulation. Based on the four successfully harvested lines, the estimated production was 1.515 kg fresh weight m⁻². This value was higher than the 1.05 kg fresh weight m⁻² reported for *Gracilaria* cultivated using a raft culture method by

Veeragurunathan *et al.* (2015) [33], indicating the potential of floating raft cultivation for enhancing *G. edulis* biomass production under suitable coastal conditions.

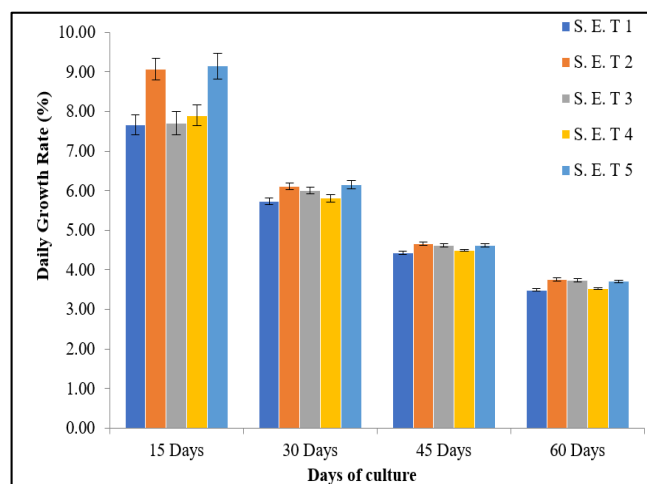


Fig 1: Mean DGR (%) of *Gracilaria edulis* during the culture period.

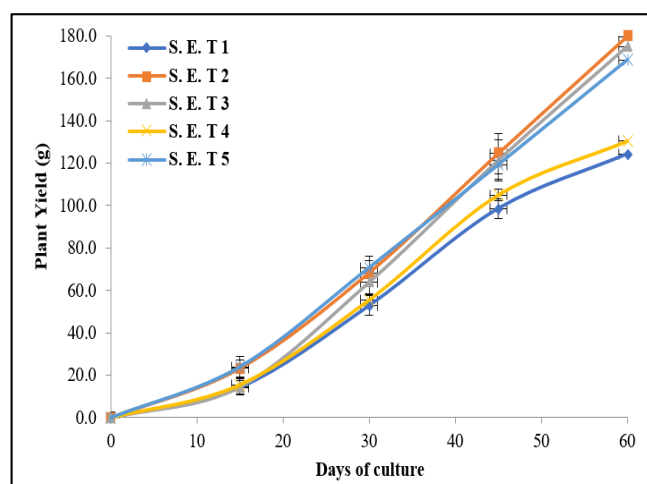


Fig 2: Mean plant yield (g) of *Gracilaria edulis* during the culture period

Environmental Parameters

The water quality parameters, including temperature (°C), pH, dissolved oxygen (DO; 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 Figure 3. The environmental conditions remained within suitable ranges during the experimental period, with water temperature ranging from 30–31 °C, salinity from 33.05–35.60 psu, and dissolved oxygen from 3.80–4.96 mg L⁻¹. Nutrient concentrations showed some temporal variation, with phosphate (0.16–3.38 mg L⁻¹) and nitrate (0.05–0.56 mg L⁻¹) exhibiting greater fluctuations, while nitrite and silicate remained comparatively low. Overall, the recorded environmental conditions were favourable for the growth and biomass production of *Gracilaria edulis*. The observed daily growth rate exceeding 2% day⁻¹ further indicates satisfactory growth performance, consistent with the criterion reported by Hendri *et al.* (2018) [14] for *Gracilaria* species. These results suggest that the environmental conditions at Mirya Bandar were suitable for the cultivation of *G. edulis* during the study period.

