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Sustainable Aquatic Research, 2(1): 40-50
DOI: 10.5281/zenodo.7881928
e-ISSN: 2822-4140

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RESEARCH PAPER

Yield enhancement of seaweed, *Gracilaria tenuistipitata* (Chang and Xia, 1976) cultured in different raft models and water depths on the Kuakata coast of the Bay of Bengal, Bangladesh

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Citation

Khan, A.B.S., Islam, M.A., Ullah, M.R., Akhter, M., Yasmin, F., Bosu, A., Hasan, M.M., Hasa, K.R. and Mahmud, Y. (2023). Yield enhancement of seaweed, *Gracilaria tenuistipitata* (Chang and Xia, 1976) cultured in different raft models and water depths on the Kuakata coast of the Bay of Bengal, Bangladesh. *Sustainable Aquatic Research, 2*(1), 40-50.

Article History

Received: 04 April 2023
Received in revised from: 18 April 2023
Accepted: 29 April 2023
Available online: 30 April 2023

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Keywords

Bay of Bengal
DGR
Gracilaria tenuistipitata
Raft shape
Water depth
Yyield.

Abstract

Research was carried out to investigate the impact of bamboo raft models (shapes) and water depths on the growth and production of the red seaweed, *Gracilaria tenuistipitata.* The bamboo raft models of a square (1.5 m x1.5 m) and a triangular raft (1.5 m x1.5 m x 1.5 m) with three different water depths i.e., surface (0 m), 0.5 m, and 1 m were used in this experiment. Water quality parameters were monitored fortnightly. The maximum daily growth rates of 2.34 ± 0.89 and 2.01 ± 0.69% d^{-1} were found in the square and triangular rafts respectively, at 0.5 m water depth after 60 d of culture period. The minimal DGR (Daily growth rate) was recorded in both the square and triangular rafts after 15 days of culture at the water depth of 1 m. The maximum biomass yield recorded was 7.14 ± 2.17 and 5.89 ± 2.56 kg fresh weight m^{-2} at 0.5 m water depth in the square and in the triangular rafts, respectively. Considering the findings of the present study, a conclusion might be drawn that *G. tenuistipitata* can be grown on the square raft at a water depth of 0.5 m to get better biomass yield.

Introduction

Seaweeds, or marine macroalgae, are eukaryotic plants known as alga that are primary producers in marine environments and contains chlorophylls (Shilpi and

Nissreen, 2011). Seaweeds contribute significantly to hydrophyte ecology by creating the foundation for the food web. Food was believed as being necessary only for bodily growth around the beginning of the 20th century. This widely held notion has been disproved by recent developments in nutrition and dietary research, and the focus of food needs is now more on the function of diet in enhancing the health of humans and preventing diseases (Admassu et al., 2015). Many types of seaweeds are consumed as nutritious food, and because of their purported health advantages, they have been employed in medicinal products. Red seaweed farming worldwide contributed 52.6% of the world's seaweed tonnage and 47.6% of the world's seaweed value (FAO, 2021). The seaweed genus *Gracilaria* contains more than 150 species, making it one of the biggest genera. The genera are widely scattered over the Atlantic, Pacific, and Indian Oceans, with the bulk of the species being found there (Cornish and Garbary, 2010). From the Indian Ocean alone, Silva et al. (1996) reported 65 species of *Gracilaria*. It is essential to increase resources through farming. Commercial *Gracilaria* cultivation is now taking place in Asian and European countries. (Santelices and Meneses, 2000; Gupta et al., 2011; Anderson et al., 1996; Rejeki et al., 2018; Bixler and Porse, 2011). The culture of seaweed is very important as wild stocks are rapidly waning. This species' limited biomass availability and seasonal occurrence make it difficult to use it for industrial output (Vaibhav et al., 2015). Therefore, creating a practical farming method for this valuable resource is essential before it can be used industrially, as well as to offer alternatives to stop the destruction of natural beds. In the science of phycology, Bangladesh's seacoast is regarded as one of the planet's last unexplored regions (Rafiquzzaman et al., 2022). There is a limited number of the study in Cox's Bazar coast, Bangladesh (Rafiquzzaman et al., 2022; Rafiquzzaman et al., 2021; Aziz et al., 2021). On the Bangladeshi Kuakata coast, there have been no attempts to cultivate red seaweed, *Gracilaria tenuistipitata* experimentally. This research wasn't designed at the size necessary for commercial farming; it is simply small-scale proof of concept investigation. That's why the immediate study was initiated to supervise the yield of *Gracilaria tenuistipitata* in on the Kuakata coast of the Bay of Bengal, Bangladesh.

