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The effectiveness of seed soaking in calcium silicate for preventing ice-ice disease and production performance of *Kappaphycus alvarezii*

Efektifitas perendaman bibit pada kalsium silikat terhadap pencegahan penyakit *ice-ice* dan performa produksi *Kappaphycus alvarezii*

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ABSTRACT

The cultivation of *Kappaphycus alvarezii* faces serious challenges due to ice-ice disease outbreaks. This disease is caused by fluctuating environmental conditions that induce stress in the seaweed. Ice-ice disease is characterized by thallus whitening, softening, and fragility, which can lead to a reduction in yield and directly impact the economic returns for seaweed farmers. This study aims to evaluate the effectiveness of calcium silicate ($CaSiO_3$) dosing as a mineral source for the prevention of ice-ice disease and the growth of *K. alvarezii* seaweed. The experimental design used was a completely randomized design with three replications across four treatments: CaSiO3 doses of 0, 1.6, 1.8, and 2 g/L. The study used an initial weight of *K. alvarezii* of 100 g per tie. The experiment was conducted through a field trial in seawater using an off-bottom cultivation method. The results indicated that the group with the highest dose of $CaSiO_3$ (2 g/L) produced the best ice-ice resistance, with treatment D showing 17.77 ± 5.09% at the population level and 0.25 ± 0.015 at the individual level, which was statistically significant (P<0.05). Optimal $CaSiO_3$ dosing can be a potential cultivation strategy to improve resistance to ice-ice disease and increase the productivity of *K. alvarezii*.

Keywords: ice-ice, *Kappaphycus alvarezii*, mineral, nutrient enrichment, seaweed

ABSTRAK

Budidaya rumput laut *K. alvarezii* menghadapi tantangan serius akibat serangan penyakit *ice-ice*. Penyakit ini disebabkan karena kondisi lingkungan yang berfluktuatif sehingga menyebabkan rumput laut menjadi stres. Penyakit *ice-ice* ditandai dengan pemutihan talus, talus menjadi lunak, dan mudah patah. Penyakit ini dapat mengurangi hasil panen yang berdampak langsung pada keuntungan ekonomi bagi pembudidaya rumput laut. Penelitian ini bertujuan untuk mengevaluasi efektivitas pemberian dosis kalsium silikat ($CaSiO_3$) sebagai sumber mineral terhadap pencegahan penyakit *ice-ice* dan pertumbuhan rumput laut *K. alvarezii*. Rancangan percobaan yang digunakan adalah rancangan acak lengkap dengan tiga kali ulangan pada empat perlakuan yaitu dosis CaSiO3 0, 1,6, 1,8, dan 2 g/L. Penelitian ini menggunakan berat awal *K. alvarezii* sebesar 100 g per ikatan. Pengujian dilakukan dengan percobaan lapangan di perairan laut dengan metode lepas dasar. Hasil penelitian menunjukkan bahwa kelompok dengan dosis $CaSiO_3$ tertinggi (2 g/L) secara signifikan (P<0,05) menghasilkan persentase *ice-ice* terbaik yaitu pada perlakuan D sebesar 17,77 ± 5,09% pada level populasi dan sebesar 0,25 ± 0,01% pada level individu. Pemberian $CaSiO_3$ pada dosis optimal dapat menjadi strategi budidaya yang potensial untuk meningkatkan ketahanan dari penyakit *ice-ice* dan produktivitas *K. alvarezii*.

Kata kunci: *ice-ice*, *Kappaphycus alvarezii*, mineral, pengayaan nutrisi, rumput laut

INTRODUCTION

Seaweed farming contributes approximately 51.3% to the total global mariculture production and continues to grow at a notable annual rate of 6.2% (Duarte *et al.,* 2021). Seaweed holds substantial economic value due to its diverse applications across the food, cosmetics, pharmaceutical, and chemical industries (Selnes *et al.,* 2021). However, the cultivation of seaweed faces several critical challenges, particularly the emergence of diseases and pest infestations, which are major factors limiting production yields. In the case of *Kappaphycus alvarezii*, one of the most significant threats to cultivation is *ice-ice* disease, which severely compromises productivity and poses a serious constraint on sustainable production (Aris & Ibrahim, 2020). Ice-ice disease is a pathological condition that negatively impacts seaweed farming activities, particularly in species of *Eucheuma* and *Kappaphycus*. Based on Ward *et al*. (2021), ice-ice disease in seaweed is a syndrome triggered by environmental and microbiological factors.

