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Effect of cultivation density and methods for *Betaphycus gelatinus* in outdoor composite tanks: Impacts on growth and carrageenan quality

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ABSTRACT

This study evaluates the effects of stocking density and cultivation methods on the growth and quality of *Betaphycus gelatinus* carrageenan in a 3 m³ composite tank system. Seaweed was collected from Thai An, Ninh Thuan, Vietnam, and cultured at densities of 2, 4, 6, and 8 kg/m³ using four methods: (1) culture in hanging net cages, (2) the long-line method, (3) culture on horizontal nets and (4) cultivation attached to artificial coral. The experiment was conducted over 90 days (from June to September 2022). Results showed that the 2 kg/m³ density achieved the highest growth rate, carrageenan content, and quality ($p < 0.05$) compared to other densities. Among the cultivation methods, mesh cages (1) yielded the lowest growth and carrageenan quality, while the remaining three methods showed no significant differences. This study is the first report on the successful cultivation of *B. gelatinus* in a 3 m³ composite tank, affirming that a stocking density of 2 kg/m³ along with the hanging rope, mesh frame, and artificial coral attachment methods are optimal choices for *B. gelatinus* cultivation.

Keywords: *B. gelatinus*, different densities, cultivation methods, carrageenan, outdoor tanks, tank culture.

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INTRODUCTION

Seaweed farming in open waters often faces numerous challenges due to attacks by harmful organisms such as fish, turtles, and sea urchins, negatively impacting survival rates, yield, and product quality [1–3]. These factors reduce the economic efficiency of seaweed farming operations. Therefore, finding solutions to mitigate the effects of these pests is essential. One potential approach is cultivating seaweed in outdoor tanks or ponds, which helps reduce the risk of pest attacks and maintains seaweed quality under better-controlled conditions [4–7]. This approach is considered a sustainable and feasible solution to ensure the long-term development of the seaweed farming industry, particularly for species at high risk of extinction.

The red alga *Betaphycus gelatinus* (Esper) Doty ex P.C. Silva 1996, formerly known as *Eucheuma gelatinae* or *Betaphycus gelatinum*, belongs to the genus *Betaphycus*, family Solieriaceae, order Gigartinales, class Florideae, phylum Rhodophyta [8–12]. This species typically attaches to coral substrates with a rough ventral surface, a 10–20 cm diameter, and a smooth upper surface. Branches arise from the ventral surface and body edges and are interconnected by dense rows of tubes measuring 3–5 mm wide and 1–2 mm thick. When alive, the algae have a purplish-red or greenish-yellow color [10, 11]. *B. gelatinus* has significant economic value and is used in food and beverage processing, especially in candy production [11]. Additionally, it is a key raw material for extracting carrageenan, a polysaccharide widely applied in the food, medical, and chemical industries, owing its gelling, thickening, and preservative properties [13, 14]. Furthermore, *B. gelatinus* contains bioactive compounds like carrageenan with antioxidant activities [15] that are believed to inhibit tumor and viral growth by enhancing the immune system [16, 17].

Currently, *B. gelatinus* is primarily harvested from natural populations along the southern coastal provinces of Vietnam. However, due to environmental degradation, pollution, climate change, and overexploitation, the natural supply

of this species has significantly declined, leading to its inclusion in Vietnam's Red List as an endangered species [10, 18–20]. Developing tank cultivation methods is essential to preserve this valuable genetic resource and meet the growing demand for this seaweed.

In China, *B. gelatinus* has been cultivated by cutting it into small pieces and attaching these to dead coral fragments, which are then placed on the seabed, yielding approximately 300 tons of dried seaweed annually [21]. Research shows this species thrives best under conditions of 24–28°C, 30–35‰ salinity, and 100 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$ light intensity while achieving the highest carrageenan content [22–24]. Co-cultivating *B. gelatinus* with the bivalve *Gafrarium tumidum* can help control algal blooms and mitigate eutrophication within the cultivation ecosystem [25].

