Effects of crude extract from the macroalgae *Kappaphycus alvarezii* on the common bean (*Phaseolus vulgaris*) crops

Efeitos do extrato bruto da macroalga *Kappaphycus alvarezii* nas culturas de feijão comum (*Phaseolus vulgaris*)

Efectos del extracto crudo de la macroalga *Kappaphycus alvarezii* en los cultivos de judía común (*Phaseolus vulgaris*)

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ABSTRACT
The current study confirmed the biostimulant potential of the crude extract from the macroalgae *Kappaphycus alvarezii* on the common bean *Phaseolus vulgaris* crop. The macroalgae extract was utilized in the pre-germinative treatment of seeds at concentrations of 0%, 1%, or 2% and in the root irrigation treatment at concentrations of 0%, 0.1%, or 0.2% of the bean plants. After 14 days, phytotechnical indices were evaluated, including total plant length (TPL), leaf length (LL), root length (RL), root volume (RV), total fresh mass (TFM), leaf fresh mass (LFM), root fresh mass (RFM), stem fresh mass (SFM), number of leaves (NL), plant height (PH), total dry mass (TDM), leaf dry mass (LDM), root dry mass (RDM), and stem dry mass (SDM). In the pre-germinative treatment, TFM, RFM, LDM, TDM and RDM were significantly higher ($p < 0.05$) in the 1% treatment than in the 0% control group. RDM was significantly higher ($p = 0.0001$) in the treated groups. SDM was significantly higher ($p = 0.004$) in the 2% treatment compared to the 1% treatment. In root application, RFM and RDM were significantly higher ($p = 0.029$) in the 0.2% treatment compared to the 0% group. TPL was significantly higher ($p = 0.031$) in the 0.1% and 0.2% treatments, while LL was significantly higher ($p = 0.036$) in the 0.1% treatment compared to the control group. It was concluded that the crude extract of *K. alvarezii* was potentially beneficial for the common bean *P. vulgaris* crop.

Keywords: seaweed, phycobiostimulants, agriculture, beans.

RESUMO
O estudo atual confirmou o potencial bioestimulante do extrato bruto da macroalga *Kappaphycus alvarezii* na cultura do feijão comum *Phaseolus vulgaris*. O extrato da macroalga foi utilizado no tratamento pré-germinativo de sementes nas concentrações de 0%, 1% ou 2% e no tratamento de irrigação radicular nas concentrações de 0%, 0,1% ou 0,2%. Após 14 dias, foram avaliados os índices fitotécnicos, incluindo comprimento total da planta (TPL), comprimento da folha (LL), comprimento da raiz (RL), volume da raiz (RV), massa fresca total (TFM), massa fresca da folha (LFM), massa fresca da raiz (RFM), massa fresca do caule (SFM), número de folhas (NL), altura da planta (PH), massa seca total (TDM), massa seca da folha (LDM), massa seca da raiz (RDM) e massa seca do caule (SDM). No tratamento pré-germinativo, TFM, RFM, LDM, TDM e RDM foram significativamente maiores ($p < 0,05$) no tratamento de 1% comparado ao controle. RDM foi significativamente maior ($p = 0,0001$) nos grupos tratados. SDM foi significativamente maior ($p = 0,004$) no tratamento de 2% comparado ao tratamento 1%. Na aplicação de raiz, RFM e RDM foram significativamente maiores ($p = 0,029$) no tratamento de 0,2% em comparação com o grupo de 0%. TPL foi significativamente maior ($p = 0,031$) nos tratamentos, enquanto LL foi significativamente maior ($p = 0,036$) no tratamento de 0,1% em comparação com o grupo controle. Concluiu-se que o extrato bruto de *K. alvarezii* foi potencialmente benéfico para a cultura do feijão comum *P. vulgaris*.

Palavras-chave: algas marinhas, ficobioestimulantes, agricultura, feijão.

