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Vigor Enhancement of Tomato (*Solanum lycopersicum*) using *Spirulina platensis* as Seed Priming Agent

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Abstract

Seed priming is a technique to enhance seed germination. Biopriming, a specific method, involves soaking seeds in biological agents such as *Spirulina platensis*, a microalga that can thrive in agricultural waste including Sugar Mill Effluent (SME). *Spirulina* sp. contains various beneficial growth hormones, making it a potential seed priming agent. This research aimed to determine the effectiveness of tomato seed priming using *Spirulina platensis* grown on SME. The research was conducted from May to August 2024 at the Seed Technology Laboratory, Politeknik Negeri Jember. The research method used a factorial Completely Randomized Design which included *Spirulina platensis* biomass concentrations (0, 30, 45, and 60%) and soaking durations (1, 2, and 3 hours). Analysis of variance using the Bonferroni post-hoc test at a 5% level using GraphPad Prism version 5.01. The results showed that seed priming with *S. platensis* positively influenced several physiological parameters, including mean germination time, vigor index, seed growth rate, and shoot length. These findings demonstrated that SME-grown *S. platensis* cells capable of improving the physiological quality of tomato seeds, making it one of the environmentally friendly seed invigorating techniques.

Keywords: Biostimulant, seed priming, *Spirulina platensis*, sugar mill effluent, tomato

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Introduction

Seed priming is a seed treatment technique before planting that aims to enhance germination capacity, seedling development, and overall plant growth (Farooq *et al.*, 2019). Seed priming can be done using several methods that essentially control the availability of water within the seeds (Gunadi & Djunaidy, 2019). Many studies have shown that seed priming can enhance the vigor and viability of various types of plant seeds. Tabassum *et al.*, (2018) and Andayani & Rosanti (2023), also mentioned that priming treatment affects seed tolerance to drought stress, and improves plant uniformity, thereby facilitating the cultivation process. One of the seed priming techniques that has been widely used on various types of plants is biopriming. Deshmukh *et al.*, (2020) showed that the biopriming technique is more environmentally friendly because it utilizes natural materials such as beneficial microorganisms to support the physiological quality of plant seeds. In addition, biopriming is also important for pest and disease management in plants. Acharya *et al.*, (2020) explained that biopriming is one example of the priming process that can provide many benefits for plants, such as increasing germination rate, germination energy, growth

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and development, tolerance to abiotic and biotic stress, and improving crop yield.

One of such promising microorganisms for biopriming is *Spirulina platensis.* This microalga has a thread-like body shape with a diameter of 1-12 µm, possesses a thin cell wall, and get its name from its cylindrical cell arrangement. *Spirulina platensis* live independently and can move freely (Ridlo *et al.*, 2016). According to AlFadhly *et al.*, (2022) *Spirulina platensis* can be cultivated in various types of waste such as agricultural, household, and industrial waste, including waste from sugar factories. In sugar factories, such liquid waste is produced from various cleaning purposes of milling houses, boiling houses, and centrifugation plants and is highly enriched with potential organic matters (Fito *et al.*, 2019). This sugarcane liquid waste, called hereafter as Sugar Mill Effluent (SME) is one of the various types of industrial waste that can be used as a cultivation medium for *Spirulina platensis.* The utilization of SME has been demonstrated previously by (Deshmane *et al.*, 2016a; Deshmane *et al.*, 2016b) which successfully grown *S. platensis* on SME and obtained up to 85% nitrogen, 65% phosphorous, and 91% potassium recovery. This means that SME is very potential wastewater to be utilized as microalgae growing medium. The final result of microalgae cultivation is biomass containing auxins and gibberellins, which can be utilized as bio-stimulants in seed priming to enhance seed germination (Ferreira *et al.*, 2023). Shedeed *et al.*, (2022) reported that *Spirulina platensis* has been proven to enhance plant growth, photosynthetic capacity, and yield in various plants such as *Lupinus luteus*. Similarly, the study of Alling *et al.*, (2023) demonstrated that the cells and supernatant of microalgae grown on municipal wastewater significantly and positively affect the germination of barley and tomato seeds.

