TRANSACTIONS ON SCIENCE AND TECHNOLOGY

Biostimulant effects of brown seaweed extract (*Sargassum polycystum*) on the growth and yield of pigmented upland rice (*Oryza sativa* cv Tadong)

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ABSTRACT Seaweed and its derivatives serve as natural sources of bioactive compounds widely used as biostimulants in agricultural practices to augment plant growth and boost productivity. Tadong rice, a pigmented upland rice variety, is becoming increasingly favoured by consumers in Malaysia, attributed to its perceived health benefits. However, limited commercialization of Tadong rice is attributed to its low grain yield. The present work aimed to address these concerns by utilizing plant biostimulants derived from seaweed, which represents a more environmentally friendly alternative. Seaweed extract (SE) of a brown seaweed species (*Sargassum polycystum*) was applied to Tadong rice plants at different concentrations (20, 40, 60, and 80%) via foliar application, along with the recommended dose of fertilizer (RDF) in an insect-proof net house. Additionally, one commercial liquid biofertilizer and one control treatment (distilled water) were tested for comparison. The growth and yield of Tadong rice were evaluated along with numerous variables. The results demonstrated that *S. polycystum* at a 20% concentration had a favorable impact on several growth and yield parameters of Tadong rice. The treatment increased plant height, flag leaf length, flag leaf width, tiller number, panicle number/plant, 1000-grain weight, and yield/plant of Tadong rice (5.73 to 44.11% higher) compared to the control treatment. This study demonstrates that applying SE through foliar applications can boost the growth and yield of pigmented upland rice, providing advantages for upland rice farmers and making a positive contribution to sustainable agriculture and food security. The use of the 20% concentration of SE is particularly notable from an economic perspective, as it achieves these benefits with a lower amount of material compared to higher concentration.

KEYWORDS: Biostimulants; *Sargassum polycystum*; seaweed extract; rice plant; growth; yield
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INTRODUCTION

Rice is widely recognized as the staple crop for most of the global population. Nevertheless, the escalating global population underscores an increasing demand for food on a global scale. Projections indicate an expected rise in the global population, ascending from roughly 7.7 billion individuals in 2019 to an estimated 8.5 billion by 2030, followed by a subsequent elevation to 9.7 billion by 2050 (DESA, 2019; Thatcher *et al*., 2018). Projected data suggests that Malaysia's population is poised to exceed 40 million by 2050 (Statistics Times, 2021). Given the inadequacy of its current rice production to meet market demands, Malaysia being a net food importer with roughly 60% of its food needs imported in 2020, heavily relies on Self-Sufficiency Levels (SSL), predominantly for rice (Anis & Farhana, 2023). Rice production in Malaysia can only meet approximately 70% of local demand, resulting in a self-sufficiency level (SSL) of 70% for rice. In 2020, Malaysia imported around 1.1 billion tons of rice, primarily from Vietnam, Thailand, Myanmar, India, and Pakistan (Dardak, 2022). Malaysia lacks the capacity to produce all its rice needs domestically. Consequently, there is a pressing need to increase domestic rice production in Malaysia to reduce reliance on imported rice from other countries.

In Malaysia, the predominant rice cultivation encompasses two primary categories: lowland and upland rice. Among the upland rice varieties, there has been a growing consumer interest in pigmented upland rice, attributed to its perceived health advantages (Thanuja & Parimalavalli, 2018). Pigmented rice varieties are recognized for their abundant phenolic compounds, known to impart various health benefits, including antioxidant properties (Colombo *et al*., 2023). Pigmented rice is rich in essential amino acids, functional lipids, dietary fibre, and vitamins (including B complex, A, and E). Additionally, it contains a diverse array of minerals such as potassium, iron, zinc, copper, magnesium, manganese, and phosphorus, alongside γ-oryzanols, tocopherols, tocotrienols, phytosterols, and phytic acid. These valuable compounds contribute to the distinctive nutritional and functional properties of pigmented rice (Ito & Lacerda, 2019; Mau *et al*., 2017; Sompong *et al*., 2011; Tang *et al*., 2016). Despite this interest, the commercialization of pigmented upland rice varieties has been limited, due to their low grain yields (Rahman *et al*., 2015; Sinton *et al*., 2019). Therefore, utilizing natural biostimulants, specifically those derived from seaweed, can be an alternative solution to improve the growth and yield of rice plants. In addition, this can be a potential alternative to mitigate environmental issues associated with mineral fertilizers as they are safe for soil and plant microbes.

Recent studies have demonstrated the beneficial effects of using seaweed extracts in agriculture. For example, the application of seaweed extract on mustard greens has been shown to improve plant growth and yield, as well as increase chlorophyll content (Yusuf *et al*., 2020). Additionally, seaweed extract treatments have also been found to enhance salinity stress tolerance, boost total chlorophyll content, reduce reactive oxygen species (ROS) production, and promote protein accumulation in tomato plants (El Boukhari *et al*., 2021). Furthermore, another research has shown that the use of seaweed extract on cucumbers can enhance stress defense mechanisms, improve growth and productivity, and elevate fruit quality (Hassan *et al*., 2021).