In *Kappaphycus alvarezii* and other seaweed species, ice-ice disease is associated with bacterial infections involving several genera, including *Pseudomonas*, *Stenotrophomonas*, *Shewanella*, *Ochrobactrum*, *Aeromonas*, and *Bacillus* (Achmad *et al.,* 2016; Ward *et al.,* 2021; Tuhumury *et al.,* 2024). In addition to microbiological factors, ice-ice disease is also triggered by environmental changes that cause stress in seaweed. According to Arasamuthu & Edward (2018) seaweed becomes more susceptible to ice-ice disease due to environmental fluctuations, including changes in temperature, salinity, water currents, and transparency. Extreme fluctuations in water temperature can induce physiological stress in seaweed. Likewise, drastic changes in salinity can also stress the seaweed, weakening its resistance to pathogenic infections.

These environmental stressors make seaweed more vulnerable to disease. Environmental changes associated with global climate change have had a significant impact on the biological and chemical responses of seaweed, primarily due to rising sea surface temperatures (Roleda & Hurd, 2019; Kumar *et al.,* 2020; Urrea-Victoria *et al.,* 2020). Ice-ice disease is a serious condition that can significantly reduce seaweed production. The formation of ice-like lesions on the thallus causes considerable economic losses for farmers. This disease is characterized by the whitening or discoloration of the thallus, leading to massive fragmentation and degradation of seaweed quality, which ultimately impacts overall yield (Aris & Labenua, 2020).

According to Tahiluddin and Terzi (2021), early signs of the disease include the appearance of white patches caused by pigment degradation, which eventually leads to softening of the thallus, making it vulnerable to damage and detachment. Darma *et al*. (2021) also reported that the disease typically begins with the appearance of reddish spots on certain parts of the thallus, which later turn pale yellow and eventually become white. One strategy to mitigate ice-ice disease in *Kappaphycus alvarezii* is through nutrient enrichment. According to Muyong and Tahiluddin (2024), nutrient enrichment is a practical approach to ensure the sustainability of seaweed farming in the face of various challenges.

Xu *et al*. (2020), explain that providing additional nutrients can enhance seaweed growth and help achieve optimal production. Nutrient supplementation also plays a role in maintaining seaweed resistance to disease. Since seaweed relies heavily on naturally available nutrients in the cultivation environment, nutrient limitations are inevitable and can lead to stunted growth, increasing susceptibility to ice-ice disease (Maryunus, 2018; Tahiluddin & Terzi, 2021). The supplementation of calcium (Ca) and silicate (Si) is believed to improve seaweed health. Both elements can help stabilize membrane structures and support the formation of more rigid cell structures (Nurhayati, 2021; Irsyad & Rachmawati, 2022). According to Mizuta *et al*. (2021), silicon is an essential element for certain marine algae, as it plays a crucial role in strengthening the cell wall and enhancing resistance to environmental stress.

Several species of green and brown macroalgae absorb and accumulate silicon in their tissues. It is suggested that the absorbed Si is stored in the cell wall in the form of silicates, thereby increasing the mechanical strength of the wall and improving resistance to physical stress. Previous research using mangrove leaf extract as nutrient enrichment for *Kappaphycus striatus* showed effective results in preventing ice-ice disease (Syafitri *et al.,* 2017). Another study reported by Tahiluddin *et al*. (2022a) also revealed that the application of powdered sea plant extract nutrients could improve growth and reduce ice-ice disease in *K. striatus.* The latest study conducted by Muyong and Tahiluddin (2024), showed that nutrient enrichment in the form of 3.5 g/L ammonium phosphate could significantly enhance growth and provide protection against the occurrence of ice-ice disease in *K. alvarezii*.

Research on the use of nutrients to enhance growth and control ice-ice disease in seaweed has been widely conducted; however, this study will examine the use of the mineral calcium silicate ($CaSiO_3$) as a preventive measure against ice-ice disease and to improve the production performance of *Kappaphycus alvarezii*. This study aims to evaluate the effectiveness of the appropriate $CaSiO_3$ dosage in cultivating *K. alvarezii*, thereby serving as a strategy and new source of information for preventing ice-ice disease in this species.

