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Growth Profile of *Kappaphycus Alvarezii* Cultivated Using A Vertical Culture System at Different Depths in Concrete Tanks

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ABSTRACT

This study aimed to evaluate the effect of different water depths on the growth performance of *K. alvarezii* cultivated in concrete tanks using a vertical culture method. The experiment was conducted from June to September 2025 at the National Research and Innovation Agency (BRIN). A completely randomized design (CRD) was applied, consisting of four depth treatments with four replicates: 10 cm (P0), 20 cm (P1), 30 cm (P2), and 40 cm (P3). Seaweed seedlings with an initial weight of 50 g were cultured for 21 days. Observed parameters included absolute weight gain (g), specific growth rate (%/day), thallus length (cm), number of thalli, survival rate (%), and water quality variables. Data were analyzed using analysis of variance (ANOVA) in SPSS at a 95% confidence level. The results indicated that water depth in the vertical culture system did not significantly affect the growth performance or survival of *K. alvarezii*. Nevertheless, based on mean values, the 10 cm depth treatment (P0) exhibited the highest growth, with an absolute weight gain of 0.73 ± 0.17 g, a specific growth rate of 0.07 ± 0.02%/day, thallus length of 0.95 ± 0.06 cm, number of thalli of 48.3 ± 0.13, and a survival rate of 100%. These outcomes were supported by favorable water quality conditions throughout the culture period, with temperatures ranging from 26.5–27.9 °C, pH values of 7.28–8.00, dissolved oxygen levels of 6.0–8.0 mg/L, and salinity of 32–34 ppt

KEYWORDS: Concrete tank, *Kappaphycus alvarezii,* depth, growth performance. vertical culture

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1. INTRODUCTION

Kappaphycus alvarezii is a red macroalga (Rhodophyta) widely recognized as the primary source of κ-carrageenan, a high-value polysaccharide with substantial economic importance. In addition to its industrial relevance, this species has been reported to contain various bioactive compounds exhibiting antioxidant, antibacterial, antifungal, anticancer, antidiabetic, and antiviral activities, indicating its strong potential for pharmaceutical and health-related applications (Haryanto et al., 2023). *K. alvarezii* is also extensively utilized in the food, cosmetic, and biotechnology industries as a natural thickening and stabilizing agent (Wenno et al., 2022). The species is widely distributed in tropical regions, particularly along the coastal waters of Indonesia, including Sulawesi, Maluku, Nusa Tenggara, and Lombok. This broad distribution is attributed to its strong dependence on optimal solar irradiance for photosynthetic activity (Rizal et al., 2021). Indonesia has consequently emerged as one of the world's leading producers of *K. alvarezii*, supplying a significant share of the global market demand (Susilowati et al., 2024).

Global demand for *K. alvarezii* continues to increase in parallel with the expanding requirements of the food, cosmetic, and biotechnology industries. This growing demand necessitates the development of more efficient and sustainable cultivation strategies to ensure continuous production while reducing reliance on natural stocks (Susilowati et al., 2024). One cultivation innovation that has gained increasing attention is the vertical culture (verticulture) method. This technique optimizes the use of aquatic space by arranging seaweed seedlings vertically in multiple tiers, thereby enhancing light exposure and water circulation around the thalli (Mulyaningrum et al., 2021). Such an approach is considered capable of creating a more stable cultivation environment and represents a promising alternative for production systems with limited spatial availability.

Several previous studies have demonstrated that vertical culture systems can yield superior growth performance compared to conventional cultivation methods. Putra et al. (2023) reported that the application of verticulture in controlled concrete pond systems significantly increased biomass accumulation and thallus length by 20–35% relative to longline and floating raft methods. These improvements were attributed to more uniform light distribution and improved water circulation among thalli within the vertical arrangement. Similarly, Laksana and Widodo (2024) observed a 22% increase in the daily growth rate of *K. alvarezii* cultivated using a vertical system, which was associated with more stable light intensity and water flow across different culture layers. Furthermore, Ardiansyah et al. (2022) documented an 18% increase in biomass production when *K. alvarezii* was cultivated using vertical racks in semi-controlled pond systems, likely due to reduced inter-thallus competition for light. Supporting these findings, Nurlaila and Hasan (2023) reported that a three-tier vertical culture system in concrete tanks resulted in thallus growth rates 25% higher than those achieved with horizontal systems, owing to more efficient light penetration at each culture level.

