INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue II February 2026

Effects of Different Planting Distances on the Growth and Survival of *Halymenia durvillei* Cultured in a Controlled Medium

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DOI: https://doi.org/10.51584/IJRIAS.2026.11020001

Received: 07 February 2026; Accepted: 17 February 2026; Published: 23 February 2026

ABSTRACT

The cultivation of seaweeds under controlled conditions represents an important alternative for achieving stable and high-quality production. *Halymenia durvillei* is a red seaweed species with considerable potential for cultivation using controlled media. This study aimed to evaluate the effects of different planting distances on the growth performance and survival rate of *H. durvillei* cultured under controlled conditions. The experiment was conducted from May to July 2025 at the National Research and Innovation Agency (BRIN), Pemenang District, North Lombok Regency, West Nusa Tenggara, Indonesia. An experimental approach was employed using a Completely Randomized Design (CRD) consisting of four planting-distance treatments with three replicates: 30 cm (P1), 25 cm (P2), 20 cm (P3), and 15 cm (P4). The parameters observed included absolute weight gain, specific growth rate, survival rate, thallus length, number of thalli, and water quality. Seedlings with an initial weight of 5 g were cultured for 30 days. The collected data were analyzed using analysis of variance (ANOVA), followed by Duncan's multiple range test using SPSS software. The results indicated that planting distance significantly affected absolute weight gain and specific growth rate, but had no significant effect on the survival rate of *H. durvillei*. Planting distances of 30 cm (P1) and 25 cm (P2) produced comparably favorable outcomes, yielding absolute weight gains of 5.20 g and 5.49 g, respectively, and specific growth rates of 2.32% day (P1) and 2.47% day (P2). In both treatments, thallus length reached approximately 1 cm, supported by an average thallus number ranging from 32 to 70. Throughout the cultivation period, water quality parameters remained within optimal ranges across all treatments, with temperatures of 25–26°C, pH values of 7.87–8.13, and salinity levels of 30–31 ppt.

Keywords: *H. durvillei*; planting distance; survival rate; controlled medium; growth

INTRODUCTION

The steadily increasing global demand for seaweed-based products necessitates the diversification and development of seaweed aquaculture beyond commonly cultivated genera such as *Eucheuma*. One promising alternative is *Halymenia durvillei*, a red seaweed species (Rhodophyta) that naturally inhabits coral reef substrates. Its distribution in Indonesia includes the Thousand Islands (Java Sea) and the Sunda Strait. Compared to *Eucheuma* species, *H. durvillei* exhibits several advantages, including a faster growth rate, resistance to ice-ice disease, and low susceptibility to herbivorous predators. These characteristics contribute to its superior growth performance relative to other cultivated seaweeds [1]. *Halymenia durvillei* also possesses high economic value and strong potential as an export-oriented fisheries commodity. In addition to its commercial importance, this species has attracted attention as a bio-pharmaceutical raw material due to its content of phenolic compounds, flavonoids, and natural pigments such as phycobiliproteins, which exhibit antioxidant, antimicrobial, and anticancer activities [2].

Given the substantial economic and biotechnological potential of *H. durvillei*, the development of efficient and sustainable intensive cultivation strategies is essential. However, seaweed farming in open waters is often constrained by fluctuations in environmental conditions. Consequently, cultivation under controlled conditions has emerged as a viable alternative. Within controlled systems, spatial optimization is a critical factor influencing production success, with planting distance playing a key role. Appropriate planting distances can enhance growth performance by optimizing light penetration, photosynthetic efficiency, and nutrient uptake. Conversely, excessively close spacing may lead to competition among thalli for light, growing space, and nutrients, ultimately reducing growth rates and biomass accumulation. On the other hand, overly wide spacing can result in inefficient use of cultivation space and reduced productivity per unit area [3].

Therefore, determining an optimal planting distance is essential for maximizing growth performance and biomass yield. In addition to spacing, environmental factors such as temperature, water movement, and nutrient availability interact with planting distance to influence the overall success of seaweed cultivation. Proper spacing is expected to enhance water circulation around the thalli, thereby improving photosynthetic activity and nutrient absorption [4]. Optimal stocking density has been shown to increase the specific growth rate (SGR) and overall yield of cultivated seaweeds [5].

