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Optimizing substrates for *Caulerpa racemosa* cultivation in Bintan Island, Indonesia

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Abstract. *Raza'i TS, Jaman S, Setiaji D, Hasby M, Pardi H, Putra IP. 2025. Optimizing substrates for* Caulerpa racemosa *cultivation in Bintan Island, Indonesia. Biodiversitas 26: 5525-5533.* This study aimed to determine the most suitable substrate medium for the cultivation of *Caulerpa racemosa* and to provide a scientific basis for the development of sustainable aquaculture practices in Bintan Island. An ex-situ experimental method was employed by culturing *C. racemosa* under different substrate treatments. Growth performance was assessed through several parameters, including total length, stolon length, number of assimilators, assimilator length, and assimilator diameter. Prior to statistical testing, the data were examined for normality and homogeneity of variance, followed by analysis of variance (ANOVA) to evaluate significant differences among treatments. The findings demonstrated that mud was the most effective substrate for *C. racemosa* culture. On average, cultures grown on mud substrates achieved a total length growth of 57.62 mm/day, stolon length growth of 2.75 mm/day, assimilator length growth of 4.85 mm/day, and assimilator diameter growth of 1.24 mm/day. Statistical analysis confirmed that there were significant differences in growth across the various substrate treatments, highlighting the influence of substrate type on the cultivation success of *C. racemosa*. Overall, this study concludes that mud represents the optimal substrate medium for the culture of *C. racemosa*. These results provide important implications for the development of environmentally friendly and sustainable aquaculture systems in Bintan Island. The promotion of *C. racemosa* as an aquaculture commodity holds strong potential to support local livelihoods and contribute to the economic development of coastal communities in Bintan Island, Indonesia.

Keywords: Bintan Island, *Caulerpa racemosa*, growth, planting media, sea grapes

INTRODUCTION

The shallow marine ecosystems of Bintan Island, located within the Riau Islands Province, Indonesia, are characterized by a rich diversity of resources that support both ecological balance and economic development. These ecosystems harbor various groups of organisms, ranging from commercially important fish and crustaceans to marine macroalgae with considerable economic potential. Among the marine resources, seaweeds are increasingly recognized not only for their ecological roles but also for their economic value as raw materials for pharmaceuticals, food, and industrial applications. Recent surveys have documented at least twelve species of seaweeds distributed along the coastal ecosystems of Bintan Island (Pradana et al. 2020). Within this diversity, three species are identified as belonging to the genus *Caulerpa*, namely *Caulerpa taxifolia* (M.Vahl) C.Agardh, *Caulerpa lentillifera* J.Ag., and *Caulerpa racemosa* (Forssk.) J.Agardh (Raza'i et al. 2019). These species, commonly referred to as sea grapes, represent a marine commodity with high potential for further development in aquaculture.

Sea grapes (*C. racemosa*) in particular have attracted growing attention due to their multifunctional applications. Members of the genus *Caulerpa* are known to contain a range of bioactive compounds that can be developed into commercially valuable products such as carrageenan and alginate (Nagaraj and Osborne 2014; Nagappan and Vairappan 2014; Kumar et al. 2019). Beyond these polysaccharide-based derivatives, *Caulerpa* has also been explored as an ingredient in cosmetic formulations (Nurjanah et al. 2016) and as a raw material for various processed food products (Gailande et al. 2017). In aquaculture systems, *Caulerpa*-based biomass has been successfully utilized as feed for cultured fish (Putri et al. 2017). Moreover, the ecological services of *Caulerpa* extend to its function as a bioremediation agent and biofilter, helping to reduce nutrient loads and improve water quality in integrated aquaculture systems (Bwapwa et al. 2017; Bambaranda et al. 2019). Nutritional studies have further revealed that *C. racemosa* contains essential amino acids (Hao et al. 2018; Lalitha and Dhandapani 2018), and with its relatively high protein content, the species is considered a valuable food source. Collectively, these attributes underscore the importance of *C. racemosa* as a marine resource with broad applications in food security, health, and environmental sustainability.

At the national scale, Indonesia plays a dominant role in the global seaweed industry. According to data reported by the Directorate General of Strengthening the Competitiveness of Marine and Fisheries Products, Indonesian Ministry of Marine Affairs and Fisheries (2023), the country exported approximately one million tons of seaweed, representing around 32.1% of global seaweed production. This contribution is expected to continue rising in the coming years. Despite these achievements, seaweed production in Indonesia is geographically concentrated in only fifteen provinces, and the Riau Islands Province is not yet included among the major production centers. This gap highlights an opportunity for expanding seaweed cultivation in regions such as Bintan Island, which already possesses diverse seaweed resources and suitable environmental conditions for aquaculture.