Previous studies have not explicitly examined the effect of varying water depths within vertical culture systems under controlled cultivation conditions and have generally focused on a single depth level. Consequently, the response of *Kappaphycus alvarezii* to variations in light intensity and microenvironmental conditions within verticulture systems has not been comprehensively evaluated. In addition, earlier investigations employed diverse cultivation designs, differing in container dimensions, culture media management, and light intensity regulation. As a result, these findings cannot be directly extrapolated to vertical culture systems operated in concrete tanks with more specifically controlled environmental settings. Therefore, the present study aims to analyze the effect of depth variation on the growth performance of *K. alvarezii* cultivated using a vertical culture method in concrete tanks, with the aim of improving cultivation efficiency and the productivity and quality of the cultured seaweed (Provide background information and objectives.

2. METHODOLOGY

2.1. Study Site and Time

This study was conducted from June to September 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, *K. alvarezii* seedlings, and NPK fertilizer. The equipment employed comprised an aeration system, concrete tanks, scissors, a smartphone camera, polypropylene ropes, cable ties, brushes, a digital balance, small PVC pipes, and a water quality checker.

Experimental Design

The experiment was conducted using a completely randomized design (CRD) with four depth treatments: P0 (10 cm), P1 (20 cm), P2 (30 cm), and P3 (40 cm). Each treatment was replicated four times, resulting in a total of 16 experimental units (Figure 1).

2.2. Preparation of Experimental Tanks

The study utilized four concrete tanks measuring 70 × 300 × 80 cm, each with an approximate capacity of 5,000 L. Prior to use, all tanks were thoroughly cleaned with brushes and freshwater to remove debris and residues from the tank walls and bottom. The tanks were then rinsed until clean and allowed to dry for 24 hours before the experiment commenced.

2.3. Preparation of the Vertical Culture System

Before filling the tanks with seawater, PVC pipes were installed in each tank at a slightly inclined position along both longitudinal sides. These pipes served as structural supports and were positioned according to the designated depth treatments: 10 cm (P0), 20 cm (P1), 30 cm (P2), and 40 cm (P3). The PVC pipes served as anchor points for polypropylene ropes used to secure seaweed seedlings. Each tank was subsequently filled with seawater to an effective water depth of approximately ±70 cm, resulting in a seawater volume of approximately 1,400–1,500 L per tank. Consequently, the total volume of seawater used throughout the experiment was approximately ±6,000 L. Aeration systems were installed to maintain adequate oxygen supply and water circulation, while the water level was kept constant to ensure that the assigned depth treatments remained unchanged.

2.4. Fertilizer Preparation

Prior to fertilizer application, a mud slurry was prepared by mixing sand with mud and manually homogenizing the mixture. The homogenized mixture was then diluted with freshwater and filtered to separate coarse particles from the liquid slurry. Liquid NPK fertilizer was subsequently added to the slurry at a 1:1 ratio and mixed thoroughly until homogeneous. The resulting fertilizer solution was applied to each concrete tank at a 1:6 dilution.

2.5. Seedling Preparation

Seaweed seedlings were collected from the waters of Serewe Bay, Serewe Village, East Lombok Regency. Selected seedlings were fresh, clean, possessed numerous healthy thalli, and were free from contamination by other seaweed species. Seed collection was conducted in the morning. During transportation to the experimental site, seedlings were placed in containers lined with newspaper on all sides to minimize moisture loss.

2.6. Seed Selection and Planting

Only seedlings exhibiting a dark green coloration, firm texture, and thalli resistant to breakage were selected for cultivation. Prior to planting, seedlings were acclimated for 30 min to reduce stress associated with environmental changes. After acclimation, *K. alvarezii* seedlings were weighed to obtain an initial biomass of 50 g per unit and secured using small cable ties (12–15 cm) to polypropylene ropes approximately 280 cm in length (adjusted to tank length) and 6–8 mm in diameter to ensure sufficient load-bearing capacity. Each rope held multiple seedling units, with 30 cm spacing between attachment points to ensure uniform light penetration and adequate water circulation. The ends of each rope were then tied to the PVC supports at the designated depth levels. Seedlings were carefully placed to prevent thallus damage, and all treatments were standardized to ensure uniform initial conditions. Planting was conducted in the morning to minimize thermal stress. After all seedlings were installed, aeration systems were activated to maintain optimal water circulation within the concrete tanks.