Although extensive studies on the growth conditions of *B. gelatinus* have been conducted in China, Japan, and Vietnam, these efforts remain limited to small-scale laboratory experiments, isolated trials, and optimization of experimental conditions. In contrast, open-sea cultivation of *B. gelatinus* in China began early. However, to date, the only reported cultivation method involves attaching the algae to dead coral reefs in the sea. This method has significant limitations: it is difficult to harvest, negatively impacts the environment and the coral reef ecosystem during harvesting, and is more suitable for resource restoration. Additionally, fielded cultivation faces challenges such as exposure to strong waves, algal pests, and uncontrollable environmental conditions. In Vietnam, no studies have been conducted on outdoor cultivation of *B. gelatinus* in composite tanks. Key questions regarding the initial stocking density and appropriate cultivation methods remain unanswered. Therefore, this study aims to determine the optimal initial stocking density and cultivation method to establish a foundation for *B. gelatinus* cultivation in outdoor tanks and open-sea environments. Moreover, it seeks to provide raw materials for seed production and maintain live *B. gelatinus* samples during the stormy season, ensuring their availability for subsequent open-sea cultivation.

This study presents various cultivation methods for *B. gelatinus* in a 3 m³ composite

tank. It determines the appropriate initial stocking density, aiming to establish a scientific basis for the future development and expansion of cultivation models for this species.

MATERIALS AND METHODS

Materials

The red alga *B. gelatinus* was collected from the wild at a depth of 4 m using scuba diving equipment in Thai An village, Ninh Hai commune, Ninh Hai district, Ninh Thuan province, Vietnam (collected on May 15, 2022, coordinates N 11°40'36.29", E 109°10'50.78").

After harvesting, the seaweed was immediately transported to the Hon Chong Aquaculture Facility, part of the Center for Advanced Research and Innovation, Nha Trang Institute of Technology Research and Application (NITRA). The seaweed was kept in a moisture-retaining foam container to maintain its quality and vitality during transport. Upon arrival at the facility, only young, healthy samples with multiple potential growth branches were selected for experimentation. Before being placed in cultivation tanks, the seaweed thalli were thoroughly rinsed with clean seawater to remove any observable epiphytes, ensuring optimal conditions for the experiment (Fig. 1).



Figure 1. *B. gelatinus* seaweed in the wild. Notes: (A) wild-collected seaweed attached to coral rock: *B. gelatinus* distributed in the Thai An coral reef area, Ninh Thuan, Vietnam; (B) a *B. gelatinus* thallus collected from the wild, cleaned, and domesticated for experimental preparation

Experimental setup for cultivating seaweed in composite tanks

The cultivation experiment for *B. gelatinus* was conducted over 90 days, from June to September 2022. The experimental system consisted of a composite tank with a volume of 3.6 m³ (1 m × 1.2 m × 3 m), with a water level maintained at a height of 1 m (1 m × 1 m × 3 m = 3 m³). The cultivation tanks were placed in a roofed aquaculture facility, where light was provided through a natural light collection system installed on the roof. The tanks were arranged to ensure uniform light distribution across all tanks (Fig. 2). The tank's continuous circulation system ensured an inflow and

outflow rate of 35 L/s to maintain hydrodynamic conditions suitable for seaweed growth.

The *B. gelatinus* thalli were randomly distributed into four experimental tanks labeled B1, B2, B3, and B4. During the first two weeks, no nutrients or fertilizers were added to allow the seaweed to acclimate to the cultivation environment. Algae and tank bottoms were cleaned weekly, and 30% of the tank water was changed. Aeration was provided by a Resun ACO 019 pump with an operating power of 620 W, ensuring a stable dissolved oxygen level optimized for seaweed growth. Physical water quality parameters in each tank were monitored twice daily (at 8:00 AM and 3:00 PM) and included: dissolved oxygen (DO), measured by

Smartsensor AR8406 (USA); pH, measured with a HI991003 pH meter (accuracy ± 0.1); temperature, measured by the HI991003 device (accuracy $\pm 0.5^{\circ}\text{C}$); light intensity, measured with

a Li-193 SA light sensor, converted to $\mu\text{mol photons m}^{-2}\text{s}^{-1}$ and salinity, measured by an RSA0028 refractometer (range: 0–100‰, accuracy $\pm 0.2\%$).