Seaweed extracts contain macro and micronutrients, vitamins, amino acids, as well as growth promoters like auxin, cytokinin, and abscisic acid and have demonstrated efficacy in promoting plant growth and yield. Additionally, they contribute to enhance antioxidant properties, develop environmental stress tolerance, and facilitate increased nutrient uptake (Pramanick *et al*., 2014). It has been reported that a brown seaweed species (Phaeophyceae) has a potential use in agricultural practices, demonstrating its capacity to improve both plant growth and productivity (Jupri *et al*., 2019; Riamayani *et al*., 2022). Polysaccharide is one of the major chemical components present in seaweed extract. The common polysaccharides that are present in brown seaweed extract like *Sargassum polycystum* include fucoidan, alginate, and laminarin, which involved in improving soil conditions, antibacterial and antiviral actions, and stimulating genes to produce special proteins that participate in microbial activity (Khan *et al*., 2009; Chojnacka *et al*., 2012; Carrasco-Gil *et al*., 2021).

In addition, brown seaweed also has the highest polyphenol content (Chojnacka *et al*., 2012). It plays essential roles in scavenging radicals like superoxide, hydroxyl, single oxygen, and antioxidant activity (Andjelković *et al*., 2006). A previous study has shown that seaweed extract, particularly brown seaweed extract contains a variety of betaines (Khan *et al*., 2009). Betaines are N-methylated compounds which act as nitrogen sources for plants when applied in low concentrations and work as an osmolyte at higher temperatures. They are also involved in protecting plants from drought stress (Shemi *et al*., 2021; Khan *et al*., 2009). Hence, this study was conducted to determine the effects of *S. polycystum* extract, a brown seaweed species, on pigmented upland rice (Tadong rice) at different concentrations, via foliar application.

METHODOLOGY

Collection and Preparation of Sample

The seaweed sample utilized in this study was purchased from seaweed supplier in Kota Kinabalu market in Sabah, Malaysia. The seaweed was collected in October 2021. The fresh seaweed underwent a thorough washing with tap water, with subsequent removal of holdfasts and epiphytes. Subsequently, the seaweed was rinsed with distilled water. The cleaned seaweeds were subjected to sun drying by evenly spreading them on a drying net and exposing them to direct sunlight for 3-4 days (Ling *et al*., 2015; Neoh *et al*., 2021). The choice of sun drying was made due to its cost-effectiveness and efficiency in reducing moisture content without the need for specialized equipment. Sun drying helps in retaining certain bioactive compounds that might degrade at higher temperatures used in artificial drying methods. After sun drying, the samples were ground into a fine powder using a high-performance grinder and sifted through a 0.5 mm sieve to achieve uniform particle size (Ling *et al*., 2013). The resulting seaweed powders were then sealed in airtight plastic bags and stored in a freezer at -20 ℃ until needed (Ling *et al*., 2015).

Preparation of Seaweed Extracts

The seaweed extracts were prepared according to the method by Vasantharaja *et al*. (2019) and Yusuf *et al*. (2020) with slight modifications. A 100 g powdered seaweed sample was mixed with 2000 mL of distilled water, with 1:20 sample-to-solvent ratio, and stirred continuously for 5 minutes at room temperature. Subsequently, the mixture underwent filtration using muslin cloth to remove coarse particles and debris from the seaweed mixture. This step ensures that the extract is free from larger unwanted materials that could interfere with its application and effectiveness. The filtrate obtained was then centrifuged at 5000 rpm for 5 minutes to separate fine particulates, obtaining a clear supernatant. This step was employed for achieving a more refined extract, which can enhance the uniformity and consistency of the bioactive compounds within the extract. The resulting supernatant was further filtered through filter paper to ensure maximum clarity and to remove any remaining fine particulates (Sunarpi *et al*., 2010; Godlewska *et al*., 2016). The resulting filtrate was designated as a 100% seaweed extract and stored in a freezer at -20 °C for preservation (Elavarasan *et al*., 2021). The seaweed extracts were later diluted to four different concentrations (20, 40, 60, and 80%) using distilled water (Layek *et al*., 2018; Senthuran *et al*., 2019). These various concentrations were selected to identify the optimal concentration for enhancing the growth and yield of Tadong rice. Previous studies have indicated that seaweed extract can effectively stimulate plant growth at lower concentrations, while higher concentrations may have an inhibitory effect (Arun *et al*., 2014; Divya *et al*., 2015; Layek *et al*., 2018). Therefore, this range of concentrations was chosen to comprehensively assess the varying effects and determine the optimum concentration for the rice plants.