MATERIALS AND METHODS

This research was conducted over 45 days, from August to September 2024, in Jungutbatu, Nusa Penida District, Klungkung Regency, Bali Province. Thallus tissue observations were conducted in the Plant Physiology and Genetics Laboratory, Department of Biology, IPB University.

Experimental Design

This study employed a completely randomized design consisting of four treatments and three replications. The cultivation method used was the off-bottom method. The application of calcium silicate ($CaSiO_3$) was carried out with four different dosages: A 0 g/L (Ca 0 g; Si 0 g), B 1.6 g/L (Ca 0.3722 g; Si 0.260 g), C 1.8 g/L (Ca 0.4188 g; Si 0.2935 g), and D 2 g/L (Ca 0.4653 g; Si 0.3261 g). $CaSiO_3$ was applied in four separate containers using buckets to prevent potential interaction between treatments. Each treatment required three cultivation lines as replications. A total of twelve cultivation lines were used across all treatments. Each cultivation line consisted of thirty bundles of *K. alvarezii*.

Research Procedure

The research began with the preparation of the cultivation medium as the experimental unit. The cultivation medium used for *Kappaphycus alvarezii* was seawater, applying the off-bottom cultivation method. Three types of ropes were used: the mainline rope, the cultivation line rope, and the tying rope for the seaweed. The mainline rope was made of multifilament polyethylene (PE) with a diameter of 8 mm. The cultivation line rope had a diameter of 3–4 mm. Raffia rope was used to tie the seaweed seedlings. Wooden stakes were used to secure the mainline, with lengths ranging from 90 to 130 cm and diameters of 5–9 cm.

The water depth at the site was at least 20 cm during the lowest tide and up to 3 meters at the highest tide (Pong-Masak & Sarira, 2020). The application of $CaSiO_3$ to *Kappaphycus alvarezii* was carried out following the procedure of (Muyong & Tahiluddin, 2024). For each treatment, seaweed seedlings were weighed at 100 grams per bundle. Each *K. alvarezii* seedling was soaked in a $CaSiO_3$ solution at a concentration of 100 g/L for one hour, according to the treatment, based on a preliminary study. The soaking process was conducted in separate bucket containers for each treatment. After soaking, the 100-gram seedlings were tied to raffia rope with a spacing of 25 cm between bundles (Supiandi *et al.,* 2020). Each cultivation line contained thirty bundles, with each bundle weighing 100 grams. Throughout the research period, the seaweed was monitored and cleaned to protect and maintain its condition. The cultivation lines were shaken to remove debris attached to *Kappaphycus alvarezii*.

Research Parameter

Sampling of *Kappaphycus alvarezii* for observation of ice-ice disease was conducted through direct visual inspection in the field. Based on the classification proposed by Tahiluddin and Damsik (2023), thallus showing discoloration to white and a softer texture were identified as signs of ice-ice disease. Bundles of *K. alvarezii* displaying symptoms of ice-ice disease were counted, and the prevalence of the disease was estimated by calculating the weight of infected thallus as a percentage of the total seaweed weight. The results were recorded based on population-level and individual damage (per bundle). The percentage of ice-ice disease was calculated using the formula by (Largo *et al.,* 1995):

$$\text{Ice-ice disease (\%)} = \frac{\text{Weight of thallus infectes by ice-ice}}{\text{Total weight of thallus}} \times 100$$

The observed parameter used to assess production performance was the measurement of *Kappaphycus alvarezii* weight using a digital scale with an accuracy of 0.01 g. The objective was to determine the daily weight growth rate and daily length growth rate. Measurements were taken before and after the cultivation period of *K. alvarezii*. The calculation of absolute weight growth followed the formula provided by (Effendie, 1997):

$$W = Wt - W0$$

Note:
W = Absolute weight (g)
Wt = Weight of *K. alvarezii* at the end of the study (g)
W0 = Weight of *K. alvarezii* at the beginning of the study (g)

Specific growth rate using the formula according to (Anggadireja *et al.,* 2006):

$$SGR = \left(\frac{(\ln Wt - \ln W0)}{t}\right) \times 100$$

Note:
SGR = Specific growth rate (%)
Wt = Final weight of seaweed (g)
W0 = Initial weight of seaweed (g)
t = Maintenance period (days)

