Effect of Salinity Differences on Growth and Chlorophyll *a* Content in *Caulerpa racemosa*

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ABSTRACT

Caulerpa racemosa (sea grapes) is a commercially valuable green macroalga widely cultivated in Indonesia for its nutritional and economic potential. Salinity is among the most critical environmental factors governing its growth and photosynthetic pigment production, yet the optimal salinity range for Indonesian pond cultivation systems remains poorly defined. This study aimed to determine the effect of different salinities on the growth and chlorophyll *a* content of *C. racemosa* and to identify the salinity level that best supported its growth and chlorophyll *a* content. This study used an experimental method with a Completely Randomized Design (CRD) consisting of four treatments and three replications: S24 (24 ppt), S27 (27 ppt), S30 (30 ppt), and S33 (33 ppt). The *C. racemosa* cultivation system used the off-bottom method, with an initial weight of 50 g and a water volume of 12 L and was maintained for 43 days. The collected data included morphological observations, absolute growth, specific growth rate (SGR), chlorophyll *a* content, and water quality. The results showed that salinity had a significant effect ($p<0.05$) on absolute growth, SGR, and chlorophyll *a* content, with the highest values observed in treatment S27. Based on the study, the S27 treatment (27 ppt) produced the highest absolute growth (133.28±16.26 g), SGR (3.01±0.21 %·day^{-1}), and chlorophyll *a* content (452.16±0.19 µg·mL^{-1}), indicating that maintaining salinity around 27 ppt can optimize physiological performance and enhance biomass yield in *C. racemosa* cultivation.

Keywords: Hue, Macroalga, Morphology, Sea grapes, Specific growth rate

INTRODUCTION

Seaweed is used as one of the efforts to revitalize fisheries to improve Indonesian fishery products and community welfare (Iskandar *et al*., 2015). One type of seaweed that has the potential to be developed is *Caulerpa racemosa* (sea grapes). Sea grapes are green macroalgae belonging to the division Chlorophyta, with amino acid, protein content, pigment, and other beneficial compounds (Nofiani *et al*., 2018; Windarto *et al*., 2025b; 2025c). This is based on the research of Merdekawati and Susanto (2009), which states that seaweed has three primary pigments: chlorophyll, carotenoids, and phycocyanin. Each type of pigment has health benefits, such as antioxidant, antibacterial, cholesterol-lowering, anticancer, and anti-inflammatory effects (Samad *et al*., 2021).

Chlorophyll plays a role in the photosynthesis process in seaweed. If seaweed's pigment content (chlorophyll) is higher, the photosynthesis process will be more optimal, as indicated by the high carbohydrate content produced (Dewi *et al*., 2016). The production of *C. racemosa* seaweed is still relatively low. Even during the growing season, *Caulerpa* is rarely found in waters (Azizah, 2006; Setiaji *et al*., 2012; Windarto *et al*., 2023). The productivity of dry seaweed in Indonesia is only 1.14 t·km^{-1}, the lowest figure compared to productivity

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in other countries, reaching 4.55 $t \cdot km^{-1}$ in the Solomon Islands (Valderrama *et al*., 2013). One cultivation effort that can be carried out is growing *C. racemosa* in controlled environmental conditions to determine the optimal salinity for cultivation, with the aim of applying the findings to large-scale cultivation (Yuliyana *et al*., 2015).