Cultivation of Tadong Rice

The Tadong rice cultivation was carried out within an insect-proof net house No. 2 at the Faculty of Sustainable Agriculture (FSA), Universiti Malaysia Sabah (UMS) Sandakan Campus, situated at coordinates latitude 5°55'56.0"N and longitude 118°00'11.4"E. The cultivation period of Tadong upland rice took about five months, from March to July 2022. The planting medium was prepared by mixing soil and goat dung in a 3:1 (w/w) ratio, utilizing topsoil in the mixture (Jupri *et al*., 2019). The soil was exposed to the sun and air-dried for 2-3 days before mixing with goat dung. The mixture of planting media was mixed homogeneously, weighed 4 kg, and placed into individual pots. The process of cultivating Tadong upland rice began with sowing the rice seeds on moist paper towels within germination boxes. These boxes were stored in a laboratory at room temperature (24 ± 2 °C), covered to prevent moisture loss through evaporation. The Tadong rice seeds were allowed to germinate and grow into seedlings over a period of 12 days after sowing. Subsequently, the 12-day-old rice seedlings were transplanted into the prepared pots, with one seedling per pot. Throughout the cultivation period, intensive care was provided to the rice plants, starting from seed sowing through the transplantation of seedlings. The net house environment was closely monitored and controlled to ensure optimal growing conditions. Temperature and humidity levels were adjusted based on the weather conditions. On sunny days, plants were given additional water to prevent dehydration, while on normal or rainy days, watering was reduced to prevent over-saturation. Comprehensive data on vegetative growth and yield components were systematically collected and recorded throughout the study. The data observed for vegetative growth and yield parameters include plant height, culm height, tiller number, flag leaf length, flag leaf width, panicle number per plant, percentage of productive tiller, grain number per panicle, 1000-grain weight, and yield per plant.

Experimental Design and Treatments

In this study, the application of six different treatments of *S. polycystum* extract were arranged using a Completely Randomized Design (CRD). The study incorporated five replicates for each treatment, utilizing a total of 30 pots. The six treatments included various concentrations of S. *polycystum* extract (20%, 40%, 60%, 80%), a commercial reference (KEN Microbes seaweed extract), and a control treatment (distilled water). The inclusion of a commercial reference aimed to establish a benchmark for comparing the effectiveness of the seaweed extract treatments. This approach allowed for an evaluation of the efficacy and potential benefits of seaweed extract treatment in comparison to the recognized industry standard. Table 1 outlines the treatment details, including the number and concentration of seaweed extracts utilized in the study. The growth and yield of Tadong upland rice were systematically observed and measured across all treatments.

Table 1. Type of seaweed extract treatments on Tadong rice.

Treatment Number	Type of Treatment
T1	Distilled water (control)
T2	KEN Microbes Seaweed Extract (commercial reference)
T3	*S. polycystum* 20%
T4	*S. polycystum* 40%
T5	*S. polycystum* 60%
T6	*S. polycystum* 80%

Application of Seaweed Extract

Seaweed extracts were applied through a foliar application, involving the spraying of liquid extracts onto entire rice plants (Sunarpi *et al*., 2020a). The application frequency of seaweed extract followed the method outlined by Layek *et al*. (2018), with slight modifications. Throughout the cultivation period, seaweed extracts were applied six times on Tadong rice plants, three times during the vegetative phase and three times during the reproductive phase. During the vegetative stage, seaweed extract applications were made at 20, 40, and 60 days after sowing (DAS), each with a volume of 30 mL per treatment. Subsequently, during the reproductive phase, seaweed extract applications were carried out at 75, 85, and 95 DAS, with a volume of 50 mL per treatment. The foliar application of seaweed extract took place in the early morning when sunlight intensity was moderate, as the stomata and epidermis of the plants were opened during this period, facilitating optimal nutrient absorption.

Statistical Analysis

The experimental data were statistically analyzed using the One-Way Analysis of Variance (ANOVA) to determine the effects of seaweed extract treatments on the observed variables. If the analysis results showed a significant effect, a further test was carried out using the Least Significant Difference (LSD) test at a 5% significant level (Anisuzzaman *et al*., 2021; Rou & Lum, 2020) with the assumption that the errors variance are independently and normally distributed among the treatments.

RESULT AND DISCUSSION

The effects of *S. polycystum* extract on the growth and yield of Tadong rice plant were observed and measured at different concentrations. Figure 1 shows the Tadong rice plant that were treated with *S. polycystum* extract during the mature grain stage. The physical appearance of Tadong rice with different concentration of SE treatment, on the harvest day (122 DAS) is shown in Figure 2. The growth and yield parameters observed included plant height, culm height, tiller number, flag leaf length, flag leaf width, panicle number per plant, percentage of productive tiller, grain number per panicle, 1000-grain weight, and yield per plant. Figure 3 to Figure 12 demonstrate the effects of different concentrations of *S. polycystum* extract on the growth and yield parameters of Tadong rice. Observation data for plant height, culm height, tiller number, flag leaf length, and flag leaf width were obtained during week 15 of the rice plants or 117 DAS. Meanwhile, the observations on panicle number per plant, percentage of productive tiller, grain number per panicle, 1000-grain weight, and yield per plant were conducted after the rice grains were harvested. The *S. polycystum* extract at 20% concentration (T3) showed the highest mean plant height compared to other treatments and demonstrated a significant difference (p-value: 0.003) with the control treatment (T1) with a percentage increase of 23.69% (Figure 3). The 20% *S. polycystum* extract (T3) also showed comparable effectiveness with the commercial reference (T2) as there was no statistical different observed between these treatments (p-value: 0.174). This result is in line with previous study that reported an increase of rice plant height that was treated with *Sargassum* sp. extract (Sunarpi *et al*., 2010).