Observation of seaweed thallus tissue was carried out by preparing thin cross-sections for microscopic examination. The seaweed was fixed using 70% ethanol. Observations were made using an Olympus CX21 microscope at a magnification of 40×10. Images of the preparations were captured using Optilab Viewer® v.2.1. Cortex thickness measurements were performed using ImageJ software (NIH, USA) (Raharja *et al.,* 2020). Water quality data were collected as supporting data and measured *in situ*, including parameters such as temperature, salinity, pH, current velocity, and depth. Water quality samples were collected from the cultivation waters of *Kappaphycus alvarezii*.

Data Analysis

The data were tabulated using Microsoft Excel 2021. Production performance parameters and the percentage of ice-ice disease were analyzed using Analysis of Variance (ANOVA) at a 95% significance level, followed by Duncan's multiple range test. Thallus tissue thickness in seaweed, as well as water quality parameters such as salinity, temperature, pH, depth, and current velocity, were analyzed descriptively.

RESULTS AND DISCUSSION

Result

The occurrence of ice-ice disease

The effect of seedling immersion in $CaSiO_3$ showed a significant result ($P<0.05$) in reducing the incidence of ice-ice disease. Data on the occurrence of ice-ice disease were recorded based on damage at the individual (bundle) level, calculated by dividing the weight of damaged *K. alvarezii* thalli by the final weight in each bundle. The control group (A) had the highest ice-ice disease rate, at 4.85% per bundle, while treatment D had the lowest rate, at 0.25%. Damage at the individual level is shown in Figure 1. Damage at the population level was recorded by evaluating all *K. alvarezii* bundles in each treatment group. In the control group (A), the incidence of ice-ice disease reached 91%. In treatment C, it was 26.66%, which was not significantly different

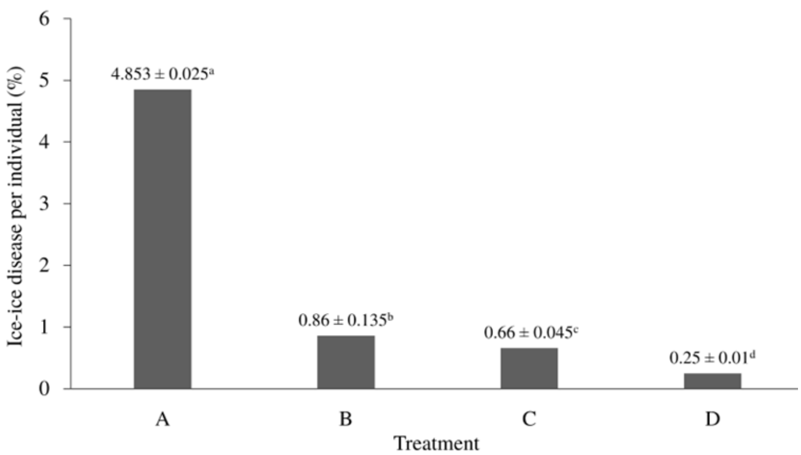

Figure 1. Percentage of ice-ice disease in *Kappaphycus alvarezii* per individual over 45 days. Dosage A ($CaSiO_3$ 0 g/L), B ($CaSiO_3$ 1.6 g/L), C ($CaSiO_3$ 1.8 g/L), D ($CaSiO_3$ 2 g/L). Data are presented as mean ± standard deviation. Different letters indicate significant differences ($P<0.05$; Duncan's test), while the same letters indicate no significant difference ($P<0.05$; Duncan's test).

from treatments D and B. The lowest incidence was observed in treatment D, at 17.77%, as presented in Figure 2.