Nevertheless, the current utilization of seaweed resources in Bintan remains limited. Although several species, including *C. racemosa*, are naturally abundant in the region, their use has thus far been restricted to simple and small-scale practices. For instance, local communities primarily exploit natural seaweed waste for composting or other low-value traditional applications (Vijayasekaran et al. 2023). The development of high-value, processed, and market-oriented seaweed products has not yet been realized in this area. This underutilization reflects both a lack of awareness of the species' economic potential and insufficient technical knowledge of sustainable cultivation practices.

Ecologically, *C. racemosa* exhibits broad adaptability, inhabiting various substrate types such as coral rubble, dead coral, coarse sand, and muddy sand (Raza'i et al. 2019). This plasticity provides opportunities for targeted aquaculture interventions that make use of natural substrates readily available in Bintan's coastal environment. Utilizing such substrates not only supports optimal growth but also aligns with environmentally friendly aquaculture practices by minimizing the need for synthetic or artificial culture media. Importantly, the application of natural substrates also has the potential to mitigate environmental degradation by recycling or stabilizing sediments in coastal ecosystems. Despite these advantages, local adoption of substrate-based *C. racemosa* culture remains limited, primarily due to knowledge gaps and the absence of systematic studies that demonstrate the effectiveness of substrate selection for large-scale aquaculture.

MATERIALS AND METHODS

Preparation of culture containers and media

This research was conducted experimentally in the period of May-July 2025 within the coastal waters of Dompak Island. *C. racemosa* seeds were taken from the north coast of Bintan Island and cultured for 30 days in aquarium containers measuring 40 cm x 30 cm x 20 cm. Subsequently, each container was placed in a substrate or planting medium with different treatments. The culture containers were filled with 15 L of water, each equipped with a water circulation system using an aeration pump. Natural light was utilized during the daytime, while at night, illumination was provided by a 10-watt fluorescent (TL) lamp. The culture of *C. racemosa* was maintained for a 30-day period, during which daily observations were conducted to document its growth progression.

The preparation of the culture medium was carried out by collecting natural materials from the surrounding area of the culture site on Dompak Island. The process began with gathering natural substrates such as mud, sand, and coral fragments. These collected materials were then filtered and cleaned to remove waste particles. Each culture container was filled with 10 kg of substrate. For mixed substrate compositions, such as mud–sand, 5 kg of mud and 5 kg of sand were weighed and thoroughly mixed. The nutrient composition of the culture medium relied solely on the natural nutrient content present in the collected substrates, with no additional external nutrients applied.

The aquarium containers were filled with six types of planting media treatments, namely mud, sand mud, coral fragments, sand, coral fragments and mud, as well as coral fragments and sand. Each treatment was repeated three times, resulting in a total of 18 culture containers. *C. racemosa* culture used a completely randomized design (CRD) method with 3 replicates of measurements for each treatment. The following describes the culture treatments applied in this study (Table 1).

Table 1. The culture treatments applied

Growing media	Number of replicates	Media composition	Media dimensions (cm)	Water volume	Measurement period
Sand	3 replicates	100% sand	Length 40 × height 30 × width 20	15 L	30 days
Mud	3 replicates	100% mud	Length 40 × height 30 × width 20	15 L	30 days
Rubble	3 replicates	100% coral rubble	Length 40 × height 30 × width 20	15 L	30 days
Muddy sand	3 replicates	50% sand + 50% mud	Length 40 × height 30 × width 20	15 L	30 days
Muddy rubble	3 replicates	50% mud + 50% coral rubble	Length 40 × height 30 × width 20	15 L	30 days
Sandy rubble	3 replicates	50% sand + 50% coral rubble	Length 40 × height 30 × width 20	15 L	30 days

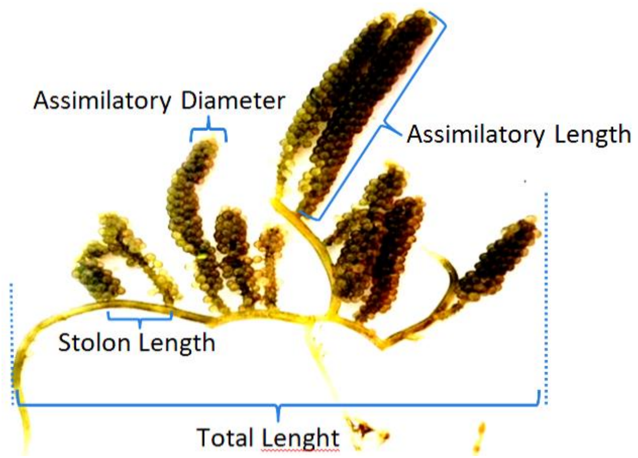

Figure 1. Morphology of *C. racemosa* for growth measurement

Measurement of water quality and growth parameters

Water quality measurements were carried out in each treatment container and conducted simultaneously with growth assessments on days 10, 20, and 30 of the culture period. The substrates used in this study coral rubble, sand, and mud were collected from the natural habitat of sea grapes in the surrounding area. An experimental method was used to measure growth for 30 days with a measurement interval of every 10 days. The growth parameters were total length, stolon length, number of assimilators, assimilator length, and assimilator diameter (Raza'i et al. 2021). Figure 1 shows the morphological description of *C. racemosa* for growth calculations.