Factors affecting macroalgae growth include environmental conditions, water quality, and salinity (Khan *et al*., 2024). Salinity is among the most critical abiotic factors governing the growth, physiology, and biochemical composition of marine macroalgae, directly influencing pigment formation, biomass production, and cell growth rate (Adenan *et al*., 2013). In the genus *Caulerpa*, salinity tolerance is broadly reported at 20–50 ppt, with optimal growth occurring between 25–35 ppt (Hui *et al*., 2014). Studies on the congener *C. lentillifera* have shown that salinity directly influences growth rate and chlorophyll synthesis: Guo *et al*. (2014) demonstrated that growth and chlorophyll fluorescence were significantly impaired below 25 ppt and above 40 ppt, with peak performance near 30 ppt. Similarly, Yuliyana *et al*. (2015) reported optimal growth of *C. lentillifera* at 27 ppt in Indonesian pond systems, while Sia *et al*. (2024) identified 25–27 ppt as the optimal range for growth and sensory quality. For *C. sertularioides*, Mosquera-Murillo and Peña-Salamanca (2016) reported reduced growth at salinities deviating from 30 ppt. According to Maslahah *et al*. (2021), variation in chlorophyll content in macroalgae is influenced by hydrological factors, including salinity. The salinity–growth relationship in *Caulerpa* is mediated through osmoregulation: at suboptimal salinities, cells must divert metabolic energy toward osmotic adjustment (ion transport and compatible solute synthesis), reducing resources available for growth and chlorophyll biosynthesis (Adenan *et al*., 2013; Yong *et al*., 2014). Despite these reports, most studies have focused on *C. lentillifera* under Vietnamese or Philippine cultivation conditions, and the specific optimal salinity for *C. racemosa* in Indonesian pond culture systems, particularly regarding simultaneous optimization of biomass and photosynthetic pigment production, has not been clearly established. This study therefore aimed to determine the effects of four salinity levels (24, 27, 30, and 33 ppt) on the absolute growth, specific growth rate, and chlorophyll *a* content of *C. racemosa* cultivated using the off-bottom method and to identify the optimal salinity for practical aquaculture application in Indonesia.

MATERIALS AND METHODS

Experimental setup and sample preparation

The study utilized *C. racemosa* seedlings sourced from the BBPBAP Jepara seaweed ponds. The cultivation substrate comprised sandy mud collected from the exact location (Windarto *et al*., 2021), and seawater with an initial salinity of 30 ppt was obtained from the BBPBAP Jepara laboratory. To support growth, Na_2SO_4 and KH_2PO_4 were applied as fertilizers at a 6:1 ratio, following Harwanto *et al*. (2020). A Completely Randomized Design (CRD) was employed with four salinity treatments (S24, S27, S30, and S33 ppt), each replicated three times. Salinity adjustments were made by either dilution or the addition of coarse salt. According to Nisa *et al*. (2020), increasing salinity involves dissolving 150 g of coarse salt in 5 L of seawater (30 ppt) to achieve 50 ppt salinity, followed by filtration. To reduce salinity, dilution was applied using the equation $V_1M_1 = V_2M_2$. The cultivation was maintained for 43 days, a duration selected based on previous *Caulerpa* cultivation studies (Harwanto *et al*., 2020; Windarto *et al*., 2021; 2024) during which measurable growth differences among salinity treatments were consistently observed.

Morphology analysis

Morphological analysis of *C. racemosa* was conducted to evaluate the treatments using a hue value test and descriptive observations. The hue value, which reflects the degree of perceived green coloration, was measured using Adobe Photoshop (Permadi *et al*., 2024; Vidyaningrum *et al*., 2026). In addition to color assessment, descriptive analysis was performed to observe

morphological traits, including texture, shape, and ramuli arrangement, at both the beginning and end of the cultivation period (Windarto *et al*., 2025a).

Growth performances

According to Basir *et al*. (2017), absolute growth in *C. racemosa* can be calculated using the formula $G = W_t - W_0$, where G represents the average absolute growth (g), W_t is the final weight, and W_0 is the initial weight. Meanwhile, specific growth rate (SGR) is determined using the formula $SGR = [(\ln W_t - \ln W_0) / t] \times 100\%$, as described by Kasim and Mustafa (2017), where SGR is expressed as the specific daily growth rate (%·day^{-1}), t is the cultivation duration (days), and W_t and W_0 refer to the final and initial weights, respectively.

Chlorophyll a analysis

According to Samad *et al*. (2021), chlorophyll analysis involves three main stages: sample preparation, pigment extraction using the maceration method, and quantification of pigment content using a UV-Visible spectrophotometer (UV-1800 Shimadzu, Japan), with absorbance measured at specific wavelengths (430 and 662 nm).

Water quality

Water quality parameters were measured twice daily, in the morning and afternoon, and included temperature, pH, salinity, dissolved oxygen (DO), and light intensity. Nitrate and phosphate concentrations were measured at the beginning and end of the study to assess nutrient dynamics throughout the cultivation period.