Thallus tissue

The condition of *Kappaphycus alvarezii* thallus tissue in each treatment showed differences in average cortex thickness, as presented in Table 1. The control group (A) had a thinner cortex compared to the treatments with $CaSiO_3$ application. As the dosage increased, the cortex thickness also tended to increase. However, in treatment C, the cortex was thinner than in treatment B, although the difference was not statistically significant. Descriptively, the cross-sectional condition of *Kappaphycus alvarezii* thallus tissue in each treatment is presented in Figure 3. At 40×10 magnification, the epidermal

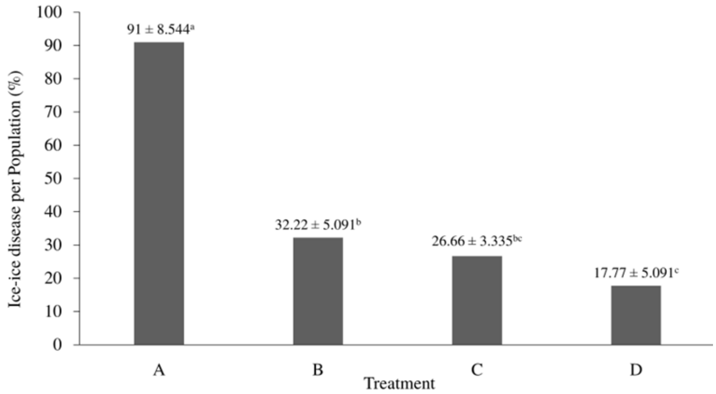

Figure 2. Percentage of ice-ice disease in *Kappaphycus alvarezii* per population over 45 days. Dosage A ($CaSiO_3$ 0 g/L), B ($CaSiO_3$ 1.6 g/L), C ($CaSiO_3$ 1.8 g/L), D ($CaSiO_3$ 2 g/L). Data are presented as mean ± standard deviation. Different letters indicate significant differences (P<0.05; Duncan's test), while the same letters indicate no significant difference (P<0.05; Duncan's test).

Table 1. Cortex Thickness of *Kappaphycus alvarezii* Thallus

Treatment	Cortex Thickness (μm)
A	8.76 ± 0.66[a]
B	14 ± 0.2[b]
C	13.3 ± 0.65[b]
D	18 ± 0.61[c]

Note: A ($CaSiO_3$ 0 g/L), B ($CaSiO_3$ 1.6 g/L), C ($CaSiO_3$ 1.8 g/L), D ($CaSiO_3$ 2 g/L). Data are presented as mean ± standard deviation. Different letters indicate significant differences (P<0.05; Duncan's test), while the same letters indicate no significant difference (P<0.05; Duncan's test).

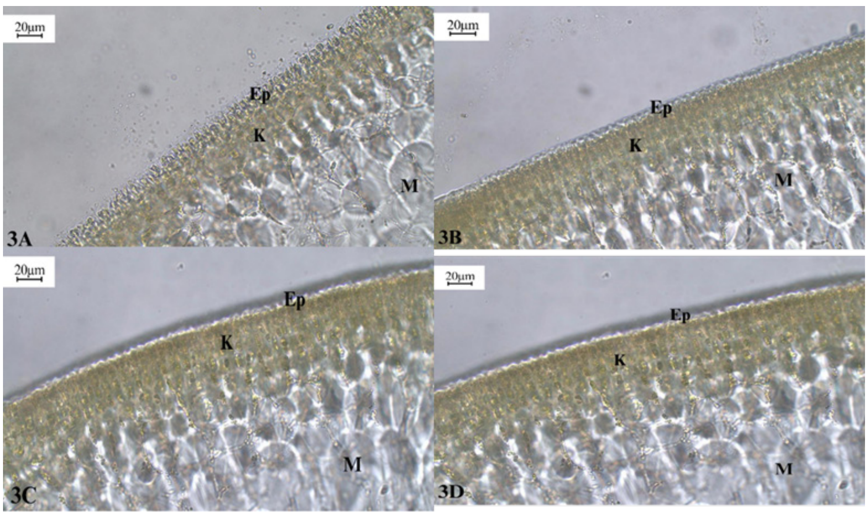

Figure 3. Cross section of *K. alvarezii* thallus. Dosage 3A ($CaSiO_3$ 0 g/L), 3B ($CaSiO_3$ 1.6 g/L), 3C ($CaSiO_3$ 1.8 g/L), 3D ($CaSiO_3$ 2 g/L). Epidermis (Ep), cortex (K), medulla (M). Bar: 20 μm.

tissue structure in the control group appeared looser compared to the treatments with $CaSiO_3$ application.

Absolute Weight

Nutrient enrichment through the application of $CaSiO_3$ can increase the weight of cultivated *Kappaphycus alvarezii*. The results showed a significant difference (P<0.05) among the treatments. The control treatment (A) had the lowest absolute weight, at 111.2 g, compared to the treatments with $CaSiO_3$ application. The highest weight was observed in treatment D, at 310.85 g, while the lowest was in the control group (A), at 111.2 g, as shown in Figure 4.