For culm height, the *S. polycystum* extract at 80% concentration (T6) exhibited the highest mean culm height compared to other treatments (Figure 4). This concentration demonstrated a significant difference (p-value: 0.005) when compared to the control treatment (T1), with a notable percentage increase of 22.45%. The efficacy of the 80% *S. polycystum* (T6) extract was found to be comparable to that of the commercial reference (T2). The outcomes align with those presented in a prior study on wheat, wherein the utilization of seaweed on plants had indicated a slight elevation in culm height with the use of seaweed on plants (Nelson & Staden, 1984). For the flag leaf length and width, Tadong rice that were treated with *S. polycystum* extract at 20% concentration (T3) demonstrated the highest values as compared to other treatments (Figure 5 & 6). The result of both parameters showed a comparable performance with the commercial reference (T2). The flag leaf length showed a significant difference (p-value: 0.012) with the control treatment (T1) with a percentage increase of 44.11%. These findings are consistent with those reported in a previous study, where the application of brown seaweed species on onion cultivars resulted in a notable increase in leaf length and width compared to the control (Abbas *et al*., 2020).

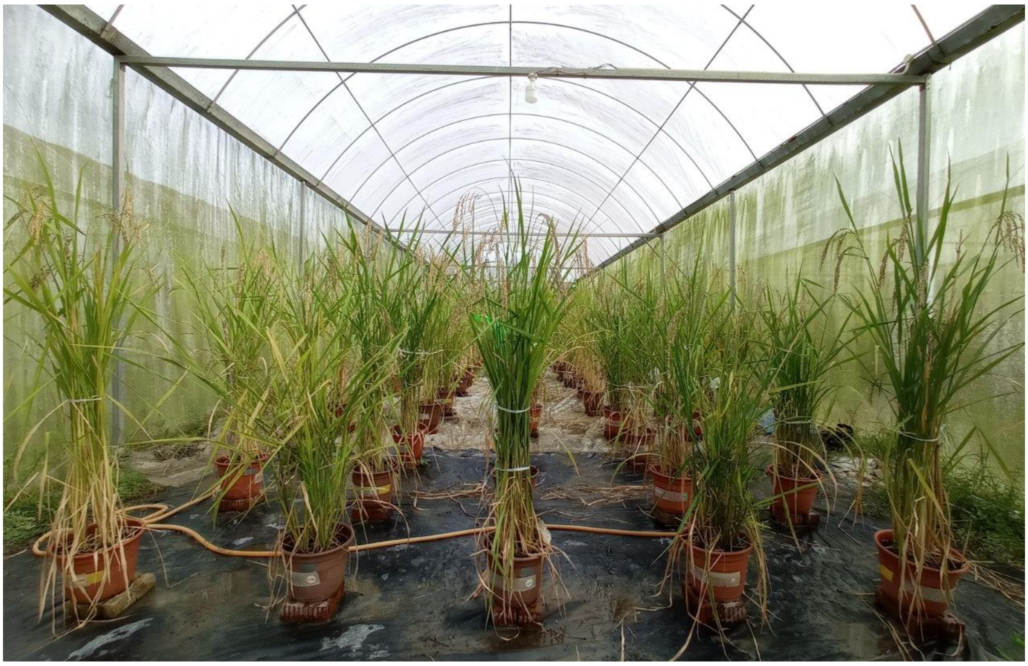

Figure 1. Tadong rice plants during the mature grain stage.