The results of *C. racemosa* growth measurements for each period were calculated using the formula: ($L = L_t - L_0$), where L_0 and L_t were the initial and final growth, respectively (Wahyudi et al. 2024).

Data analysis

Caulerpa racemosa growth measurements were carried out using calipers, and the results were tested through SPSS software. Before performing statistical analysis, the data obtained from the study were first tested for the assumptions of normality and homogeneity of variance. Analysis of the data used ANOVA, and correlation testing was carried out to determine the relationship between growth parameters. Water quality testing was also carried out in the culture container with the parameters measured being pH, temperature, turbidity and salinity, measurements were carried out in situ in the culture container.

RESULTS AND DISCUSSION

Growth of *Caulerpa racemosa*

Growth performance of Caulerpa racemosa

The growth of *Caulerpa racemosa* during the research varied among treatments. The measurements included total length, stolon length, number of assimilators, assimilator length, and assimilator diameter, as shown in Table 2.

The results showed that there was an increase in growth during the *C. racemosa* culture period from the initial (T_0) to the final time (T_3). The highest total length growth was in the mud substrate media treatment, with an average growth reaching 57.62±37.62 mm/day. For the mixed sand and coral fragments substrate, the total growth was only 10.32±0.109 mm/day and was the lowest of the other treatments. Furthermore, mud and mixed mud and coral fragments planting media treatment produced the highest and lowest stolon growth, with an average reaching 2.75±2.19 mm/day and 0.66±0.02 mm/day, respectively.

The highest and lowest growth in length of assimilators was in the treatment of mixed mud and coral fragments and sand planting media at 5.51±1.45 mm/day and 3.65±0.86 mm/day, respectively. Meanwhile, the highest and lowest growth in diameter of assimilators was in the treatment of mud and coral fragments planting media, with an average of 1.24±0.46 mm/day and 0.87±0.05 mm/day, respectively. Figure 2 shows the growth pattern of each treatment of *C. racemosa* planting media.

The growth of total length, stolon length, assimilator length, and assimilator diameter occurred during the culture period, reaching 988.70 mm, 27.51 mm, 55.06 mm, and 17.29 mm with a culture period of 30 days. Naturally, a single colony of *C. racemosa* had a total length, assimilator length, and assimilator diameter between 190-209 mm, 72-110 mm, and 18-25 mm, respectively (Wahyudi et al. 2024). In another research, the natural total length of *C. racemosa* ranged between 134-247 mm (Manas et al. 2015). Estrada et al. (2020) showed that the total length could reach 94.2 mm with an assimilator diameter of 12.1 mm. Therefore, the growth of total and stolon length, as well as the diameter and assimilator, was quite high.

Based on the results of the present study on *Caulerpa* growth in Bintan Island, the growth performance of *C. racemosa* was relatively high. This can be compared with the findings of Estrada et al. (2020) in several coastal areas of the Philippines, where the assimilator length of *Caulerpa* ranged between 100-130 mm. Similarly, a study conducted by Hwang et al. (2003) along the southern coast of Korea reported that the total length of *Caulerpa* could reach 31-140 mm, with assimilator height ranging from 21 to 27.4 mm.

The graph in Figure 2 shows that maximum growth occurred on day 30 in the mud substrate. Figure 2 reports the growth of total length, stolon length, assimilator length, and assimilator diameter of *C. racemosa* in the culture container from day 10 to day 30.

Figure 3 shows that *C. racemosa* experiences significant stolon and assimilator growth. On day 10, the seedlings started experiencing growth in total length and stolons. The growth in length became more visible on day 20 of culture, with stolons spreading and forming a pattern. On day 30 of culture, the growth in stolon length and assimilator growth became increasingly apparent. The stolon and assimilator length experienced maximum growth on day 30. In addition, the culture experienced a phase of increasing the number of assimilators, as presented in Table 3.

Table 2. Growth in total length, stolon length, assimilator length, and assimilator diameter of *Caulerpa racemosa* based on differences in growing media