Among Solanaceae family, tomato (*Solanum lycopersicum*) is one of most widely cultivated crops worldwide (García-Locascio *et al.*, 2024). Despite a steady tomato consumption reported by Indonesian Central Bureau of Statistics (BPS) (2024) with 106,364 tons in 2021, 106,673 tons in 2022, 106,551 tons in 2023, there was shrinkage in harvesting area from in 63.369 in 2022 to 58.782 Ha in 2024 partly due to seasonal change and alteration of land function. Subsequently, this trend followed by decrease of national tomato production from 1.168.743,7 tons in 2022 to 1.146.607 tons in 2024. Thus, to meet the current demand for high productivity, the use of high-quality tomato seeds for excellent plant growth is fundamental. The life stages of the plant growth were initiated with seed germination, which is indicated by the emergence of the radicle in the seed (Junaidi & Ahmad, 2021). The suboptimal processes of germination and growth of tomato seeds can cause losses for farmers; thus a technology to improve germination and growth are essentials. Aside from the quality aspect, Prasetya *et al.*, (2017) mentioned that there is also physical dormancy that affects the germination of tomato seeds. This physical dormancy is caused by the presence of mucus on the surface of tomato seeds that contains ascorbic acid and acts as an inhibitor. The mucus covers the seeds, blocking their pores from imbibing water. Furthermore, the report of Geshnizjani *et al.*, (2018) explained that in addition of external mucus, the internal physiological properties of tomato embryos might lead to seed dormancy. While the former type of dormancy lies on physical dormancy which can be removed by removal of mucus, the latter type of dormancy can be alleviated by treatment of nutrients such as nitrate or phytohormone such as gibberellic acid (GA). Therefore, given that the cell of *Spirulina platensis* is rich of nitrate, phytohormones, and GA or GA-like substances (Thinh *et al.*, 2021), biopriming using *Spirulina platensis* offers an appealing approach to address the external and internal dormancy aspects of tomato seeds, consequently enhancing seeds overall quality.

This study investigated the effect of seed priming using *Spirulina platensis* with various concentrations and soaking durations on the physiological quality of DREZA F1 tomato seeds. By utilizing *S. platensis* cultivated in an SME-based medium, this research introduces a novel approach to tomato seed invigoration while simultaneously exploring sugarcane waste processing and management.

While previous research (Deshmane *et al.*, 2016a; Deshmane *et al.*, 2016b) focused on growing *S. platensis* in SME for nutrients removal and wastewater treatment, this work focuses on its application for enhancing agricultural productivity, particularly as seed priming agents. Additionally, this study used a simple photobioreactor system in the cultivation of *S. platensis*. This system leads to the determinations of distinctive concentrations and soaking time parameters with previous research (Alling *et al.*, 2023). Thus, this research is promising to provide possible strategies for sustainable agricultural development.

Materials and Methods

Materials

The equipment and materials used included a simple photobioreactor consisting of sterile plastic bottles, a Laminar Air Flow Cabinet (LAFC), a centrifuge, a germination box, *Spirulina platensis* isolate obtained from BBPBAP Jepara, Sugar Mill Effluent (SME), DREZA F1 Tomato (Batch No. 2406016 – CV. Nasienie Indonesia, Jember, Indonesia) with an expiration date in December 2025, and Bold Basal Medium (BBM) UTEX (2019) with modifications (Supplementary).

Research Methods

The experimental design used was a factorial Completely Randomized Design with two factors. The first factor was the concentration of *Spirulina platensis* (v/v), which consisted of four treatment levels: C0 (0%), C1 (30%), C2 (45%), and C3 (60%). Treatment C0 used water, while C1–C3 used water with added *Spirulina platensis* according to the respective concentrations (v/v). As a comparison, the seeds without the soaking treatment were denoted as the control. The second factor was the duration of soaking, which consisted of three levels: T1 (1 hour), T2 (2 hours), and T3 (3 hours). The total treatment combinations were 15 with 4 replications, resulting in 60 experimental units with 50 seeds per unit (Alling *et al.*, 2023).

Microalgae Biomass Production

The research began with the production of *Spirulina platensis* biomass by cultivating the microalgae in BBM media mixed with 25% SME (v/v) in a total culture volume of 400 ml per bottle. The culture was subsequently placed on a culture rack equipped with illumination (190 lux) and aeration for 24 hours at room temperature. Biomass harvesting was carried out by centrifugation at a speed of 8,000 rpm at a temperature of 10°C for 10 minutes.

