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Evaluation of *Sargassum fluitans* extract as liquid organic fertilizer to improve vegetative growth of Inpari 32 Rice on saline soil

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ABSTRACT

This study aims to evaluate the potential of S. fluitans bioalgae extract as a liquid organic fertilizer to enhance the vegetative growth of Inpari 32 Rice in saline soils in Southeast Sulawesi. The research was conducted at the Phytopathology Laboratory and Experimental Garden of the Faculty of Agriculture, Halu Oleo University. The study was carried out from February to May 2025. The research used a randomized block design (RBD) with four treatment concentrations, each repeated 3 times as groups. The experiment was conducted by applying S. fluitans at the following concentrations: P0 = 0%, P1 = 10%, P2 = 20%, and P3 = 30%. The variables observed included plant height, leaf number, and clump number. If there was a significant effect in the analysis of variance, the least significant difference (LSD) test was performed at a significance level of a = 0,05. The results showed that the application of S. fluitans significantly increased all growth parameters compared with the control. The 10% concentration produced the highest plant height, while the 20% concentration produced the highest number of leaves. An increase in the number of tillers was also observed across all S. fluitans treatments. These findings indicate that S. fluitans contains bioactive compounds that stimulate rice vegetative growth. The optimal concentration variation for different parameters shows the complexity of the dose response and the need for further optimization. This study concludes that S. fluitans has the potential to serve as a sustainable organic fertilizer alternative to increase rice productivity in saline soils of Southeast Sulawesi, contributing to food security and environmentally friendly agriculture.

Keywords:
Inpari 32 Rice, Liquid organic fertilizer, S. fluitans, Saline soil

1. Introduction

Indonesia is known as an agricultural country with abundant natural resources, but this does not necessarily mean that Indonesians have easy and affordable access to food. According to data from the Central Statistics Agency (BPS), Indonesia still imported 4.52 million tons of rice in 2024. This is the highest amount in the last seven years, indicating a gap between national rice production and demand [1]. Food security is very important because Indonesia's population, which currently stands at 275 million, is projected to continue to increase to 319 million by 2045 [2]. Therefore, increasing the productivity of rice as the main food source is crucial to ensuring sufficient and affordable food availability for all Indonesians.

Rice production in Indonesia can increase or decrease each year depending on the fertility of the land and environmental conditions in the region [3]. Southeast Sulawesi Province, with its lowlands and islands, has great agricultural potential, but faces challenges in the form of soil types that are generally classified as low in fertility and often exposed to high salinity. Salinity generally occurs in agricultural land near the coast, caused by sea level rise due to climate change. It is estimated that 12.020

million ha of land near the coast, or 6.20% of Indonesia's total land area, is vulnerable to salinity [4]. Based on research [5,6], high salt concentrations in the root medium cause the water potential of the rhizosphere environment to decrease, thereby disrupting the water supply and nutrient transport to plant tissues, which ultimately inhibits growth and reduces rice yields. Salinity can cause osmotic stress, ionic toxicity, and nutritional imbalance in rice plants, which significantly affects physiological processes such as photosynthesis, respiration, and protein synthesis [7]. In addition to salinity stress, another significant challenge in rice cultivation is the declining fertility of paddy fields. To restore soil fertility, fertilization plays an important role in efforts to increase agricultural yields [8]. In addition to inorganic fertilizers, the use of organic fertilizers is becoming increasingly important because they can improve soil structure, increase nutrient availability, and reduce negative impacts on the environment. Efforts can be made to increase crop production and reduce farmers' dependence on inorganic fertilizers, which are needed to encourage the development of more environmentally friendly, inexpensive, and sustainable technologies [9–11].

One promising approach to improving rice growth and yield under these conditions is the application of bioalgae organic fertilizer made from seaweed. Seaweed of the species *Sargassum fluitans* is a type of brown algae that is widely distributed in Indonesian waters, including the islands of Southeast Sulawesi Province. This type of seaweed has not been commercially cultivated, is easily accessible, grows wild, and often accumulates on beaches. Therefore, efforts are needed to optimally utilize seaweed (*S. fluitans*). The use of *S. fluitans* waste as organic fertilizer not only reduces environmental problems caused by accumulation on beaches but also has the potential to reduce dependence on imported chemical fertilizers and create economic opportunities for coastal communities. In line with several studies [12–14] on the results of recycling into bio-organic fertilizer (BIO), it offers a sustainable solution, improves soil health, reduces dependence on chemical fertilizers, and stimulates plant growth.