Substrate type	Total length (mm/day)			
	Culture on day 10	**Culture on day 20**	**Culture on day 30**	**Average**
Sand	13.03	18.86	22.84	18.24±4.93
Mud	25.18	48.81	98.87	57.62±37.62*
Rubble	10.68	10.92	12.68	11.43±1.09
Muddy sand	11.97	26.61	61.22	33.27±25.28
Muddy rubble	11.21	12.02	14.04	12.42±1.45
Sandy gravel	10.20	10.34	10.42	10.32±0.109**
Substrate type	**Stolon length (mm/day)**			
	Culture on day 10	**Culture on day 20**	**Culture on day 30**	**Average**
Sand	0.61	0.65	1.08	0.78±0.25
Mud	0.78	2.35	5.12	2.75±2.19*
Rubble	0.69	0.71	0.81	0.73±0.06
Muddy sand	0.71	1.67	3.53	1.97±1.43
Muddy rubble	0.64	0.66	0.69	0.66±0.02**
Sandy gravel	0.72	0.76	0.78	0.75±0.02
Substrate type	**Assimilatory length (mm/day)**			
	Culture on day 10	**Culture on day 20**	**Culture on day 30**	**Average**
Sand	3.03	3.29	4.64	3.65±0.86**
Mud	3.43	4.74	6.39	4.85±1.48
Rubble	3.55	3.79	4.70	4.01±0.60
Muddy sand	3.28	4.57	6.84	4.90±1.80
Muddy rubble	3.92	5.82	6.78	5.51±1.45*
Sandy gravel	3.94	4.02	4.48	4.15±0.29
Substrate type	**Assimilatory diameter (mm/day)**			
	Culture on day 10	**Culture on day 20**	**Culture on day 30**	**Average**
Sand	0.85	0.94	1.12	0.97±0.13
Mud	0.80	1.19	1.73	1.24±0.46*
Rubble	0.82	0.87	0.92	0.87±0.05**
Muddy sand	0.81	1.18	1.58	1.19±0.38
Muddy rubble	0.85	1.24	1.32	1.14±0.25
Sandy gravel	0.92	0.96	1.00	0.96±0.04

Note: *: highest growth, **: lowest growth. Source: Study results (2025)

During the culture period, *C. racemosa* seedlings continued to grow, including an increase in the number of assimilators. In the sand substrate medium, *C. racemosa* culture experienced an increase in the number of assimilators by 2 stands. The assimilators increased by 3 stands during the culture period in the coral rubble and sand mixed coral rubble media. The coral rubble mud substrate medium experienced an increase in the number of assimilators by 6 stands. Meanwhile, the number of assimilators increased by 18 stands during the culture period in the mud and sand mud planting media. The increase in the number of assimilators observed in this study was relatively high during the culture period, particularly on fine mud substrates. In comparison, Park et al. (2022) reported that in Korean coastal waters, the number of new assimilators added during a 15-day culture period ranged from 1 to 3 shoots, with the highest growth occurring on fine sand substrates.

This shows that the increase in assimilators occurred most frequently in the mud and sand mud media. Figure 3 reports the condition of the increase in assimilators during the culture period.

During the culture period from day 10 to 30, *C. racemosa* sea grapes experienced an assimilator addition phase. The addition of new assimilators had slightly different characteristics at the time of initial seed planting (T_0). The growing assimilators had a smaller diameter with a bright green color, and the number of seeds (Fronds) was still not optimal. The growth of *C. racemosa* in the culture container started with an increase in stolon length, branches, as well as the number and development of assimilators. This condition continued from the beginning of the culture until day 30.

The research results show that the growth of *C. racemosa* is supported by suitable substrate characteristics. The substrate conditions in the *C. racemosa* growing medium are natural media taken from nature and reused as a growing medium. This concept is a concept adopted by researchers with the invited aquafarm system that prioritizes the use of natural growing media as a form of supporting environmental sustainability. In this system, *C. racemosa* seedlings can utilize the nutrient content in the natural substrate used in culture, so that large-scale culture in nature will not have the effect of other pollution in the environment.