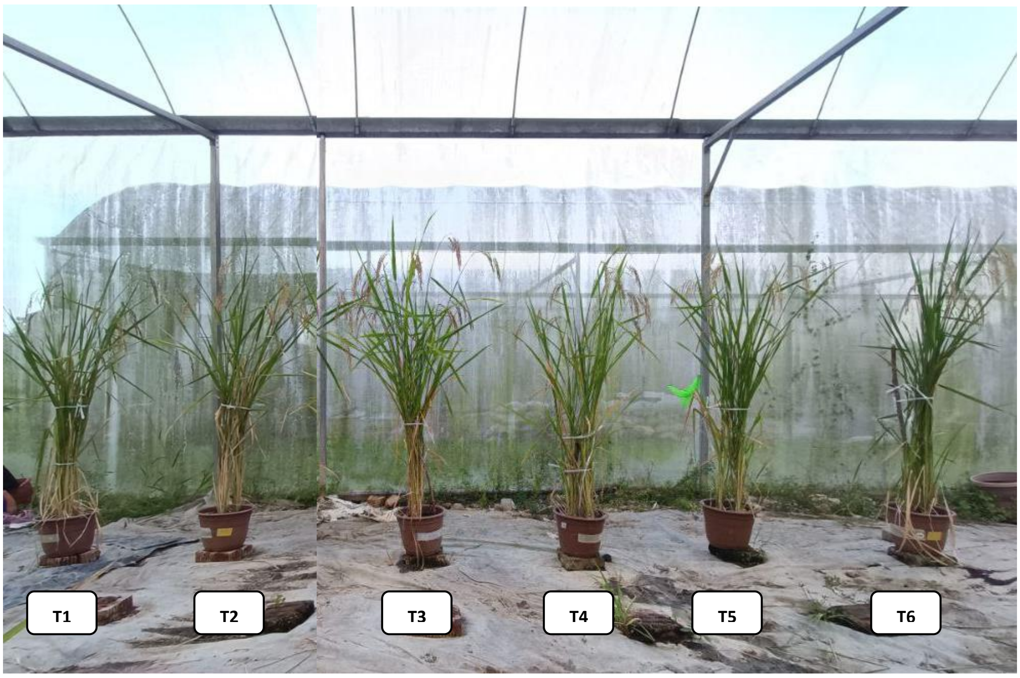

Figure 2. Physical appearance of Tadong rice plants on the harvest day after the treatment of *S. polycystum* extract (arrangement from left to right: T1-control; T2-commercial reference; T3-20%; T4-40%; T5-60%; T6-80%).

The highest tiller number and panicle number were observed in the 20% concentration of *S. polycystum* extract (T3) and 60% concentration of *S. polycystum* extract (T5) (Figure 7 & 8). Both treatments exhibited comparable effectiveness with the commercial reference (T2) on both parameters. This finding aligns with previous research, which demonstrated the efficacy of applying brown seaweed species to crops in enhancing the tiller number of rice plants (Sunarpi *et al*., 2020b). The application of *S. polycystum* extract at 40% concentration (T4) has shown the highest value of percentage of productive tillers as compared to other treatments, with a percentage increase of 11.55% than the control treatment (Figure 9). This finding is consistent with a prior study conducted by

Sriyuni *et al*. (2020), which observed that the application of *Sargassum* sp. in combination with amino acids led to a notable increase in the productive tillers of upland rice. The highest total grains per panicle was observed on the rice plant that was treated with 80% *S. polycystum* extract (T6) (Figure 10). In addition, the commercial reference (T2) has shown the highest 1000-grain weight as compared to other treatments. Among all the tested treatments, the 20% and 80% *S. polycystum* extracts have a comparable performance with the commercial reference (T2) in term of 1000-grain weight (Figure 11). This result aligns with earlier research that observed an enhancement in the 100-grain weight of upland rice through the application of *Sargassum* sp. in combination with amino acids (Sriyuni *et al*., 2020). The highest yield per plant was observed at lower concentration of *S. polycystum* extract (20%), with a percentage increase of 7.56% compared to control treatment (T1) (Figure 12). In the context of this research, yield per plant refers to the total weight of grains generated by each individual rice plant. The result is in line with earlier study that observed an enhancement of grain weight of rice plants with the use of seaweed extract derived from brown seaweed species in combination with inorganic fertilizer (Sunarpi *et al*., 2019).

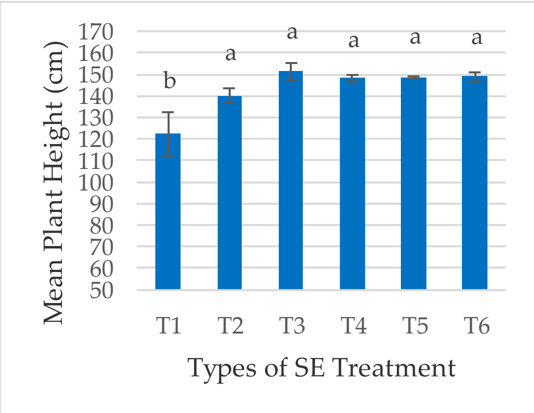

Figure 3. Effect of SE on the mean plant height of Tadong rice.

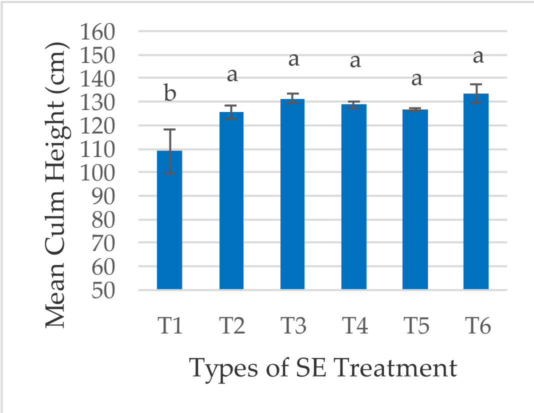

Figure 4. Effect of SE on the mean culm height of Tadong rice.

