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Optimizing *Kappaphycus alvarezii* Productivity Using Biofertilizer Derived from a Combination of Black Soldier Fly Larvae Frass and Seaweed

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Abstract

Kappaphycus alvarezii is an important seaweed for various industries. Indonesia, as one of the largest producers, cultivates it extensively in South Sulawesi, particularly on Tanakeke Island. However, because the adoption of aquaculture technologies among local farmers remains limited, the quality and quantity of production are not yet optimal, making the use of biofertilizers one solution to increase cultivation yields. Biofertilizers are necessary because they are environmentally friendly and can be made from industrial waste to improve productivity. However, their effectiveness is not yet known, and the basic materials are very limited. Therefore, this study aims to evaluate the effectiveness of using biofertilizers made from black soldier fly frass (BSFF) and K. alvarezii in increasing the specific growth rate and carrageenan content of K. alvarezii. Water-quality parameters were also measured to support the interpretation of the experimental results. Samples were collected in Mallasoro Bay, South Sulawesi, and laboratory analysis were conducted at Pangkajene Pangkep Island State Polytechnic Laboratory. This research used four treatments: treatment A (BSFF-based biofertilizer), treatment B (K. alvarezii-based biofertilizer), treatment C (combination of BSFF and K. Alvarezii-based biofertilizer), and treatment D (control). The results showed that treatment C had the highest average specific growth rate of 5.41 ± 0.84%. Treatment C also had the highest carrageenan content of 56.61 ± 0.63%. This study highlights the potential of a combination of biofertilizer based on BSFF and seaweed as an environmentally friendly and cost-effective alternative to chemical fertilizers for increasing K. alvarezii cultivation productivity while utilizing BSFF waste. However, commercial use of these biofertilizer combinations requires further study.

Keywords: *BSFF, Seaweed Cultivation, Specific Growth Rate, Carrageenan*

Introduction

Seaweed is an aquaculture product used as a raw material in food and medicine that is rich in nutrients and has high economic value globally. Therefore, seaweed has been widely cultivated to meet 0.13% of global food energy demand (Snethlage *et al*., 2023). Economically, seaweed farming contributes to national and local economies by providing employment opportunities and increasing foreign exchange earnings. Therefore, it is critical to enhance the production and quality of seaweed.

One option for increasing seaweed production and improving seaweed quality is the appropriate application of aquaculture technologies that can minimize negative impacts on the environment. Utilization of aquaculture technology can be used in seaweed cultivation. One of the common red seaweed species found in tropical and subtropical areas, especially in Southeast Asian countries such as Indonesia, is *Kappaphycus alvarezii* (commercially known as *Eucheuma cottonii*) (Rimmer *et al*., 2021). *K. alvarezii* is generally found at depths of 1-2 m above sandy or craggy bottoms and grows better in clean, shallow waters under fairly strong light. It is a rich resource of carrageenan, a form of polysaccharide widely used in the food industry as a thickener and stabilizer (Ha *et al*., 2022).

K. alvarezii farming supports the balance of marine ecosystems and provides income opportunities for coastal communities. It acts as a biofilter by reducing excess NO_3 in the sea (Hayashi

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et al., 2008; Mualam *et al.,* 2022), and its CO_2 absorption capacity can be utilized for climate change mitigation (Erlania and Radiata, 2014). Its cultivation has also been shown to increase the abundance, biomass, and diversity of macrobenthos in surrounding ecosystems (Bhowmik *et al.,* 2025).

In addition, global *K. alvarezii* production in 2018 reached 1.5 million tons, most of which was cultivated. Its economic value is also significant globally, reaching approximately USD 214.8 million, mainly for the production of kappa-carrageenan in the pharmaceutical, food, cosmetics, and textile industries. Indonesia is one of the world's largest seaweed producer, where *K. alvarezii* accounts 65% of Indonesia's total seaweed production. Its cultivation also provides job opportunities for 1 million people in the marine aquaculture sector (local coastal communities), as it contributes 40% of Indonesia's total fishery production (Mirwan *et al.,* 2025).

K. alvarezii cultivation in Indonesia is extensively practiced in South Sulawesi, particularly on Tanakeke Island. This island has a maritime ecosystem with abundant aquatic flora and fauna, as it is surrounded by many small islands. According to Jamaluddin *et al.* (2019), stable ocean currents and good water quality make it suitable for the cultivation of red seaweed. However, seaweed farmers on this island face various challenges, such as limited access to modern aquaculture technology and inputs that can improve the seaweed quality and productivity. This is supported by the results of a study by Mirwan *et al.* (2025) in Tompotana Village on this island, which revealed that the income and productivity of seaweed farmers are not only influenced by capital; production techniques and market dynamics also contribute significantly. This condition indicates a gap in cultivation practices and in the adoption of technology.

Improving the quality and productivity of seaweed can be achieved through the use of biofertilizers. Their environmentally friendly characteristics make it preferable to chemical fertilizers that are commonly used commercially. Biofertilizers derived from organic materials such as biotic residues and agricultural waste sometimes contain nutrients, but their effectiveness is not yet known. Therefore, the feedsctocks used to produce biofertilizers is important to consider because it will affect the growth of cultivated plants. In addition, the biofertilizer production can be costly, and the availability of feedstocks with sufficient nutritional quality is limited (Thi *et al*., 2024). For these reasons, it is becoming a challenge to produce biofertilizers for small and medium-scale aquaculture industries.