Materials and methods

Cultivation zone and collection of the samples

This experiment of field cultivation of *Gracilaria tenuistipitata* was performed at Gangamoti estuary (21˚48'21.3" N and 90˚08'44.5" E) in the Kuakata seashore, on the south-eastern coast of Bangladesh, where there is no coral reef or marine flora in and around the region. There is modest water circulation in the culture region, as well as sandy mud sedimentation (Figure 1). Healthy fronds of *G. tenuistipitata* were collected between the surface and one-meter depth in Nuniachara, Cox's Bazar, Bangladesh (21°28'26" N and 91°57′51" E). The Nuniachara shore includes sand-flat tidal regions that are 300 meters east-west and 2000 meters north-south, with minimal turbulence but frequent 2-meter tidal waves. Native seaweeds are present in the Bakkhali River's Nuniarchara regions. This area's water quality attributes are ideal for the growth and periodic availability of various macroalgae species. As a result, Nuniachara is a unique location for wild macroalgae supply. The collection of different macroalgae from the seafloor was approved by the local authorities, and the biological identity of seaweed species was confirmed by the reference sample recorded at the Bangladesh Fisheries Research Institute (BFRI) herbarium. The fronds were brought in an icebox under a dark condition.

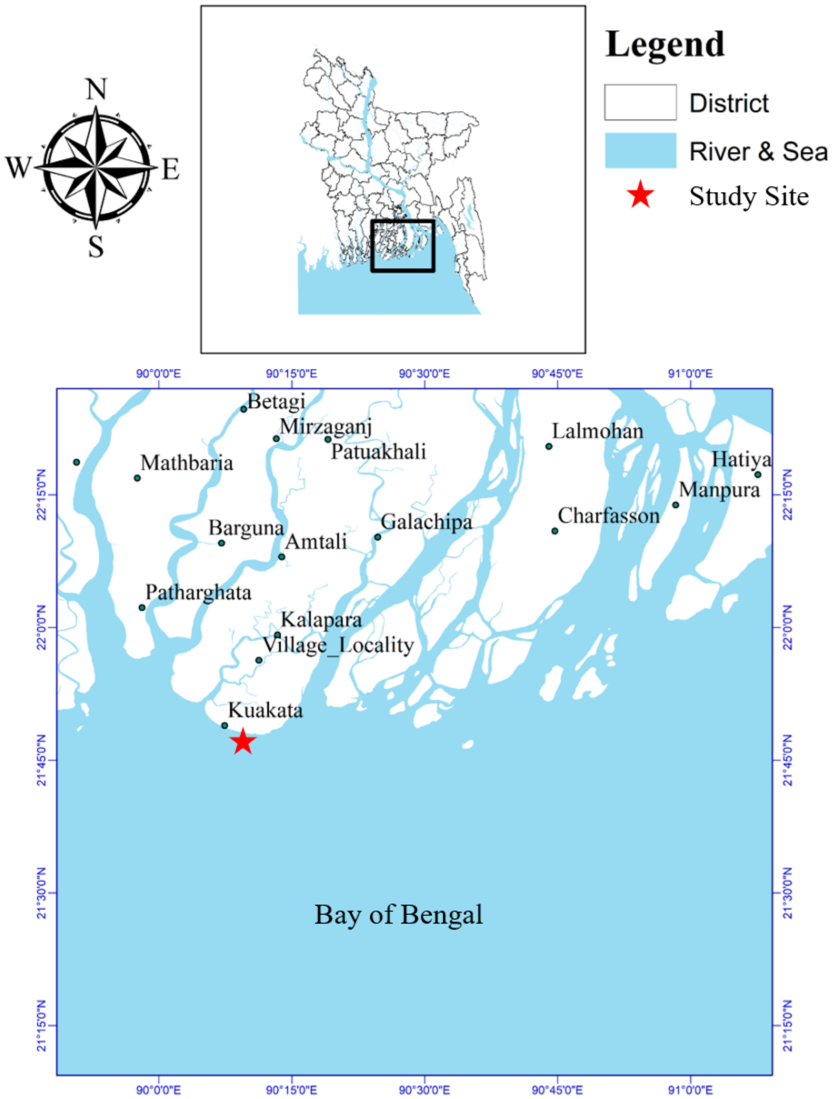

Figure 1. Culture site is located on the Kuakata coast, Bay of Bengal, Bangladesh

Modified drifting bamboo raft method

A square bamboo raft (1.5 m x1.5 m) and a triangular bamboo raft (1.5 m x1.5 m x 1.5 m) with 7.0-11.5 cm diameters were applied for cultivation studies (Figure 2). The corners were braced slantly by bamboo to repose the raft square and unimpaired. The square raft comprised 5 polypropylene ropes of 3 mm diameter (Tiger Ropes Ltd., Munshiganj, Bangladesh), and the triangular raft contained 10 polypropylene ropes of 3 mm diameter (Tiger Ropes Ltd., Munshiganj, Bangladesh) spaced at 10 cm intervals for pawning seedlings.