Figure 2. *B. gelatinus* cultivation tank system in the experiment

The experimental design included two main factors: initial stocking density and cultivation method. For initial stocking density, four density levels were used: 2, 4, 6 and 8 kg/m^3 to evaluate the effects of density and cultivation method on the growth of *B. gelatinus* in the 3 m^3 -tank under conditions of 30‰ salinity, with nutrient supplementation occurring twice a week, using 1 mL/L of NaNO_3 and 1 mL/L of NaH_2PO_4 as nutrient sources for the seaweed. Cultivation methods in the tank (cultivation density was used: 2 kg/m^3): (1) culture in hanging net cages, seaweed was placed in mesh enclosures measuring 20 cm $\times$ 20 cm $\times$ 20 cm with a mesh size of 1 cm and

then submerged in the cultivation tank [26]; (2) the long-line method, seaweed was suspended on ropes following the cultivation methods for *Kappaphycus alvarezii*, *K. striatum*, and *Eucheuma denticulatum* [27]; (3) culture on horizontal nets, seaweed was attached to a cultivation rack sized 1 m $\times$ 1 m $\times$ 1 m before being placed in the tank [28]; (4) attachment to artificial coral (cylindrical stone block, diameter $\times$ height: 10 cm by 10 cm, material is 100% plaster, cast into blocks in Germany) seaweed was affixed to coral rocks and subsequently placed into the cultivation tank [21] (Fig. 3, Table 1), with four replicates were examined.

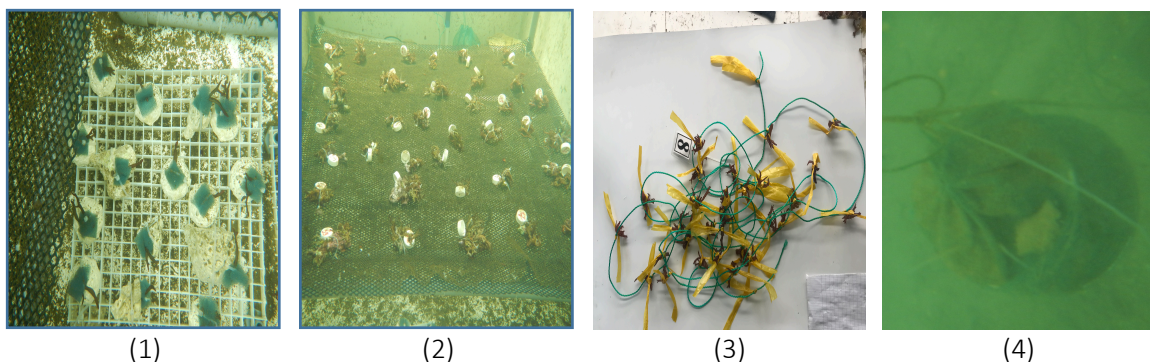


Figure 3. Cultivation methods for *B. gelatinus*. Notes: (1) culture in hanging net cages; (2) the long-line method; (3) culture on horizontal nets; (4) artificial coral attachment method

Table 1. Experimental setup for evaluating the effect of stocking density

Density	Tank 1	Tank 2	Tank 3	Tank 4
Cultivation methods	2 kg/m ³	4 kg/m ³	6 kg/m ³	8 kg/m ³
Culture in hanging net cages (1)	×	×	×	×
The long-line method (2)	×	×	×	×
Culture on horizontal nets (3)	×	×	×	×
Attached to artificial coral rock (4)	×	×	×	×

Calculation methods and analysis methods

Growth rate analysis

The growth rate of cultivated seaweed, expressed as the Daily Growth Rate (DGR, %/day), is calculated using the following formula [29]:

$$DGR = \sqrt[d]{\frac{W_t}{W_0}} - 1 * 100$$

where: DGR: daily Growth Rate in biomass (%/day); W_0 : initial fresh weight of the seaweed (g); W_t : fresh weight of the seaweed after d days of cultivation (g).

Determining carrageenan content

After 90 days of the experiment to determine the effect of stocking density, seaweed was collected to extract carrageenan and evaluate the content and quality of carrageenan (through the gelling index and viscosity of the collected carrageenan).

The carrageenan extraction method was conducted: first, the seaweed was dried to a constant weight. Then, 2 g of dried seaweed was weighed and immersed in distilled water at a ratio of 1 g of seaweed to 50 mL of distilled water. This mixture was heated at 90°C for approximately 2–3 hours. Next, the heated mixture was filtered through a mesh bag to obtain filtrate. The filtrate was then precipitated using 96° alcohol at a ratio of 1 ml of filtrate to 4 ml of alcohol. Finally, the obtained carrageenan was air-dried and further dried at 60°C until a constant weight was achieved, after which it was weighed to determine the final carrageenan mass [30]. The carrageenan content (%) was calculated using the following formula:

$$\text{Carrageenan content (\%)} = \frac{W_2}{W_1} * 100$$

where: W_1 : dry weight of the seaweed (g); W_2 : weight of the extracted carrageenan (g).