Organic industrial waste that has been used as a base for biofertilizers over the last five years is black soldier fly larvae frass (BSFF). BSFF is waste from the maggot industry or the larvae of *Hermetia illucens.* BSFF contains chitin, protein, biostimulants, and various micro and macronutrients that are important for soil fertilization (Manan *et al*., 2024). BSFF also contains many decomposing microbes that convert organic waste into biomass, such as fat, protein, and vitamins, making it widely used as a feed in aquaculture (Manan *et al*., 2024). *K. alvarezii* has also been used as a base material for making biofertilizers. *K. alvarezii* contains bioactive compounds and minerals that can stimulate decomposer microorganisms and improve nutrients in the soil (El-Beltagi *et al*., 2022). *K. alvarezii* is processed by crushing and extracting the sap to be used as a commercial plant fertilizer.

BSFF and seaweed-based biofertilizers have been widely used in agriculture and as animal feed. However, few studies have evaluated their effects on marine plants, especially *K. alvarezii*. Empirical data on its effectiveness and processing techniques for biofertilizers remain key research gaps (Shang *et al*., 2023). With the increasing demand for seaweed along with sustainable aquatic ecosystems, it is necessary to conduct extensive research on both materials as components of biofertilizer ingredients for *K. alvarezii* cultivation. This will help reduce the carbon footprint and the need for chemical fertilizers that can pollute the environment (Filbee-Dexter *et al*., 2023).

Given the current situation and requirements, this research aims to examine the effectiveness of the use of biofertilizers made from BSFF and *K. alvarezii* in increasing the productivity of *K. alvarezii* cultivation. The focus of this research is on the specific growth rate and carrageenan content of *K. alvarezii* as primary response variables for evaluating biofertilizer effectiveness. The research provides information on sustainable and efficient seaweed cultivation practices, utilizing the potential of maggot industry waste and improving the Indonesian seaweed industry.

Materials and Methods

This study was conducted for 45 days in Mallasoro Bay, Jeneponto Regency, Indonesia. This research employed a quantitative experimental approach with a completely randomized design (CRD). The experiment was conducted with four treatments, each with three replicates, resulting in 12 experimental units

Table 1. Treatment Combination of Biofertilizer Types

Treatment	Biofertilizer Type
A	Black soldier fly larvae frass (BSFF) 10 mL L^{-1}
B	Seaweed (*Kappaphycus alvarezii*) 10 ML L^{-1}
C	Black soldier fly larvae frass (BSFF) 5 ML L^{-1} + Seaweed (*Kappaphycus alvarezii*) 5 ml.L^{-1}
D	Seawater (control)

Preparation of biofertilizer from black soldier fly larval frass (BSFF)

This research was conducted by adopting research by Susilo *et al*. (2024) on the preparation of BSFF-based biofertilizers. The BSFF used in this study was dried under sunlight and mashed into a fine powder. Afterwards, the fermentation process was started by adding Effective Microorganisms-4 (EM4) at a concentration of 2% of the total weight of BSFF powder. The mixture was stirred thoroughly to ensure homogeneity and stored in a closed container at room temperature for two weeks to facilitate fermentation. After fermentation, the organic fertilizer was filtered and dissolved in water according to the dosage shown in Table 1.

Preparation of biofertilizer from Seaweed (Kappaphycus alvarezii)

The preparation of biofertilizer made from *K. alvarezii* was carried out based on the method by Nasmia *et al*. (2021). The seaweed was dried in sunlight for three days, followed by a salt and dirt removal process under running water. The seaweed was chopped into small pieces to simplify decomposition and fermentation. Afterwards, the seaweed is soaked in pure water for two days to tenderize the seaweed pieces and trigger the decomposition process, which facilitates fermentation. Then, Effective Microorganism-4 (EM4) was added at a concentration of 2% of the total weight of the fermentation material. This fermentation process was conducted for 2 weeks to help break down seaweed's organic content into a more absorbable material for plants. After fermentation, the biofertilizer solution was filtered to separate the solids from the liquid. Subsequently, the biofertilizer was dissolved in water with the dosage according to the treatment listed in Table 1.