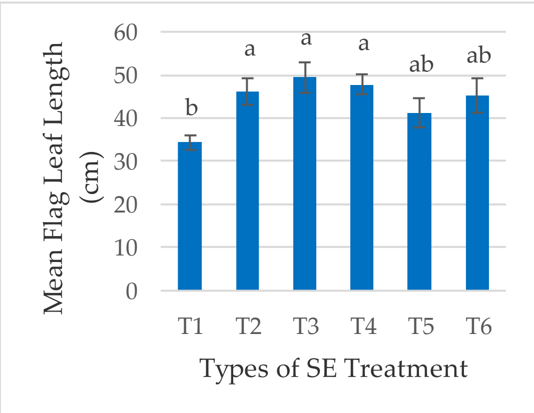

Figure 5. Effect of SE on the mean flag leaf length of Tadong rice.

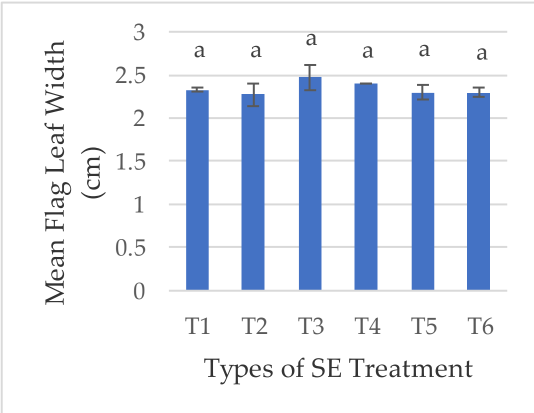

Figure 6. Effect of SE on the mean flag leaf width of Tadong rice.

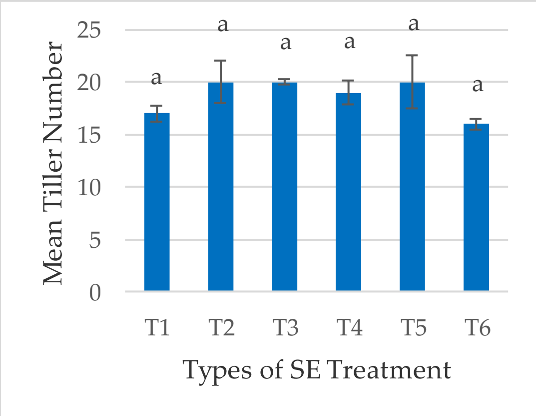

Figure 7. Effect of SE on the mean tiller number of Tadong rice.

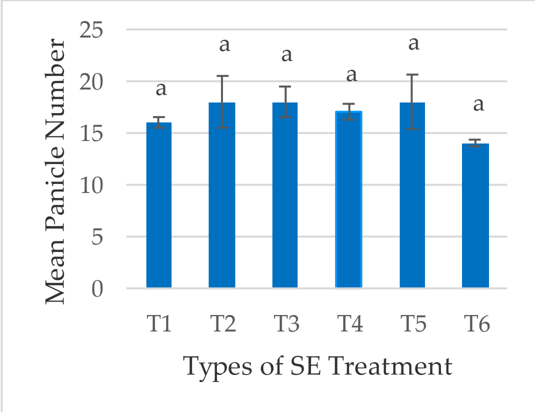

Figure 8. Effect of SE on the mean panicle number per plant number of Tadong rice.

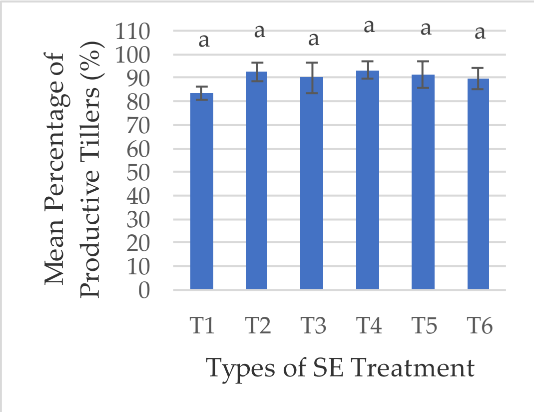

Figure 9. Effect of SE on the mean percentage of productive tillers of Tadong rice

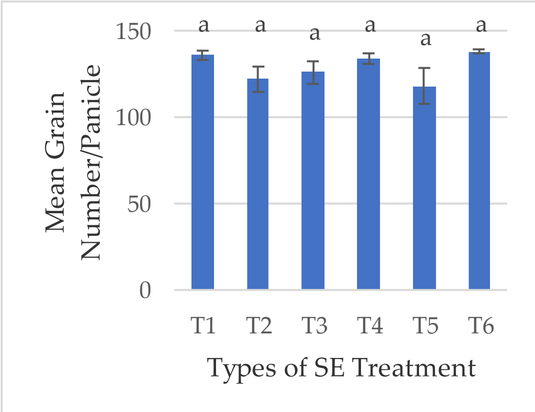

Figure 10. Effect of SE on the mean total grains per panicle of Tadong rice.