Evaluation of carrageenan quality

Carrageenan quality was assessed using two primary parameters: gel strength and viscosity. Measurements were conducted at a carrageenan concentration of 1.5% using a Rheo Meter (Model CR-500DX, Sun Scientific Co., Ltd) to ensure precise quantification of these properties [31].

Data analysis

Statistical analyses, including Two-way Anova (Two-factor of cultivation density and cultivation methods), were conducted using SPSS software version 26. Chart was drawn using Origin Pro 2022.

RESULTS

Analysis of environmental parameters in culture tanks

In this study, the environmental parameters of *B. gelatinus* culture tanks, including temperature, pH, and dissolved oxygen concentration, were monitored and analyzed. The analysis results are presented in Table 2.

The results indicated no significant differences in tank temperature between the culture tanks in the morning and afternoon. Specifically, morning temperatures ranged from 27.5°C to 27.6°C, while afternoon temperatures ranged from 28.5°C to 28.6°C. This minor variation was insignificant ($p > 0.05$), suggesting

stable temperature conditions across tanks. However, as reported in previous studies, afternoon temperatures were slightly higher than the optimal temperature for *B. gelatinus*. The pH also remained within a narrow range of 7.5 to 7.6 with low standard error, reflecting consistent pH conditions across tanks. Additionally, dissolved oxygen concentrations ranged from 5.1 mg/L to 5.3 mg/L, with no statistically significant difference between tanks in either morning or afternoon measurements. This indicates that dissolved oxygen levels were

maintained stable throughout the monitoring period. The light intensity across the tanks was consistent, averaging 90 $\mu\text{mol photon m}^{-2}\text{s}^{-1}$, with no statistically significant variation ($p > 0.05$). Overall, the environmental parameters in the *B. gelatinus* culture tanks temperature, pH, dissolved oxygen concentration, and light intensity were stable and uniform across the tanks. These results confirm that the environmental conditions were well-controlled, supporting the optimal growth of *B. gelatinus* within the tank-based culture system.

Table 2. Environmental parameters of *B. gelatinus* culture tanks

Criteria		Culture tank			
		Tank 1	Tank 2	Tank 3	Tank 4
Mean temperature ($^{\circ}\text{C}$)	Morning	27.5 ^a $\pm$ 1.0	27.6 ^a $\pm$ 1.0	27.5 ^a $\pm$ 1.0	27.5 ^a $\pm$ 1.0
	Afternoon	28.6 ^a $\pm$ 1.0	28.6 ^a $\pm$ 1.0	28.5 ^a $\pm$ 1.0	28.5 ^a $\pm$ 1.0
Mean pH		7.5 ^a $\pm$ 0.4	7.6 ^a $\pm$ 0.4	7.5 ^a $\pm$ 0.5	7.6 ^a $\pm$ 0.5
Mean light intensity ($\mu\text{mol photons m}^{-2}\text{s}^{-1}$)		90.50 ^a $\pm$ 10	90.30 ^a $\pm$ 15	91.00 ^a $\pm$ 10	90.30 ^a $\pm$ 12
Mean oxy (mg/L)	Morning	5.1 ^a $\pm$ 1.0	5.2 ^a $\pm$ 1.0	5.1 ^a $\pm$ 1.1	5.2 ^a $\pm$ 1.0
	Afternoon	5.2 ^a $\pm$ 0.9	5.3 ^a $\pm$ 0.9	5.2 ^a $\pm$ 1.1	5.2 ^a $\pm$ 1.0

Notes: Values with the same letter in the same row indicate no statistically significant difference ($p > 0.05$).

Effect of stocking density on growth rate of *B. gelatinus*

The results presented in Table 3 and Figure 4 show that the growth rate of *B. gelatinus* decreases as stocking density increases in all four different culture methods. The growth rate of algae was highest when the stocking density was 2 kg/m^3 or 4 kg/m^3 , while the growth rate decreased sharply at the corresponding stocking

density of 6 kg/m^3 and reached negative growth at the stocking density of 8 kg/m^3 . At stocking densities of 2 kg/m^3 and 4 kg/m^3 , the growth rates were relatively high, reaching from 0.97 $\pm$ 0.06 %/day (at stocking densities of 2 kg/m^3 using the hanging net cages method) to 1.67 $\pm$ 0.06 %/day (at stocking densities of 4 kg/m^3 using the horizontal nets cultivated method), respectively, with no statistically significant difference between these two treatments ($p > 0.05$).