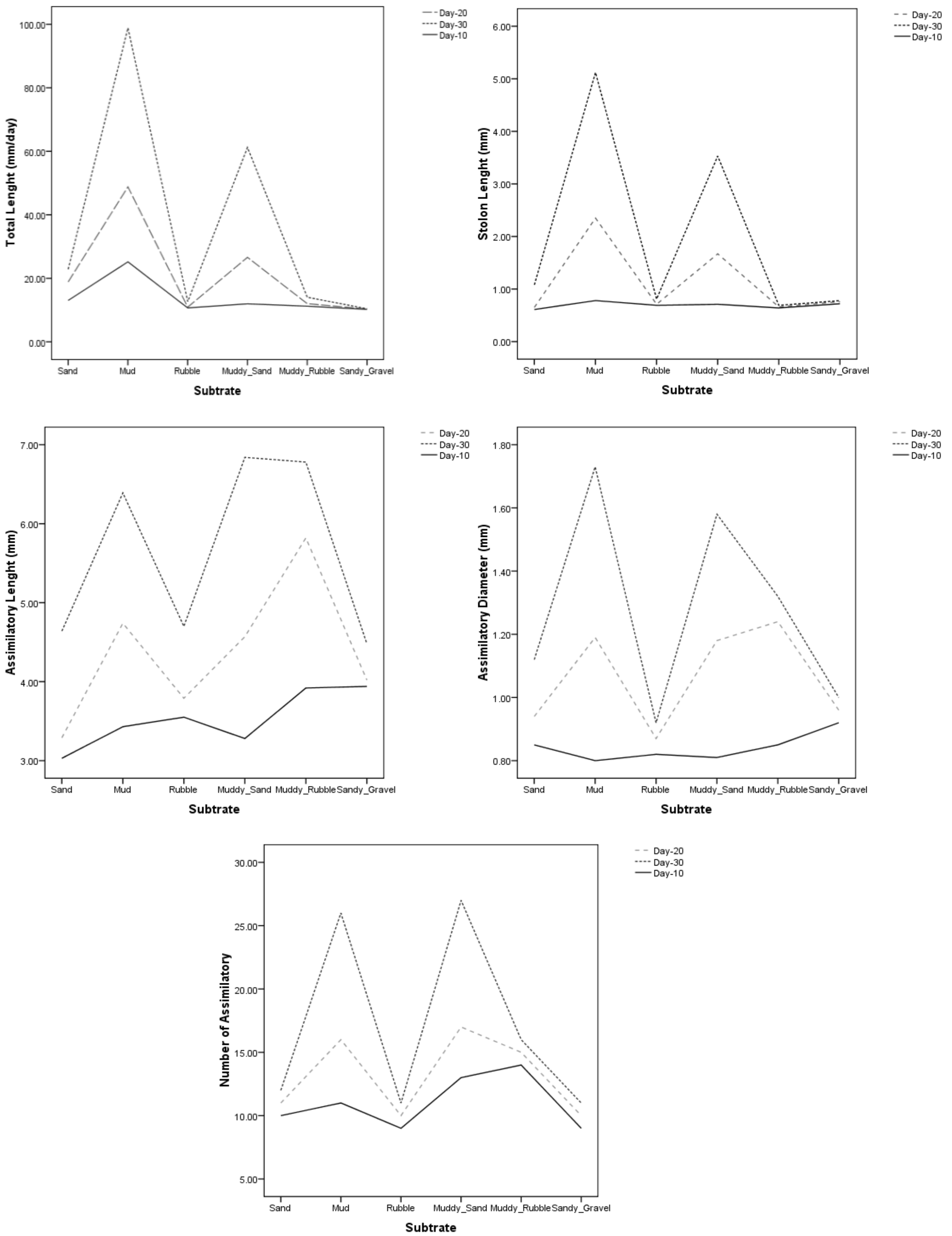

Figure 2. Growth of *Caulerpa racemosa* based on differences in planting media. A. Total length growth; B. Stolon length, C. Assimilator length, D. Assimilator diameter, E. Number of assimilators

Growth comparison based on planting media

Figure 5 shows the comparison of *C. racemosa* after calculating the growth with different planting media on 5 measurement parameters, namely total length growth, stolon length, assimilator length, assimilator diameter, and the number of assimilators.

Based on the overall difference in planting media, the growth of *C. racemosa* was highest in the mud media type. Therefore, mud media was the best type of planting media compared to other treatments. The smooth texture of the mud allowed the roots/rhizoids of *C. racemosa* to grow and adapt more easily. The nutrient content in the mud media could also be a cause of the high growth.

The distribution of sea grape species naturally had quite diverse habitat types, ranging from hard (coral and rocks) to soft (sand and mud). Generally, *C. racemosa* was found in areas with muddy sand substrates (Raza'i et al. 2019) with a fairly high nutrient content, supporting the growth of organisms. According to (Raza'i et al. 2020), nutrient distribution significantly influenced the growth of *Caulerpa* seaweed, specifically on muddy sand substrates. *C. racemosa* sea grapes easily absorbed organic material as evidenced by the high productivity of 127.09 kg/ha (Raza'i et al. 2020).

The high growth in mud and sandy mud substrates was due to the characteristics of the sea grape species, which could adapt to various types. *C. racemosa* had a very wide distribution, ranging from seagrass ecosystems to coral reefs (Handayani et al. 2016; Raza'i et al. 2020; Sihotang et al. 2024). In addition, mud substrates had a fairly high nutrient content and were quite supportive of *C. racemosa* compared to other types. This was reported by Handayani et al. (2016) since the organic content was higher with the characteristics of finer mud substrates compared to coarser types.

Table 3. The increase in the number of *Caulerpa racemosa* assimilators is based on differences in planting media

Number of assimilatory	Culture on day 0	Culture on day 10	Culture on day 20	Culture on day 30	Description
Sand	10	10	11	12	+2
Mud	8	11	16	26	+18
Rubble	8	9	10	11	+3
Muddy sand	9	13	17	27	+18
Muddy rubble	10	14	15	16	+6
Sandy gravel	8	9	10	11	+3

Note: Source: Study results (2025)