Specific growth rate (SGR)

Based on the ANOVA results, the use of $CaSiO_3$ had a significant effect (P<0.05) on the specific growth rate (SGR) of *Kappaphycus alvarezii*. The results showed that the control group (A) had the lowest SGR at 1.66%. Treatments B and C had the same average SGR of 2.62%. The highest result was observed in treatment D, with an SGR of 3.14%. This is shown in Figure 5.

Water quality

Water quality measurements at the cultivation site were conducted over a 45-day period and are presented in Table 2. During the study, water quality was assessed by observing several

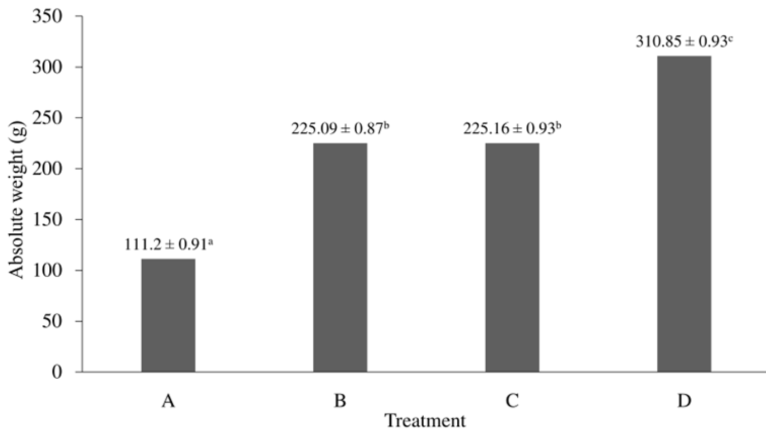

Figure 4. Absolute weight of *Kappaphycus alvarezii*. Dosage A ($CaSiO_3$ 0 g/L), B ($CaSiO_3$ 1.6 g/L), C ($CaSiO_3$ 1.8 g/L), D ($CaSiO_3$ 2 g/L). Data are presented as mean ± standard deviation. Different letters indicate significant differences (P<0.05; Duncan's test), while the same letters indicate no significant difference (P<0.05; Duncan's test).

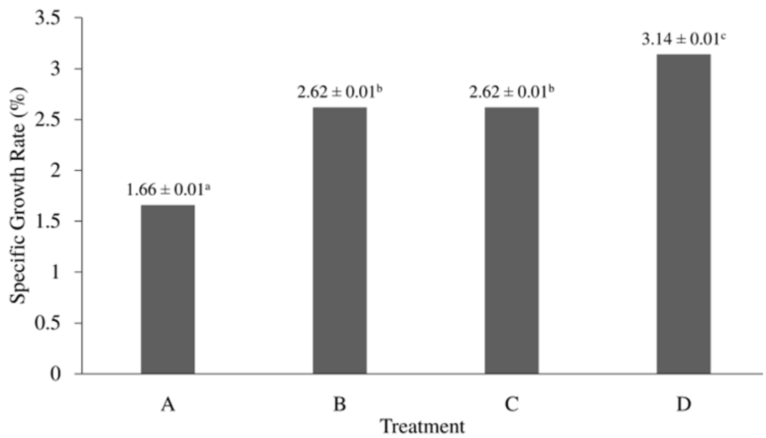

Figure 5. Specific growth rate of *Kappaphycus alvarezii*. Dosage A ($CaSiO_3$ 0 g/L), B ($CaSiO_3$ 1.6 g/L), C ($CaSiO_3$ 1.8 g/L), D ($CaSiO_3$ 2 g/L). Data are presented as mean ± standard deviation. Different letters indicate significant differences (P<0.05; Duncan's test), while the same letters indicate no significant difference (P<0.05; Duncan's test).

parameters, including temperature, salinity, pH, depth, and current velocity. Temperature and salinity fluctuated throughout the data collection period but remained within the optimal range. Overall, some water quality parameters at the research site were found to be outside the optimal range for *Kappaphycus alvarezii* cultivation. The measurement results for each water quality parameter are presented in Table 2.