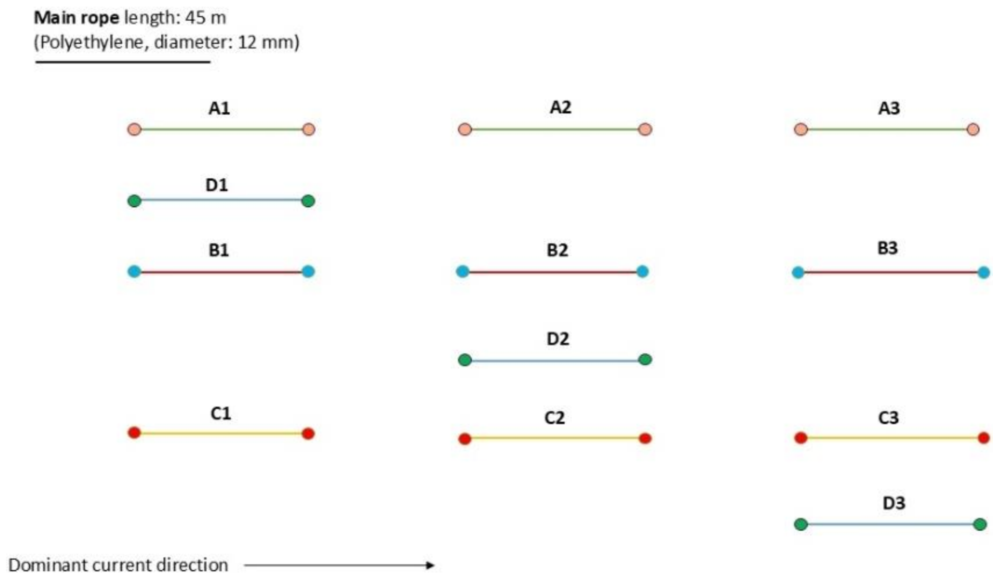
K. alvarezii cultivation

The biofertilizer was prepared by dissolving each ingredient according to the treatment into a ton of seawater. The combination of biofertilizer mixture doses for each treatment can be seen in Table 1. The dosage for each type of biofertilizer is 10 ml.L^{-1} (Treatment A and B), based on studies by Daadoush and Lateef Al-Doori (2024) and Sopha *et al*. (2025). This dosage is adjusted to avoid growth inhibition and to maintain the nutritional benefits of the biofertilizer. The 1:1 dosage in treatment C was used to maintain the total dosage of each type of biofertilizer (equal split approach) to observe the combined effect test as an initial screening stage for its use (Aamer *et al*., 2025).

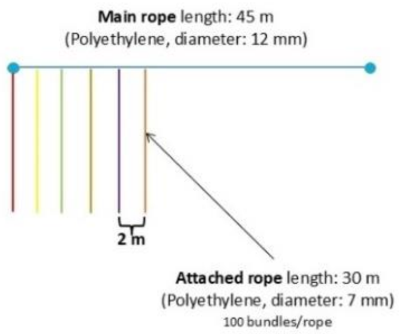
This study used 30-day-old *K. alvarezii* seeds from local farmers with an initial weight of 50 g. The seeds were soaked in a solution of biofertilizer mixture according to the treatment doses for three hours. The duration of soaking was determined based on research by Doolotkeldieva *et al*. (2015) and Khan and Bano (2019). The soaking time of three hours was chosen to ensure that the seeds could absorb the maximum amount of nutrients and bioactivity from the biofertilizer solution without suffering from stress conditions.

After the soaking process, the seeds were tied and planted at the cultivation site. The *K. alvarezii* were cultivated for 45 days using the long-line method. This method uses a 45 m polyethylene rope with a 12 mm diameter as the main rope, attached to a weight and float at a depth of 5 m. The seeds were tied to polyethylene rope with a diameter of 7 mm and tied at 30-cm intervals. The length of this rope is 30 m and produces 100 bundles of *K. alvarezii* seeds (Wijayanto *et al*., 2020). After all the *K. alvarezii* seeds were tied, they were attached to the main rope, spaced 2 m apart.

In the experiment, each replication consisted of independent long-line cultivation units, individually equipped with a main rope fitted with its own anchor/weight and float. A total of 12 long-line units were installed and spatially separated within the cultivation area, with three replicates for each treatment (A1-A3, B1-B3, C1-C3, and D1-D3). The units were randomly allocated to the available space in the bay, and no main ropes, anchors, floats, or seed ropes were shared between units. It ensures experimental independence and avoids pseudo replication. This physical layout can be seen in Figure 1. Furthermore, each 45 m long-line unit described was treated as one experimental unit (replication) for statistical analysis.



a. The overall physical layout of the experiment



b. Detail of one experimental unit

Figure 1. Experiment physical layout for *K. alvarezii* cultivation. A (Biofertilizer from BSFF); B (Biofertilizer from *K. alvarezii*); C. (Biofertilizer from BSFF + *K. alvarezii*); D (control: sea water); Replication: A1-A3, B1-B3, C1-C3, D1-D3; Each label: one independent long-line unit (separate anchors/weights and float, not shared)

Chemical characterization of biofertilizer solutions

To determine the chemical content of the soaking solutions prepared according to each treatment (in Table 1), the solutions were analysed at the Pangkajene Pangkep Islands State Polytechnic Laboratory. The parameters measured included total nitrogen (N), phosphorus (P), potassium (K), pH, and salinity. Each parameter was analysed using the following methods.

The analysis was performed using the Kjeldahl method (Greenberg *et al.,* 1992; American Public Health Association, 2017). The biofertilizer sample was mixed with H_2SO_4 under heat to convert organic nitrogen into ammonia (NH_3). The ammonia was then evaporated and absorbed in a borate solution. The ammonia was then distilled and titrated with a standard acid solution (HCl) to measure the nitrogen content. Total nitrogen was calculated using the following formula:

$$\text{Nitrogen (mg.L}^{-1}\text{)} = \frac{V_{\text{titration}} \times N_{\text{acid}} \times 14.01 \times 1000}{V_{\text{sample}}} \quad (1)$$

Note: $V_{\text{titration}}$= volume of acid used for titration (mL); V_{sample}= volume sample; N_{acid}= normality of the acid (eq.L^{-1}); 14.01 = molar mass of nitrogen (g.mol^{-1}); 1000= conversion factor from mL to L (since normality is per liter)

The analysis was performed using the Molybdenum Blue method (Murphy and Riley, 1962; American Public Health Association, 2017). The biofertilizer sample was dissolved with acid and oxidized to convert phosphorus into orthophosphate. It reacted with molybdate in an acid solution to form a molybdate complex, which was then reduced to a blue complex. The intensity of the blue colour was measured using a spectrophotometer at a wavelength of 880 nm. The phosphorus content was calculated using the following formula:

Orthophosphate standard curve

$$A = mC + b \quad (2)$$

$$\text{Phosphorus (mg.L}^{-1}) = \frac{(Asample - Ablank) - b \times DF}{m} \quad (3)$$