Depth	**Replication 1**										
10 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	**CONCRETE TANK**
20 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
30 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
40 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
Depths	**Replication 4**										
10 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	**CONCRETE TANK**
20 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
30 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
40 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
Depths	**Replication 2**										
10 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	**CONCRETE TANK**
20 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
30 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
40 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
Depths	**Replication 3**										
10 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	**CONCRETE TANK**
20 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
30 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	
40 cm	RL1	RL2	RL3	RL4	RL5	RL6	RL7	RL8	RL9	RL10	

Experimental Tank Design of *K.alvarezii*

2.7. Seedling Maintenance and Monitoring

Seedling maintenance was conducted for 21 days through regular monitoring of seaweed growth and survival. A routine inspection was performed to prevent pest infestations, and damaged thalli were removed from healthy individuals to prevent further deterioration. Growth monitoring was carried out once a week by measuring thallus weight, thallus length, and the number of thalli. Water quality management was also implemented by performing partial water exchange twice a week, carefully designed to minimize stress on the seaweed. Simultaneously, water quality parameters were measured, including temperature, pH, dissolved oxygen (DO), and salinity.

2.8 Experimental Parameters

Absolute Weight (g)

Absolute weight gain (G) was calculated as the difference between final and initial biomass (Mulyani et al., 2021):

$G = Wt - Wo$

Where:

G = Absolute weight (g)

Wt = final weight at the end of the culture period (g)

Wo = initial weight at the beginning of the culture period (g)

Specific Growth Rate (%/day)

Specific growth rate (SGR) was expressed as the daily percentage increase in biomass based on the natural logarithmic difference between final and initial weights, following the standard approach for tropical macroalgae growth analysis (Hayashi et al., 2018):

$$\text{SGR (\%/day)} = \left(\frac{\ln Wt - \ln Wo}{t}\right) \times 100\%$$

S G R (%/day) = Specific Growth Rate (%/day)

Wo = initial weight (g)

Wt = final weight (g)

t = culture period (days)

Thallus Length (cm)

Thallus length was measured by directly recording the length of seaweed thalli in each experimental unit on a weekly basis throughout the culture period. The resulting data represent the gradual increase in thallus size over time and were used to evaluate the growth response of *K. alvarezii* to the applied treatments. Thallus length was employed as an indicator of vegetative growth during cultivation (Tisera & Wijesinghe, 2018).

Thallus Number

The number of thalli was determined by directly counting the total number of thallus branches in each experimental unit every week during the culture period. The recorded values represent the actual number of thalli observed in the field, without calculating incremental differences between sampling intervals. This parameter was used to assess vegetative branching development of *K. alvarezii* during cultivation (Mulyani et al., 2021).

Survival Rate (%)

Survival rate (SR) was calculated as the percentage of thalli that remained alive at the end of the culture period (Putra et al., 2019):

$$\text{SR (\%)} = \left(\frac{Nt}{No}\right) \times 100\%$$

Where:

SR= survival rate (%)

Nt = number of seaweed individuals surviving at the end of the culture period

No= number of seaweed individuals at the beginning of the culture period

Water Quality Parameters

As supporting data, water quality parameters, including temperature, salinity, pH, dissolved oxygen (DO), and light intensity, were measured regularly. Temperature was measured using a digital thermometer, salinity using a refractometer, pH using a pH meter, and dissolved oxygen using a DO meter.

Data Analysis

Growth and survival data were analyzed using analysis of variance (ANOVA) with SPSS software. The results were visualized as histograms in Microsoft Excel. Water quality data were analyzed descriptively to evaluate environmental conditions during the culture period (Explain materials, methods, and data collection process.)

3. RESULTS AND DISCUSSION

3.1. Absolute Weight Gain (g)

The results showed that the mean absolute weight gain of *K. alvarezii* cultivated in concrete tanks at different depth treatments ranged from 0.34 ± 0.17 g to 0.73 ± 0.17 g. A decreasing trend in absolute weight gain was observed with increasing cultivation depth. The 10 cm depth treatment (P0) resulted in the highest mean absolute weight gain (0.73 ± 0.17 g), followed by the 20 cm depth treatment (P1) with a mean value of 0.59 ± 0.28 g, and the 30 cm depth treatment (P2) with a mean value of 0.42 ± 0.12 g. In contrast, the 40 cm depth treatment (P3) exhibited the lowest mean absolute weight gain, amounting to 0.34 ± 0.17 g (Figure 1). Analysis of variance (ANOVA) indicated that cultivation of *K. alvarezii* using a vertical culture system at different depths in concrete tanks had no significant effect on absolute weight gain ($p > 0.05$).