RESUMEN
El presente estudio confirmó el potencial bioestimulante del extracto crudo de la macroalga *Kappaphycus alvarezii* en el cultivo de frijol común *Phaseolus vulgaris*. El extracto de macroalga se utilizó en el tratamiento pregerminativo de semillas en concentraciones de 0%, 1% o 2% y en el tratamiento de riego de raíces en concentraciones de 0%, 0,1% o 0,2%. Después de 14 días, se evaluaron índices fitotécnicos, incluyendo longitud total de la planta (TPL), longitud de la hoja (LL), longitud de la raíz (RL), volumen de la raíz (RV), masa fresca total (TFM), masa fresca de la hoja (LFM), masa fresca de raíz (RFM), masa fresca de tallo (SFM), número de hojas (NL), altura de planta (PH), masa seca total (TDM), masa seca de hojas (LDM), masa seca de raíces (RDM) y masa seca de tallo masa (MDS). En el tratamiento pregerminación, TFM, RFM, LDM, TDM y RDM fueron significativamente mayores ($p < 0,05$) en el tratamiento al 1% en comparación con el control. La RDM fue significativamente mayor ($p = 0,0001$) en los grupos tratados. La SDM fue significativamente mayor ($p = 0,004$) en el tratamiento al 2% en comparación con el tratamiento al 1%. En la aplicación radicular, RFM y RDM fueron significativamente mayores ($p = 0,029$) en el tratamiento al 0,2% en comparación con el grupo del 0%. TPL fue significativamente mayor ($p = 0,031$) en los tratamientos, mientras que LL fue significativamente mayor ($p = 0,036$) en el tratamiento al 0,1% en comparación con el grupo control. Se concluyó que el extracto crudo de *K. alvarezii* fue potencialmente beneficioso para el cultivo de frijol *P. vulgaris*.

Palabras clave: algas, ficobioestimulantes, agricultura, frijol.

1 INTRODUCTION

The cultivation of common beans (*Phaseolus vulgaris*) is a prevalent and important agricultural practice globally, especially in tropical and subtropical regions, with particular significance in Brazil (Amaral et al., 2022). Nevertheless, the increased intensification of crops to enhance productivity has led to a higher reliance on chemical fertilizers (Shimada, 2022), potentially jeopardizing the sustainability of the crops. In response to this challenge, natural biofertilizers or biostimulants have become increasingly important.

Biostimulants, such as seaweed extracts, are natural formulations that enhance plant growth and provide protection from stress. Research indicates that these biostimulants can boost plant health, increase yields, and improve stress resistance. The plant growth regulators found in seaweed extracts, such as vitamins, minerals, and other bioactive compounds, are essential for supporting sustainable agriculture (Rajesaheb et al., 2024; Mughunth et al., 2024).

Algae-based biostimulants, commonly known as phycobiostimulants, have become increasingly popular in agriculture for their various benefits in enhancing plant growth and development. They are being extensively researched as a sustainable alternative to chemical fertilizers in the agricultural industry (El Chami and Galli, 2020; Illera-Vives et al., 2020). Extracted from seaweed, these biostimulants contain a range of bioactive compounds including plant hormones, polysaccharides, amino acids, and essential minerals. These components enable macroalgae extracts to function as natural plant stimulants, enhancing plant resistance to environmental stresses, improving mineral nutrition, and boosting productivity (El Chami and Galli, 2020; Illera-Vives et al., 2020).

Additionally, these extracts can enhance soil quality and promote root growth, leading to higher crop yields and improved sustainability. Given their environmentally friendly properties, macroalgae extracts offer a promising alternative for contemporary agriculture (Kumar et al., 2020; Trivedi et al., 2023; Nivetha et al., 2024).

Extracts of *Kappaphycus alvarezii*, a type of red seaweed extensively cultivated in tropical regions for its high hydrocolloid content (Trivedi et al., 2023), have become increasingly popular in agriculture for their positive impact on plant growth. This seaweed is packed with bioactive compounds like polysaccharides (κ-carrageenan), amino acids, minerals, and plant hormones, making it a valuable natural biostimulant (Rupert et al., 2022). The application of *K. alvarezii* extracts in agriculture has been proven to enhance plant resilience against various stresses, including drought and pest infestations, while also boosting nutrient uptake efficiency (Mughunth et al., 2024). With its natural origins and numerous benefits, *K. alvarezii* extracts present a promising alternative for Brazilian agriculture.

In recent years, biostimulants derived from *K. alvarezii* have become increasingly popular in Brazil due to their potential to enhance plant growth and yield while maintaining a low carbon footprint. This makes them a promising sustainable option compared to traditional chemical fertilizers. Despite this, the effectiveness of *K. alvarezii* extracts as biostimulants still requires further scientific validation and data to support their use in agriculture. Therefore, this study aimed to explore the biostimulant potential of the crude extract of the macroalga *K. alvarezii* in seed pre-germination treatment and root treatment of common bean *P. vulgaris*.