Note: $Asample$ = sample absorbance; $Ablank$ = blank reagent absorbance; m = slope of the standard curve; b = intercept of the standard curve; DF = dilution factor

The analysis was performed using flame photometry at a wavelength of 766.5 nm (Harris and Lucy, 2015; American Public Health Association, 2017). The sample was heated in a flame, and the potassium contained in the solution emitted radiation. The flame emission intensity was measured using flame photometry to determine the potassium concentration. The formulas used to determine the concentration are as follows:

Emission intensity (I)

$$I = mC + b \quad (4)$$

$$\text{Potassium (mg.L}^{-1}) = \frac{(Isample - Iblank) - b \times DF}{m} \quad (5)$$

Note: $Isample$ = sample emission intensity; $Iblank$ = blank emission intensity; m = slope of the standard curve; b = intercept of the standard curve; DF = dilution factor

The pH of the biofertilizer solution sample was measured with a pH meter calibrated using a pH buffer solution (American Public Health Association, 2017).

The biofertilizer sample was placed on a refractometer, which measures the refractive index of light reflected by the solution (American Public Health Association, 2017). Salinity is calculated from refractive index measurements, which are converted to ppt (parts per thousand).

After all parameter analyses were conducted, their values were averaged and used to assess the chemical content of the biofertilizer solution.

Measurement of specific growth rate

Within each experimental unit (independent long-line), 30 *K. alvarezii* bunches were randomly selected as subsamples. They were weighed, and this procedure was repeated weekly for six weeks. For statistical analysis, subsample values were averaged to obtain a single value for each experimental unit. The specific growth rate was calculated using the formula of Tanoeiro *et al*. (2023).

$$SGR = \frac{lnln\ Wt - lnln\ Wo}{t} x\ 100 \quad (6)$$

Note: SGR = Specific Growth Rate (%.day^{-1}); Wt = *K. alvarezii* weight during research (day) (g); Wo = *K. alvarezii* initial weight (day-0) (g); t = cultivation duration (days)

Measurement of carrageenan content

At the end of the experiment (day 45), *K. alvarezii* samples were collected from each experimental unit (three long-line replicates per treatment) for carrageenan analysis. Carrageenan content was calculated based on the formula of Jayasinghe *et al*. (2016):

$$Carrageenan\ content\ (\%) = \frac{weight\ of\ carrageenan\ extract\ (g)}{Dry\ weight\ of\ sample\ (g)} \text{x } 100 \quad (7)$$

Measurement of water quality

This study examined water quality in the *K. alvarezii* cultivation area to support specific growth rate and carrageenan content data. The water-quality parameters included salinity, dissolved oxygen, temperature, and pH. Ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-), and phosphate (PO_4) were measured by using a spectrophotometer (American Public Health Association, 2017).

Table 2. Basic chemical composition of prepared Biofertilizer solutions (mean values)

Treatments	N (mg.L^{-1})	P (mg.L^{-1})	K (mg.L^{-1})	pH	Salinity (ppt)
A (Biofertilizer from BSFF)	159	97	255.5	7.38	33
B (Biofertilizer from *K. alvarezii*)	112	25	138	7.50	33
C (Biofertilizer from BSFF + *K. alvarezii*)	271	122	393.5	7.44	33
D (control: sea water)	185	124	380	7.80	33

Table 3. Specific Growth Rate of *K. alvarezii* (mean±SD)

Treatments	Specific Growth Rate (%)
A (Biofertilizer from BSFF)	5.30±0.98^{ab}
B (Biofertilizer from *K. alvarezii*)	5.12±1.11^{ab}
C (Biofertilizer from BSFF + *K. alvarezii*)	5.41±0.84^{b}
D (control: sea water)	3.86±0.22^{a}

*Values with different superscript letters within a column are significantly different (*P*< 0.05) based on Tukey's HSD test

Results and Discussion

The chemical composition of each biofertilizer solution is shown in Table 2. The chemical composition of the soaking solution prepared differed between treatments. Treatment C (BSFF + *K. alvarezii*) showed the highest average total N (271 mg.L^{-1}) and K (393.5 mg.L^{-1}) values, while treatment B had lower macronutrient levels (N = 112 mg.L^{-1}; K = 138 mg.L^{-1}). The pH of all biofertilizer solutions was close to neutral (7.38-7.80), and salinity was constant at 33 ppt.

Specific growth rate

The mean specific growth rate of K. alvarezii under each treatment is presented in Table 3. The type of treatment (biofertilizer mixture dose) has a significantly different effect (P<0.05) on the specific growth rate average based on the analysis of variance. In the Tuckey test, treatment C was significantly different from treatment D, with a confidence level of 95%. In contrast, treatments A, B, and C had results that were not significantly different.

Compared to all treatments, treatment C had the highest specific growth rate (5.41 ± 0.84%). This pattern is consistent with the chemical profile of the immersion solution, where treatment C had the highest average total N (271 mg.L^{-1}) and K (393.5 mg.L^{-1}) among the biofertilizer treatments (Table 2). pH (7.38 - 7.80) and salinity (33 ppt) were similar among all treatments (Table 2), indicating that the seedlings were soaked in similar physicochemical conditions.

In addition to mineral nutrients, BSFF extract and seaweed can also provide organic nitrogen, amino acids, polysaccharides, and other bioactive compounds that can function as bio stimulants, thereby enhancing seedling formation and subsequent growth. However, these organic components and micronutrients were not measured in this study.