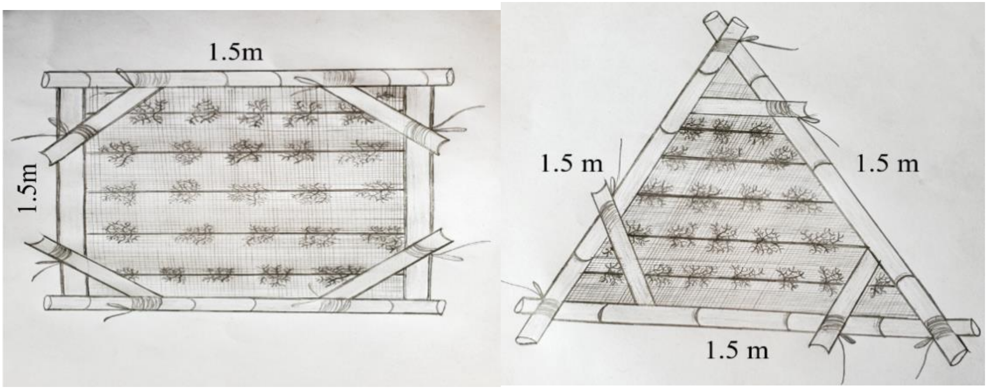

Figure 2. Schematic diagram of bamboo square and triangular shape rafts for *G. tenuistipitata* cultivation.

Every rope included 5 propagules totaling 100 g of fresh weight per rope. A square raft with 5 ropes and a triangular raft with 10 ropes had an elementary mass of propagules of 1.0 kg fresh weight raft^{-1}. Two rafts were shrouded with fish abandonment nets (1 mm diameter, 1.5 cm mesh size) to detain ingression by fish and lessen the diminution of any materials that might detach from the ropes. Rafts were moored using 10mm polypropylene rope and cemented anchor which had a weight of approximately 35 kg. Harvesting was done by the clipping technique. The seaweeds were harvested after 60 d of culture period between December 2021 and January 2022.

Cultivation of seaweeds in three different depths

The square and triangle bamboo rafts with three replicates were planted with 1 kg of seed material of *G. tenuistipitata* for this experiment. Seaweeds were positioned at three distinct depths: on the sea surface (0 m), 0.5 m, and 1 m depth. After 60 d of cultivation, they were harvested.

Appraisal of biomass yield and daily growth rate

After washing with seawater, the harvested seaweed biomass was weighed. Then, transferring the seaweeds on a mat over a wooden platform for 10 minutes to remove the excess water, the fresh weight of *G. tenuistipitata* was calculated as mean kg fw m^{-2}. Using a slightly modified Doty's (1986) method biomass was calculated as follows:

$$Y = (W_f - W_i) \div m^2$$

where, W_f is the final fresh weight, W_i is the initial fresh weight, m^2 is the area covered, and Y is the biomass yield, Kg m^{-2}.