Recycled bioalgae from the *S. fluitans* species contains many plant growth regulators (PGRs) such as auxin, gibberellin, and cytokinin, which play an important role in plant growth. Based on research results [15], nitrogen-fixing algae extracts contain auxin, cytokinin, and gibberellic acid. Auxin plays a role in stimulating root formation and elongation, increasing water and nutrient absorption from the soil. The plant growth regulators (PGRs) contained in the *Sargassum* sp. group can improve plants' ability to adapt to drought stress and pest attacks and help improve soil structure [16–18]. Analysis of the content of *Sargassum* sp. shows that this seaweed contains carbohydrates (67.01%), water (6.66%), ash (17.75%), protein (8.19%), fat (0.39%), and mineral content of Fe (19.48 mg/L), Mg (16.58 mg/L), Ca (10.15 mg/L), and K (28.50 mg/L). The bioactive compounds contained in Sargassum are alkaloids, saponins, and steroids [19]. The high potassium (K) content in S. fluitans, in particular, is very important because potassium plays a role in plant osmotic regulation, helping plants cope with stress due to salinity [20,21].

In this study, the Inpari 32 Rice variety was chosen because it is widely cultivated in Southeast Sulawesi and is known to have high yield potential in the region, despite being relatively sensitive to salinity. Therefore, research was needed to test various concentrations of bioalgae extract, namely *S. fluitans*, as an alternative ingredient for liquid organic fertilizer on the vegetative growth of Inpari 32 Rice plants in saline soil. This study provides the first experimental evaluation of *S. fluitans* extract on Inpari 32 Rice grown in saline soil in Southeast Sulawesi. This study is expected to provide new information on the effectiveness of *S. fluitans* liquid organic fertilizer in enhancing the growth of Inpari 32 Rice in saline land in Southeast Sulawesi. Therefore, this study aims to determine the optimal concentration of liquid organic fertilizer that provides the highest vegetative growth of Inpari 32 Rice in saline soil, based on the parameters of plant height, number of tillers, and leaf area. It is hypothesized that the application of liquid organic fertilizer at a certain concentration will increase the vegetative growth of Inpari 32 Rice in saline soil.

2. Methods

The experiment was conducted from February to May 2025 at the Experimental Garden of the Faculty of Agriculture, Halu Oleo University, Indonesia. The equipment used in this study included a rotary vacuum evaporator, desiccator, blender, shaker, analytical balance, Whatman filter paper, oven, 25 cm x 30 cm polybags, sprayer, and writing instruments. The materials used in this study were 70% ethanol, topsoil, cow manure, charcoal husks, Inpari 32 Rice seeds, and *S. fluitans* seaweed from the Toronipa coast at Southeast Sulawesi Province.

This study used a Randomized Block Design (RBD) consisting of 4 treatments, namely P0 = 0 ml.L^{-1} (0%), P1 = 10 ml.L^{-1} (10%), P2 = 20 ml.L^{-1} (20%), and P3 = 30 ml.L^{-1} (30%). Each treatment was repeated 3 times as a group, resulting in 12 observation units. In 1 unit, there were 5 polybag samples, with a total of 60 observation samples. The analysis in this study used Analysis of Variance (ANOVA). If the treatment results showed a significant effect, then the Least Significant Difference (LSD) multiple comparison test at the 5% level was continued.

2.1. Seaweed Sampling Procedure

Seaweed of the genus *S. fluitans* was obtained from the coastal area of Toronipa, Kendari City, Konawe Regency, Southeast Sulawesi Province, with the sampling site located at coordinates 3°54'12.96"S and 122°39'54.54"E. The location map is presented in Appendix 2. Sample handling in the field was carried out using a cooling method by placing ice blocks in an ice box to maintain freshness during transportation from the sampling site to the extraction site (laboratory).

2.2. Preparation and Extraction of S. fluitans

The collected seaweed samples were thoroughly washed, then dried in an oven at 50 °C for three days. The dried seaweed was ground into powder using a blender. A total of 1 kg of seaweed powder was weighed and placed into a glass container, followed by the addition of 1000 mL of 70% ethanol with a material-to-solvent ratio of 1:1 (b/v). The mixture was macerated for 3 × 24 hours at 40 °C. The maceration result was filtered using Whatman filter paper to obtain a solution (Filtrate I). Filtrate I was then subjected to solvent removal using a rotary vacuum evaporator at 78 °C until all ethanol had evaporated, resulting in a crude extract (Filtrate II). Filtrate II was further incubated in a desiccator for 2 days to remove residual moisture until a thick extract was obtained, which was ready for testing [22].