The lowest average specific growth rate was observed in treatment D (seawater as a control). Although the control immersion solution contained measurable amounts of nitrogen (N), phosphorus (P), and potassium (K) (Table 2), it did not contain organic matter and bioactive compounds derived from biofertilizer, which may affect nutrient uptake efficiency and metabolic activity. Further chemical analysis (*e.g.*, micronutrients and dissolved organic constituents) is needed to explain this mechanism.

In Figure 2, the specific growth rate of *K. alvarezii* in treatments A, B, and C in week 2 was higher than in other weeks. In week 2, *K. alvarezii* is still adapting to the environment. At the beginning of cultivation, *K. alvarezii* requires a high amount of nutrients. According to Purbosari *et al*. (2021), *K. alvarezii* is in the exponential phase, resulting in a fairly high growth rate in this situation. When the availability of nutrients is sufficient, the growth will be faster.

The availability of nutrients and potential bio stimulant compounds from biofertilizers can accelerate nutrient uptake and metabolic activity. External environmental factors such as temperature, salinity, pH, and dissolved oxygen also influence growth, highlighting the importance of optimal cultivation conditions. Overall, the results of this study highlight the potential benefits of biofertilizer soaking prior to planting for *K. alvarezii* cultivation. Due to limited resources and the focus of this study on primary nutrients, future studies should measure additional parameters (*e.g.,* Mg, Ca, Fe, TDS, and dissolved organic carbon) in the soaking solution prepared to better optimize the composition for biological response.

Carrageenan content

The carrageenan content average of *K. alvarezii* during the study can be seen in Table 4. The analysis of variance showed that the biofertilizer treatment significantly affected carrageenan content (P<0.05). Furthermore, the Tuckey test results showed that treatment A was not significantly different from treatment B. However, treatments A and B were significantly different from treatments C and D. Treatment C was significantly different from treatment D at the 95% confidence level.

Based on Table 3, the results of carrageenan content in *K. alvarezii* show variations. The carrageenan content produced is quite good because it ranges from 36.67%-56.61%. Ha *et al*. (2022) stated that the antioxidant carrageenan extracted from *Eucheuma* gelatinae has a 42.68 ± 2.37% purity. The study of Álvarez-Viñas *et al*. (2023) showed that the carrageenan content ranged from 42.68% to 64%, depending on the extraction and processing methods used.

Treatment C produced the highest carrageenan content (56.61%). Carrageenan synthesis is closely related to nutritional status, especially nitrogen. Our chemical analysis showed that the biofertilizer solution in treatment C contained a higher average total N (271 mg.L^{-1}) than treatments A and B (Table 5), providing an empirical basis for discussing nutrition-supported biosynthesis during the early stages of cultivation. However, carrageenan production is multifactorial and may also depend on the availability of other nutrients and bioactive compounds that were not measured in this study.

Table 4. Carrageenan Content of *K. alvarezii* (mean±SD)

Treatments	Carrageenan Content (%)
A (Biofertilizer from BSFF)	52.84±1.80[a]
B (Biofertilizer from *K. alvarezii*)	51.39±1.95[a]
C (Biofertilizer from BSFF + *K. alvarezii*)	56.61±0.63[b]
D (control: sea water)	36.67±1.11[c]

*Values with different superscript letters within a column are significantly different (*P*< 0.05) based on Tukey's HSD test

Table 5. Water quality of *K. alvarezii* cultivation area

Method	Water Quality	Value	Standard levels by BSN
In situ analysis	Temperature (°C)	26.00 - 32.00	25.00 – 32.00
	Dissolved Oxygen (ppm)	4.00 - 4.90	>3.00
	Salinity (ppt)	25.72 - 29.80	12.00 – 30.00
	pH	7.48 - 8.23	6.20 – 8.20
Spectrophotometry	Ammonia (ppm)	0.069	<1.00
	Phosphate (ppm)	0.125	0.02-0.20
	Nitrate (ppm)	0.050	0.01 – 0.07
	Nitrite (ppm)	0.181	<0.30

**BSN: National Standardization Agency*

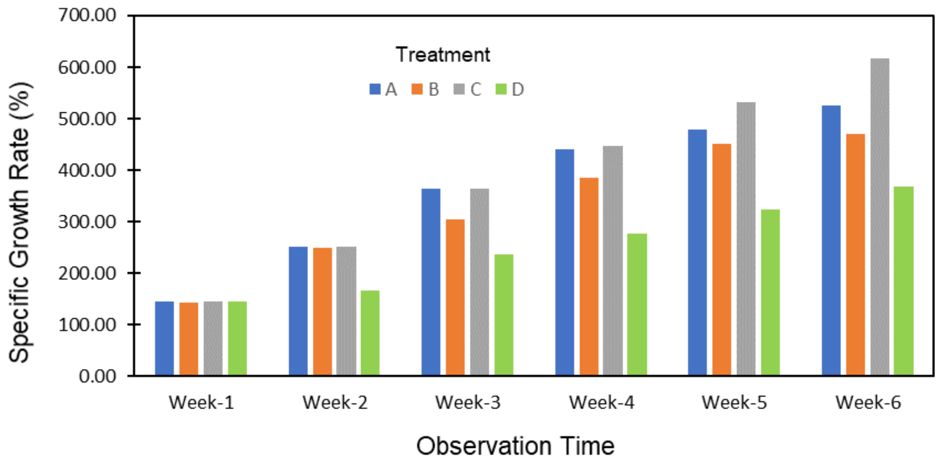


Figure 2. The specific growth rate of *Kappaphycus alvarezii* every week in each treatment.