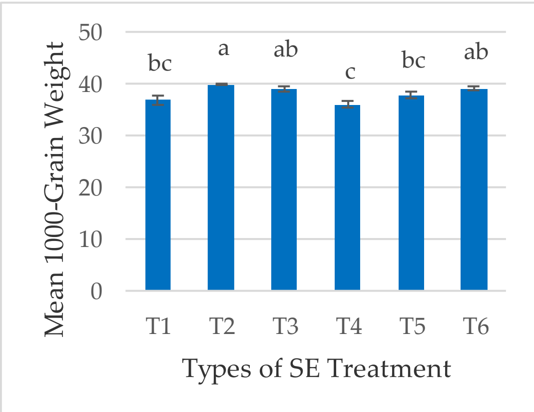

Figure 11. Effect of SE on the mean 1000-grains weight of Tadong rice.

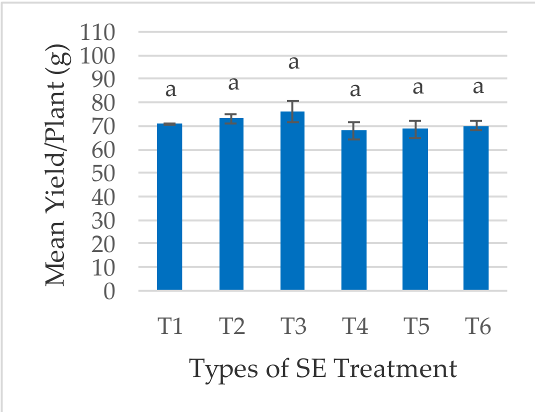

Figure 12. Effect of SE on the mean yield per plant of Tadong rice.

Figure 13 shows the comparison of the effects of *S. polycystum* extract at different concentrations on the growth and yield of Tadong rice grains with the control treatment (T1). The radar chart used as a tool to determine the most favourable treatment among various concentrations of *S. polycystum* extract. This chart is used to compare multiple variables or treatments simultaneously. Each variable is represented by an axis radiating from a central point, and the data points for each treatment are plotted along these axes. The resulting shape formed by the data points can help visualize the overall performance or characteristics of each treatment. By visually examining the radar chart, it was possible to identify the treatment that exhibited the highest percentage improvement across all the parameters, indicating its effectiveness in promoting the growth and yield of the Tadong rice plants. Based on the findings, it can be concluded that the 20% concentration of *S. polycystum* extract (T3) exhibited consistent positive effects on the growth and yield parameters, including plant height, flag leaf length, flag leaf width, tiller number, panicle number, 1000-grain weight, and yield per plant. This result suggested that the 20% concentration of *S. polycystum* extract has a potential as an optimal treatment for enhancing the growth and productivity of Tadong rice plants. This aligns with a previous study, which reported that lower concentrations of liquid extract from brown seaweed species were more effective in promoting plant growth and yield compared to higher concentrations (Divya *et al*., 2015). The presence of active components within the *S. polycystum* extract, possibly growth-promoting phytohormones, bioactive compounds, and essential nutrients, which collectively exert a positive and harmonious influence on the developmental processes of rice plants (Layek *et al*., 2018). The essential nutrients within the seaweed extracts, such as nitrogen (N), phosphorus (P), and Potassium (K) may play a crucial role in diverse physiological processes in plants (Vasantharaja *et al*., 2019). These nutrients are recognized for their involvement in fundamental processes such as cell division (Malhotra *et al*., 2018), photosynthesis (Lawlor, 2002), enzyme activation (Hassan *et al*., 2020), and facilitation of cell signalling (Thor, 2019), all contributing to the enhancement of plant yield.

Additionally, previous study has reported that the phytohormonal compounds present in seaweed extract have the potential to regulate intrinsic pathways related to phytohormone biosynthesis in plants, leading to an improvement in plant yield (Nabti *et al*., 2017). Some phytohormones that are detected in seaweed extract include auxins, cytokinins, and gibberellins (Khan *et al*., 2009; Ghaderiardakan *et al*., 2019; Ali *et al*., 2021). Auxin is one of the plant growth-promoting hormones present in seaweed extract, which plays a role in improving the root system of a plant by enhancing root elongation and formation (Abbas *et al*., 2020; Khan *et al*., 2009). Auxins are involved in promoting lateral root primordia initiation, formed lateral root development and primary root elongation (Wally et al., 2013; Nibau et al., 2008). Meanwhile, cytokinin plays an important role in controlling cell division, the development of buds, the retardation of senescence and leaf blade development (Tarakhovskaya *et al*., 2007). They control the rate of cell differentiation during the development of root meristem by suppressing the signalling and transport of auxin, whereas auxin counteracts the signalling of cytokinin at the early stages of embryo development for the niche establishment of embryonic root stem-cell (Perili *et al*., 2010). In addition, gibberellin is an essential hormone for numerous plant development processes. They are responsible for the initiation of seeds germination, elongation of organs, development of trichome, the growth transition from vegetative to reproductive and the development of seed, fruit, and flower (Binenbaum *et al*., 2018; Chojnacka *et al*., 2012).