Data analysis

The data obtained, including absolute growth, specific growth rate (SGR), and chlorophyll *a* content (n = 3), were analyzed using one-way ANOVA ($p<0.05$) followed by Duncan's post hoc test, while morphological observations and water quality parameters were analyzed descriptively. All statistical analyses were performed using SPSS version 25.

RESULTS AND DISCUSSION

Morphological observation

Morphological analysis of *C. racemosa* cultivated at varying salinities was conducted through hue value measurements and descriptive observations. The assessed morphological traits included color, texture, shape, and ramuli arrangement. Detailed results of the morphological characteristics are presented in Table 1.

Table 1 shows consistent changes across all treatments in the texture, shape, and arrangement of *C. racemosa* ramuli by the end of the cultivation period. The ramuli became softer, elongated, and arranged regularly in two opposing rows. These morphological changes are likely influenced by the increasing age of the thalli, as supported by Putriani *et al*. (2020), who reported that algal aging can lead to anatomical alterations that affect overall morphology. Color changes were further quantified through hue value analysis, with detailed results presented in Table 2.

Salinity variations significantly influenced the coloration of *C. racemosa*, as reflected in the hue value analysis (Table 2). Color changes were observed in the stolons, fronds, ramuli tips, and rhizoids. The highest hue values were recorded in the S27 treatment (S = 90°, UR = 74°, F = 84°, Rz = 72°), followed by S33, S30, and lowest in S24. These results indicate that S27 produced the darkest green coloration. Salinity is closely associated with phenolic content in *C. racemosa*, which affects sensory and morphological traits. Previous studies have shown that abiotic factors, such as salinity, regulate phenolic accumulation (Wichachucherd *et al*., 2019; Fariman *et al*., 2016), thereby influencing pigmentation and visual appearance.

Salinity also plays a critical role in osmoregulation, influencing seaweed metabolic activities and pigment synthesis (Yong *et al*., 2014). Optimal salinity supports healthy metabolism, enhancing chlorophyll production and deeper green pigmentation. Valentine *et al*. (2021) reported that darker coloration in stolons reflects high

Table 1. Morphology of texture, shape, and arrangement of ramuli at the beginning and end of *Caulerpa racemosa* culture period.

Treatment	Beginning (Day 0)	End (Day 43)
S24 (24 ppt)	 • Chewy texture with a plump appearance • Ramuli arranged in irregular clusters • Small, round ramuli resembling grapes	 • Soft texture • Ramuli regularly arranged in two opposing rows • Small, round ramuli resembling grapes
S27 (27 ppt)	 • Chewy texture with a full appearance • Ramuli arranged in irregular clusters • Small, round ramuli resembling grapes	 • Soft texture • Ramuli arranged regularly in two opposing rows • Cylindrical ramuli, flattened like coconut leaf blades
S30 (30 ppt)	 • Chewy texture with a full appearance • Ramuli arranged in irregular clusters • Small, round ramuli resembling grapes	 • Soft texture • Ramuli arranged regularly in two opposing rows • Cylindrical ramuli, flattened like coconut leaf blades

Table 1. Conted.

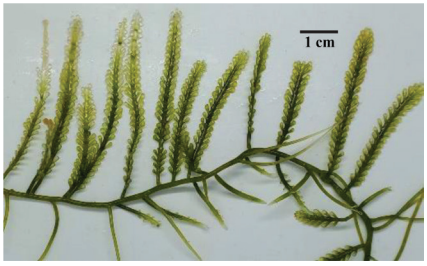
Treatment	Beginning (Day 0)	End (Day 43)
S33 (33 ppt)	 • Chewy texture with a full appearance • Ramuli arranged in irregular cluster • Small, round ramuli resembling grapes	 • Soft texture • The ramuli are arranged regularly in two opposing rows • Ramuli arranged regularly in two opposing rows • Cylindrical ramuli, flattened like coconut leaf blades

Table 2. Hue values of *Caulerpa racemosa* color at the beginning and end of the cultivation period.