Seed Priming Application with Microalgae Biomass

The seed priming application began by soaking the seeds according to the specified concentration levels and soaking durations in 50 ml falcon tubes. The falcon tubes containing the seeds and culture were vigorously shaken using a shaker at a frequency of 100 rotations per minute at room temperature. Subsequently, the seeds were germinated using the top-of-paper method in germination boxes lined with rice straw paper. The germination process was conducted on a germination rack with a light: dark cycle of 16:8 hours, a temperature of 26 °C, and a relative humidity of 70% (Alling *et al.*, 2023).

Seed Priming Test Result Analysis

The parameters observed in this study were based on ISTA (2020), which included:

Mean Germination Time (days)

Mean Germination Time was calculated based on the number of seeds that exhibited radicle emergence (≥ 2 mm), measured daily, using the following formula:

$$Mean\ Germination\ Time\ (days) = \frac{\Sigma(n\ x\ t)}{\Sigma\ numbers\ of\ germinated\ seed}$$

n : numbers of seed with radicle emergence ≥ 2 mm

t : time to emerge radicle (days)

Vigor Index (%)

Vigor Index was determined by counting the number of normal seedlings that grew at the first count (day 5). The formula used was:

$$Vigor\ Index\ (\%) = \frac{\Sigma\ normal\ seedling\ at\ first\ count}{\Sigma\ numbers\ of\ germinated\ seed} X100\%$$

Germination Rate (%)

Germination rate was determined by counting the number of normal seedlings at both the first and final counts (days 5 and 14), using the formula:

$$Germination\ Rate\ (\%) = \frac{\Sigma\ normal\ seedling\ at\ first + final\ count}{\Sigma\ numbers\ of\ germinated\ seed} X100\%$$

Growth Rate (%/day)

Growth rate was calculated based on the number of normal seedlings that grew each day until the final count, using the formula:

$$Growth\ Rate\ (\%) = \Sigma \frac{(\%)\ normal\ seedling}{observation\ day - i}$$

Seed Growth Simultaneity (%)

Growth simultaneity was determined by counting the number of normal seedlings that grew between the first and final counts (day 10), using the formula:

$$Seed\ Growth\ Simultaneity\ (\%) = \frac{\Sigma\ normal\ seedling\ day\ 10}{\Sigma\ numbers\ of\ germinated\ seed} X100\%$$

Maximum Growth Potential (%)

Maximum growth potential was observed by counting the number of normal and abnormal seedlings at the final count using the formula:

$$Maximum\ Growth\ Potential\ (\%) = \frac{\Sigma\ normal\ + abnormal\ seedling}{\Sigma\ numbers\ of\ germinated\ seed} X100\%$$

Shoot Length (cm)

Shoot length was measured on 20 samples of normal seedlings from each replication at the final count, from the base to the tip of the shoot.

Radicle Length (cm)

The length of the radicle was measured in 20 samples of normal/repeat seedlings at the final count, from the base of the radicle to the tip of the radicle.

Dry Weight of Normal Seedlings (gram)

Observation of the dry weight of normal seedling was conducted on 20 samples of normal seedlings, each repeat for every treatment at the final count. Normal seedling samples were oven-dried at a temperature of 104°C for 3 hours then weighed with analytical balance.

Data Anaysis

The research data were analyzed using factorial analysis of variance, and if significant differences were found, the analysis was continued with the Bonferroni post-hoc test at a 5% significance level using GraphPad Prism version 5.01 software.

Results and Discussion

This study was conducted to observe the effects of seed priming using *Spirulina platensis*, cultured in sugar mill effluent (SME)-based medium, on the physiological quality of DREZA F1 tomato seeds. By applying different concentrations and soaking durations, the research aimed to evaluate the potential of *S. platensis* as an innovative and sustainable biostimulant in seed invigoration, while also promoting the reuse of agro-industrial waste in a sustainable agricultural approach. Overall, the findings offer insights into how biological priming treatments can contribute to more efficient seed management practices and sustainable agricultural development. Henceforth, the effect of biopriming using *S. platensis* on tomato seeds were discussed into two parts, the affected group and non-affected group of parameters.

Parameters Affected by The Treatment

Based on the results, not all physiological parameters responded significantly to the treatments. However, several key indicators such as mean germination time, vigor index, seed growth rate, and shoot length showed positive responses. The following discussion will focus on these affected parameters first.