Table 3. Effect of stocking density on growth rate of *B. gelatinus*

Cultivation methods	Stocking density (kg/m^3)			
	2	4	6	8
Hanging net cages (1)	0.97 $\pm$ 0.06	0.92 $\pm$ 0.06	0.41 $\pm$ 0.06	-0.42 $\pm$ 0.15
The long-line method (2)	1.22 $\pm$ 0.03	1.16 $\pm$ 0.05	0.06 $\pm$ 0.06	-0.31 $\pm$ 0.09
Horizontal nets (3)	1.23 $\pm$ 0.06	1.67 $\pm$ 0.06	0.06 $\pm$ 0.09	-0.31 $\pm$ 0.1
Attached to artificial coral rock (4)	1.23 $\pm$ 0.05	1.17 $\pm$ 0.06	0.06 $\pm$ 0.01	-0.33 $\pm$ 0.09

Notes: Daily growth rate (DGR), %/day.

Statistical analysis indicated that the 2 and 4 kg/m^3 treatments showed a significantly higher growth rate compared to

the 6 and 8 kg/m^3 treatments ($p > 0.05$), with the 8 kg/m^3 treatment being significantly different from all others ($p < 0.05$). In

conclusion, stocking density plays a crucial role in the growth rate of *B. gelatinus*. Stocking densities of 2 and 4 kg/m³ are

optimal for achieving the best growth, while higher stocking densities (8 kg/m³) negatively impact growth.

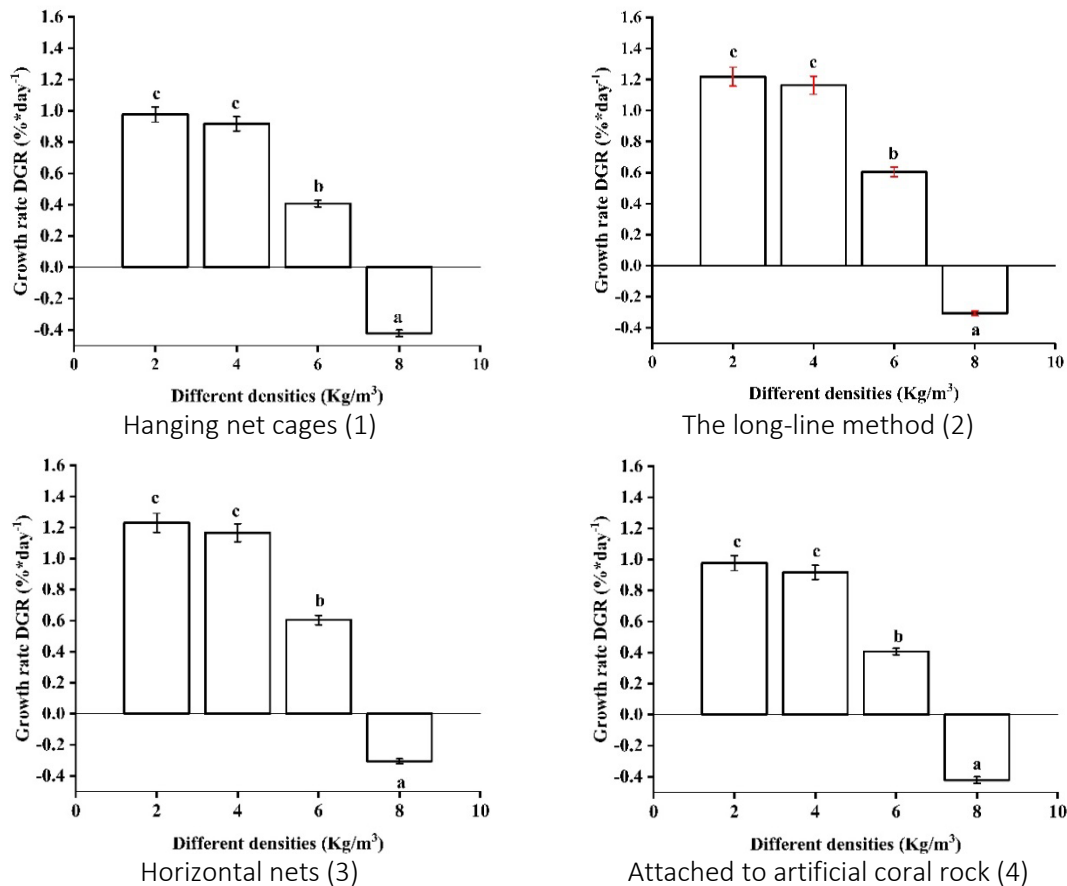


Figure 4. Growth rate of *B. gelatinus* at different stocking densities and culture methods