Treatment	S (°)		UR (°)		F (°)		Rz (°)	
	Beginning	End	Beginning	End	Beginning	End	Beginning	End
S_{24}	71	80	78	70	74	81	60	61
S_{27}	76	90	79	74	75	84	70	72
S_{30}	71	84	84	71	77	81	70	74
S_{33}	76	86	80	72	75	77	74	78
Optimum	120° [a]							

Note: S = Stolon; UR = Ramuli tip; F = Fronds; Rz = Rhizoid; (a) Risvita (2017)

pigment content, especially under favorable light and salinity conditions. In this study, the S27 treatment consistently produced green hues within the 60°–120° range, as defined by Risvita (2017), whereas the other treatments, particularly S24, showed hues closer to yellow, indicating suboptimal pigmentation.

Although salinities in S24, S30, and S33 fall within acceptable ranges for *C. racemosa* cultivation, differences in environmental conditions such as light intensity and nutrient availability may contribute to variation in color expression. *C. racemosa* exhibits high phenotypic plasticity (Belton *et al*., 2014; Estrada *et al*., 2020), meaning that its morphological traits, including color, are highly responsive to environmental factors. As such, even within optimal salinity ranges, variations in light and nutrient uptake can affect hue values and pigment accumulation.

The pale yellowish-white color and softer texture observed in the S24 treatment suggest that low salinity imposes physiological stress on *C. racemosa*. Similar findings by Hui *et al*. (2014) show that the species cannot tolerate extremes of 15 or 55 ppt, resulting in tissue whitening and degeneration. Salinity stress disrupts photosynthesis

and osmoregulation (Bunsom and Prathep, 2012; Aris *et al*., 2021), reducing pigment synthesis and thus the dark green coloration. Furthermore, as Fan *et al*. (2015) described, catechin oxidation and condensation may contribute to yellow pigmentation under stress. This results in a lower hue value, approaching the yellow range, as observed by Kader and Gerung (2020).

Absolute growth

ANOVA and Duncan's test results showed that the absolute growth of *C. racemosa* after 43 days of cultivation was significantly higher in the S27 salinity treatment, while no significant differences were observed among the S24, S30, and S33 treatments. These results are shown in Figure 2.

Figure 2 shows that salinity significantly affected the absolute growth of *C. racemosa* ($p<0.05$), with the S27 treatment yielding the highest growth (133.28±16.26 g), followed by S24, S30, and S33, which showed no significant differences. The superior growth at S27 may be attributed to optimal salinity conditions that enhance nutrient uptake, supporting biomass accumulation. These results align with findings by Mosquera-Murillo and Peña-Salamanca (2016) and Sia *et al*. (2024), who reported improved growth of *Caulerpa* species at salinities between 25–27 ppt due to better nutrient assimilation and physiological performance.

Salinity is critical in maintaining cellular balance, directly influencing nutrient absorption and photosynthesis in seaweed (Yuliyana *et al*., 2015). In this study, higher nitrate absorption in the S27 treatment likely contributed to improved growth. Tran *et al*. (2023) emphasized nitrate as a key nutrient driving growth in *C. racemosa*, further supporting the results observed. Optimal salinity ensures stable osmotic regulation, promoting efficient metabolic processes and structural development in seaweed.

Although salinities in the S30 and S33 treatments fall within the acceptable range for *C. racemosa* cultivation (Windarto *et al*., 2024), growth was lower than in S27. This may be due to environmental differences such as light intensity and water quality, which can affect metabolic activity and growth rates (Iskandar *et al*., 2015). Excessive light exposure, for example, can cause physiological stress and inhibit growth, as reported by Elisabeth *et al*. (2023). While Pan *et al*. (2024) identified 30 ppt as optimal in China, differences in cultivation environments likely explain the lower growth observed at this salinity in the present study.