Mean Germination Time (day)

Mean Germination Time (MGT) is the average time required for seeds to germinate, starting from the imbibition stage until the emergence of the radicle (Matthews & Hosseini, 2006). During the MGT test, seeds with faster radicle emergence time indicate good growth rates and have the potential to produce higher growth performances. As illustrated in Figure 1, all seed priming treatments generally resulted in a lower MGT compared to the unprimed control. The control treatment exhibited an MGT of 5.42 days, whereas the most effective treatment, which involved soaking for two hours at a concentration of 45 percent, achieved the shortest MGT of 4.35 days. Interestingly, the treatment involving three hours of soaking at a concentration of 30 percent resulted in an MGT of 5.32 days, which was not significantly different from the control. This finding suggests that extended soaking duration at that concentration may not provide additional benefits for germination speed.

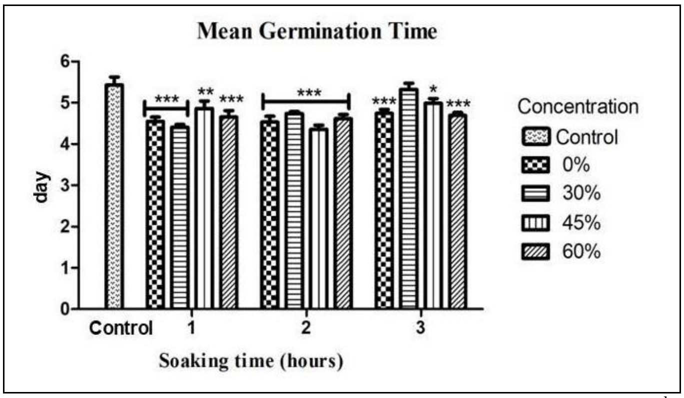

Figure 1. Mean Germination Time. Data were observed daily until day 14th (final count).

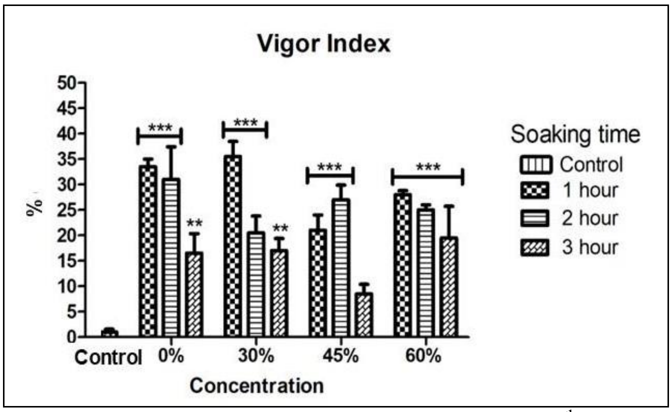

Figure 2. Vigor Index (%). Data were observed on day 5th (first count).

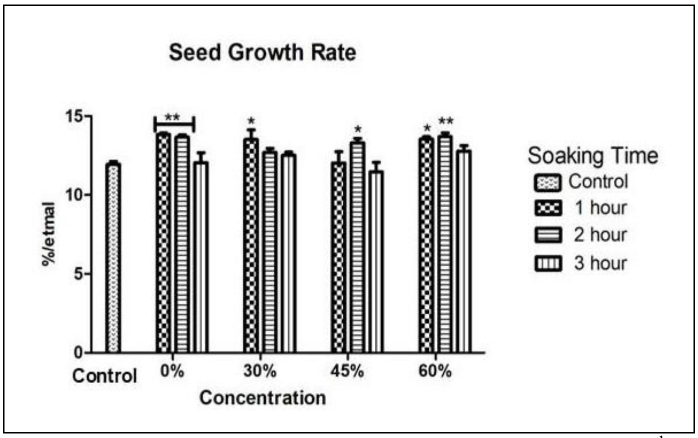

Figure 3. Seed Growth Rate (%). Data were observed daily until day 14th (final count).

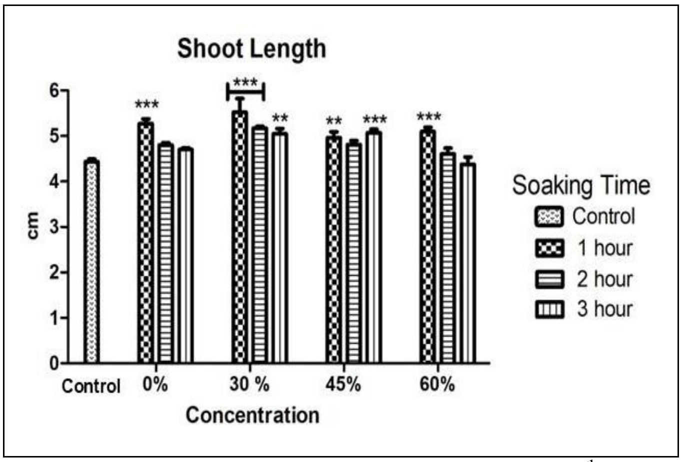

Figure 4. Shoot Length (cm). Data were observed on day 14th (final count).