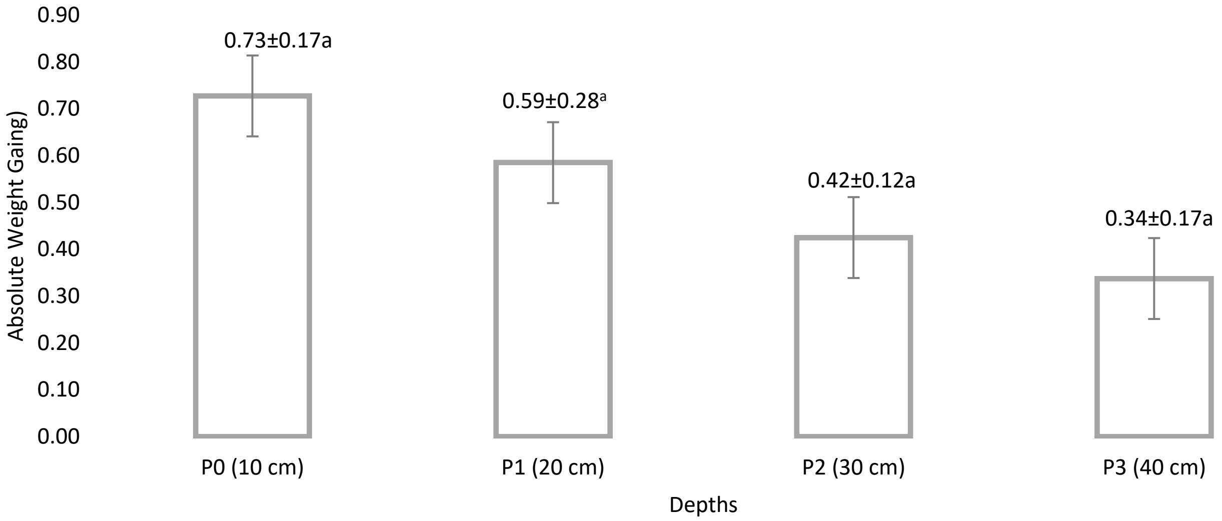

Figure 1. Absolute Weight Gain of *K. alvarezii*

3.2. Specific Growth Rate (%/day)

The results showed that the mean specific growth rate (SGR) of *K. alvarezii* cultivated in concrete tanks at different depth treatments ranged from 0.03 ± 0.02%/day to 0.07±0.02%/day. Overall, a declining trend in SGR was observed with increasing cultivation depth. The 10 cm depth treatment (P0) produced the highest mean SGR (0.07±0.02%/day), followed by the 20 cm depth treatment (P1) with a mean value of 0.06±0.03%/day and the 30 cm depth treatment (P2) with a mean value of 0.04 ± 0.01%/day. In contrast, the 40 cm depth treatment (P3) yielded the lowest mean SGR, at 0.03 ± 0.02%/day (Figure 2). Analysis of variance (ANOVA) showed that cultivation of *K. alvarezii* using a vertical culture system at different depths in concrete tanks had no significant effect on specific growth rate ($p > 0.05$).