2.3. *Preparation of Concentrations and Treatment Application*

The prepared test solution was diluted into four concentration series according to the treatments: 0%, 10%, 20%, and 30%, using the dilution formula (1) [23]:

$$\mathbf{M1 \times V1 = M2 \times V2} \tag{1}$$

where:
M1 = Molarity before dilution
V1 = Volume before dilution
M2 = Molarity after dilution
V2 = Volume after dilution

P0 = 0% concentration obtained from:

M1.V1	=	M2.V2
100.V1	=	0.100
V1	=	100/100
V1	=	0 ml

(0 ml extract and 100 ml sterile water)

P1 = 10% concentration obtained from:

M1.V1	=	M2.V2
100.V1	=	10.100
V1	=	1000/100
V1	=	10 ml

(10 ml extract and 90 ml sterile water)

P2 = 20% concentration obtained from:

M1.V1	=	M2.V2
100.V1	=	20.100
V1	=	2000/100
V1	=	20 ml

(20 ml extract and 80 ml sterile water)

P3 = 30% concentration obtained from:

M1.V1	=	M2.V2
100.V1	=	30.100
V1	=	3000/100
V1	=	30 ml

(30 ml extract and 70 ml sterile water)

The application of treatment concentrations to Inpari 32 Rice seeds was carried out using the soaking method, in which 25 seeds were soaked in a 250 ml Erlenmeyer flask and then shaken for 12 hours. Afterward, the seeds were planted in the prepared growing media (polybag).

2.4. *Preparation of Growing Media and Rice Seed Planting*

Prepare the planting medium using 50 kg of topsoil per bag, 25 kg of rice husk charcoal per bag, and 25 kg of cow manure per bag in a ratio of 3:1:1 per bag. Mix the soil to make the planting medium, then fill the polybags according to the number of treatments, including the control treatment.

2.5. *Planting of Inpari 32 Rice Seeds and Cultivation Management*

A total of 25 Inpari 32 Rice seeds that had been treated with solution concentrations of 0%, 10%, 20%, and 30% for 12 hours were planted in the growing media, with two seeds per prepared polybag. Maintenance was carried out by watering with a hose in the morning and afternoon, followed by daily observation of plant growth.

2.6. *Observation Variables*

The observation variables in this study were plant height (at 4, 5, 6, and 7 weeks after planting), number of leaves (at 4, 5, 6, and 7 weeks after planting), and number of tillers (at 5, 6, and 7 weeks after planting).

3. Results and Discussion

3.1. Plant Height

The observed plant height growth of Inpari 32 Rice, measured at 4, 5, 6, and 7 weeks after planting (WAP) under the application of *S. fluitans*. seaweed extract at various concentrations, showed no significant effect at 4 WAP and 5 WAP. However, a significant effect was observed at 6 WAP, and a highly significant effect was recorded at 7 WAP. These results are presented in Table 1 and Figure 1.

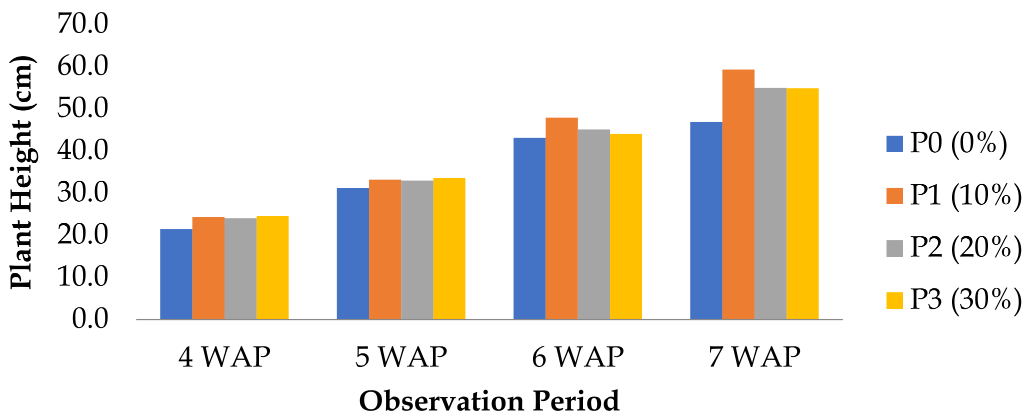

Figure 1. Plant height growth dynamics

Table 1. Average plant height of Inpari 32 Rice (cm)