2 MATERIAL AND METHODS

The study was conducted at the Aquaculture Department of the Federal University of Santa Catarina (UFSC). The biofertilizer was manually harvested from red strains of *K. alvarezii* grown in Ribeirão da Ilha, Florianópolis, Santa Catarina. The algae underwent a washing process with fresh running water to eliminate any fouling fauna and impurities. Subsequently, 0.5 kg of fresh algae was blended in a household blender and filtered using a cloth filter to obtain the crude extract. The crude extract was then diluted in water for either pre-germination treatment of seeds (0%, 1%, or 2%) or root treatment (0%, 0.1%, or 0.2%) of the common bean *P. vulgaris*.

2.1 EXPERIMENTAL DESIGN

The study focused on examining the impact of macroalgae extract when used alone for pre-germination treatment of seeds and root application in common bean plants. Eighteen experimental units (EUs) measuring 20 cm in diameter were filled with 830 g of stabilized inert soil with a pH of 7.0, ideal for monitoring the development of common beans.

For pre-germination treatment, seeds were treated with *K. alvarezii* extract at concentrations of 0%, 1%, or 2% for 2 h before being sown in the EU (five per EU). For root treatment, *P. vulgaris* seeds were germinated in a germination foam (Floraflex®), then, during the emergence phase (Fernández et al., 1985), were transferred to the EU (three per EU) and irrigated with a solution containing *K. alvarezii* extract at concentrations of 0%, 0.1%, or 0.2%. Plants were watered at the root zone with 5.0 mL of treatment solutions every other day.

Throughout the experiment, the cultures were exposed to artificial white LED light (6,500 K, Taschibra, 75 W) with a consistent irradiance of 400 µMol. The temperature in the experimental room was kept stable at 25.5 ± 1.0 °C for the entire 14-day duration of the study.

2.2 PHYTOTECHNICAL INDICATORS

After 14 days of cultivation, the phytotechnical measurements were taken including total plant length (TPL cm), leaf length (LL cm), root length (RL cm), root volume (RV cm^3), total fresh

mass (TFM g), leaf fresh mass (LFM g), root fresh mass (RFM g), stem fresh mass (SFM g), number of leaves (NL), plant height (PH cm) (from the substrate to the apex of the true leaf), total dry mass (TDM g), leaf dry mass (LDM g), root dry mass (RDM g), and stem dry mass (SDM g) were evaluated. The measurements were conducted using a precision scale (± 0.001 g) (BEL, Série L, SP, Brazil). Samples for dry mass analysis were dried in an oven for 72 h at 65°C.

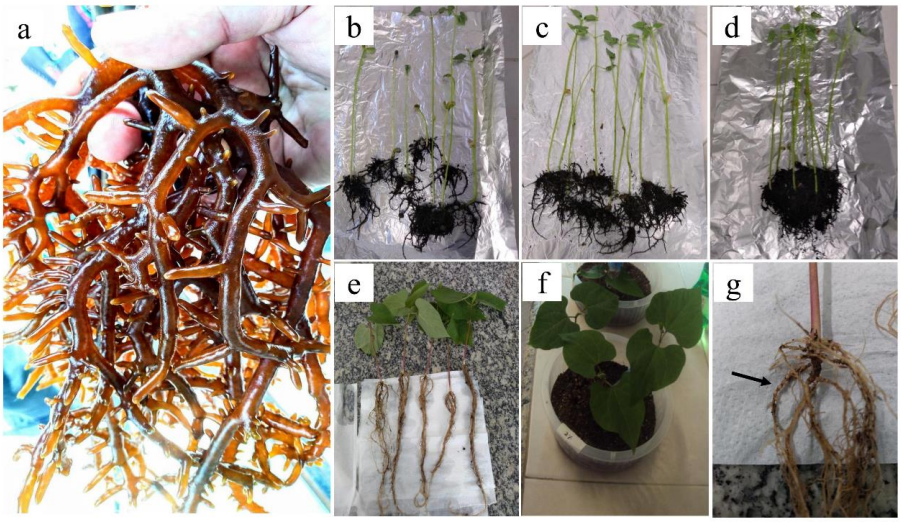
2.3 STATISTICAL ANALYSIS

The data that met the criteria of normality and homoscedasticity were analyzed using one-way analysis of variance (ANOVA), and the means were compared with Tukey's test ($p < 0.05$) using the Statistica 10.0 software.