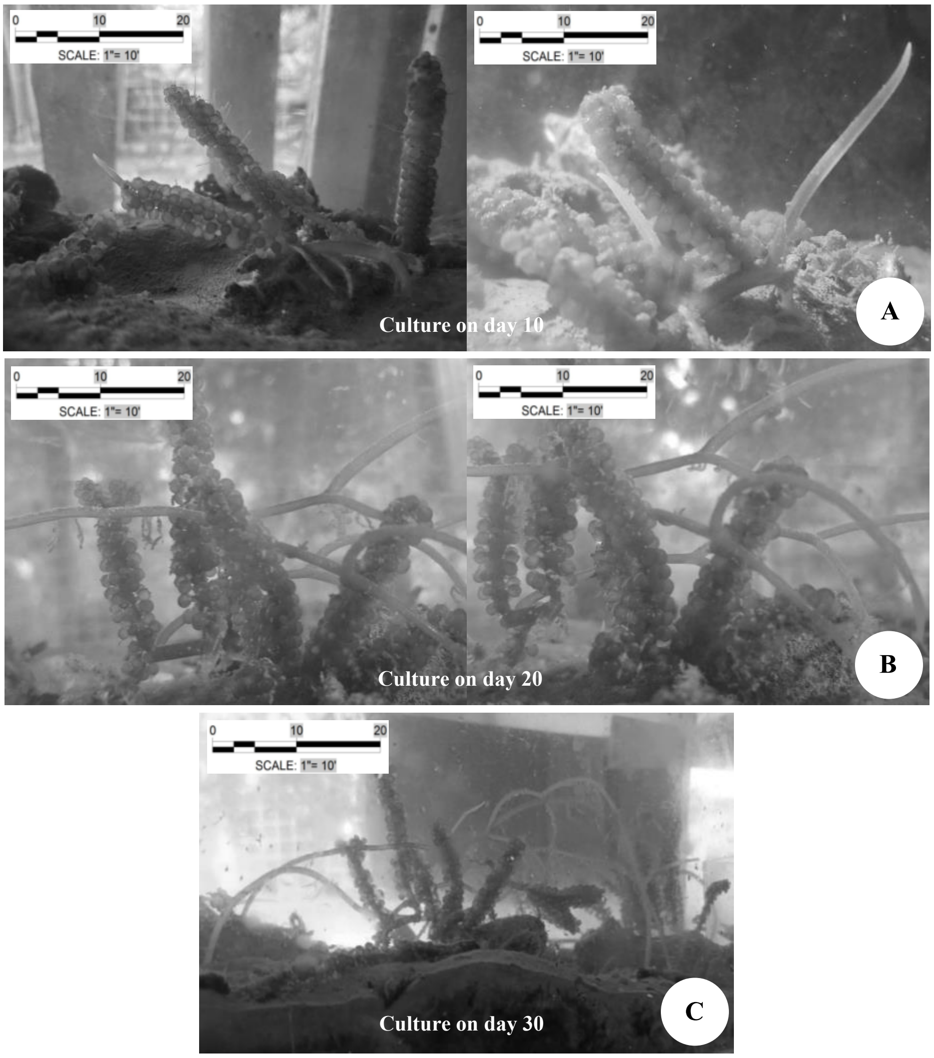

Figure 3. Total length and stolon growth conditions in *Caulerpa racemosa* cultures. A. Culture on day 10, B. Culture on day 20, C. Culture on day 30

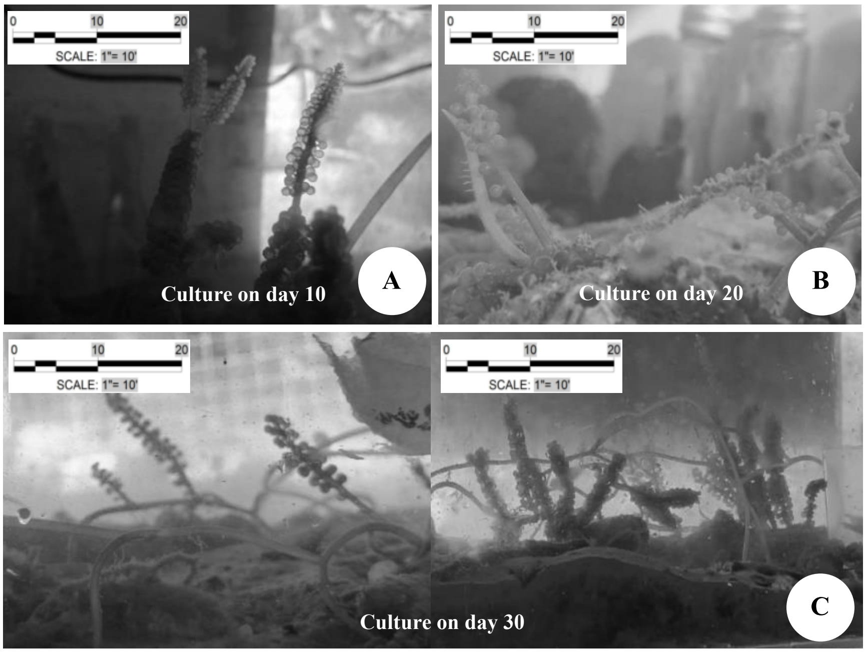

Figure 4. Assimilator growth conditions in *Caulerpa racemosa* cultures. A. Culture on day 10, B. Culture on day 20, C. Culture on day 30