Despite the considerable cultivation potential of *H. durvillei*, information regarding optimal planting distances under controlled cultivation systems remains limited. Previous studies on other seaweed species have demonstrated that planting distance significantly affects growth rate and productivity. [1] reported that a planting distance of 25 cm resulted in higher growth rates and carrageenan yield in H. durvillei cultured using the long-line method with ropes. Similarly, [6] found that wider spacing in *Kappaphycus alvarezii* cultivation reduced inter-thallus competition for light and nutrients, thereby enhancing growth performance. Furthermore, [7] demonstrated that optimized planting distances in *Eucheuma* species significantly improved biomass accumulation and carrageenan quality in rope-based cultivation systems.

Based on these considerations, the present study was conducted to analyze the effects of varying planting distances on the growth and survival of *H. durvillei* cultivated in a controlled medium. The findings of this study are expected to provide a scientific basis for the development of standard operating procedures (SOPs) for *H. durvillei* cultivation under controlled conditions, thereby contributing to improved production efficiency and supporting the development of the national seaweed industry.

MATERIAL AND METHOD

Study Site and Experimental Materials

The study was conducted from May to July 2025 at the National Research and Innovation Agency (BRIN), Pemenang District, North Lombok Regency, West Nusa Tenggara, Indonesia. The materials used in this experiment included seawater, NPK fertilizer, and *Halymenia durvillei* seedlings. The equipment comprised aeration systems, concrete tanks, scissors, a smartphone camera, net bags (*waring*), brushes, digital balances, water-quality measuring instruments, and ris lines.

Experimental Design

This study employed a Completely Randomized Design (CRD) with four treatments and three replicates, yielding a total of 12 experimental units. The treatments consisted of planting distances of 30 cm (P1), 25 cm (P2), 20 cm (P3), and 15 cm (P4).

Research Method

Preparation of Culture Tanks and Fertilization

Concrete tanks measuring 70 × 300 × 80 cm with a total capacity of 5,000 L were used as culture containers. Prior to the experiment, the tanks were thoroughly cleaned using running water and brushes to remove any adhering debris. Each tank was then filled with 4,000 L of seawater. NPK fertilizer was applied following the preparation of a mud suspension solution. This suspension was produced by collecting sand mixed with mud, which was then manually homogenized. Freshwater was added to facilitate the filtration process, after which the mixture was filtered to separate coarse particles from the mud suspension. Liquid NPK fertilizer was subsequently added to the mud suspension at a concentration of 10 mg L^{-1} and mixed until homogeneous. The fertilizer solution was evenly distributed into the culture tanks at a 1:6 ratio **exclusively at the beginning of the rearing period** to support initial growth and ensure adequate nutrient availability **for the duration of the 30-day experiment**.

Controlled Cultivation System Specifications

The cultivation system was designed to maintain a stable environment within the concrete tanks. Water circulation was managed using an aeration system installed along the bottom of the tank to ensure uniform mixing of water and nutrients and to prevent stagnation. Lighting relied on natural sunlight with intensity regulated by the laboratory's transparent roofing, following a natural photoperiod of approximately 12 hours of light and 12 hours of darkness. To maintain water quality stability, a 20% water exchange was performed every 10 days to remove metabolic waste without adding further nutrients

Preparation of the Planting Medium

The seaweed cultivation medium consisted of ris lines used as the planting substrate. The ris lines were arranged using nylon lines, with planting distances adjusted according to each experimental treatment. The lines were secured to PVC pipes installed at both ends of the concrete tanks, serving as structural supports for the cultivation system throughout the experimental period.

Each tank was equipped with two pairs of parallel pipes designed to maintain the stability and alignment of the ris lines, ensuring consistent spacing and orderly positioning during the rearing period (Fig 1).

Seedling Preparation

H. durvillei seedlings were collected from coastal waters in Bali and were pre-selected for quality. Only healthy, fresh thalli, free of physical damage and epiphytes, were used. During transportation, the seedlings were placed in Styrofoam boxes to maintain stable temperature and moisture conditions. The seedlings were neatly arranged and covered with moist media to preserve freshness until arrival at the cultivation site. Upon arrival, the seedlings were acclimated by culturing *H. durvillei* in the culture tanks for seven days to adapt to the new environmental conditions prior to use in the experiment.