Discussion

Ice-ice disease in *Kappaphycus alvarezii* is caused by a combination of environmental factors and pathogen infection. Sudden changes in water quality, such as fluctuations in temperature and salinity, can increase physiological stress in algae, making them more susceptible to pathogen attacks (Ward *et al.,* 2020). *K. alvarezii,* experiencing stress due to environmental conditions, releases moist organic substances, which facilitate bacterial infection of the thallus (Riyaz *et al.,* 2020). Ice-ice infection is characterized by discoloration of the thallus to white, followed by softening and easy breakage of the thallus. Bacterial species identified as pathogenic agents in seaweed infected by ice-ice disease include *Vibrio alginolyticus*, *Vibrio fluvialis*, *Vibrio cholerae*, and *Aeromonas caviae* (Tuhumury *et al.,* 2024). Damage to the thallus can hinder the photosynthesis process and seaweed growth. In more severe cases, this disease can significantly reduce the overall seaweed population at the cultivation site, resulting in substantial economic losses.

During the ice-ice season, *Kappaphycus alvarezii* enriched with calcium silicate ($CaSiO_3$) at the highest dosage (2 g/L) was able to significantly reduce ice-ice disease incidence to 0.25% at the individual level and 17.77% at the population level over a 45-day cultivation period. In comparison, the control group experienced a relatively high incidence of ice-ice, with 4.85% at the individual level and 91% at the population level. Another study, conducted by Tahiluddin *et al*. (2022b), using ammonium phosphate fertilizer at a concentration of 8.82 g/L over 49 days, also reduced the incidence of ice-ice by 42.37%. In contrast, at a low concentration of 0.01 g/L, the incidence reached 78.07%. Another study involving inorganic nutrient enrichment with urea and pure phosphorus showed no significant effect on the incidence of ice-ice disease. On day 45, treatment with urea resulted in 39.95% incidence, phosphorus 45.90%, and the group without nutrient enrichment reached 61.48% (Sarri *et al.,* 2022).

A study by Patadjai *et al*. (2019), using immersion in lantana flower leaf extract also showed that *K. alvarezii* remained healthy and unaffected by ice-ice disease. In the control group of that study, ice-ice symptoms appeared, indicated by the presence of white spots on the thallus. The results of this study indicate that $CaSiO_3$ also plays a role in reducing ice-ice disease by strengthening the structural and physiological resistance of *Kappaphycus alvarezii* to environmental stress and ice-ice-causing pathogens, thereby helping to prevent the disease from occurring. The elements Ca and Si are known to support the formation of stronger cell walls and enhance resistance to environmental stress. As shown in Figure 3, the control group exhibited weakened cell wall strength, with visible damage to the epidermis. This damage appeared as loosely packed epidermal tissue, reducing its function as a physical barrier against pathogens and as a structural defense.

An increase in $CaSiO_3$ dosage also increased cortex cell thickness, as shown in Figure 3. The increase in cortex thickness and the strengthening of epidermal cell walls can enhance the physical barrier against environmental stress and pathogens. Silicon (Si) is an essential element for marine algae, as it plays a crucial role in strengthening the cell wall and enhancing resistance to environmental stress. In marine ecosystems, various marine

Table 2. Water quality of *K. alvarezii* cultivation research location.

Parameter	Unit	Value	Optimum standard	Reference
Temperature	°C	28.6–32.9	28–31	(Syahrul *et al*., 2023)
Salinity	ppt	29.9–34.6	25–35	(Aris *et al*., 2021)
pH	-	7.2–8.4	7.5–8.5	(SNI, 2011)
Water depth	cm	20–78	30–50	(Prayudha *et al*., 2024)
Current velocity	m/s	0.1–0.4	0.2–0.4	(SNI, 2011)

organisms (algae and phytoplankton) absorb Si in the form of monosilicic acid ($Si(OH)_4$). This absorption process allows marine organisms to store Si within their tissues as biogenic silica (BSi) (Yacano *et al.,* 2022).

Biogenic silica plays a key role in forming strong cell wall structures that help resist environmental pressures and support metabolic functions. Si absorbed and stored in the cell wall can increase the mechanical strength of the cell wall, making it more resistant to physical stress (Mizuta *et al.,* 2021). This is important for marine algae because aquatic environments are often dynamic and can change rapidly; thus, the presence of Si helps algae adapt to fluctuating environmental conditions. Silicon (Si) is not considered essential for all plants; however, it provides substantial benefits for tissue strength and resistance, especially in plants that require higher protection against environmental stress.