3 RESULTS

The extract of *K. alvarezii* had a significant effect ($p < 0.05$) on the phytotechnical parameters of the common bean *P. vulgaris* (Figure 1).

Figure 1. Effects of crude extract from the macroalgae *K. alvarezii* on bean (*P. vulgaris*) crops. (a) Sample of *K. alvarezii* used for the extract. The algae were grown in Ribeirão da Ilha, Florianópolis - SC. (b) *P. vulgaris* from root treatment in control group 0%. (c) *P. vulgaris* from root treatment watered with a solution containing *K. alvarezii* extract at a concentration of 0.1%. (d) *P. vulgaris* from root treatment watered with a solution containing *K. alvarezii* extract at a concentration of 0.2%. (e and f) *P. vulgaris* from pre-germination treatment with a solution containing *K. alvarezii* extract at a concentration of 2%. (g) *P. vulgaris* from pre-germination treatment with *K. alvarezii* extract at a concentration of 1%. The black arrow indicates root nodulation, which is essential for plant nutrition.

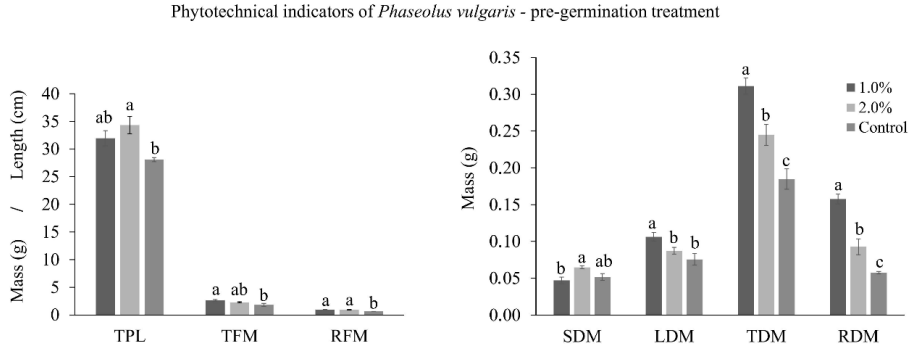


Source: created by the authors (2025).

When applied in pre-germinative treatment, the crude extract of *K. alvarezii* significantly altered ($p < 0.05$) TPL, TFM, RFM, SDM, LDM, TDM and RDM. TPL was significantly higher ($p = 0.036$) in the 2% treatment (34.336±1.571 cm) than in the 0% control group (28.083±0.375 cm). TFM (2.633±0.149 g), LDM (0.106±0.006 g), TDM (0.311±0.011 g), and RDM (0.158±0.007 g)

were significantly higher ($p < 0.05$) in the 1% treatment than in the 0% control group (TFM 1.825±0.279 g; LDM 0.076±0.008 g; TDM 0.185±0.014 g; and RDM 0.058±0.002 g). RFM was significantly higher ($p = 0.0001$) in the treated than in the control (0%) group. SDM was significantly higher (0.004) in the 2% treatment compared to the 1% treatment (Figure 2).

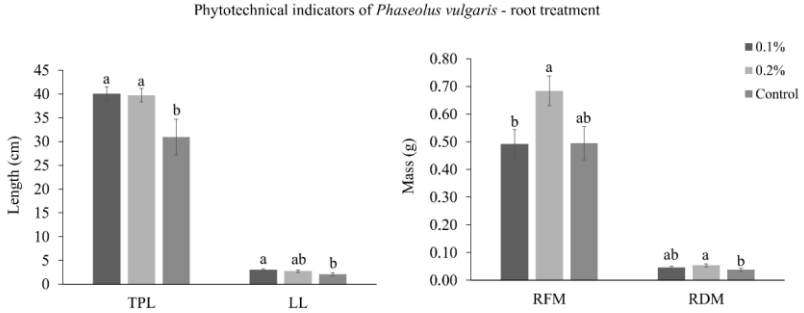
Figure 2. Phytotechnical indicators of *P. vulgaris* after pre-germinative treatment with seeds treated with *K. alvarezii* extract at concentrations of 0%, 1%, or 2%. The treatment caused significant changes in the following parameters: total plant length (TPL), total fresh mass (TFM), root fresh mass (RFM), stem dry mass (SDM), leaf dry mass (LDM), total dry mass (TDM), and root dry mass (RDM). The means were compared with Tukey's test ($p < 0.05$).