Seedling Maintenance and Planting

Following acclimation, seedlings suitable for cultivation were selected based on health status, characterized by bright red coloration and uniform size. Selected seedlings were tied at the basal part of the thallus using raffia string and attached to the ris lines. The ris lines were then installed on the supporting pipes at the ends of the concrete tanks, approximately 10 cm below the water surface, to ensure optimal water circulation and light exposure. Each tie on the ris lines consisted of two seaweed fragments with a combined initial weight of 5 g. Standardization of seedling number and weight was applied to minimize growth variation caused by differences in planting distance.

Seed Monitoring and Control

The cultivation period lasted for 30 days. Throughout the rearing period, seedlings were routinely inspected to remove attached debris or pests, and damaged thallus sections were trimmed to maintain optimal growth conditions. Growth monitoring was conducted every 10 days through visual assessment of biomass increase, morphological condition, and overall seedling health. Water quality parameters, including temperature, pH, dissolved oxygen (DO), and salinity, were measured at 10-day intervals during the experimental period.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue II February 2026

Research Parameters

Absolute Weight Gain

According to [8] absolute growth was calculated using the following formula:

$$W = Wt - Wo$$

Where:
W : average absolute growth (g)
Wt : final seaweed biomass (g)
Wo : initial seaweed biomass (g)

Specific Growth Rate (SGR)

According to [9] the specific growth rate (SGR) was calculated using the following equation:

$$SGR = \frac{In\ Wt - In\ Wo}{t} x100\%$$

Where:
SGR : average specific growth rate (%/day)
Wt : final biomass (g)
W0 : initial biomass (g)
T : cultivation period

Survival Rate

Survival rate was calculated at the end of the experimental period following the method described by [10] using the formula:

$$SR = Nt/No \times 100$$

Where:
SR = survival rate (%)
Nt = number of surviving thalli at the end of the study
No = number of thalli at the beginning of the study

Thallus Length and Thallus Number

Measurements of thallus length and thallus number were conducted at 10-day intervals throughout the cultivation period. Thallus length was measured using a ruler, while the number of thalli was determined manually by counting all thalli present on each ris line.

Water-Quality Parameters

Water quality parameters monitored during the experiment included temperature, pH, dissolved oxygen (DO), and salinity. Measurements were taken every 10 days using a thermometer, a pH meter, a DO meter, and a refractometer.

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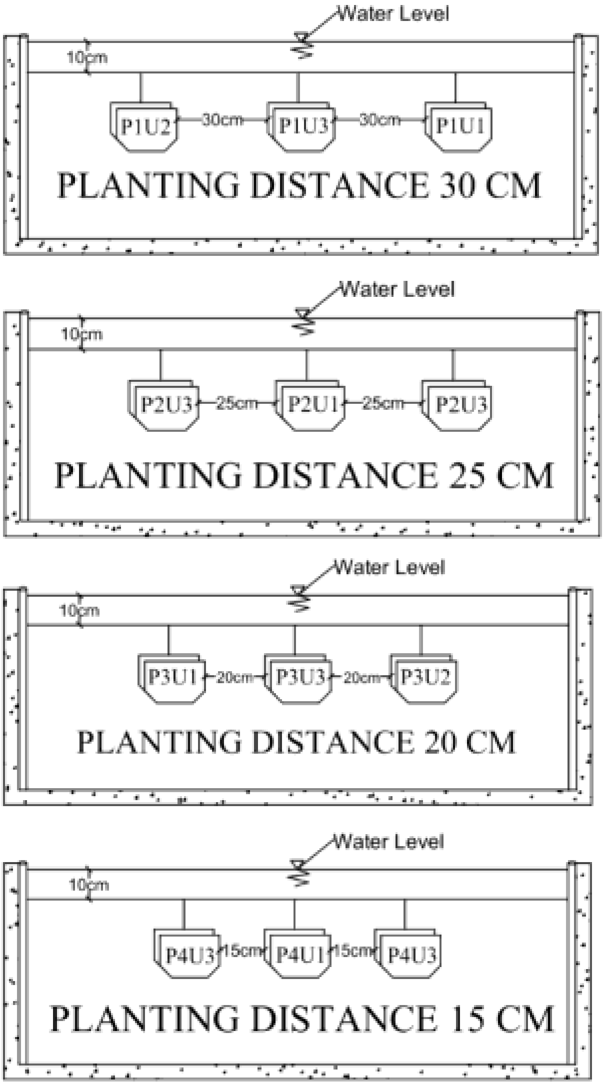


Fig 1. Design of the Culture Tank System

Data Analysis

All data obtained were analyzed using analysis of variance (ANOVA) to evaluate the effects of planting distance on the measured parameters. When significant differences were detected, Duncan's multiple range test was applied as a post hoc analysis. Statistical analyses were performed using SPSS software. The results were subsequently presented as histograms generated in Microsoft Excel.