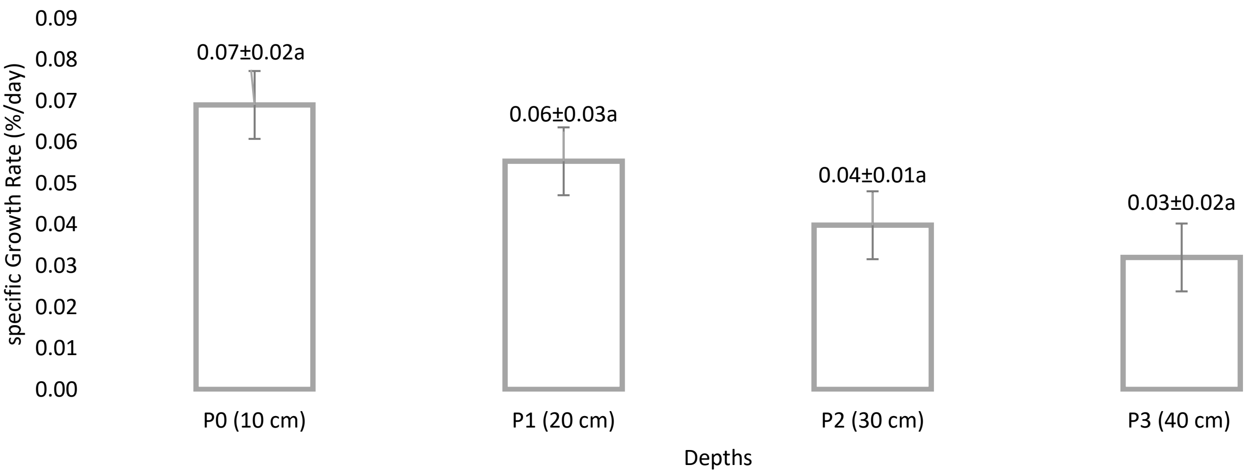

Figure 2. Specific Growth Rate of *K. alvarezii*

3.3. Thallus Length (cm)

The results indicated that the mean thallus length of *K. alvarezii* cultivated in concrete tanks under different depth treatments ranged from 0.225±0.05 cm to 0.95±0.06 cm. Overall, a decreasing trend in thallus length was observed with increasing cultivation depth across all treatments. The 10 cm depth treatment (P0) consistently produced the highest mean thallus length, whereas the 40 cm depth treatment (P3) resulted in the lowest mean values throughout the observation period (weeks 1–3). At the end of the culture period (week 3), the highest mean thallus length was recorded in the 10 cm depth treatment (P0), reaching 0.95±0.06 cm, while the lowest value was observed in the 40 cm depth treatment (P3), amounting to 0.225±0.05 cm (Figure 3). Analysis of variance (ANOVA) showed that cultivation of *K. alvarezii* using a vertical culture system at different depths in concrete tanks had no significant effect on thallus length at any observation time ($p > 0.05$).

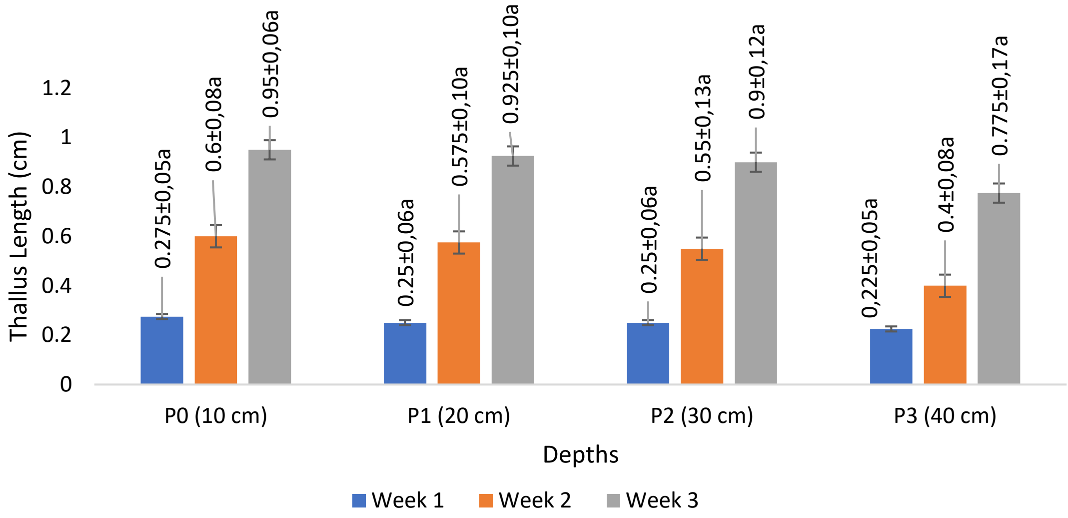

Figure 3. Thallus Length of *K.alvarezii*

3.4. Thallus Number

The results indicated that the mean number of thalli of *Kappaphycus alvarezii* cultivated in concrete tanks under different depth treatments ranged from 19.3±11.50 to 48.3±20.13. A decreasing trend in the number of thalli was observed with increasing cultivation depth, with the highest values consistently recorded in the shallowest treatment (P0). The 10 cm depth treatment (P0) produced the highest mean number of thalli (48.3±20.13), followed by the 20 cm depth treatment (P1) with a mean value of 34.7±14.57, and the 30 cm depth treatment (P2) with a mean value of 30.7±13.50. In contrast, the 40 cm depth treatment (P3) resulted in the lowest mean number of thalli, amounting to 19.3±11.50 (Figure 4).