Daily growth rate (DGR %) was calculated using the formula of Hung et al., (2009) as follows:

$$DGR\ (\%) = [(W_t/W_0)^{1/t} - 1] \times 100\ \%/day$$

where W_0 is the initial fresh weight and W_t is the final fresh weight following t days of culture.

Water quality parameters

Seawater temperature, salinity, transparency, pH and dissolved oxygen were recorded fortnightly at the cultivation site. A multiparameter device was used to measure the water temperature, transparency, salinity, pH, and dissolved oxygen (HANNA multiparameter, HI98194, Romania).

Statistical analysis

The ANOVA was used to determine the significant changes in the daily growth rate and water quality indicators. Tukey's HSD test was used for post hoc comparisons when significant differences ($P < 0.05$) were observed. Pearson correlation analysis was instituted to ordain the relationship between water quality parameters and the daily growth rate of *G. tenuistipitata* in different raft shapes. The Statistical Package for the Social Sciences (SPSS version 25) was used to perform all the statistical analyses.

Results

Environmental factors

During the 60d culture period, water quality parameters such as water temperature, water transparency, dissolved oxygen, pH, and salinity were significantly different (Table 1). The temperature of the Gangamati estuary varied from 27.6°C to 29.4°C and water transparency ranged from 60.3 cm to 65.8 cm (Table 1).

Table 1. Water quality parameters (mean ± SE) of seaweed culture site at Kuakata, Patuakhali, Bangladesh.

Duration (d)	Water quality parameters				
	Water temperature (°C)	Water transparency (cm)	DO (mg l^{-1})	pH	Salinity (ppt)
15	27.6 ± 0.5^{b}	62.3 ± 0.2^{ab}	6.3 ± 0.2^{a}	7.9 ± 0.1^{ab}	19.8 ± 0.3^{a}
30	28.3 ± 0.3^{b}	64.6 ± 0.1^{a}	5.8 ± 0.3^{ab}	8.1 ± 0.3^{a}	20.6 ± 0.4^{a}
45	28.7 ± 0.3^{b}	60.3 ± 0.5^{b}	5.2 ± 0.2^{b}	7.5 ± 0.2^{b}	20.1 ± 0.6^{a}
60	29.4 ± 0.4^{a}	65.8 ± 0.3^{a}	5.3 ± 0.1^{b}	7.8 ± 0.3^{ab}	21.4 ± 0.5^{b}

DO = dissolved oxygen. Different superscript in a same column indicates significant variation ($P<0.05$).

The amount of dissolved oxygen at the experimental site ranged from 5.2 to 6.3 mg/L, the pH ranged from 7.5 to 8.1., the salinity ranged from 19.8 to 21.4 ppt (Table 1). Consistent and moderate salinity was the most important factor in achieving the highest biomass production of seaweed (Ullah et al., 2023). However, all the parameters of water quality in the Gangamati estuary were suitable for the production of seaweed, *G. tenuistipitata* culture.

Appraisal of daily growth rate and biomass production

The highest daily growth rate of seaweed, *G. tenuistipitata* in square shape raft was 2.34 ± 0.89% day-1 at 0.5 m water depth after the 60 d of culture period, whilst the highest DGR (2.01 ± 0.69% day-1) was found in triangular shape raft at 0.5 m water depth in 60 d of culture period (Table. 2).

Table 2. Daily growth rate (%) of *G. tenuistipitata* in different raft shapes and water depths at Kuakata, Patuakhali, Bangladesh.

Days	**Bamboo raft models**					
	Square	**Triangular**	**Square**	**Triangular**	**Square**	**Triangular**
15	0.64 ± 0.12^{c}	0.38 ± 0.17^{c}	1.10 ± 0.10^{c}	0.70 ± 0.14^{b}	0.32 ± 0.13^{c}	0.23 ± 0.06^{b}
30	1.05 ± 0.16^{b}	0.59 ± 0.11^{c}	1.90 ± 0.15^{b}	1.20 ± 0.17^{b}	0.51 ± 0.19^{c}	0.39 ± 0.10^{b}
45	1.77 ± 0.19^{a}	1.12 ± 0.21^{b}	2.21 ± 0.20^{a}	1.80 ± 0.21^{a}	1.07 ± 0.22^{b}	0.88 ± 0.14^{b}
60	1.97 ± 0.20^{a}	1.58 ± 0.24^{a}	2.34 ± 0.14^{a}	2.01 ± 0.15^{a}	1.46 ± 0.24^{a}	1.03 ± 0.19^{a}

Different superscript in a same column indicates significant variation ($P \leq 0.05$).