In addition, the application of seaweed extract also has positive impacts on soil conditions. Seaweed extract contains alginate which is a common polysaccharide that is present in brown seaweed extract. It helps in improving soil conditions by promoting the formation of aggregates between soil particles, which results in an increase in the translocation and absorption of nutrients, microbial activity of soil and root growth (Carrasco-Gil *et al*., 2021). While the application of seaweed extracts has demonstrated numerous benefits in enhancing plant growth and yield, it is also crucial to consider the potential side effects and risks associated with their use, particularly at high concentrations. High concentrations of seaweed extracts may have inhibitory effects on plant growth. For instance, previous study has indicated that lower concentrations of seaweed extracts can promote growth, meanwhile higher concentration has the inhibitory effects on plant growth (Khan et al., 2009). This inhibition can manifest as stunted growth, reduced leaf size, and lower overall biomass. In this study, although the 80% *S. polycystum* extract showed some positive effects on specific parameters, it is essential to note that excessive application could potentially lead to nutrient imbalances and osmotic stress in the plants.

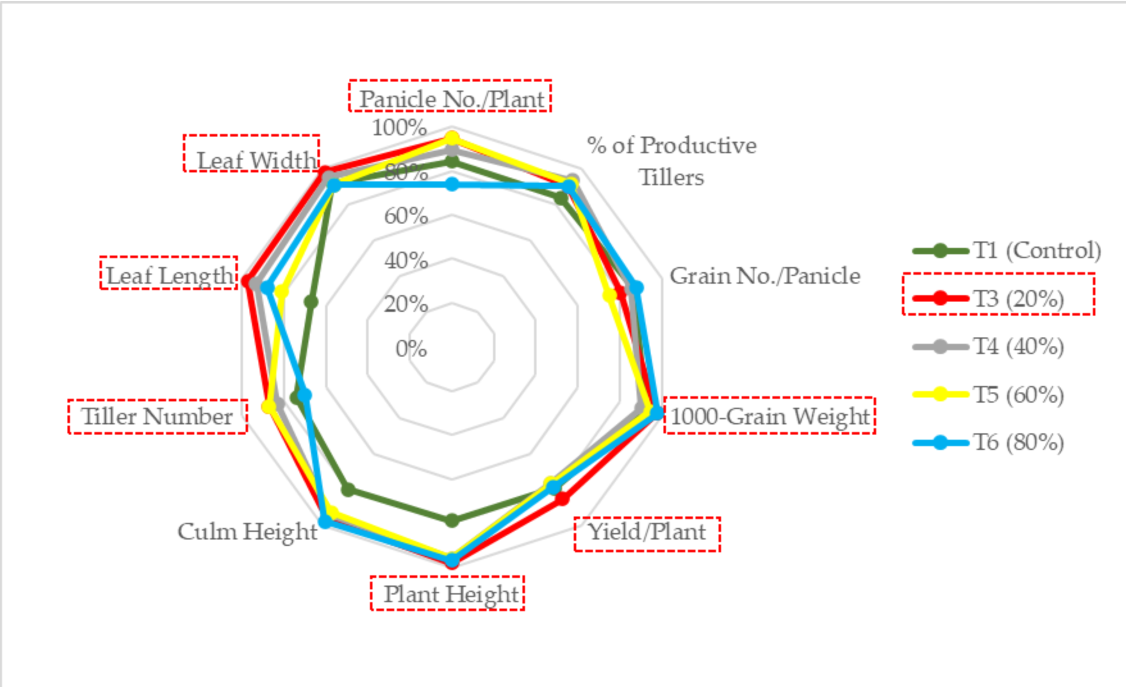

Figure 13. Comparison of the effects of *S. polycystum* extract at different concentrations on the growth and yield of Tadong rice grains.

CONCLUSION

This study demonstrates the significant potential of the aqueous extract of brown seaweed (*S. polycystum*) as plant biostimulants. The finding suggests that the foliar application of *S. polycystum* extract at lower concentration (20%) is an optimal treatment for improving the growth and yield of pigmented upland rice (Tadong rice). For practical application, it is recommended that farmers apply the lower concentration of seaweed extract at specific growth stages for optimal results. The extract should be applied during the early vegetative stage, mid-tillering stage, and panicle initiation stages (three times during the vegetative phase and three times during the reproductive phase. This schedule ensures that the plants receive the growth-promoting benefits of the extract during critical periods of development. While the positive effects of seaweed extracts on rice growth and certain yield parameters were evident, variations in outcomes among treatments highlight the need for further optimization and refinement. Understanding the significance of choosing suitable seaweed extracts and optimum concentrations is crucial for achieving desired outcomes. Field trials and scaling-up can be conducted in future studies to determine the impact of seaweed extracts on Tadong rice in real-world agricultural conditions. This involves testing the effectiveness of the identified optimal concentrations and application methods across various soil types, climates, and under conditions where stress treatments are applied to the plants. In addition, future work also can investigate the long-term effects of using seaweed extracts as plant biostimulants on soil health, crop productivity, and environmental sustainability. Assess the impact of repeated application of seaweed extracts on soil fertility, microbial communities, and the overall ecosystem. This research will contribute to understanding the sustainability and long-term viability of incorporating seaweed extracts into agricultural practices.

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