Effect of stocking density on carrageenan content, carrageenan quality of *B. gelatinus*

The carrageenan content analysis results shown in Figure 5 correspond to the changes in stocking density in all four farming methods. At a 2 kg/m³ density, the carrageenan content was highest and higher than other stocking densities; the carrageenan content decreased and reached the lowest at 8 kg/m³ in all four farming methods. Statistical analysis revealed no significant difference between the 2 and 4 kg/m³ treatments ($p > 0.05$), but significant differences were observed when comparing 2 kg/m³ with 6 and 8 kg/m³ treatments ($p < 0.05$). Similarly, the 4 kg/m³ treatment did not show statistical

differences with the 6 kg/m³ treatment ($p > 0.05$), but there was a significant difference compared to the 8 kg/m³ treatment ($p < 0.05$). The 8 kg/m³ treatment differed significantly from all other treatments ($p < 0.05$). Therefore, the 2 and 4 kg/m³ stocking densities resulted in the highest carrageenan content, making them the optimal densities for maximizing carrageenan production.

Regarding carrageenan's gel strength and viscosity, the results in Figure 5 indicate that lower stocking densities lead to better carrageenan quality. The highest gel strength was recorded at 2 kg/m³. Viscosity followed a similar trend, with the 2 kg/m³ treatment yielding and the lowest viscosity observed at 8

kg/m³. Statistical comparisons showed no significant difference in gel strength between the 2 and 4 kg/m³ treatments ($p > 0.05$). However, both differed significantly from the 6

and 8 kg/m³ treatments ($p < 0.05$), indicating that a stocking density of 2 kg/m³ is optimal for carrageenan quality regarding gel strength and viscosity.

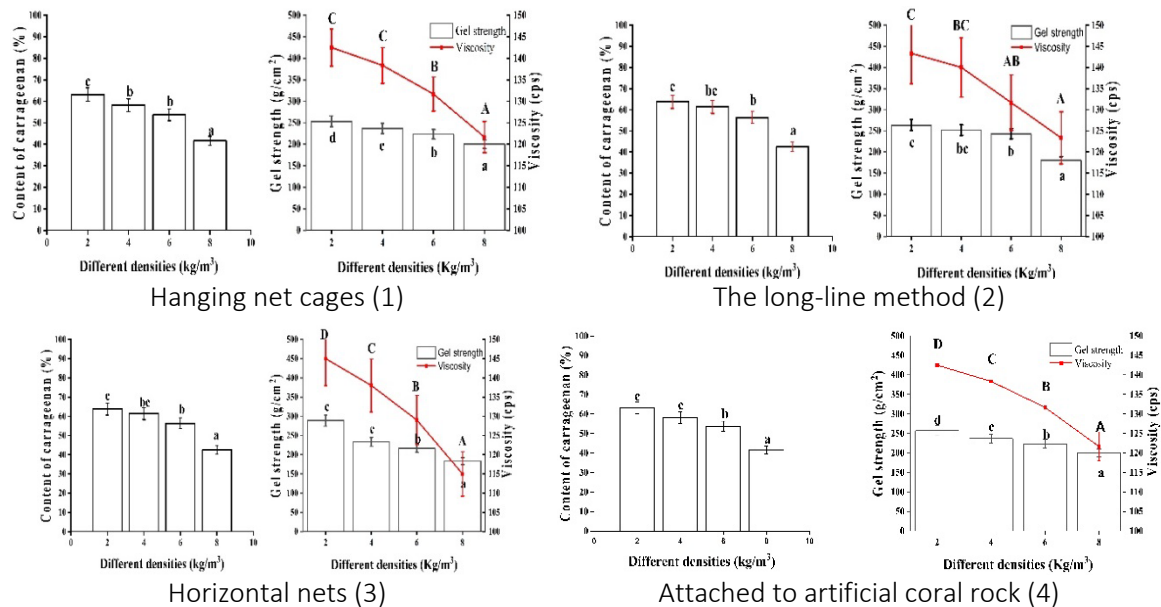


Figure 5. Carrageenan content, carrageenan quality of *B. gelatinus* at different stocking densities and culture methods