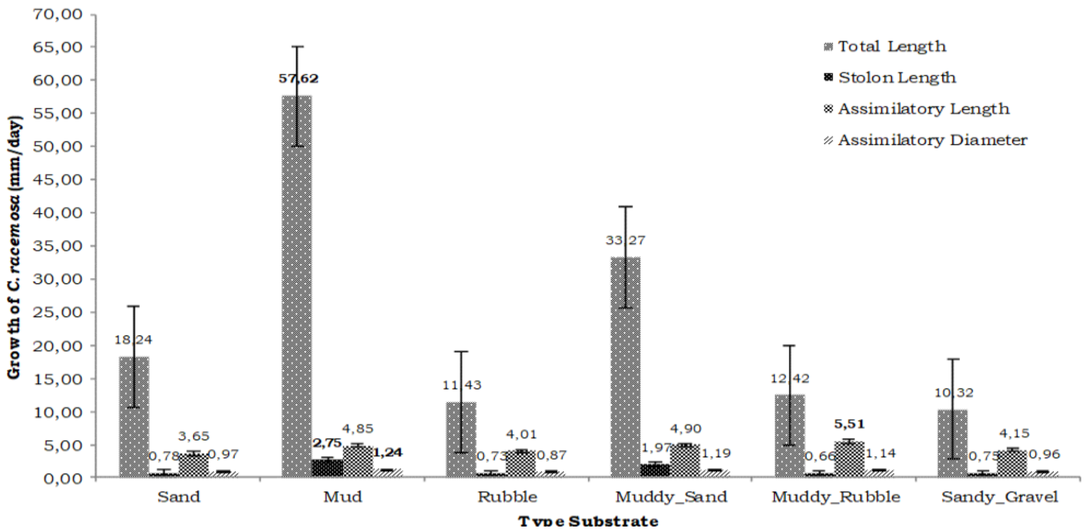

Figure 5. Comparison of *Caulerpa racemosa* growth based on different planting media

Although *C. racemosa* naturally attaches to hard substrates (coral debris), ex-situ research yielded different results. In ex-situ culture, fine substrates (mud) significantly influence sea grape growth. This condition is related to the nutrient absorption by the holdfast/roots of *C. racemosa*, which are then utilized for growth. The green algae's adhesive ability to adhere to various substrate types is also one reason this species is able to thrive on fine substrates. A study by Zainee et al. (2019) found that green algae can survive in this habitat because its gripping power can penetrate deep into muddy sediments.

Considering the growth potential of *Caulerpa* as demonstrated in this study, large-scale cultivation initiatives should be developed that actively involve local communities to improve livelihoods and strengthen the regional economy. The cultivation of *C. racemosa* in Bintan Island is highly feasible through the utilization of natural substrates available in the environment, thereby minimizing potential ecological impacts. The application of natural substrates also supports the promotion of the Environment Technology Aquaculture Farming (Enviteg Aquafarm) concept, which introduces an environmentally based innovation in aquaculture practices. However, to fully support the sustainable management of *C. racemosa* cultivation in Bintan, further studies are required on large-scale field culture with extended cultivation periods to better understand the growth dynamics.

Water quality

During the *C. racemosa* culture period, water quality measurements were conducted, including temperature, turbidity, pH, and salinity. Measurements were taken in sample containers from the first day of culture through the 30th day. The results of the water quality tests are as follows (Table 4).

The results of water quality testing during the culture period have different values, but in general the acidity (pH) in the research container ranges from 7-7.66, while the salinity ranges from 29-29.6 ppt, turbidity ranges from 3.95-6.31 NTU, and the temperature ranges from 28.6-29.2°C. In general, the water quality conditions are still suitable for the growth of sea grapes *C. racemosa*.

Statistical analysis

Statistical testing, such as ANOVA, was conducted to determine the differences between growing media treatments on the growth of *C. racemosa*. However, the normality of the data collected from field measurements was tested before conducting statistical testing. The normality test showed that total length growth, stolon length, assimilator length, and diameter were in normal condition. This was because the data had a fairly good distribution as seen from the histogram graph and normality table. Therefore, the data distribution was normal and worthy of further testing. Table 3 shows the ANOVA results of *C. racemosa* growth based on different planting media (Table 5).