RESULTS

Absolute Weight

The results showed that the average absolute weight gain of *E. cottonii* cultivated using the verticulture system at different depths ranged from 7 g to 29 g. The highest average absolute weight was recorded at the 0-m treatment (P0), with a value of 29 g, whereas the lowest was observed at the 3-m depth (P3), with an average weight of 7 g (Fig 2).

ANOVA results indicated that planting distance had a significant effect on the absolute weight of *H. durvillei* ($P < 0.05$). Duncan's multiple range test further revealed that the 25 cm treatment (P2) produced the highest absolute weight, which was not significantly different from the 30 cm treatment (P1). Both P1 and P2, however, differed significantly from the 20 cm (P3) and 15 cm (P4) treatments.

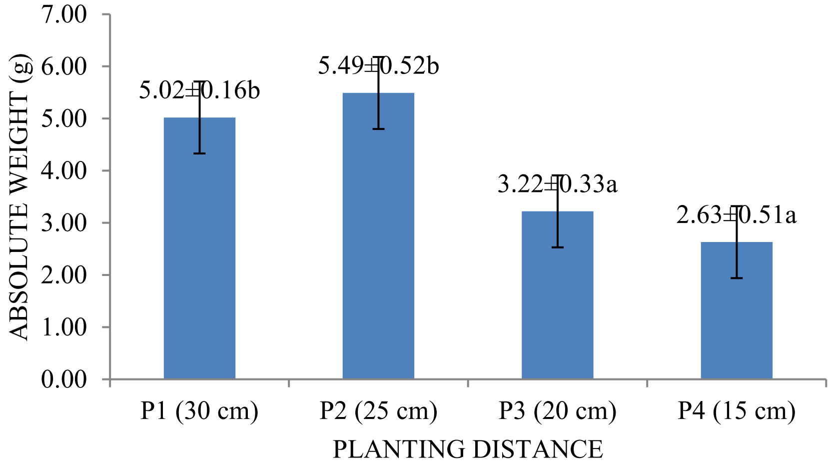


Fig 2. Absolute weight of *H. durvillei*

Specific Growth Rate (SGR)

The mean specific growth rate of *H. durvillei* under different planting distances in controlled media ranged from 1.41%/day to 2.47%/day. The highest SGR was observed at the 25 cm planting distance (P2), at 2.47%/day, while the lowest was found at 15 cm (P4), at 1.41%/day (Fig 3).

ANOVA results indicated that different planting distances had a significant effect on the specific growth rate of *Halymenia durvillei* under controlled media ($P < 0.05$). Duncan's multiple range test showed that the 25 cm planting distance treatment (P2) yielded the highest SGR, which was not significantly different from the 30 cm treatment (P1). Both P1 and P2, however, differed significantly from the 20 cm (P3) and 15 cm (P4) treatments.