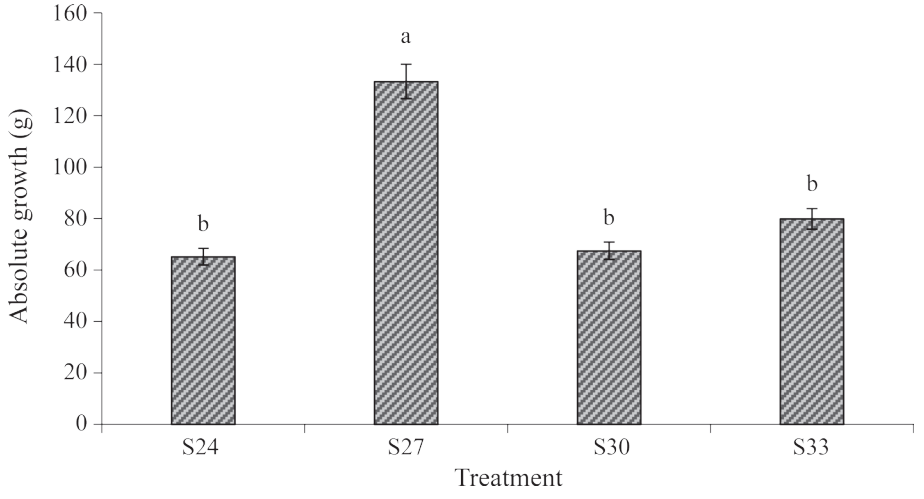


Figure 2. Absolute growth of *Caulerpa racemosa*. Bars represent mean values, and error bars indicate SD. Bars with different superscripts with different letters are significantly different ($p<0.05$).

The S24 treatment resulted in the lowest growth, likely due to suboptimal salinity (<25 ppt) (Rabia, 2016), which can impair physiological functions such as osmoregulation and photosynthesis (Rahmawati and Rahim, 2025). Disrupted osmoregulation leads to cellular stress, reduced protein synthesis, and impaired growth (Sunaryo *et al*., 2015). This supports the findings of Bermejo *et al*. (2020), who noted that extreme salinity levels combined with nutrient imbalances can significantly reduce seaweed growth. Additionally, low nitrate uptake in S24 may have further limited growth, as nitrate and phosphate are essential for *C. racemosa* development (Valentine *et al*., 2021).

Specific growth rate

The ANOVA and Duncan's test results showed that the specific growth rate (SGR) of *C. racemosa* cultivated for 43 days was significantly higher in the S27 salinity treatment compared to S24, S30, and S33 treatments, which showed no significant differences. These results are presented in the histogram in Figure 3.

Figure 3 shows that salinity significantly affected the specific growth rate (SGR) of *C. racemosa* ($p<0.05$), with the highest SGR observed in the S27 treatment (3.01±0.21 %·day^{-1}). In contrast, the S24, S30, and S33 treatments showed no significant differences, with SGR values of 1.93±0.27, 1.98±0.28, and 2.21±0.25 %·day^{-1}, respectively. These results are consistent with the absolute growth data, reinforcing that S27 provides optimal growth conditions. The differences in growth are likely due to variations in cellular osmoregulation, which affects nutrient absorption and metabolic activity (Nurfebrianti *et al*., 2015; Hidayah *et al*., 2019).

Salinity, along with other environmental factors such as light intensity, plays a crucial role in determining seaweed growth performance and biomass quality (Niwa and Harada, 2013; Hurd *et al*., 2014). Adequate light exposure supports photosynthesis, enhancing nutrient uptake and daily growth through cell division (Hurd *et al*., 2014). The influence of these environmental factors is generally determined by measuring the specific growth rate (SGR) (Guo *et al*., 2015) and biochemical composition (Hurd *et al*., 2014; Endo *et al*., 2017). In pond culture, *Caulerpa* (including *C. racemosa*) has shown strong productivity at salinities around 27–29 ppt. Salinities near this range may reduce osmotic stress and the need for extensive osmotic adjustment (ion/compatible-solute regulation), helping maintain stable physiological processes and growth (Azis *et al*., 2019; Salsabiela, 2020).