Seaweed extract and frass-based organic fertilizer are reported to contain various organic compounds that can support photosynthesis and metabolism. In this study, the pH was close to neutral, and the salinity of the immersion solution was stable (Table 5), indicating that the initial immersion step was carried out under conditions suitable for seaweed survival. However, targeted analysis of bioactive compounds is needed to confirm specific pathways.

Treatment D (control) had the lowest carrageenan content (36.67%). It is related to the absence of pre-biofertilizer soaking, which may reduce exposure to additional nutrients and bioactive compounds present in treatments A, B and C. Further research characterizing the micronutrients and organic components in the prepared soaking solution will strengthen the mechanistic interpretation.

The results of this study state that the use of BSFF and *K. alvarezii* as the basic ingredients of biofertilizers combination can improve the quality of *K. alvarezii* cultivation. These results are supported by the research of Yun *et al*. (2023) and Manan *et al*. (2024). With various nutrients and bioactive compounds in this biofertilizer combination, it can produce about 20% higher carrageenan than without its use. In addition, the right composition of biofertilizers also increases the ability of *K. alvarezii* to adapt to its environmental conditions (Zhu *et al*., 2022).

Water quality parameter

The overall water quality results can be seen in Table 5. According to the Indonesian National Standardization Agency (BSN) in 2010 and 2011, all parameters remain within the ideal water quality range for the growth of *K. alvarezii.* The temperature of the cultivation area ranges from 26.00 to 32.00 °C, which means that the light intensity of the water is optimal for photosynthesis (Kinnby *et al.*, 2021). The dissolved oxygen (DO) level is also optimal for K. alvarezii respiration, ranging from 4.0 to 4.9 ppm. This is crucial because if the level is less than 2 ppm, it can inhibit the metabolic process of seaweed (Manurung *et al.,* 2021). In addition, the pH level (7.45 to 8.23) and salinity (25.72 to 29.80 ppt) are also consistent with the survival standards. Salinity and pH levels are strongly determined by the growth of seaweed and the content of carrageenan produced (Kinnby *et al*., 2021). Heavy metal levels influence pH waters. Low pH can encourage the occurrence of an ammonium and ammonia imbalance.

Based on BSN standard from 2010 and 2011, the nutrient content in the *K. alvarezii* cultivation area is still within the range that supports its growth. The ammonia (NH_3) level is still below 1.00 ppm, so it is not toxic and does not inhibit their growth. The phosphate (PO_4) level is still within the standard range of around 0.125 ppm. It is an important nutrient in plant cell formation, so its level in the cultivation area needs to be monitored (Hauck *et al*., 2022). The nitrite (NO_2^-) level (0.05 ppm) and nitrate (NO_3^-) level (0.181 ppm) are also still considered normal for supporting carrageenan production from *K. alvarezii.* However, if their levels exceed the normal standard, it can reduce the growth rate (Rupert *et al*., 2022).

In this study, the chemical characteristics analysed in the biofertilizer solution used only basic chemical components (N, P, K, pH, and salinity). To develop more sustainable and adaptive aquaculture strategies, analysis of other parameters is needed for mechanistic interpretation (*e.g.,* Mg, Ca, Fe, and TDS) and bioactive compounds to increase *K. alvarezii* productivity and improve their quality.

Conclusion

This study shows that the specific growth rate and carrageenan content of *K. alvarezii* can be increased through the use of a combined black soldier fly larvae frass (BSFF) and *K. Alvarezii-based fertilizer* (treatment C). Treatment C achieved the highest specific growth rate (5.41 ± 0.84%) and the highest carrageenan content (56.61 ± 0.63%). Basic chemical analysis of the immersion solution showed that treatment C had a higher average total N (271 mg.L^{-1}) and K (393.5 mg.L^{-1}) compared to single-source biofertilizers (BSFF or *K. alvarezii.* This study highlights the potential of biofertilizers derived from BSFF and *K. alvarezii* as environmentally friendly and potentially sustainable alternative to chemical fertilizers for seaweed cultivation. In addition, waste from the BSFF industry can also be utilized through the production of this biofertilizer, thereby reducing waste accumulation and creating valuable materials. This treatment not only increases the productivity and quality of *K. alvarezii* but also potentially reducing reliance on synthetic fertilizers.

References

Aamer, M., Guoqin, H., Zhang, J., Wei, H., Rasul, F., Sun, D., Huang, W., Liu, S., Haseeb, A., Asseri, T.A.Y. & Hashem, M. 2025. Biochar–seaweed fertilizer blend: a multifaceted strategy for mitigating nitrous oxide emissions, soil rejuvenation, and improving rice crop performance. *J. Soil Sci. Plant Nutr.*, 25(4): 8909–8923. https://doi.org/10.1007/s42729-025-02702-7

Álvarez-Viñas, M., Rivas, S., Torres, M.D. & Domínguez, H. 2023. Microwave-assisted extraction of carrageenan from *Sarcopeltis skottsbergii*. *Mar. Drugs*, 21(2): 83. https://doi.org/10.3390/md21020083

American Public Health Association. 2017. Standard Methods for the Examination of Water and Wastewater (23rd ed.). American Public Health Association*.* 7-10 pp.