Treatment	4 WAP	5 WAP	6 WAP	7 WAP
P0 (0%)	21.4^{a}	31.2^{a}	43.1^{b}	46.8^{b}
P1 (10%)	24.3^{a}	33.2^{a}	47.9^{a}	59.3^{a}
P2 (20%)	24.0^{a}	33.0^{a}	45.1^{a}	55.0^{a}
P3 (30%)	24.6^{a}	33.6^{a}	44.0^{a}	54.9^{a}
$LSD_{\alpha = 0.05}$	nsd	nsd	2.97	4.01

Note: Numbers followed by the same letter in the same column are not significantly different based on the LSD test α = 0.05. nsd= not statistically different.

The results of the LSD test at α = 0.05 on the average plant height at the 6 WAP observation showed that the highest value was obtained in treatment P1 = 47.9 cm, which was not significantly different from P2 = 45.1 cm and P3 = 44.0 cm, but was significantly different from P0 = 43.1 cm. Similarly, at the 7 WAP observation, the results of the LSD test at α = 0.05 showed that the highest average plant height was found in treatment P1 = 59.3 cm, which was not significantly different from P2 = 55.0 cm and P3 = 54.9 cm, but was significantly different from P0 = 46.8 cm.

3.2. Number of Leaves

The observation results of leaf number growth in Inpari 32 Rice, measured at 4, 5, 6, and 7 weeks after planting (WAP) with the application of *S. fluitans*. seaweed extract at various concentrations, showed no significant effect at 4 WAP and 5 WAP. However, a significant effect was observed at 6 WAP, and a highly significant effect was recorded at 7 WAP. These results are presented in Table 2 and Figure 2.

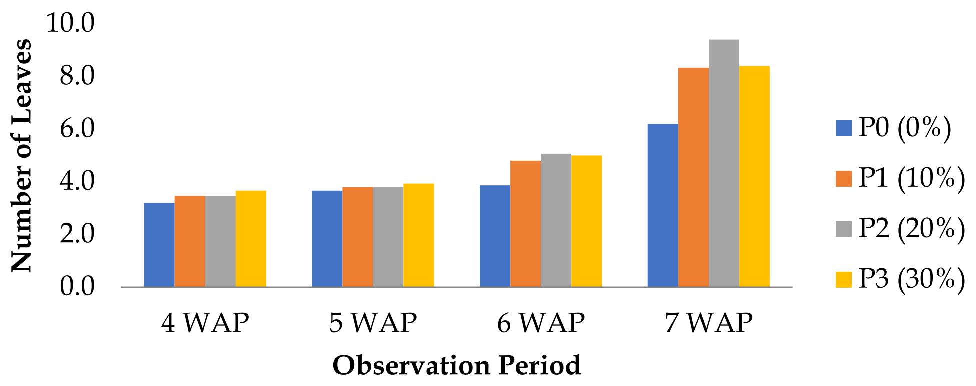

Figure 2. Dynamics of leaf number growth

Table 2. Average percentage of number of leaves of Inpari 32 Rice

Treatment	4 WAP	5 WAP	6 WAP	7 WAP
P0 (0%)	3.2[a]	3.7[a]	3.9[b]	6.2[b]
P1 (10%)	3.5[a]	3.8[a]	48[a]	8.3[a]
P2 (20%)	3.5[a]	3.8[a]	5.1[a]	9.4[a]
P3 (30%)	3.7[a]	3.9[a]	5.0[a]	8.4[a]
$LSD_{\alpha = 0.05}$	nsd	nsd	0.88	1.35

Note: Numbers followed by the same letter in the same column are not significantly different based on the LSD test α = 0.05. nsd= not statistically different.

The results of the LSD test at α = 0.05 on the average number of leaves at the 6 WAP observation showed that the highest value was obtained in treatment P2 = 5.1 leaves, which was not significantly different from P3 = 5.0 leaves and P1 = 4.8 leaves, but was significantly different from P0 = 3.9 leaves. Similarly, at the 7 WAP observation, the results of the LSD test at α = 0.05 showed that the highest average number of leaves was found in treatment P2 = 9.4 leaves, which was not significantly different from P3 = 8.4 leaves and P1 = 8.3 leaves, but was significantly different from P0 = 6.2 leaves.