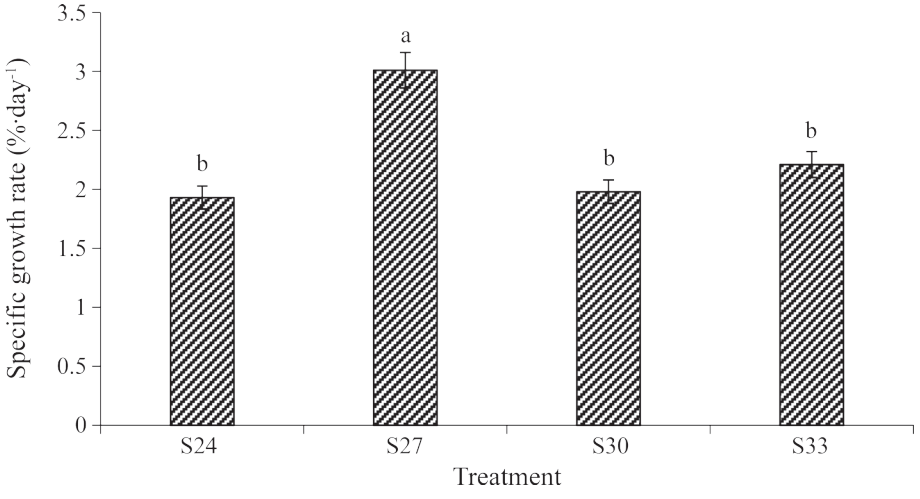


Figure 3. Specific growth rate of *Caulerpa racemosa*. Bars represent mean values, and error bars indicate SD. Bars with different superscripts letters are significantly different ($p<0.05$).

Isoosmotic conditions, typically around 28 ppt for green algae (Tartari and Forlani, 2008), allow for optimal cellular function and physiological balance.

The low SGR observed in the S24 treatment is likely due to salinity stress caused by conditions below 25 ppt. Suboptimal salinity can disrupt enzymatic activity and photosynthesis, reducing nutrient absorption and overall growth performance (Guo *et al*., 2014). Under such stress, *C. racemosa* exhibits impaired cellular function, resulting in inhibited metabolic processes and reduced growth efficiency.

Chlorophyll a

The ANOVA and Duncan's test results after 43 days of cultivation showed that the chlorophyll *a* content in *C. racemosa* was highest in the S27 treatment and significantly different from the S24, S30, and S33 treatments, which also differed significantly. These findings are illustrated in the histogram in Figure 4.

Figure 4 shows that salinity significantly affected the chlorophyll a content of *C. racemosa* ($p<0.05$) on. The highest chlorophyll *a* content was recorded in the S27 treatment (452.16±0.19 $\mu g \cdot mL^{-1}$), followed by S24 (398.58±1.26 $\mu g \cdot mL^{-1}$), S30 (300.61±0.49 $\mu g \cdot mL^{-1}$), and the lowest in S33 (260.16±0.44 $\mu g \cdot mL^{-1}$). As a green alga, *C. racemosa* is rich in chlorophyll pigments, especially chlorophyll *a*, which is essential for photosynthesis (Salido *et al*., 2023). According to Aryawati and Thoha (2011), chlorophyll *a* abundance is closely related to oceanographic conditions, including salinity. Salinity is directly related to osmoregulation that occurs in cells. Salinity is a key environmental factor that influences chlorophyll levels by affecting osmoregulation and cell membrane function, which are vital for photosynthetic processes (Hayashi *et al*., 2010; Araújo *et al*., 2014; Castro and Yokoya, 2018).

The high chlorophyll *a* content in S27 aligns with the highest growth rate and colour intensity observed in the hue value analysis (Table 2). Optimal photosynthesis likely occurred under this treatment, driven by enhanced chloroplast activity and increased light absorption. According to Lee *et al*. (2013), higher chlorophyll a content directly correlates with increased photosynthetic efficiency. This relationship is supported by Iskandar *et al*. (2015) and Dewi *et al*. (2016), who report a positive association between chlorophyll concentration and photosynthetic rate in *C. racemosa*.