Bhowmik, M., Panja, A.K., Gurumoorthy, U., Gopalakrishnan, S., Veeraprakasam, V. & Haldar, S. 2025. Impact of long-term seaweed (*Kappaphycus alvarezii*) aquaculture on species and functional diversity of macrobenthic communities in Southeastern coast, India. *Aquacul. Intern.*, 33(2): 94. https://doi.org/10.1007/s10499-024-01722-x

Daadoush, H.K. & Lateef Al-Doori, M.F. 2024. The impact of seaweed extract and biofertilizer on root growth and some mineral content of orange seedlings. *IOP Conf. Ser. Earth Environ. Sci.*, 1371(4): 1-9. https://doi.org/10.1088/1755-1315/1371/4/042039

Doolotkeldieva, T., Bobusheva, S. & Konurbaeva, M. 2015. Effects of *Streptomyces* biofertilizer to soil fertility and rhizosphere's functional biodiversity of agricultural plants. *Adv. Microbiol.*, 5(7): 555–571. https://doi.org/10.4236/aim.2015.57058

El-Beltagi, H.S., Mohamed, A.A., Mohamed, H.I., Ramadan, K.M.A., Barqawi, A.A. & Mansour, A.T.

2022. Phytochemical and potential properties of seaweeds and their recent applications: a review. *Mar. Drugs*, 20(6): 342. https://doi.org/10.3390/md20060342

Erlania, & Nyoman Radiarta, I. 2014. Management of Sustainable Seaweed (*Kappaphycus alvarezii*) Aquaculture in the Context of Climate Change Mitigation. *Indonesian Aquacul. J.,* 9(1), 65–75. https://doi.org/https://doi.org/10.15578/iaj.9.1.2014.65-72

Filbee-Dexter, K., Pessarrodona, A., Duarte, C.M., Krause-Jensen, D., Hancke, K. & Smale, D. 2023. Seaweed forests are carbon sinks that may help mitigate CO_2 emissions: a comment on Gallagher et al. (2022). *ICES J. Mar. Sci.*, 80(6): 1814–1819. https://doi.org/10.1093/icesjms/fsad107

Greenberg, A.E., Clesceri, L.S. & Eaton, A.D. 1992. Standard Methods for Examination of Water and Wastewater (18th ed.). American Public Health Association.

Ha, H.T., Cuong, D.X., Thuy, L.H., Thuan, P.T., Tuyen, D.T.T. & Mo, V.T. 2022. Carrageenan of red algae *Eucheuma gelatinae*: extraction, antioxidant activity, rheology characteristics, and physicochemistry characterization. *Molecules*, 27(4): 1268. https://doi.org/10.3390/molecules27041268

Harris, D.C. & Lucy, C.A. 2015. Quantitative Chemical Analysis (9th ed.). W.H. Freeman & Company.

Hauck, D., Lohr, D., Meinken, E. & Schmidhalter, U. 2022. Phosphorus availability from German sewage sludge ashes to plants cultivated in soilless growing media of contrasting pH. *Agronomy*, 12(11): 2610. https://doi.org/10.3390/agronomy12112610

Hayashi, L., Yokoya, N.S., Ostini, S., Pereira, R.T.L., Braga, E.S. & Oliveira, E.C. 2008. Nutrients removed by *Kappaphycus alvarezii* (Rhodophyta, Solieriaceae) in integrated cultivation with fishes in re-circulating water. *Aquacul.*, 277(3–4): 185–191. https://doi.org/10.1016/j.aquaculture.2008.02.024

Jamaluddin, A., Syam, H., Mustarin, A. & Rivai, A.A. 2019. Spatial multi-criteria approach for determining the cultivation location of seaweed *Eucheuma cottonii* in Takalar Regency, South Sulawesi, Indonesia. *AACL Bioflux*, 12(4): 1413–1430.

Jayasinghe, P., Pahalawattaarachchi, V. & Ranaweera, K.K.D.S. 2016. Effect of extraction methods on the yield and physiochemical properties of polysaccharides extracted from seaweed available in Sri Lanka. *Poult. Fish. Wildl. Sci.*, 4(1): 1-6. https://doi.org/10.4172/2375-446X.1000150

Khan, N. & Bano, A. 2019. Exopolysaccharide producing rhizobacteria and their impact on growth and drought tolerance of wheat grown under rainfed conditions. *PLoS One*, 14(9): e0222365. https://doi.org/10.1371/journal.pone.0222302

Kinnby, A., Toth, G.B. & Pavia, H. 2021. Climate change increases susceptibility to grazers in a foundation seaweed. *Front. Mar. Sci.*, 8: 773480. https://doi.org/10.3389/fmars.2021.688406

Manan, F.A., Yeoh, Y.K., Chai, T.T. & Wong, F.C. 2024. Unlocking the potential of black soldier fly frass as a sustainable organic fertilizer: a review of recent studies. *J. Environ. Manage.*, 367: 117685. https://doi.org/10.1016/j.jenvman.2024.121997

Manurung, D.F., Rosmasita, R., Windarti, W., Ghazali, T.M. & Sibuea, N.U.S. 2021. Suitability of seaweed culture (*Eucheuma cottonii*) in the Sorkam Barat Sub-District, Tapanuli Tengah Indonesia. *IOP Conf. Ser. Earth Environ. Sci.*, 934(1): p.012012. https://doi.org/10.1088/1755-1315/934/1/012012

Mirwan, Akhmad, & Jam'an, A. 2025. Factors Affecting Income Seaweed Farmers in Tompotana Village Tanakeke Islands District Takalar Regency. *J. Soc. Society*, 5(1): 86–96. https://doi.org/10.30605/jss.5.1.2025.632