Table 4. Water quality in *Caulerpa racemosa* culture containers

Substrate	Water quality															
	pH				Salinity (ppt)				Turbidity (NTU)				Temperature (°C)			
	T1	T2	T3	Average	T1	T2	T3	Average	T1	T2	T3	Average	T1	T2	T3	Average
Sand	7.1	7.2	7.1	7.13±0.057	29	30	30	29.6±0.57	5.05	4.91	4.02	4.66±0.55	29.4	29.1	29.2	29.23±0.152
Mud	7	7.1	6.9	7.0±0.1	28	29	30	29.0±1	6.07	6.47	6.41	6.31±0.215	29.1	28.9	29.2	29.06±0.15
Rubble	7.4	7.6	7.9	7.63±0.251	29	29	30	29.3±0.57	3.98	4.08	4.27	4.11±0.147	28.7	28.7	29.1	28.83±0.23
Muddy sand	7.9	8.1	7.2	7.73±0.472	29	29	30	29.33±0.57	5.11	4.97	5.61	5.23±0.33	28.7	28.4	28.7	28.6±0.17
Muddy rubble	7.5	7.6	7.2	7.43±0.208	29	30	30	29.66±0.57	5.72	5.77	5.09	5.52±0.37	28.9	28.9	28.5	28.76±0.23
Sandy gravel	7.8	7.8	7.4	7.66±0.23	28	29	30	29±1	4.21	4.09	3.56	3.95±0.34	28.6	28.7	29.1	28.8±0.26

Table 5. Analysis of variance (ANOVA) of *Caulerpa racemosa* growth based on differences in planting media

		Sum of squares	df	Mean square	F	Sig.
Total length	Between groups	2146.519	5	429.304	4.259	.018
	Within groups	1209.576	12	100.798		
	Total	3356.096	17			
Stolon length	Between groups	688.061	5	137.612	3.034	.053
	Within groups	544.193	12	45.349		
	Total	1232.254	17			
Assimilatory length	Between groups	34.921	5	6.984	1.104	.408
	Within groups	75.891	12	6.324		
	Total	110.812	17			
Assimilatory diameter	Between groups	1.457	5	.291	3.000	.055
	Within groups	1.166	12	.097		
	Total	2.622	17			

Table 6. Correlation analysis of each growth parameter of *Caulerpa racemosa*

		Total length	Stolon length	Assimilatory length	Assimilatory diameter
Total length	Pearson Correlation	1	.567*	.631**	.951**
	Sig. (2-tailed)		.014	.005	.000
	N	18	18	18	18
Stolon length	Pearson Correlation	.567*	1	-.021	.556*
	Sig. (2-tailed)	.014		.934	.017
	N	18	18	18	18
Assimilatory length	Pearson Correlation	.631**	-.021	1	.726**
	Sig. (2-tailed)	.005	.934		.001
	N	18	18	18	18
Assimilatory diameter	Pearson Correlation	.951**	.556*	.726**	1
	Sig. (2-tailed)	.000	.017	.001	
	N	18	18	18	18

Note: *: Correlation is significant at the 0.05 level (2-tailed), **: Correlation is significant at the 0.01 level (2-tailed)

Based on the analysis of variance (ANOVA) performed using SPSS, the results indicated that the measured parameters total length, stolon length, assimilator length, and assimilator diameter showed varying levels of statistical significance. The ANOVA results revealed that the significance value for total length was 0.018 (<0.05) and for stolon length was 0.053 (<0.05). These findings suggest that variations in substrate type had a significant effect on total length and stolon length. In contrast, the differences in substrate composition did not have a significant effect on assimilator length and assimilator diameter. The planting media treatment had a significant effect on the growth of *C. racemosa*, with the best substrate composition being the mud type. A correlation analysis was conducted with the results to determine the relationship between the test parameters (Table 6).

To determine the relationships among the growth parameters of *C. racemosa*, a Pearson correlation analysis was conducted. The results showed that total length exhibited a strong correlation with assimilator diameter, with a correlation coefficient of 0.951. Furthermore, assimilator length demonstrated a strong correlation with assimilator diameter, with a correlation coefficient of 0.726. However, assimilator length showed no significant correlation with stolon length. Overall, the analysis indicated that all measured parameters were interrelated, although the strength of their correlations varied. In the statistical journal, Sihotang et al. (2024) explained that a correlation value between 0.80-1.00 had a strong level.

In conclusion, the total length growth, stolon length, assimilator length, and assimilator diameter of *C. racemosa* reached 988.70 mm, 27.51 mm, 55.06 mm, and 17.29 mm, respectively. The addition of assimilators reached 28 stands with a culture period of 30 days. The results showed that the overall growth of *C. racemosa* was highest and lowest in the mud and coral rubble media, respectively. The treatment of the planting media had a very significant effect on the growth of *C. racemosa*, with the best substrate composition in the mud type. Based on the findings of this study, it is necessary to upscale cultivation to a mass-production level by applying the concept of environmentally based aquaculture (Enviteg Aquafarm) while also enhancing the processing of seaweed products into high-value commodities. Such efforts would support their acceptance and further development into sustainable industrial enterprises. These research results can also serve as a basis for sustainable sea grape cultivation and serve as a reference for relevant agencies in formulating sustainable cultivation policies.

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