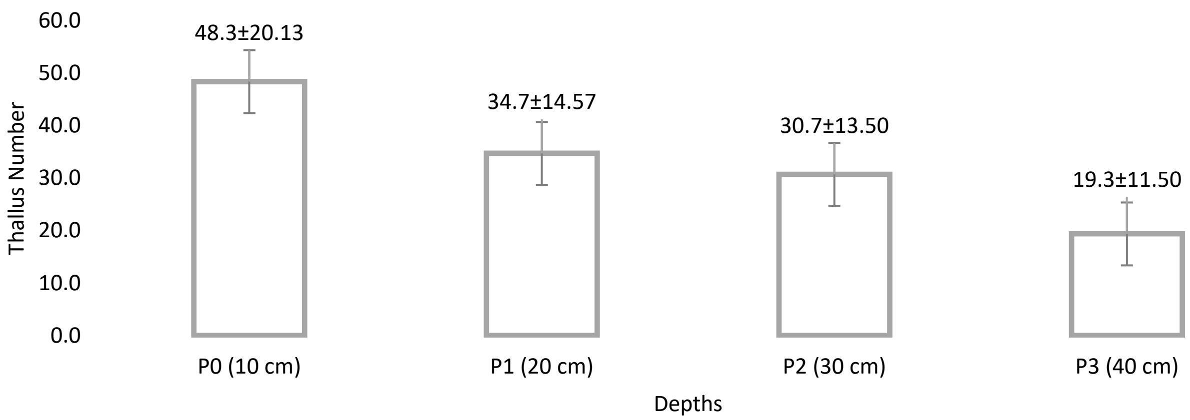

Figure 4. Thallus Number of *K. alvarezii*

3.5. Survival Rate (%)

The results showed that the mean survival rate of *K. alvarezii* cultivated in concrete tanks was 100% across all depth treatments. This indicates that differences in cultivation depth had no effect on the survival of *K. alvarezii* under the experimental conditions (Figure 5).

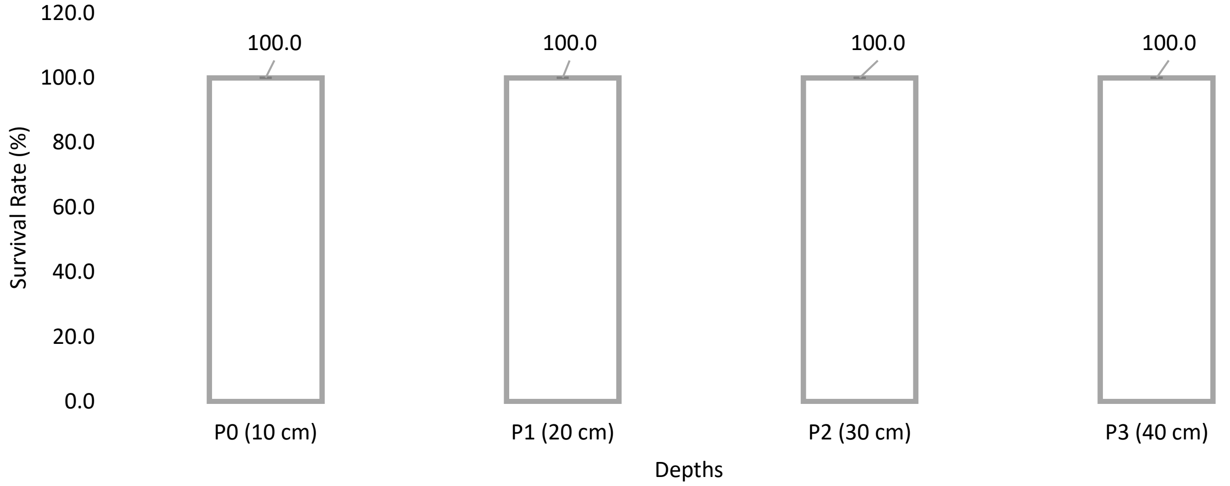

Figure 5. Survival Rate of *K. Alvarezii*

3.6. Water Quality

Water quality parameters measured during the experimental period remained within optimal ranges for the growth of *K. alvarezii* (Table 1).