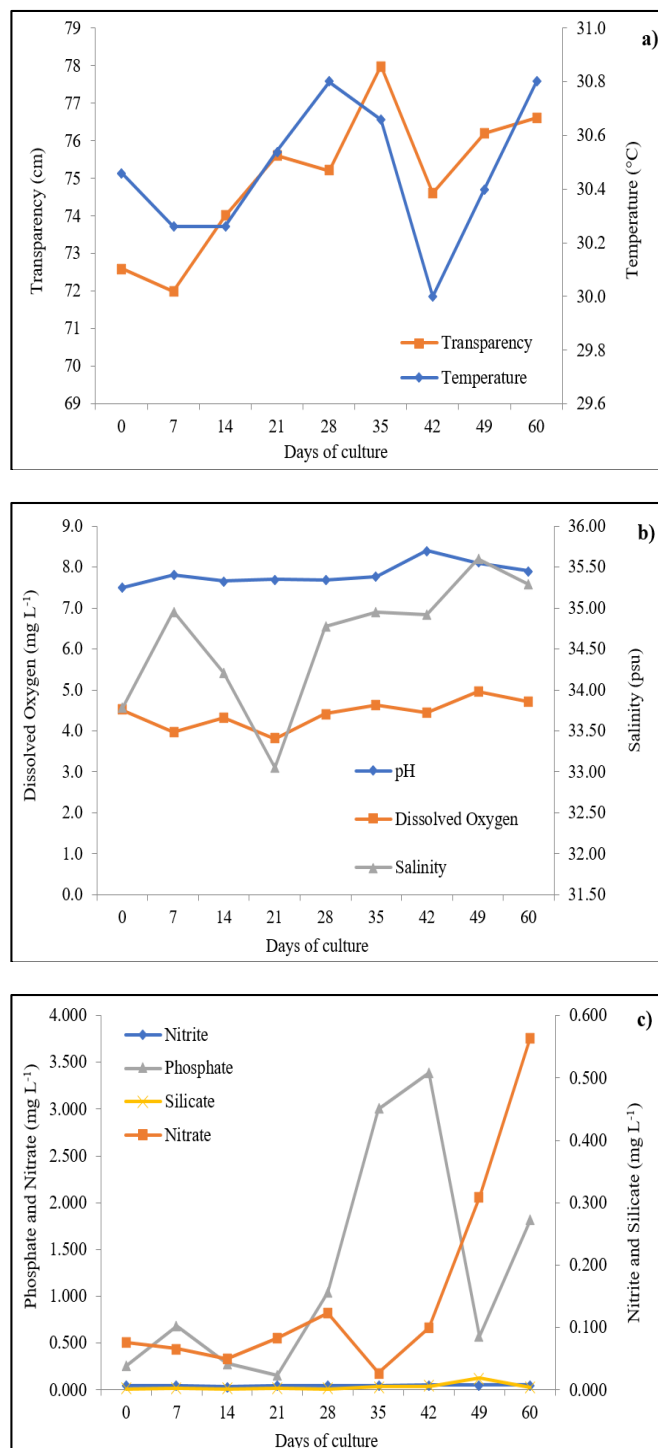


Fig 3: Variations in environmental parameters during the culture period: a) Physical parameters b) Chemical parameters c) Nutrient contents

The average optimum plant yield of *Gracilaria edulis* was achieved at a stocking density of 187.5 g/line, producing 179.7 ± 9.47 g, while the lowest yield was observed at 125 g/line with 124.2 ± 4.52 g. Considering four lines, the total yield reached 1.515 kg fresh weight per square meter. These results confirm that moderate stocking density supports superior growth and productivity compared to lower densities. The findings highlight the importance of density optimization in maximizing biomass yield. Overall, *G. edulis* demonstrated strong potential for commercial cultivation under raft culture conditions at Ratnagiri, Maharashtra.

Conclusion

The present study demonstrated the feasibility of cultivating *Gracilaria edulis* using a floating bamboo raft system at Mirya Bandar, Ratnagiri, Maharashtra, during the pre-monsoon season. Among the five stocking densities evaluated, 187.5 g line⁻¹ (T₂) recorded the highest daily growth rate ($3.75 \pm 0.04\%$ day⁻¹) and final plant yield (179.70 ± 9.47 g line⁻¹), indicating favourable biomass production under the prevailing environmental conditions. The recorded water quality parameters remained within suitable ranges throughout the 60-day culture period and supported satisfactory growth of *G. edulis*. Although some biomass losses occurred due to grazing, epiphytes, wave action, currents, and other field-related factors, the overall growth performance was satisfactory, with DGR values exceeding 2% day⁻¹ in all treatments. The estimated production of 1.515 kg fresh weight m⁻² from the successfully harvested culture lines further indicates the potential of floating raft culture for *G. edulis* production along the Ratnagiri coast. Therefore, a stocking density of 187.5 g line⁻¹ may be considered suitable for field cultivation of *G. edulis* under conditions similar to those of the present study. The findings provide useful baseline information for optimizing raft-based seaweed cultivation in the Maharashtra coastal region and support its potential for sustainable seaweed production and livelihood development. Further studies covering different seasons, culture durations, raft configurations, and larger-scale field trials are recommended to validate and optimize production at a commercial scale.

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