Note : The data above represent the mean with SEM error bars from the ANOVA analysis with Bonferroni Post Hoc Test compared to the control. No sign = Non-Significant, * = Significant ($P \leq 0.05$), ** = Significant ($P \leq 0.01$), *** = Significant ($P \leq 0.001$).

Vigor Index (%)

The seed vigor index (VI) is the ability of seeds to grow under sub-optimal environmental conditions (Mora et. al, 2022). As shown in Figure 2, nearly all priming treatments had a positive effect on seed vigor compared to the untreated control group. The seeds without any treatment exhibited a VI of only 1%, whereas the highest VI was 35.5%, observed in seeds soaked for one hours at a concentration of 30%. However, this value was not significantly different from the treatment involving water soaking for one hour, which produced a VI of 33.5%. Another noteworthy observation is that across all biomass concentrations as well as the water control, longer soaking durations tended to result in a decline of seed priming effectiveness in enhancing VI, suggesting that excessive soaking duration may not promote enhanced effects of seed priming on seed vigor.

Seed Growth Rate (%/etmal)

The growth rate of seeds reflects their strength to grow, so seeds that grow quickly have better growth potential in sub-optimal land due to their unhindered metabolic processes. Additionally, seeds that grow faster can maximize environmental potential more quickly by utilizing available resources before environmental conditions become more challenging for seed growth. As shown in Figure 3, the results were consistent with the previous two parameters, indicating that seed priming using either *Spirulina platensis* or water alone (water control) improved seed growth rate compared to the untreated control. However, no significant differences were observed between treatments using water and those using *Spirulina platensis* in terms of seed growth rate. The growth rate observed in the control treatment was 11.9%. The highest growth rate, 13.84%, was obtained from the treatment involving water soaking for one hour. This value was not significantly different from those obtained with soaking in *S. platensis* at concentrations of 60% for two hours. Overall, the entire treatment resulted in growth rates ranging from 12,0% to 13,7%. Extended soaking durations within 3 hours appeared to not give an additional seed growth rate enhancement in all treatments.This suggests that brief soaking periods can be adequate to enhance the early growth performance of seedlings.

Shoot Length (cm)

The shoot length parameter is used to evaluate the effects of algal biomass bio-stimulants on post-germination seed growth. The shoot is the precursor to the stem that grows during the germination process and will continue to develop into the plant's stem. A long shoot indicates optimal nutrient availability in the seed, ensuring that nutrient needs and absorption are met. According to Figure 4, treatments involving seed soaking in either water or *Spirulina platensis* consistently resulted in improved shoot lengths compared to the untreated control. The control group exhibited an average shoot length of 4.4 cm, whereas the best result, a length of 5.5 cm, was obtained with seeds soaked at a 30% concentration for one hour. Consistent with the three previously discussed parameters, there was a noticeable trend indicating that prolonged soaking durations tended not to yield additional benefits. Nevertheless, no negative impact such as growth inhibition was observed in such parameters.

The four observed parameters: Mean Germination Time (MGT), Vigor Index, Seed Growth Rate, and Shoot Length demonstrated that seed priming with either *Spirulina platensis* or water (hydropriming) generally improves seed physiological performance compared to untreated controls. This beneficial effect was particularly evident at shorter soaking durations (1–2 hours) and moderate *Spirulina* concentrations (30–45%), while extended soaking periods tend to diminish priming effectiveness. Physiologically, seed priming initiates early metabolic processes, such as protein synthesis, enzyme activation (e.g., α-amylase and dehydrogenase) (Hacisalihoglu *et al.*, 2018), and increases levels of growth hormones like gibberellic acid. *Spirulina platensis* contains numerous essential nutrients, including amino acids, vitamins, and antioxidants that enhance these metabolic processes of seeds upon germination (Thinh *et al.*, 2021).