Square and triangular shapes displayed higher DGR of *G. tenuistipitata* at the water depth of 0.5 m than the other two water depths. However, there are significant differences of DGR among different raft shapes and water depths (*P*<0.05). Since the growing performance of seaweed daily growth rate at 0.5 m depth in both shapes was comparatively better, periodical significance was examined separately for 0.5 m in square and triangular shapes (Figure 3).

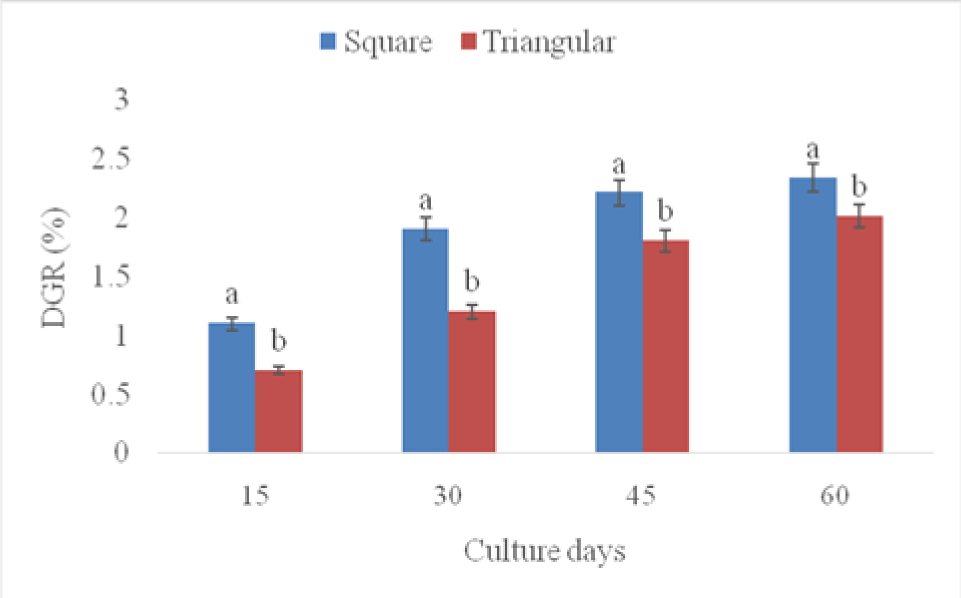

Figure 3. Daily Growth Rates (DGR) of *Gracilaria tenuistipitata* for 60 days at 0.5 m water depth in Kuakata, Patuakhali, Bangladesh. Error bars are standard errors. Different small letters denote significant differences at *p*≤0.05.

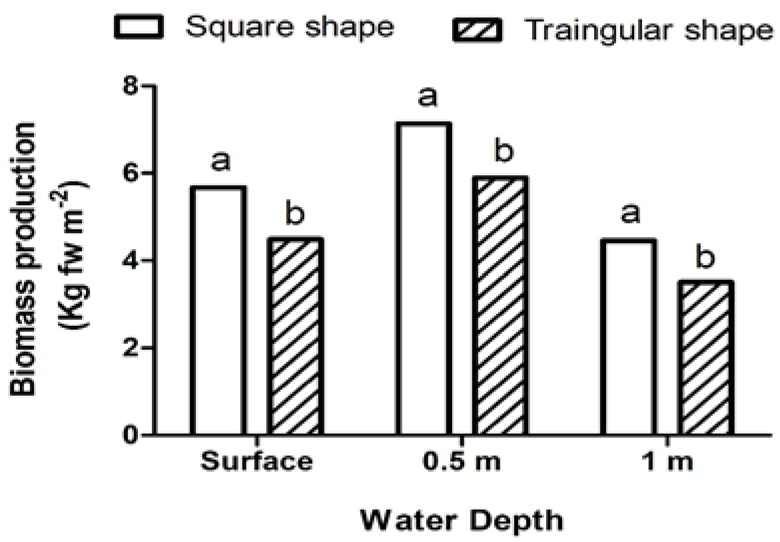

Figure 4. Biomass production of *G. tenuitipitata* at several depths in Kuakata, Patuakhali, Bangladesh.