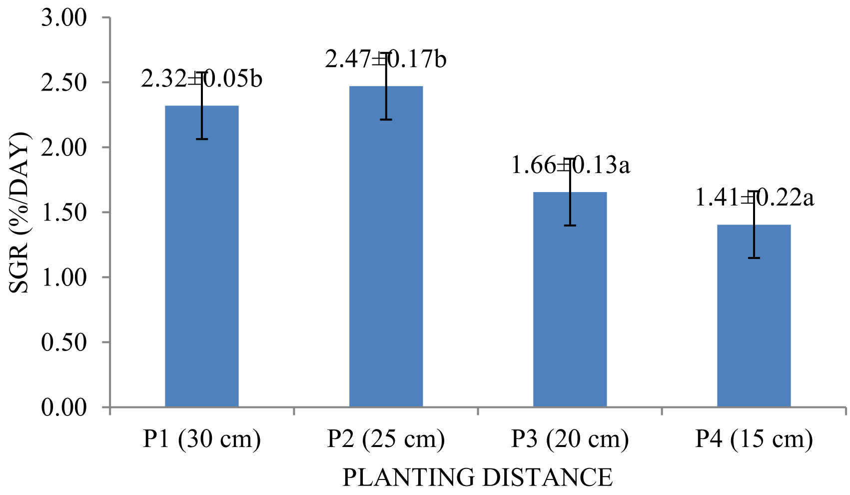


Fig 3. Specific Growth Rate of *H. durvillei*

Survival Rate

The mean survival rate of *H. durvillei* across different planting distances under controlled conditions ranged from 50% to 83.3%. The highest survival rates were observed in the 30 cm (P1) and 20 cm (P3) treatments, both 83.3%, followed by the 25 cm (P2) treatment at 66.7%. The lowest survival rate was recorded in the 15 cm treatment (P4) at 50% (Fig 4).

ANOVA results indicated that planting distance did not have a significant effect on the survival rate of *H. durvillei* ($P > 0.05$).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue II February 2026

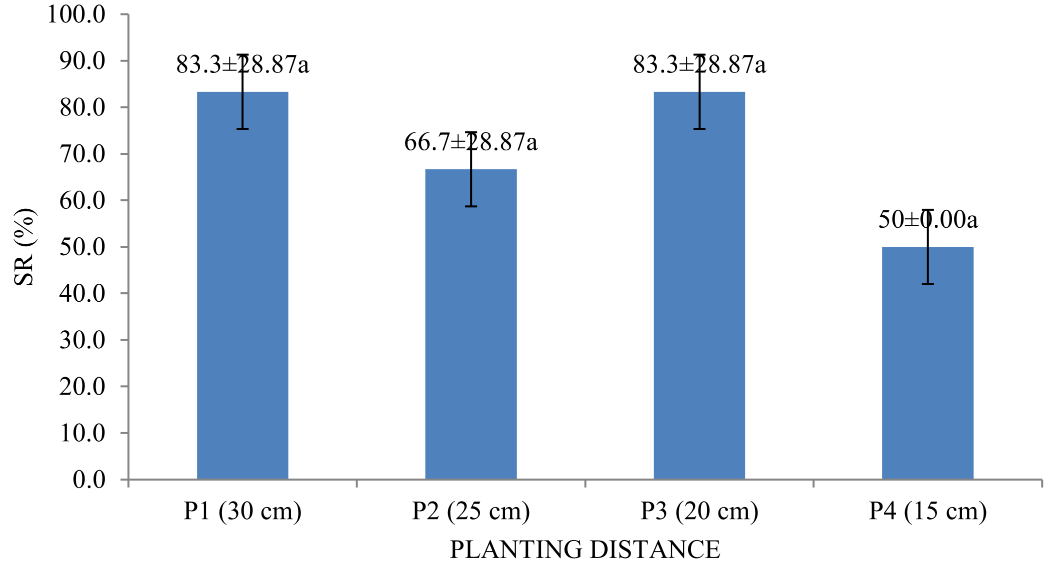


Fig 4. Survival Rate of *H. durvillei*

Thallus Number

The mean number of thalli in *H. durvillei* cultivated at different planting distances ranged from 32 to 70. Overall, the number of thalli increased over time in all treatments. At day 10, the average number of thalli ranged from 29 to 38; at day 20, from 33 to 58; and at day 30, from 35 to 70. At the end of the cultivation period, the 25 cm planting distance (P2) produced the highest mean number of thalli (70), whereas the 15 cm treatment (P4) had the lowest (35) (Fig 5).