Mualam, A., Widigdo, B. & Zairion. 2022. Analysis of Seaweed (*Kappaphycus alvarezii*) Farming Area Based Suitability and Carrying Capacity Indicator in The Coastal of Babau City. *J. Ilmu & Tek. Kelaut. Trop.*, 14(1): 81–93. https://doi.org/10.29244/jitkt.v14i1.37659

Murphy, J. & Riley, J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta*, 27(C): 31–36. https://doi.org/10.1016/S0003-2670(00)88444-5

Nasmia, Rosyida, E., Masyahoro, A., Putera, F.H.A. & Natsir, S. 2021. The utilization of seaweed-based liquid organic fertilizer to stimulate growth and quality of *Gracilaria verrucosa*. *Int. J. Environ. Sci. Technol.*, 18(6): 1637–1644. https://doi.org/10.1007/s13762-020-02921-8

National Standardization Agency (BSN). 2011. *Cottoni seaweed (Eucheuma cottonii) seedling production-Part 1: the basic escape method*. BSN, Indonesia.

National Standardization Agency (BSN). 2010. *Production of cottoni seaweed (Eucheuma cottonii)-Part 2: the long-line method*. BSN, Indonesia.

Purbosari, N., Warsiki, E., Syamsu, K., Santoso, J. & Effendi, I. 2021. Evaluation of the application of seaweed (*Eucheuma cottonii*) extract as fish anesthetic agent. *Aquacult. Int.*, 29(4): 1545–1560. https://doi.org/10.1007/s10499-021-00693-7

Rimmer, M.A., Larson, S., Lapong, I., Purnomo, A.H., Pong-Masak, P.R., Swanepoel, L. & Paul, N.A. 2021. Seaweed aquaculture in Indonesia contributes to social and economic aspects of livelihoods and community wellbeing. *Sustainability*, 13(19): 10946. https://doi.org/10.3390/su131910946

Rupert, R., Rodrigues, K.F., Thien, V.Y. & Yong, W.T.L. 2022. Carrageenan from *Kappaphycus alvarezii* (*Rhodophyta*, *Solieriaceae*): metabolism, structure, production, and application. *Front. Plant Sci.*, 13: 859635. https://doi.org/10.3389/fpls.2022.859635

Shang, X.Chao, Zhang, M., Zhang, Y., Li, Y., Hou, X. & Yang, L. 2023. Combinations of waste seaweed liquid fertilizer and biochar on tomato (*Solanum lycopersicum* L.) seedling growth in an acid-affected soil of Jiaodong Peninsula, China. *Ecotoxicol. Environ. Saf.*, 246: 114133. https://doi.org/10.1016/j.ecoenv.2023.114133

Snethlage, J.S., de Koning, S., Giesbers, E., Veraart, J.A., Debrot, A.O., Harkes, I., et al. 2023. Knowledge needs in realising the full potential of seaweed for world food provisioning. *Glob. Food Sec.*, 37: 100692. https://doi.org/10.1016/j.gfs.2023.100692

Sopha, G.A., Murtiningsih, R., Cartika, I., Hamdani, K.K., Handayani, T., Lestari, I.P., Haryati, Y., Indrasti, R., Marpaung, A.E.B., Rawung, J.B.M., Gunadi, N., Amisnaipa, A., Adi, E.B.M., Priadi, D., Tan, S.S. & Surono, S. 2025. Liquid organic fertilizer derived from black soldier fly frass improves yield and quality of tropical vegetables, shallot, and red-hot chili peppers. *Int. J. Hortic. Sci. Technol.*, 12(2): 479–490. https://doi.org/10.22059/ijhst.2024.373373.797

Susilo, H., Nurmayulis, N., Syahbana, M.A. & Sodiq, A.H. 2024. The potential of frass BSF as an organic fertilizer for making sustainable agriculture a reality. *J. Biol. Trop.*, 24(2): 209–215. https://doi.org/10.29303/jbt.v24i2.6782

Tanoeiro, J.R., Fortunato, D., Cotas, J., Morais, T., Afonso, C. & Pereira, L. 2023. Different *Chondrus crispus* aquaculture methods and carrageenan extraction. *Appl. Sci.*, 13(9): 5184. https://doi.org/10.3390/app13095184

Thi, Q.V.C., Nhan, T.H., Hung, N.V.K. & Thuy, N.P. 2024. Isolation of *Trichoderma* strains from rhizospheric soil and assessment of their potential for biofertilizer from freshwater aquaculture pond sediment. *Biodiversitas*, 25(7): 3912–3920. https://doi.org/10.13057/biodiv/d250747

Wijayanto, D., Bambang, A.N., Nugroho, R.A. & Kurohman, F. 2020. The impact of planting distance on productivity and profit of *Eucheuma cottonii* seaweed cultivation in Karimunjawa Islands, Indonesia. *AACL Bioflux*, 13(4): 1946–1956. https://bioflux.com.ro/docs/2020.2170-2179.pdf

Yun, J.H., Archer, S.D. & Price, N.N. 2023. Valorization of waste materials from seaweed industry: an industry survey based biorefinery approach. *Rev. Aquac.*, 15(3): 655–668. https://doi.org/10.1111/raq.12808

Zhu, Y., Lv, X., Li, T., Zhong, M., Song, J., Wang, H., et al. 2022. Cotton straw biochar and compound *Bacillus* biofertilizer reduce Cd stress on cotton root growth by regulating root exudates and antioxidant enzymes system. *Front. Plant Sci.*, 13: 944884. https://doi.org/10.3389/fpls.2022.1051935