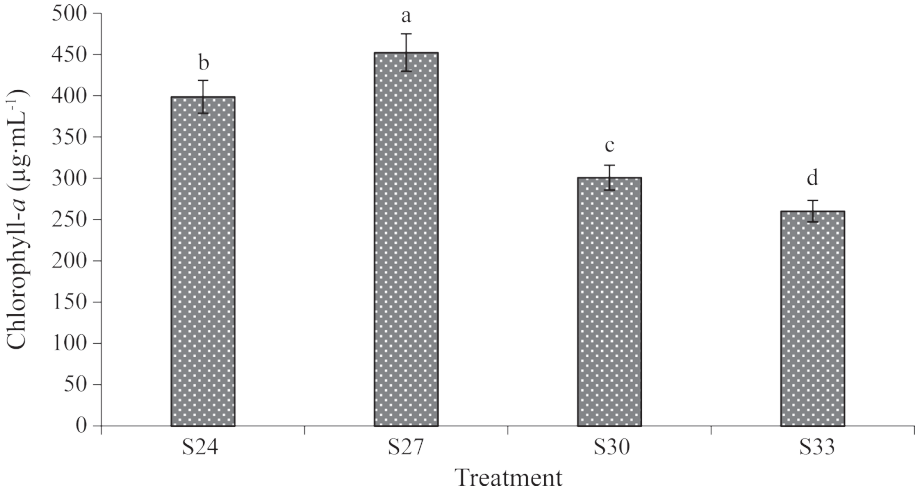


Figure 4. Chlorophyll *a* content of *Caulerpa racemosa*. Bars represent mean values, and error bars indicate SD. Bars with different superscripts with different letters are significantly different ($p<0.05$).

The reduced chlorophyll *a* content in S24 may be attributed to salinity stress under conditions below 25 ppt, which can disrupt enzyme activity and cellular metabolism (Kamer and Fong, 2000). Such stress inhibits photosynthesis by reducing chlorophyll synthesis and impairing chloroplast function (Li *et al*., 2019; Aulia *et al*., 2021). Guo *et al*. (2014) further confirm that *Caulerpa* experiences photosynthetic inhibition at salinities below 25 ppt, leading to a decline in chlorophyll content and overall growth performance. According to Anggraeni *et al*. (2022), the higher the salinity (≥30 ppt), the lower the concentration of chlorophyll *a* in macroalgae compared with the lower salinity levels. Based on the results of research conducted by Eismaputeri (2013), in macroalgae, salinity affects the amount of chlorophyll *a* during cultivation, with an increase in chlorophyll content from 25 ppt to 30 ppt and a decrease at salinities above 30 ppt.

In the S30 and S33 treatments, chlorophyll *a* levels decreased, likely due to high salinity disrupting osmoregulation and pigment synthesis (Aris *et al*., 2021). Elevated salinity can suppress photosynthetic pigment production in green algae, reducing chlorophyll levels (Zhang *et al*., 2010; Ren *et al*., 2020). This inhibition of photosynthesis under high salinity conditions has been confirmed by both Zhang *et al*. (2010) and Yao *et al*. (2013). Pan *et al*. (2024) also reported a similar pattern, where chlorophyll content increased with salinity up to 30 ppt, but declined at higher levels, further supporting the present findings.

Water quality

The water quality parameters measured during the study included temperature, dissolved oxygen, pH, salinity, light intensity, nitrate, and phosphate in the cultivation media. The results of water quality measurements during the study are presented in Table 3.

Nitrate and phosphate concentrations in the *C. racemosa* cultivation media at the beginning and end of cultivation are presented in Table 4.

Table 3. Water quality parameters in *Caulerpa racemosa* cultivation media measured in the morning and afternoon.

Treatment	Salinity (ppt)	pH	DO (mg·L^{-1})	Temperature (°C)	Light Intensity (Lux)
S_{24}	24	8.12–9.50	3.4–8.9	26.6–32.7	210–5,406
S_{27}	27	8.40–9.55	4.5–9.2	26.6–32.5	237–6,029
S_{30}	30	8.20–9.50	4.4–9.3	26.6–32.6	210–6,715
S_{33}	33	8.26–9.49	4.6–9.6	26.6–32.5	219–6,328
Optimum	25–35[1]	6.0– 8.5[2]	> 3.5[3]	25°–32°[4]	±2,500[5]

Note: ([1]) Burhanuddin (2014); ([2]) Ardiansyah *et al*. (2020); ([3]) Sunaryo *et al*. (2015); ([4]) Guo *et al*. (2015); ([5]) Sitorus *et al*. (2020).