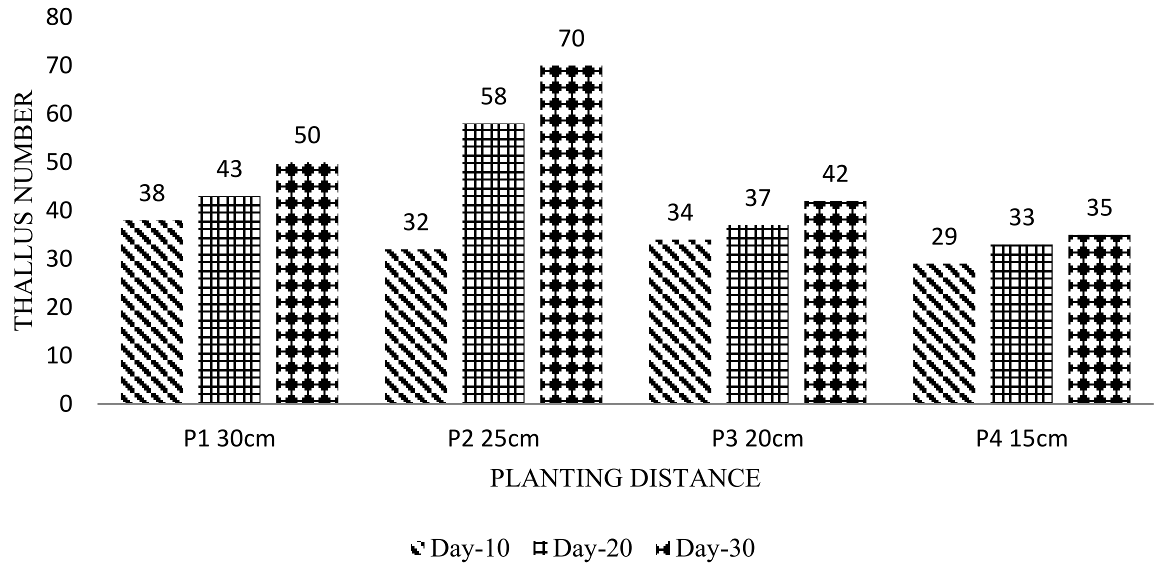
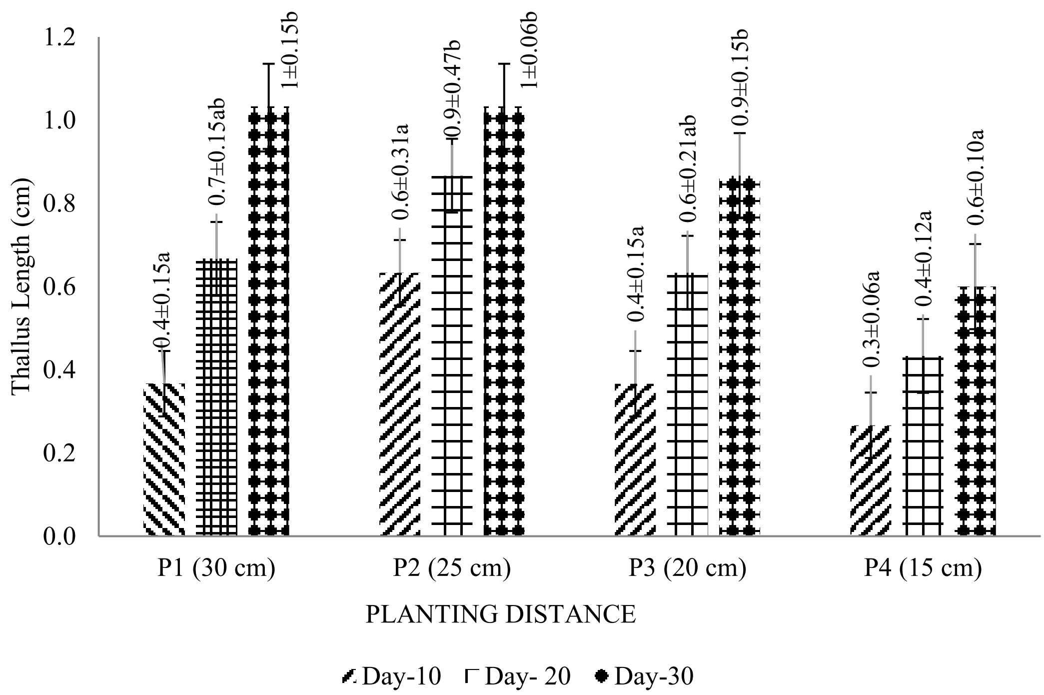


Fig 5. Thallus Number of *H. durvillei*

Thallus Length

The research results showed that the average thallus length of *H. durvillei* cultured at different planting distances ranged from 0.3 to 1 cm. Overall, an increase in thallus length was observed in all treatments as the culture period progressed. The average thallus length at day 10 of cultivation ranged from 0.3 to 0.6 cm, increased to 0.4–0.9 cm at day 20, and reached 0.6–1 cm at day 30. At the end of the cultivation period, the treatments with planting distances of 30 cm (P1) and 25 cm (P2) produced the highest average thallus length, both reaching 1 cm, while the lowest thallus length was observed in the treatment with a planting distance of 15 cm (P4), measuring 0.6 cm (Fig 6).