Research by Nguyen & Sundareswaran (2018) indicates that priming with *Spirulina platensis* extracts significantly improves germination speed, shoot length, biomass production, and vigor index compared to controls and hydropriming alone. These results were consistent with the research by Alling *et al.* (2023) which showed that the use of supernatant from the microalgae *Chlorella vulgaris* resulted in a germination time that was approximately 0.5 days faster than the control in tomato seeds. According to Mukherjee (2018) faster germination is the result of accelerated pre-germination metabolism during the priming process. Additionally, seeds treated with priming accelerate the metabolic process by increasing the imbibition rate (Shrestha *et al.*, 2019). Therefore, priming treatment with *Spirulina platensis* produces seeds that are ready to germinate faster and vigorously compared to the control.

The increase in seed vigor can be influenced by various factors including hormones. The exogenous growth hormones contained in algal biomass, leading to enhanced early plant growth. Do *et al.* (2020) mentioned that the biomass of microalgae contains auxins and gibberellins that exhibited a stimulating effect on the germination process of tomato seeds. According to Andianingsih *et al.* (2021) auxins played a role in stimulating cell elongation, and gibberellins affected the development and germination of embryos. In addition, the increase in seed VI indicated that the seeds have a higher ability to grow, resulting in stronger and more uniform plants' growth. Seeds with higher vigor characteristics can produce more tolerant plants and can thrive in suboptimal land conditions (Mora *et al.*, 2022). Consistent with the results of the current study, Thinh (2021) reported enhanced growth rates in black bean seeds primed with *Spirulina platensis* extract. Similarly, Akgul (2019) demonstrated that priming barley seeds with the lowest concentration of *Spirulina platensis* extract over a 24-hour soaking period produced the greatest shoot length, while higher concentrations led to decreased shoot length. Additionally, Alling *et al.* (2023) observed an improved shoot growth in tomato seeds primed with *Chlorella vulgaris*, attributing this to the presence of phytohormones that promote seedling growth after germination.

To obtain an optimum effect of seed growth enhancement, the application of microalgae cells for seed priming must be carefully examined. An excessive concentration or soaking duration may lead to over-imbibition, potentially damaging cell membrane integrity and disrupting seed metabolic balance. Such conditions can reduce enzyme activity and hinder early seedling growth. Komalasari and Arief (2020), in a study on sorghum seeds, observed significant positive effects on seed vigor with a soaking duration of two hours, whereas longer durations did not yield additional benefits. Overall, these findings support the theory that priming seeds with *Spirulina platensis* or water can enhance seed physiological quality and early plant growth, particularly when applied at optimal durations and concentrations.

Conversely, prolonged soaking durations or inappropriate concentrations can diminish priming effectiveness in promoting improvement of growth parameters.

Parameters Not Affected by The Treatment

In contrast to the previous parameters, several parameters including germination rate, seed growth simultaneity, maximum seed growth potential, radicle length, and dry weight of normal seedlings showed no significant response to the priming treatments applied in this study. These findings suggested that certain physiological traits might biologically be less responsive to seed priming treatments with *Spirulina platensis*. Therefore, this insight emphasizes the value of precisely selecting evaluation parameters for biological seed treatments and the importance of identifying optimal priming strategies to effectively enhance these specific physiological attributes (Paparella *et al.*, 2015).

Germination Rate (%), Seed Growth Simultaenity (%), Maximum Seed Growth Potential (%), Radicle Length (%), and Dry Weight of Normal Seedling (gram)

Germination rate is the ability of seeds to grow into normal seedlings under supportive environmental conditions (Nurwiati & Budiman, 2023). Furthermore, the germination rate of seeds is influenced by several factors, including the environment, water, seeds nutrient content, and phytohormones needed during the seed germination process (Xue *et al.*, 2021). Building upon the concept of successful germination, another important aspect of seed vigor is seed growth simultaneity. Seed growth simultaneity is one of the vigor tests to determine the ability of seeds to germinate simultaneously. Similarly, maximum seed growth potential is one of the seed viability parameters that describes the seed's growth capacity, indicated by the presence of metabolic activity. This parameter is calculated based on the number of seeds that can grow normally or abnormally under optimal environmental conditions (Harsono *et al.*, 2021). Following the initial stages of germination and the overall potential for growth, the development of the seedling's primary root is a critical step. Radicle is the embryonic root that emerges and grows on the seed during the germination process (Wibowo, 2020). In the early stages of growth, the radicle will elongate due to seed metabolism, providing nutrients supply for photosynthesis. The radicle would finally develop into and serve as the plant’s primary root. Ultimately, the peak of successful germination and early growth can be quantified by measuring the total biomass accumulation in the seedling. The dry weight of normal seedling (DW) is one of the seed quality tests aimed at determining seed vigor. Plant biomass is composed of cellulose, lipids, proteins, starch, nitrogen, and other compounds produced during the photosynthesis process and formed according to growth conditions (Kumar *et al.*, 2023).