3.1. Number of Clumps

The observation results of clump number growth in Inpari 32 Rice, measured at 5, 6, and 7 weeks after planting (WAP) with the application of *S. fluitans*. seaweed extract at various concentrations, showed no significant effect at 5 WAP and 6 WAP. However, a significant effect was observed at 7 WAP. These results are presented in Table 3 and Figure 3.

Table 3. Average percentage of number of clumps of Inpari 32 Rice

Treatment	5 WAP	6 WAP	7 WAP
P0 (0%)	3.0[a]	3.8[a]	4.1[b]
P1 (10%)	3.2[a]	3.9[a]	5.3[a]
P2 (20%)	3.4[a]	3.9[a]	5.2[a]
P3 (30%)	3.4[a]	3.9[a]	5.1[a]
$LSD_{\alpha = 0.05}$	nsd	nsd	0.91

Note: Numbers followed by the same letter in the same column are not significantly different based on the LSD test α = 0.05. nsd= not statistically different.

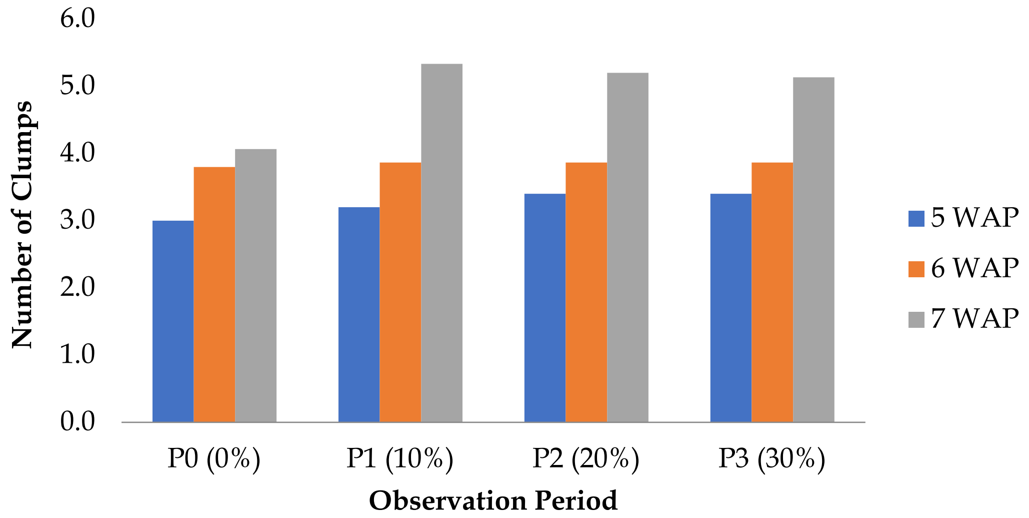

Figure 3. Dynamics of number of clumps

The results of the LSD test at α = 0.05 on the average number of clumps at the 6 WAP observation showed that the highest value was obtained in treatment P1 = 3.9 clumps, which was not significantly different from P2 = 3.9 clumps, P3 = 3.9 clumps, and P0 = 3.8 clumps. In contrast, at the 7 WAP observation, the results of the LSD test at α = 0.05 showed that the highest average number of clumps was found in treatment P1 = 5.3 clumps, which was not significantly different from P2 = 5.2 clumps and P3 = 5.1 clumps, but was significantly different from P0 = 4.1 clumps.

This study investigates the potential of *S. fluitans* bioalgae extract as a liquid organic fertilizer to enhance the vegetative growth of Inpari 32 Rice in saline soils in Southeast Sulawesi. The results show that the application of *S. fluitans* liquid fertilizer has a positive effect on rice plant growth, as indicated by significant increases in plant height, number of leaves, and number of tillers compared to the control (without *S. fluitans* fertilizer application). Plant growth is influenced by the availability of nutrients in the growing medium. The provision of nutrients from organic materials combined with chemical fertilizers is very good for the vegetative and generative growth of plants [24,25]. Optimal rice plant growth is greatly influenced by the nutritional conditions in the growing medium. The nutrients needed at the beginning of growth (vegetative phase) include N, P, and K [26]. Various media such as soil, sand, rice husks, and sawdust can be used and combined to meet plant nutritional needs [27]. Liquid fertilizer made from seaweed can increase plant production through a simple extraction method [28].