Source: created by the authors (2025).

In root application, the crude extract of *K. alvarezii* significantly altered ($p < 0.05$) the TPL, LL, RFM, and RDM of common bean. RFM was significantly higher ($p = 0.029$) in the 0.2% treatment (0.684±0.053 g), when compared to the 0% group (0.495±0.060 g). Likewise, RDM was significantly higher ($p = 0.003$) in the 0.2% treatment (0.054±0.004 g), when compared to the 0% group (0.038±0.005 g). TPL was significantly higher ($p = 0.031$) in treatments 0.1% (40.055±1.496 cm) and 0.2% (39.750±1.423 cm) compared to the control group (30.928±3.756 cm), while LL was significantly higher ($p = 0.036$) in treatment 0.1% (3.012±0.240 cm) when compared to the control group (2.071±0.303 cm) (Figure 3). The other phytotechnical indices did not differ significantly (Table 1).

Figure 3. Phytotechnical indicators of *P. vulgaris* after root treatment with *K. alvarezii* extract at concentrations of 0%, 0.1%, or 0.2%. The treatment caused significant changes in the following parameters: total plant length (TPL), leaf length (LL), root fresh mass (RFM), and root dry mass (RDM). The means were compared with Tukey's test ($p < 0.05$).



Source: created by the authors (2025).

Table 1. Phytotechnical indicators of *P. vulgaris* after pre-germinative treatment of seeds with *K. alvarezii* extract at concentrations of 0%, 1%, or 2% or root treatment at concentrations of 0%, 0.1%, or 0.2%. Total plant length (TPL), leaf length (LL), root length (RL), root volume (RV), total fresh mass (TFM), leaf fresh mass (LFM), root fresh mass (RFM), stem fresh mass (SFM), number of leaves (NL), plant height (PH), total dry mass (TDM), leaf dry mass (LDM), root dry mass (RDM), and stem dry mass (SDM). The means were compared with Tukey's test ($p < 0.05$).

	Treatments							
	Pre-germinative				**Root irrigation**			
Indices	0%	1%	2%	***p-value***	0%	0.1%	0.2%	***p-value***
TPL	28.08±0.37	31.95±1.37	34.64±1.57	0.036	30.92±3.75	40.05±1.49	39.75±1.42	0.018
LL	8.46±0.53	8.53±0.42	8.84±0.21	0.763	2.07±0.30	3.01±0.24	2.74±0.23	0.049
RL	16.00±2.11	21.79±1.54	21.63±1.36	0.062	10.47±0.92	11.11±0.68	10.33±0.39	0.687
RV	1.08±0.08	1.30±0.13	1.20±0.10	0.504	0.67±0.07	1.68±0.17	1.86±0.14	0.320
TFM	1.82±0.27	2.63±0.14	2.28±0.09	0.010	1.38±0.17	1.68±0.17	1.86±0.14	0.137
LFM	0.75±0.08	0.83±0.08	0.87±0.04	0.560	0.09±0.02	1.14±0.01	0.13±0.01	0.188
RFM	0.65±0.01	0.99±0.05	0.92±0.03	0.001	0.49±0.06	0.49±0.05	0.68±0.05	0.030
SFM	0.52±0.08	0.52±0.02	0.61±0.02	0.156	0.80±0.02	1.04±0.10	1.04±0.80	0.589
NL	2.16±0.30	2.66±0.33	3.00±0.33	0.319	2.85±0.45	2.55±0.29	2.22±0.14	0.363
PH	11.75±0.25	11.29±0.46	12.31±0.51	0.284	26.50±3.62	29.20±1.29	29.43±1.63	0.611
TDM	0.18±0.01	0.31±0.01	0.24±0.01	0.001	0.15±0.02	0.17±0.01	0.16±0.01	0.744
LDM	0.076±0.01	0.106±0.01	0.087±0.01	0.005	0.018±0.00	0.023±0.00	0.021±0.00	0.424
RDM	0.058±0.00	0.158±0.01	0.093±0.01	0.001	0.038±0.01	0.046±0.00	0.053±0.00	0.048
SDM	0.052±0.00	0.047±0.00	0.065±0.00	0.004	0.099±0.02	0.093±0.01	0.093±0.01	0.943

Source: created by the authors (2025).