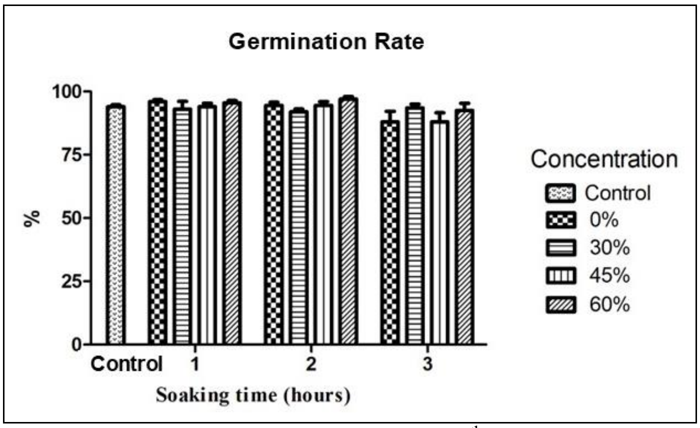

Figure 5. Germination Rate (%). Data were observed on day 5th (first count) and day 14th (final count).

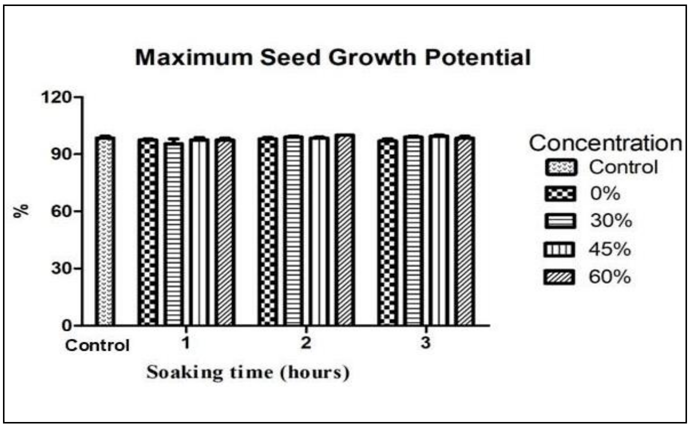

Figure 6. Maximum Seed Growth Potential (MGP) Data were observed on day 14th (final count).

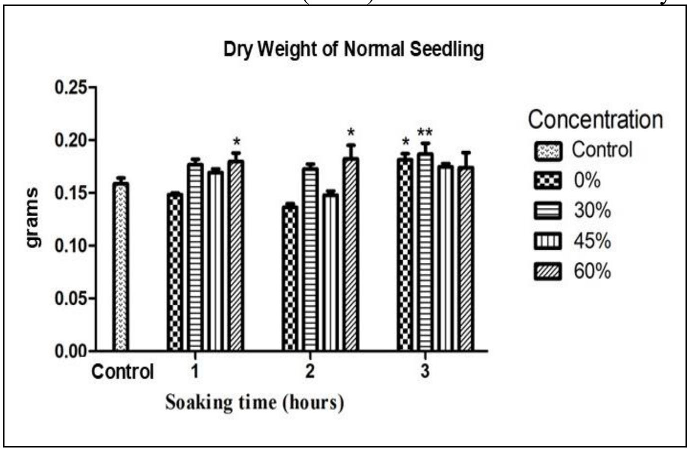

Figure 7. Normal Seedling Dry Weight (grams). Data were observed on day 14th (Final Count)