During 60 d culture period, the highest average biomass yields (7.14 ± 2.17 and 5.89 ± 2.56 kg fresh weight m^{-2}) of *G. tenuistipitata* were found at 0.5 m depth in square and triangular shape rafts, respectively. At Gangamoti estuary, total mass production of *G. tenuistipitata* ranged from 4.45 ± 1.58 to 7.14 ± 2.17 kg fw m^{-2} in square shape raft, and 3.51 ± 1.18 to 5.89 ±

2.56 kg fw m^{-2} in triangular shape raft (Figure 4).

Correlation among daily growth rate and different water quality parameters

The daily growth rate of triangular shape was found to be significantly positively correlated with temperature and negatively correlated with dissolved oxygen, pH, and salinity. The majority of the other parameters had a non-significant correlation.

Table 3. Correlations among daily growth rate (%) *G. tenuistipitata* and different water quality parameters in Kuakata coast of Bangladesh

DGR (%)	Temp.	W.T.	DO	pH	Salinity
Square shape	0.937	0.108	-0.962*	-0.412	-0.225
Triangular shape	0.968*	-0.461	-0.973*	-0.567	-0.450

*Correlation is significant at the 0.05 level (2-tailed). Temp. = Temperature; W.T.= Water transparency; DO= Dissolved oxygen.

The daily growth rate was found to have a substantial negative correlation with dissolved oxygen whereas a negative association with pH and salinity in a square shape (Table 3).

Discussion

Red Seaweed, *Gracilaria* sp. is one of the beneficial seaweeds in the world, mainly used for agar and phycocolloid markets. There were many endeavors to culture *Gracilaria* in the confined area (Baghel et al., 2014). This is meant to be the very first inquisition of *G. tenuistipitata* culture on the Kuakata coast, Bangladesh. The pecuniary of feasible seeds is the main hindrance to the cultivation of *Gracilaria* between March to June (Khan et al., 2021). Nonetheless, the objective of this trial was to control the *Gracilaria tenuistipitata* culture in several raft shapes and depths. Temperatures ranging from 27.6 to 29.4°C were shown to be ideal for the culture of *G. tenuistipitata* and this optimum temperature significantly accelerated the typical growth of *G. tenuistipitata* at Gangamati estuary. The achieved level of water transparency was ideal for seaweed growth. Maximum growth rate (2.34 ± 0.89% d^{-1} and 2.01 ± 0.69% d^{-1}) in both shapes occurred at 29.4°C, 65.8 cm water transparency, and 24.2 ppt salinity, which was slightly lower than the 4.07% d^{-1} observed in *G. tenuistipitata* cultivated in Cox's Bazar at 32 ppt salinity, 74.2 cm transparency and 7.2 ppm DO (Rafiquzzaman et al., 2022), the 4.72% d^{-1} resulted in *G. verrucosa* at 32°C, 36 ppt salinity and 50 cm transparency (Sobuj et al., 2022). Moreover, the present study was inferior to the 4.885 ± 1.042% d^{-1}at 25°C, 20 ppt salinity, pH 7.5 observed in *Gracilaria edulis* (Mantri et al., 2015), the 5.88 ± 0.69% d^{-1} in *Gracilaria crassa* cultivated at 25°C, 35 ppt salinity (Baghel et al. 2014) and the 3.58±0.69% d^{-1} indicated for *G. corticata* grown at 22°C, 35 ppt salinity by Kumar et al. (2011). Ganesan et al. (2011) achieved the daily growth rate (2.6 ± 0.69% d^{-1}) in *G. edulis* during January in India which is more or less similar to our study. *G. tenuistipitata* documented lower DGRs as likened to several *Gracilaria* sp. being indicated as *Gracilaria chilensis* (7.0% d^{-1}) by Troell et al., (1997), *G. gracilis* (5.0% d^{-1}) by Anderson et al., (1996), *G. verrucosa* (8.96% d^{-1}) by Padhi et al., (2011) and *G. edulis* (7.4% d^{-1}) by Ganesan et al., (2011).The average daily growth rate (2.34 ± 0.89% and 2.01 ± 0.69% d^{-1}) attained in the present study in square and triangular shape rafts was lower than the DGR (4.58 ± 0.25% d^{-1} and 5.01 ± 0.64% d^{-1}) gained in agrophyte *G. edulis*, cultivated for 5-month culture period (Mantri et al., 2009). In the present study, excellent crop output was highlighted in the harvest of 60 d. Higher biomass yield was exposition in the depth of