Effect of cultivation methods on the growth rate, carrageenan content, carrageenan quality of *B. gelatinus*

Based on the survey's results on the impact of seaweed stocking density on the growth rate, carrageenan content, and quality, we chose the seeding density of 2 kg/m³ to evaluate the impact of farming methods on the objective functions in the study. The results in Figure 6A show that the growth rate in the cultivation methods culture in hanging net cages (1), the long-line method (2), culture on horizontal nets (3), and cultivation attached to artificial coral (4) were as follows: 0.98 ± 0.06 %/day, 1.22 ± 0.03 %/day, 1.23 ± 0.06 %/day, and 1.23 ± 0.05 %/day, respectively. Statistical comparison indicates that cultivation method 1 differs significantly ($p < 0.05$) from methods 2, 3, and 4; however, no significant difference was observed between methods 2, 3, and 4 ($p > 0.05$). Thus, the cultivation method affects the growth rate of *B. gelatinus* grown in the 3 m³

tank, with culture in hanging net cages (method 1) resulting in the lowest growth rate.

The results in Figure 6B reflect changes in carrageenan content according to the cultivation method. The carrageenan contents recorded for cultivation method 1 (culture in hanging net cages), method 2 (the long-line method), method 3 (culture on horizontal nets), and method 4 (cultivation attached to artificial coral) were: 63.17 ± 4.35 , 63.83 ± 3.62 , and 63.85 ± 3.20 and 63.68 ± 3.50 %, respectively. Although there were slight variations in carrageenan content among the methods, statistical analysis indicates no significant differences between the cultivation methods ($p > 0.05$). Therefore, the cultivation method did not affect the carrageenan content.

Carrageenan quality, measured by gel strength and viscosity (Figure 6C), also shows that the cultivation method did not affect the product quality. In method 1 (culture in hanging net cages), 2 (the long-line method), 3

(culture on horizontal nets) and 4 (cultivation attached to artificial coral), the gel strengths and viscosities were as follows: 253.33 ± 4.71 , 263.35 ± 4.55 , 288.33 ± 4.50 , 256.67 ± 4.70 g/cm², and 142.50 ± 3.20 , 143.00 ± 3.40 , 145 ± 3.25 , 142.50 ± 3.30 cPs, respectively. Gel strength and viscosity increased from method 1

to method 3, peaked at method 3, and decreased in method 4. However, statistical analysis indicates that no significant differences in gel strength or viscosity among the treatments ($p > 0.05$). Thus, the cultivation method does not affect the quality of carrageenan.

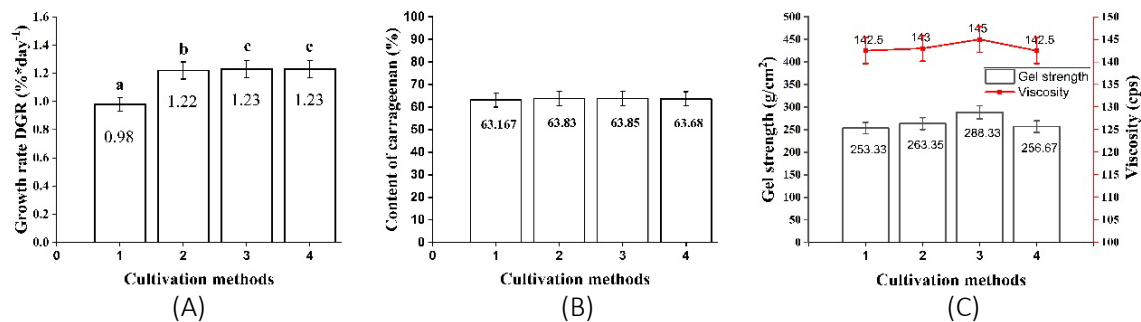


Figure 6. Effect of cultivation methods on the growth rate, carrageenan content, and carrageenan quality of *B. gelatinus*. (A) daily growth rate; (B) carrageenan content; (C) carrageenan quality: gel strength and viscosity; about cultivated methods: 1) hanging net cages; 2) long-line method; 3) horizontal nets; 4) attached to artificial coral rock