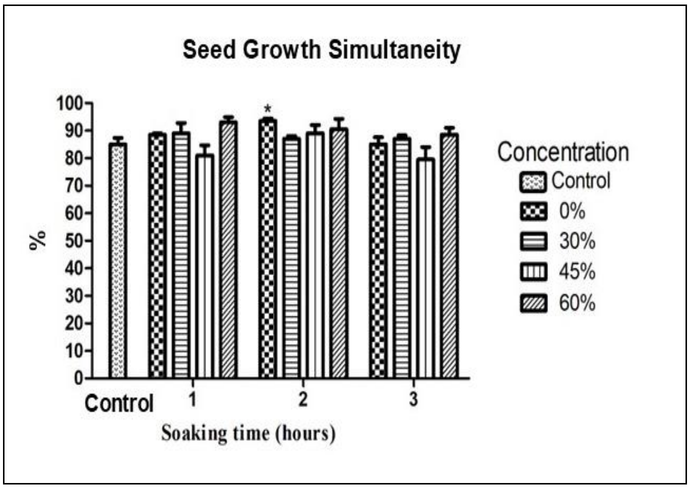

Figure 8. Seed Growth Simultaneity (%). Data were observed on the 10th

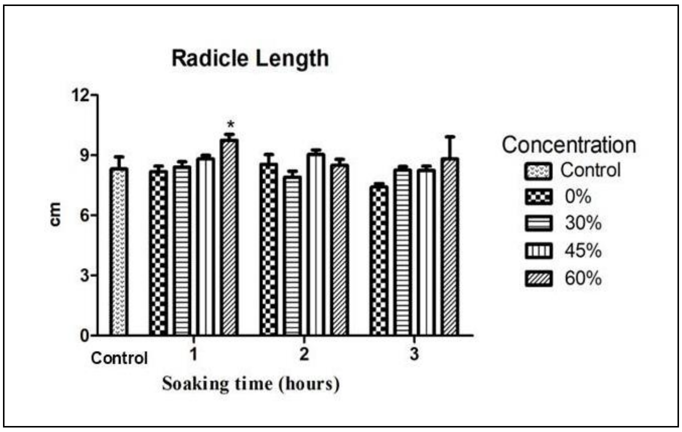

Figure 9. Radicle Length (cm). Data were observed on day 14th (final count).

The data above represent the mean with SEM error bars from the ANOVA analysis with Bonferroni Post Hoc Test compared to the control. No sign = Non-Significant, * = Significant ($P \leq 0.05$), ** = Significant ($P \leq 0.01$), *** = Significant ($P \leq 0.001$).

As shown in Figures 5 to 9 above, it can be observed that nearly all parameters were not affected by the treatments and showed statistically no significant differences in $P \leq 0.01$. The germination rate observed in this study ranged from 85% to 95%. The insignificant effects observed for this and three other parameters are likely attributable to the inherently high baseline performance of these seed parameters. Seed priming generally offer much distinct benefit on the vigor and viability of seeds that have experienced deterioration. This observation aligned with findings from previous studies. For instance, research by Jisha *et al.* (2013) and Paparella *et al.* (2015) indicate that seed priming techniques were particularly effective in improving germination and vigor in seeds that have experienced deterioration or are of lower quality. In contrast, seeds already exhibiting high vigor and viability may not show significant improvements in all growth parameters upon priming, as their physiological processes may already be operating at an optimum level. Therefore, while *S. platensis* seed priming exhibited both dominant and subtle effects across various parameters in these high-quality seeds, this study positively confirms that it did not cause any seed growth inhibition. This result indicated its safe and potential use as seed biostimulating agent without negatively impacting most of seed growth parameters. Consequently, to maintain excellent performance of high-quality seeds, focusing on other agronomic practices alongside the appropriate application of *S. platensis* biomass could be a productive strategy for sustained seedling establishment and growth.

Conclusion and Recommendation

This study demonstrated the potential of *Spirulina platensis*, cultured in a sugar mill effluent (SME)-based media, as a sustainable biostimulant for seed priming in DREZA F1 tomato seeds. Priming treatments, particularly those involving moderate concentrations and short soaking durations, positively influenced several key physiological parameters, including mean germination time, vigor index, seed growth rate, and shoot length. These improvements suggest that *S. platensis* can effectively enhance early seedling performance, offering a promising strategy for seed invigoration within a circular agricultural framework. While other parameters such as germination rate, seed growth simultaneity, maximum seed growth potential, radicle length, and dry weight of normal seedlings did not respond significantly to the treatments, the application of *S. platensis* did not show any negative impact on tomato seed growth. This underlines the safety of microalgae biomass for agriculture application purposes. Future studies should explore its application in lower-quality seeds or under abiotic stress conditions to further validate its broad utility and optimize its potential use in sustainable seed management practices.

Overall, this research supports the use of *S. platensis* as an innovative and ecofriendly priming agent, especially in enhancing seed performance under specific conditions.

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