The application of $CaSiO_3$ can enhance tolerance to abiotic stresses such as temperature and salinity, as well as tolerance to biotic stress caused by pathogenic organisms (Kovács *et al.,* 2022). $CaSiO_3$ serves as an additional physical barrier, reinforcing the cell wall and protecting against pathogen penetration. With the presence of Ca and Si layers, pathogens face difficulty penetrating the tissue, thereby preventing infection and physical damage (Song *et al.,* 2021). Seaweed treated with $CaSiO_3$ tends to exhibit milder stress symptoms, as indicated by the lower percentage of ice-ice disease in *K. alvarezii* compared to the control.

The application of different $CaSiO_3$ dosages showed a significant effect on the absolute weight and specific growth rate (SGR) of *Kappaphycus alvarezii*. The group with the highest $CaSiO_3$ dosage (2 g/L) produced the highest absolute weight (310.85 g) and SGR (3.14% per day). These results indicate that the application of $CaSiO_3$ is effective in reducing ice-ice disease by strengthening the algal thallus. With a strong thallus, *K. alvarezii* can grow optimally without expending energy to repair tissue damaged by infection. A recent study conducted by Muyong and Tahiluddin (2024), reported an average final weight of 325 g with an SGR below 3%, using a combination of 3.5 g/L ammonium phosphate immersion and off-bottom cultivation method.

Immersion in ammonium phosphate resulted in a lower SGR, as ammonium phosphate supports growth without directly strengthening the thallus, unlike $CaSiO_3$. Therefore, daily growth efficiency was slightly lower, although it remained effective in increasing biomass. Another study conducted by Rahman *et al*. (2023), showed that the application of fermented mangrove leaves (*Avicennia marina*) enriched with *Bacillus subtilis* with a 2-hour immersion duration was able to control ice-ice disease and resulted in the highest SGR of 2.34% per day. A similar study by Rahman *et al*. (2020), which utilized a fermented extract of *Sonneratia alba* mangrove leaves at varying dilution levels, achieved an SGR of 4.32%. Fermented mangrove leaf extract contains macro- and micronutrients that support metabolic activity and accelerate the growth rate of seaweed (Rahman *et al.,* 2022). This allows algae to utilize nutrients and energy for growth, thereby increasing absolute weight and SGR.

Another study by Tahiluddin *et al*. (2022a) farmers and researchers have been considering nutrient enrichment as one way of easing these issues to increase production to meet the growing demand for carrageenan in the world market. In this study, we determined the effects of Acadian Marine Plant Extract Powder (AMPEP, showed that the application of Acadian Marine Plant Extract Powder (AMPEP) resulted in an SGR of 4.27% per day, which is higher than the application of $CaSiO_3$, which produced an SGR of 3.14% per day. This difference is due to the distinct composition and function of each substance. AMPEP, derived from marine plant extracts, is rich in phytohormones and growth regulators that stimulate cell growth and accelerate cell division. In contrast, $CaSiO_3$ plays a role in strengthening the cell wall and enhancing resistance to ice-ice disease, so its effect is more prominent in physical resistance rather than growth rate.

According to Simanungkalit *et al*. (2024), a reasonable seaweed growth rate is above 3%, indicating that the application of $CaSiO_3$ is capable of achieving optimal growth standards for *K. alvarezii*. Water quality measurements were carried out throughout the study to ensure optimal environmental conditions. Water quality has a direct impact on the health and growth of seaweed. The observed water quality parameters included temperature, pH, salinity, current velocity, and water depth. The measurement results showed that several water quality parameters were within the optimal range, while others were still below or above the optimal standard.

CONCLUSION

Nutrient immersion using the mineral $CaSiO_3$ had an effect on the prevention of ice-ice disease, which in turn affected the absolute weight and specific growth rate of *Kappaphycus alvarezii*. The lowest percentage of ice-ice, based on the results obtained, was found in treatment D, with 17.77 ± 5.09% at the population level and 0.25 ± 0.01% at the individual level. The highest specific growth rate was also found in treatment D, at 3.14 ± 0.01%.

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