Table 1. Water Quality Observations during the Cultivation of *K. alvarezii*

Parameter	Value	Ideal	Reference
Temperature (°C)	26.5°C – 27.9°C	26°C – 30°C.	Kumar et al. (2020)
pH	7.28 – 8.00	7.00 – 8.5	Kumar et al. (2020)
DO (gr/L)	6.0 – 8.0 mg/L	0.4 – 8.6 mg/L	Situmorang et al. (2021)
Salinity (ppt)	32 – 34 ppt	15 – 35 ppt	Nur et al. (2018)

4. DISCUSSION

The growth of *K. alvarezii* is determined by the interaction between environmental conditions and the physiological capacity of the thalli to utilize available resources for metabolic processes and tissue formation (Hurd et al., 2018). One environmental factor frequently examined in seaweed cultivation is planting depth, as depth is closely associated with light availability, nutrient distribution, and physical water conditions that directly influence photosynthesis and biomass production (Kirk, 2016). Theoretically, variations in planting depth may affect seaweed growth if they substantially alter light availability or other environmental factors essential for growth (Pereira & Neto, 2019). However, under relatively homogeneous and stable environmental conditions within the organism’s physiological tolerance limits, seaweed growth responses tend to remain similar across depth levels (Buschmann et al., 2017). Therefore, the effect of planting depth on seaweed growth should be interpreted within the context of environmental stability and physiological tolerance thresholds.

Overall, the results of this study demonstrated that cultivation of *K. alvarezii* using a vertical culture system at different depths in concrete tanks did not result in significant differences ($p > 0.05$) among depth treatments for any of the evaluated parameters, including absolute weight gain, specific growth rate (SGR), thallus length, number of thalli, and survival rate (Figures 1–5). These findings indicate that all applied depth treatments elicited comparable growth and survival responses. Similar outcomes have been reported in seaweed cultivation studies conducted under stable environmental conditions, in which variations in technical parameters did not necessarily yield significant differences in growth performance (Novianti et al., 2015). In contrast, Rukisah et al. (2020) reported that a shallower depth of 10 cm resulted in higher relative growth and SGR compared to depths of 20 and 30 cm, suggesting that higher light intensity at shallower depths can enhance photosynthetic efficiency. This comparison implies that as long as environmental conditions remain within optimal ranges, *K. alvarezii* can tolerate variations in planting depth and exhibit relatively uniform growth responses across treatments (Novianti et al., 2015).

Descriptively, the 10 cm depth treatment (P0) produced higher mean values of absolute weight gain compared to the deeper treatments (Figure 1). Nevertheless, these differences were not statistically significant, which is likely attributable to the homogeneity of environmental conditions throughout the experimental period. All depth treatments experienced stable and optimal culture conditions, as supported by water quality measurements that remained within suitable ranges for *K. alvarezii* growth across all treatments: temperature (26.5–27.9 °C), pH (7.28–8.00), dissolved oxygen (6.0–8.0 mg/L, and salinity (32–34 ppt) (Table 1). The stability of these parameters suggests that environmental conditions were not limiting, thereby minimizing the influence of depth variation on growth performance. Under these relatively uniform conditions, each depth treatment provided a comparable growth environment, particularly with respect to light availability and nutrient availability, resulting in similar photosynthetic activity and biomass formation. Relatively homogeneous environmental conditions are well known to produce uniform growth responses in seaweed cultivation, even when technical cultivation variables differ.

The findings of this study are consistent with those reported by Novianti et al. (2015), who investigated the cultivation of *K. alvarezii* using an off-bottom (bottom-line) method over a 30-day culture period. Their study demonstrated no significant differences in growth among planting depths of 10, 20, 30, and 40 cm under relatively homogeneous and stable environmental conditions. Although the cultivation system applied in the present study differs from the off-bottom method, the similarity in outcomes suggests that depth variation within a limited range does not constitute a growth-limiting factor for *K. alvarezii* as long as environmental conditions remain within optimal thresholds. When key environmental variables are maintained within suitable ranges, moderate variations in technical cultivation treatments generally do not induce significant differences in biomass accumulation (Pereira et al., 2021). In the present study, natural water currents were absent because the cultivation system employed concrete tanks. Nevertheless, limited water movement was generated through periodic water exchange and continuous aeration during the culture period. This artificial circulation likely facilitated the distribution of nutrients around the thalli, allowing individual *K. alvarezii* plants to experience relatively similar nutrient availability and, consequently, comparable opportunities for biomass formation across treatments.