ANOVA results showed that different planting distances had a significant effect on the thallus length of *Halymenia durvillei* under controlled media ($P < 0.05$). Duncan's multiple range test indicated that the 30 cm (P1), 25 cm (P2), and 20 cm (P3) treatments produced thallus lengths that were not significantly different from each other at any time point during the culture period. These three treatments also resulted in significantly longer thalli compared to the 15 cm planting distance (P4). The 15 cm treatment (P4) did not show significant differences in thallus length across all measurement intervals.



Water Quality

Water quality parameters including temperature, pH, dissolved oxygen (DO), and salinity remained within optimal ranges throughout the cultivation period (Table 1).

Table 1. Water Quality Observations during the Cultivation of *H. durvillei*

Parameters	**Value**	**Ideal**	**Reference**
Temperature	25.80-26.83°C	25°C-31°C	[11]
pH	7.88-8.13	6-9	[12]
DO	4.15-10.9 mg/l	>3.5	[13]
Salinity	30.33-31.33	15-35 ppt	[14]

DISCUSSION

Seaweed growth is influenced by a complex interplay of internal and external factors. Internal factors include biological characteristics such as species, seedling quality, and thallus condition, whereas external factors encompass environmental conditions, as well as the cultivation system and techniques applied. Differences in growth reflect the physiological responses of seaweed to variations in these factors. According to

[15] external factors affecting seaweed growth include the environment, planting distance, initial seedling weight, planting techniques, and cultivation methods.

This study aimed to examine one key external factor influencing the growth of *H. durvillei*, namely, planting distance in a controlled cultivation system. Overall, the results indicate that variations in planting distance significantly affected the growth of *H. durvillei*, while the survival rate remained unaffected under controlled conditions. These findings suggest that planting distance is an important factor for optimizing seaweed growth in controlled systems. [3] reported that appropriate planting distances can influence growth, photosynthetic rate, and nutrient uptake. If seedlings are planted too closely, competition for light, space, and nutrients increases, thereby reducing growth rates and wet biomass accumulation.

During the 30-day culture period, growth increased across all treatments, as indicated by absolute weight, specific growth rate, and thallus length (Figures 2, 3, and 6). Planting distances of 30 cm (P1) and 25 cm (P2) exhibited similar efficacy in promoting the growth of *H. durvillei* seedlings compared to other treatments. **Biologically, this is closely related to the mechanisms of light interception and nutrient diffusion. At wider planting distances, each thallus receives more uniform light exposure without being obstructed by neighboring thalli, effectively minimizing self-shading. Sufficient light is vital for maximizing photosynthetic activity**. This suggests that these planting distances provide an optimal balance between available space, light, and nutrients for each individual thallus. [16] stated that seaweed growth is strongly influenced by the spacing of individual plants, as wider distances increase water movement across the cultivation area. Similarly, [17] reported that higher seaweed density results in lower growth rates.

Furthermore, optimal spacing facilitates better water circulation around the thallus surface. Smooth water flow, supported by the aeration system, enhances the nutrient diffusion rate from the water medium into the seaweed tissue through the boundary layer. In contrast, closer planting distances of 20 cm (P3) and 15 cm (P4) resulted in reduced thallus growth. This decrease is likely due to increased competition among thalli for light and nutrients, as well as restricted water circulation around the plants. **Thallus overlap creates self-shading conditions, drastically reducing the light intensity reaching the inner parts of the seaweed clumps. This inhibits photosynthetic efficiency and leads to intense nutrient competition, which ultimately reduces individual growth rates and total productivity per unit area.** These observations are consistent with ecological principles in seaweed aquaculture, where high density reduces physiological efficiency due to internal competition. [18] also reported that closer planting distances yield lower relative growth rates than wider spacing, supporting the notion that dense planting limits access to essential resources, including nutrients, light, and space.

The growth patterns of *H. durvillei* observed in this study align with previous research. [19] reported that a 25 cm planting distance in *Kappaphycus alvarezii* cultivated using the long-line method increased biomass by 331.4 g and specific growth rate by 4.87%/day, which was higher than both narrower (<25 cm) and wider (30 cm) spacing. Similarly, [20] found that a 25 cm planting distance in *Gracilaria* cultivated using bottom-stake methods increased thallus length to 15.33 cm, whereas a 20 cm spacing resulted in lower growth in both biomass and thallus length, compared to 25 cm planting distance or wider.