Table 4. Nitrate and phosphate concentrations at the beginning and end of *Caulerpa racemosa* cultivation.

Treatment	Nitrate (mg·L^{-1})		Phosphate (mg·L^{-1})	
	Beginning	End	Beginning	End
S_{24}	0.116	0.007	<0.001	0.035
S_{27}	0.116	0.002	<0.001	0.028
S_{30}	0.116	0.032	<0.001	0.016
S_{33}	0.116	0.010	<0,001	0.051
Optimum		0.9–3.5[1]		0.09–0.1[2]

Note: : ([1]) Azizah (2006), ([2]) Burhanuddin (2014)

Water quality parameters measured during the study, as shown in Tables 3 and 4, indicate conditions suitable for *C. racemosa* cultivation. Salinity levels ranged from 24 to 33 ppt, within the tolerable range of 20–50 ppt for *Caulerpa* (Hui *et al*., 2014). Temperature readings ranged from 26.6–31.8 °C in the morning and 27.3–32.7 °C in the afternoon, aligning with the optimal range of 25–32 °C for seaweed growth (Guo *et al*., 2015; SNI, 2015). Dissolved oxygen levels varied from 3–7 $mg \cdot L^{-1}$ in the morning to 4–9 $mg \cdot L^{-1}$ in the afternoon, with levels above 3.5 $mg \cdot L^{-1}$ still considered sufficient (Sunaryo *et al*., 2015), though ≥5 $mg \cdot L^{-1}$ is ideal (SNI, 2015).

The pH values recorded ranged from 8.12 to 9.27 in the morning and 8.34 to 9.55 in the afternoon. These levels are mainly within the tolerance range of 6.5–9.0 for *C. racemosa* (Valentine *et al*., 2021), although some exceed the optimal upper limit of 8.5 (Ardiansyah *et al*., 2020). Light intensity ranged from 244 to 6,715 lux in the morning and from 210 to 2,694 lux in the afternoon. This range remains suitable for growth, as *Caulerpa* can thrive in light intensities between 400–7,500 lux (Masyahoro and Mappiratu, 2010), with optimal levels around 2,500 lux (Sitorus *et al*., 2020).

Final nitrate concentrations ranged from 0.002–0.032 $mg \cdot L^{-1}$. While this exceeds normal seawater levels (0.001–0.007 $mg \cdot L^{-1}$; Patty *et al*., 2015), it remains far below the 0.9–3.5 ppm range identified as optimal for *Caulerpa* growth (Azizah, 2006). Phosphate concentrations ranged from 0.016–0.051 $mg \cdot L^{-1}$, meeting the minimum threshold of 0.010 $mg \cdot L^{-1}$ needed to support seaweed growth (Cahyanurani and Ummah, 2020). These values fall within the acceptable range of 0.005–0.200 $mg \cdot L^{-1}$ (Susanto *et al*., 2021), although they remain slightly below the optimum level of 0.090–0.100 $mg \cdot L^{-1}$ suggested by Burhanuddin (2014). Phosphate levels also serve as a valuable indicator of water fertility (Moira *et al*., 2020).

CONCLUSIONS

This study demonstrates that salinity significantly influences the growth performance and chlorophyll *a* content of *C. racemosa*. Among the tested salinity levels, 27 ppt resulted in the highest absolute growth, specific growth rate, and chlorophyll *a* concentration, indicating that this was the most suitable salinity for cultivation. From a practical perspective, maintaining salinity near 27 ppt is recommended for mass-production systems, as it minimizes osmotic stress, enhances photosynthetic efficiency, and promotes higher biomass accumulation. Optimizing salinity within this range can therefore improve yield and *C. racemosa* production more consistently in controlled pond- or tank-based cultivation. Future studies should investigate the combined effects of salinity with other key environmental factors, such as nutrient enrichment and light intensity, under large-scale farming conditions to further maximize the productivity and economic viability of *Caulerpa* cultivation.

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