4 DISCUSSION

Commercial cultivation of the macroalgae *K. alvarezii* is now a successful venture along the coast of Santa Catarina. The estimated production for the 2023/2024 season is 750 tons, making algae farming a profitable option for local shellfish farmers. This growth is largely attributed to the demand from the biofertilizer industry (Santos, 2024). Therefore, research into the use of *K. alvarezii* extract in agriculture is crucial for the sector's advancement.

In the current research, the *K. alvarezii* extract resulted in significant improvements in various phytotechnical indicators (TPL, TFM, RFM, SDM, LDM, TDM, and RDM) of common beans when used for pre-germination treatment. Trivedi et al. (2023) reported that a variety of biostimulants derived from *K. alvarezii* are utilized in agriculture globally. These biostimulants come in liquid extracts and solid formulations and are applied through various methods such as foliar coatings, seed coating, seed immersion, or seed soaking. The effectiveness of phytotechnical production enhancements is influenced by factors such as the extraction method, extract concentration, and timing of application during the plant's growth cycle. Therefore, the source and application method of the extract can result in different types of biostimulatory products, supporting the findings of the current study.

In a study by Nunes et al. (2024), it was found that a biofertilizer derived from *K. alvarezii* enhanced the growth of basil (*Ocimum basilicum*) in a hydroponic system. The extract, tested at

various concentrations (1%, 3%, 5%, and 7%), consistently showed positive effects on the plant. Similarly, Nivetha et al. (2024) demonstrated that foliar sprays of a biostimulant derived from the red algae *K. alvarezii* promoted the phenotypic growth of corn (*Zea mays*), leading to increased leaf area, plant height, and fresh and dry weights of shoots. These findings suggest that the application of the extract can yield promising results across different cultivation systems.

Additionally, the extract of *K. alvarezii* has been shown to induce transcriptional changes in maize roots when exposed to drought stress. Kumar et al. (2020) found that an extract of *K. alvarezii* seaweed grown in Mandapam (India) led to altered expression of genes related to various pathways such as protein-RNA synthesis, cell wall-RNA, stress-RNA, hormone metabolism-RNA, lipid metabolism-DNA, amino acid metabolism-DNA, and N metabolism. These results expand the scope of research in this area.

The use of *K. alvarezii* extract stimulated flowering and enhanced the growth of common pea (*Pisum sativum*) under ideal conditions and nitrogen restriction. Furthermore, it had a beneficial impact on the plant's biochemical, molecular, and physiological functions (Shukla et al., 2024). In contrast, applying *K. alvarezii* extracts at 2% and 10% through foliar and root methods to rice plants (*Oryza sativa*) enhanced photosynthetic transport efficiency and stress adaptation. This resulted in improved uptake of N and K, leading to higher levels of N-NO_3- and amino-N, ultimately boosting biomass production, growth, and root development. Notably, root application stimulated plant growth at later times compared to foliar application (Castro et al., 2024).

The current research demonstrated that the extract of *K. alvarezii* effectively enhanced the growth and development of common beans, including seed germination. Seaweed extracts have diverse effects on plants due to their rich composition of bioactive compounds, including plant hormones (auxins, gibberellins, and cytokinins), amino acids, vitamins, and polysaccharides, which can impact various physiological and growth processes in plants. Previous studies have indicated that seaweed extracts can elicit specific responses in different crops, reflecting the intricate interplay between the compounds in seaweed extracts and the biological processes of plants (Trivedi et al., 2023).

K. alvarezii is becoming increasingly popular in Brazilian aquaculture because of its hydrocolloid content, which is used in the agricultural sector. There is currently a consensus supporting the cultivation of *K. alvarezii* along the coast of Santa Catarina due to recent legislative advancements and government incentives that have enhanced the credibility of the production chain. However, more research is needed to characterize the extracts obtained from different regions of Santa Catarina and to enhance their effectiveness in various cultures, thereby maximizing the potential of *K. alvarezii* for a more sustainable future in Brazilian aquaculture.

5 CONCLUSION

The small-scale laboratory study found that the crude extract of *K. alvarezii* could benefit the common bean *P. Vulgaris* crop. These results are crucial for further research into biostimulants made from *K. alvarezii* seaweed. However, additional studies on a larger scale are needed to validate these findings.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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