A similar pattern was observed for specific growth rate (SGR), where no significant differences ($p > 0.05$) were detected among depth treatments, although the 10 cm depth treatment (P0) consistently exhibited the highest mean SGR values. In this study, SGR values ranged from 0.03±0.02 to 0.07±0.02%/day (Figure 2). These SGR values are relatively low compared to those reported for *K. alvarezii* during early growth phases or in open-water cultivation systems with more dynamic light exposure and nutrient availability, where SGR values commonly exceed 1%/day (Nurdin et al., 2021). This discrepancy is expected, given that the present experiment was conducted in concrete tanks with limited water circulation, relying primarily on aeration, which may constrain nutrient flux and light dynamics, thereby reducing growth rates. The relatively low SGR values observed in this study are also likely associated with the growth phase of the thalli during the culture period. As seaweed matures, growth rates typically decline, as a greater proportion of photosynthetically derived energy is allocated to tissue maintenance rather than the formation of new biomass (Nurdin et al., 2021). Under such conditions, growth responses across treatments tend to converge, resulting in relatively uniform SGR values despite differences in technical treatments. When seaweed thalli are in comparable growth stages, and environmental conditions remain optimal, growth responses are generally homogeneous, and statistically significant differences are unlikely to emerge (Kumar et al., 2020).

Similarly, for thallus length, the 10 cm depth treatment (P0) exhibited the highest mean value of 0.95±0.06 cm, whereas the 40 cm treatment (P3) showed the lowest mean value of 0.40±0.02 cm. However, statistical analysis indicated that these differences were not significant ($P > 0.05$) (Figure 3). Observations revealed a gradual decrease in thallus length across all treatments over the three-week culture period. This reduction is likely due to physiological adaptation and the reallocation of photosynthetic energy, whereby more energy is directed toward branch formation and biomass accumulation rather than to longitudinal thallus growth. Moreover, the range of planting depths used in this study remained within the physiological tolerance of *K. alvarezii*, resulting in no pronounced differences in thallus elongation among treatments. Depth effects on seaweed growth generally become apparent only when light intensity decreases sharply, or significant changes occur in hydrodynamic conditions (Nurdin et al., 2021). During this study, light availability at all depths remained sufficient to support photosynthesis, ensuring relatively uniform energy allocation for growth.

Regarding thallus number, the highest mean value was also observed in the 10 cm depth treatment (P0), reaching 48.3±20.13. Statistical analysis showed no significant differences ($P > 0.05$) among the different depth treatments, indicating that the processes of thallus formation and branching occurred at comparable rates across all treatments. This uniformity is likely influenced by the culture's homogeneity and optimal environmental conditions. Under stable environmental conditions with adequate light and nutrient availability, photosynthetic energy is generally utilized evenly for vegetative growth. Consequently, variations in planting depth within the limited range tested did not produce significant differences in thallus number. These findings are consistent with

Nurdin et al. (2021), who reported that planting depth did not significantly affect thallus number in *K. alvarezii* cultivated under stable water conditions.

The lack of significant differences in *K. alvarezii* growth across planting depths in this study is consistent with the observed 100% survival rate in all treatments (Figure 5). This indicates that no thalli died during cultivation, and thus planting depth was not a limiting factor for survival under the conditions of this experiment. The high survival rate suggests that environmental conditions in the concrete tanks—such as water quality and nutrient availability—remained within optimal ranges, thereby supporting uniform thallus survival across all treatments. Similar findings were reported by Kumar et al. (2022), who noted that *K. alvarezii* can maintain high survival rates as long as water quality parameters remain within its physiological tolerance, even when technical variations are applied in the cultivation system. In line with this, water quality parameters measured in the present study were stable across treatments: temperature ranged from 26.5 to 27.9 °C, pH from 7.28 to 8.00, dissolved oxygen (DO) from 6.0 to 8.0 mg/L, and salinity from 32 to 34 ppt.

Therefore, the absence of significant differences in growth and survival across planting depths indicates that all treatments experienced optimal, relatively homogeneous environmental conditions for *K. alvarezii* growth. The planting depths tested, ranging from 10 to 40 cm, fell within the tolerable range for this species. Under stable and supportive water conditions, limited variations in planting depth are insufficient to produce significant differences in growth (Novianti et al., 2015). Similarly, Pereira et al. (2021) reported that when major environmental factors remain within optimal ranges, non-extreme technical variations in cultivation generally elicit comparable growth responses.

5. CONCLUSION

The study demonstrated that differences in planting depth between 10 and 40 cm did not significantly affect the growth or survival of *K. alvarezii* in vertical culture using concrete tanks. Descriptively, the 10 cm depth treatment (P0) showed the highest growth, with mean values of absolute weight 0.73±0.17 g, specific growth rate (SGR) 0.07±0.02 %/day, thallus length 0.95±0.06 cm, thallus number 48.3±0.13, and survival rate 100%. These results were supported by optimal water quality during the cultivation period, with temperature 26.5–27.9°C, pH 7.28–8.00, DO 6.0–8.0 mg/L, and salinity 32–34 ppt.

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