DISCUSSION

This study presents significant findings on the cultivation potential of *B. gelatinus* in outdoor tank systems, highlighting the impact of initial stocking density and cultivation methods on growth rate, carrageenan content, and quality. The results indicated that *B. gelatinus* can thrive in tanks at various densities (2, 4, 6 and 8 kg/m³). However, after 90 days of cultivation, seaweed at the density of 8 kg/m³ began to exhibit signs of mortality, while the highest recorded growth rate was 1.23 ± 0.05 %/day at 2 kg/m³. Although this growth rate is comparable to some previous studies conducted in China [22], it is lower than findings from Japan (maximum on the growth rate of *B. gelatinus* was 2.1 %/day at 24°C) and laboratory experiments in Viet Nam (the growth rate of *B. gelatinus* was 2.5 %/day) [24]. When compared with *Kappaphycus* cultivation studies in Malaysia, the growth rate of *B. gelatinus* in tanks was also significantly lower, potentially due to differences in temperature and environmental conditions in the cultivation tanks.

A significant finding of this study is that the carrageenan content of *B. gelatinus* in the cultivation tanks exceeded 60%, consistent with previous studies on natural and laboratory-cultivated seaweed [24]. However, the viscosity and gel strength of the carrageenan derived from tank-cultivated seaweed were lower than those from wild seaweed, possibly due to the immaturity of the seaweed in this study or the need for optimization in cultivation duration and extraction methods. The density of 2 kg/m³ yielded the best results for gel strength and viscosity, measuring 288.33 ± 4.71 g/cm² and 145.00 ± 3.50 cPs, respectively, although still lower than values reported in earlier studies on natural seaweed [32]. This discrepancy could be attributed to various factors, such as the maturity of the seaweed, extraction methods, and differing cultivation conditions.

The initial stocking 2 kg/m³ density yielded the highest growth rate, carrageenan content, and quality. These parameters gradually decreased with increasing density, with the lowest results observed at 8 kg/m³. This can be explained by the influence of initial stocking density on environmental factors such as light

availability, temperature, and the concentration of nutrients accessible to the seaweed. These findings are consistent with previous studies on the impact of stocking density on nutrient availability and light absorption in seaweed cultivation [33].

The study indicated that the horizontal net rack method was the most effective for cultivation methods. In contrast, the mesh enclosure method yielded unsatisfactory results due to limited light exposure and restricted water exchange. Methods 3 and 4 (culture on horizontal nets and cultivation attached to artificial coral) demonstrated optimal effectiveness within the tank system, allowing for better exposure to light and water, thereby enhancing growth rates and carrageenan quality. In contrast, method 1 (culture in hanging net cages) limited water circulation and light exposure, reducing photosynthesis and metabolic activity and resulting in poorer growth rates and product quality. Previous studies on *Kappaphycus alvarezii* have demonstrated that the growth rate achieved using culture in hanging net cages was the highest at $2.13 \pm 0.34\%$ per day, while the lowest was $1.26 \pm 0.04\%$ per day [26]. For the long-line method, our results exceeded those reported for *K. alvarezii* (0.14% per day) [27]. However, the growth rates for the other two cultivation methods were not specified, leaving no basis for comparison. Additionally, as *B. gelatinus* has not yet been cultivated using various methods worldwide or in Vietnam, we currently lack sufficient data to compare the results of this study with previous research.

CONCLUSION

This study confirms that *B. gelatinus* can be successfully cultivated in outdoor composite tank systems, with stocking density and cultivation methods playing crucial roles in optimizing yield and carrageenan quality. The results indicate that a 2 kg/m^3 density is optimal, providing the highest growth rate, the greatest carrageenan content, and the best product quality. In contrast, higher densities, particularly 8 kg/m^3 , inhibited growth and

significantly reduced carrageenan quality, including gel strength and viscosity. Regarding cultivation methods, all three methods, including long-line farming, horizontal net farming, and artificial coral-mounted farming showed good results, with no significant differences in growth rate and product quality. However, the mesh enclosure method performed poorly due to limited light exposure and restricted water flow. These findings provide a scientific basis for developing *B. gelatinus* cultivation models in outdoor tanks, helping to alleviate pressure on natural harvesting and maintain a sustainable supply. Moreover, implementing appropriate cultivation methods will ensure high productivity and good carrageenan quality, thus meeting the increasing market demand in the food and pharmaceutical industries. This research significantly contributes to conserving and developing valuable marine genetic resources in Vietnam. However, further studies on the effects of seasonal variations, tank and pond structure, temperature, pH, light, and nutrient levels are needed to optimize cultivation models in the future.

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