In contrast, survival rates of *H. durvillei* were not significantly affected by planting distance (Figure 4). This suggests that planting distance does not directly influence seaweed survivability during the culture period, likely because all treatments shared the same controlled media conditions and received uniform light exposure at a depth of 10 cm. Survival rates across all treatments were relatively high, ranging from 50% to 83%. According to [21] survival rates above 50% are considered good, indicating that environmental conditions and maintenance methods were sufficient to support both growth and survival. [22] similarly noted that survival rates ≥50% indicate strong adaptability to cultivation conditions.

The lack of significant differences in survival among treatments was further supported by the consistently optimal water quality parameters in all treatments, including temperature, pH, DO, and salinity (Table 1). [23] reported that red seaweeds generally maintain high survivability under optimal water quality conditions, even with variations in planting density. During this study, the culture medium temperature ranged from 25.80 to 26.83°C, which falls within the optimal range for seaweed growth 25–31°C [11]. The pH ranged from 7.88 to

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS | Volume XI Issue II February 2026

8.13, consistent with the tolerable range for seaweeds pH 6–9 [5]. Salinity ranged from 30.33 to 31.33 ppt, which is within the optimal range for seaweed cultivation 15–35 ppt [12]. Maintaining stable, physiologically appropriate environmental conditions is critical for cultivation success, as it supports photosynthesis, respiration, and nutrient uptake, thereby optimizing growth and reducing stress [24].

Optimal growth of *H. durvillei* at planting distances of 25–30 cm was also supported by a higher average thallus count in these treatments (Figure 5). An increased number of thalli indicates that the environmental conditions in these treatments favored branching and tissue regeneration. [6] reported that optimal planting density enhances the formation of new branches or thalli, as competition for light and nutrients remains within tolerable levels. Similarly, [20] noted that optimal planting distances provide sufficient spacing between thalli, minimizing shading and enhancing light utilization and nutrient flow, thereby accelerating growth and promoting the development of new branches. The formation of new branches in red seaweeds is an important indicator of vegetative growth and is directly linked to physiological adaptability and biomass productivity.

Thus, both stocking density and planting distance are critical factors to consider in the cultivation of *H. durvillei* to achieve optimal growth. The results of this study also indicate that the balance between planting distance and environmental conditions is interrelated. Excessively wide planting distances can result in underutilized space and resources, while overly dense planting leads to competition among individuals, reducing growth rates. This finding aligns with [25], who noted that excessively wide spacing results in inefficient use of space and unused cultivation area.

Optimal growth observed in treatments P1 and P2, with planting distances of 25–30 cm, suggests that these conditions provide sufficient space for *H. durvillei* to efficiently carry out photosynthesis and nutrient absorption. [26] similarly reported that the morphological growth of seaweed is more strongly influenced by macro-environmental factors such as light and nutrient availability than by density, provided that the density remains within the species' tolerance limits. **From an economic feasibility perspective, determining the optimal planting distance is crucial for maximizing yield. While very wide spacing (30 cm) promotes excellent individual growth, excessively large gaps lead to the inefficient use of cultivation space. The findings of this study suggest that a 25 cm distance represents the best equilibrium between optimal biological growth and efficient space utilization to achieve maximum productivity.**

CONCLUSION

Variations in planting distance significantly affected absolute weight and specific growth rate, but did not influence the survival rate of *H. durvillei*. Treatments with planting distances of 30 cm (P1) and 25 cm (P2) demonstrated similar effectiveness in enhancing absolute weight, reaching 5.2 g (P1) and 5.49 g (P2), and specific growth rates of 2.32%/day (P1) and 2.47%/day (P2), with thallus lengths of 1 cm in both treatments. These growth patterns were supported by an average thallus count of 32-70 per treatment. Water quality parameters remained within optimal ranges throughout the cultivation period, with temperatures of 25–26°C, pH of 7.87–8.13, and salinity of 30–31 ppt. **The 25 cm planting distance is recommended as it provides an optimal balance between individual growth and space-use efficiency in controlled cultivation systems.**

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