In this study, the significant increase in plant height and number of leaves in the treatment with *S. fluitans* application is in line with the study [29] which shows that *S. aquifolium* liquid extract has potential as an organic "biostimulant." This indicates that *S. fluitans*, similar to *S. aquifolium*, contains bioactive compounds that can stimulate nutrient uptake by plant roots, increase the rate of photosynthesis, and ultimately promote vegetative growth. The content of plant growth regulators (PGRs) such as auxin, cytokinin, and gibberellin, as well as trace minerals (Fe, B, Ca, Cu, Cl, K, Mg, and Mn) commonly found in seaweed [30–32], likely play an important role in this growth-enhancing mechanism. However, it is important to note that there are differences between algae species (*S. fluitans* vs. *S. aquifolium*), so specific effectiveness may vary depending on the unique composition of each species. Identification and quantification of specific PGR and mineral content in S. fluitans extracts could provide a deeper understanding of their mechanism of action.

Interestingly, the optimal concentration of *S. fluitans* appears to vary depending on the growth parameters observed. Treatment P1 (10%) showed the best results in plant height, while P2 (20%) produced the highest number of leaves. The effectiveness of the 10% concentration (P1) on plant height can be explained by the optimal balance between nutrient availability and hormonal stimulation in the early stages of growth. Higher concentrations (20% and 30%) may contain compounds that, although increasing the number of leaves (as in P2), may inhibit cell elongation in the stem, or may cause mild toxic effects that limit plant height growth under saline conditions. It is important to note that plant response to liquid organic fertilizer is complex and influenced by many factors, including soil type, plant variety, and environmental conditions [33]. This variation indicates that there is a complex dose response, and that the concentration of *S. fluitans* needs to be specifically adjusted to achieve optimal results for specific growth parameters. Further research with a wider range of concentrations and combinations of growth parameters could help identify the optimal concentration that provides the best overall results. Plant performance can be seen in the image below.

Figure 4. Vegetative growth of Inpari 32 Rice

The increase in the number of clumps in the treatment with *S. fluitans* application also supports the effectiveness of this bioalgae as an organic fertilizer. In line with various studies [34–36], these results show that the application of algal biofertilizer can maximize plant growth rates, potentially increase crop yields, and contribute to long-term soil quality improvement. Physiologically, plant height, number of leaves, and number of tillers are interrelated. Optimal plant height (as in P1 10%) allows for more efficient capture of sunlight, which is important for photosynthesis. An increase in the number of leaves (as in P2 20%) further increases the photosynthetic capacity of plants. The number of tillers, as an indicator of the number of productive tillers, shows the plant's potential to produce more panicles and seeds [37]. The combination of these three factors contributes to strong vegetative growth, which is the foundation for high yields. Thus, *S. fluitans* has the potential to be an innovative solution to support food security in Southeast Sulawesi.

Overall, this study provides promising evidence regarding the potential of *S. fluitans* as a liquid organic fertilizer to enhance the vegetative growth of Inpari 32 Rice in saline soils. These results are in line with previous studies on the benefits of algae-based organic fertilizers [38–40] and support the idea that the appropriate use of bioalgae can be a sustainable alternative to chemical fertilizers, contributing to more environmentally friendly agriculture and improving soil health and plant resistance to salinity stress. Further research should focus on optimizing the concentration of *S. fluitans*, identifying and quantifying bioactive compounds, and evaluating its effectiveness in improving grain yield and quality under various saline soil conditions.

4. Conclusion

The application of bioalgae extract derived from *S. fluitans* during the early growth stage (vegetative phase) had a significant effect at 6 and 7 weeks after planting (WAP) on the variables of plant height and number of leaves, while the number of tillers showed a significant effect at 7 WAP. The most effective concentration of bioalgae extract from *S. fluitans* in enhancing plant height, number of leaves, and number of tillers was P1 (10%), which reached 59.3 cm in height, 8.3 leaves, and 5.3 tillers. Bioalgae from the *S. fluitans* group can be used as a source of nutrients and a growth stimulant for plants. The nutrient content of bioalgae, such as nitrogen, phosphorus, and potassium, is highly beneficial for rice growth. In addition, bioalgae contain growth hormones that can stimulate root and leaf development.

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