0.5 m for both culture systems that resembled the previous reports. Yang et al. (2006) reported optimum biomass yield occurrence of *G. lamaneiformis* at 0.5 m depth. On the other hand, the relative growth rate for *G. lamaneiformis* at 1.0 m depth was narrated as a good result by Xu and Gao (2007). Oliveira et al., (2012) observed the excellent growth rate of *Gracilaria birdiae* at 1.0 m depth and highlighted that the surface circumstances are apt to water diminution in the thallus concerning dehydration and light penetration. High radiation of light ranked the declining pattern of *G. edulis*, reported by Kaladharan and Chennubala (1993). In addition, surfaces with a higher level of light at low tide resulted in a fall in DGR and impairment of DNA (Zacher et al., 2007). Mantri et al. (2009) reported average total mass of *G. tenuistipitata* harvested from the square and the triangular raft as 11.08 ± 3.43 kg fw m^{-2} and 15.25 ± 1.43 kg fw.m^{-2}, respectively, whereas, the immediate study highlighted the lower biomass output (7.14 ± 2.17 and 5.89 ± 2.56 kg fw m^{-2}). The total biomass of *G. edulis* was reported 7.21 ± 0.83 kg fw m^{-2} in the horizontal netting method by Mantri et al. (2015) which is more or less similar with the existing study. However, a significantly superior yield of 12.2 kg fw m^{-2} was reported by Chennubhotla et al. (1992), 7.94 kg fw.m^{-2} by Chennubhotla et al. (1978), 12.5 kg fw.m^{-2} by Ganesan et al. (2011). The current study found a link between seaweed daily growth rate and temperature and dissolved oxygen, implying that these can affect seaweed growth. Out of the studied two shapes, the daily growth rate of the square shape had the highest growth rate. The Gangamati estuary's water quality can be better for *G. tenuistipitata* in square shape raft culture system. The current study concluded that the cultivation of *G. tenuistipitata* is possible and that fishermen can enjoy an income generator while also reducing fishing pressure along the mid-southern coast.

Conclusion

The current study suggests that *G. tenuistipitata* can be propagated at the Kuakata coast, Bangladesh. Seaweeds have the potential to become a stand-alone export business in Bangladesh. As a result, more detailed research on the current state of naturally available seaweeds and their current possibility for exploitation should be considered, as well as establishing a long-term plan for utilizing these resources. The current study found that seaweed, particularly *G. tenuistipitata*, can be grown in the winter season from January to February throughout the mid-southern coast, notably in Kuakata, Bangladesh suggesting a new tract to Bangladesh's mariculture prospects. Further intensive research is needed for the confirmation of the present study.

Acknowledgments

The authors gratefully acknowledge the financial support by Bangladesh Fisheries Research Institute to conduct the research successfully.

Ethical approval

The author declares that this study complies with research and publication ethics.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author.

Authors Contribution

Abu Bakker Siddique Khan contributed to actual design of the study. Md. Amirul Islam and Mousumi Akhter made substantial contribution in the data design, Farhana Yasmin contributed to the investigation and Md. Rahamat Ullah made undeniable contribution in revision and editing. Aovijite Bosu and Md. Monjurul Hasan made critical contribution in editing. Khandaker Rashidul Hasan and Yahia Mahmud contributed to supervision and validation of the study.

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