Effect of Seaweed Extract on Potato (*Solanum tuberosum* L.) Varieties grown under Heat Stress Conditions

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ABSTRACT

Climate Heat stress has been known to negatively impact the growth and yield of various crop plants, including potatoes. In recent years, the use of seaweed extract as a potential bio stimulant has gained interest due to its reported positive effect on plant growth and stress tolerance. This study aimed to investigate the effect of seaweed extract on potato growth and yield under heat-stress conditions. Three potato varieties (Diamant, Marabel, and Nicola) grown under heat stress were treated with three concentrations of seaweed extract (0.5 mL, 1.0 mL, and 1.5 mL). The treatments, including a control without seaweed extract, were arranged in a Completely Randomized Design (CRD) with three replications. The data collected were analyzed using ANOVA, and significant treatment means were separated using Tukey's HSD test. Results showed that the varieties differed significantly in plant height, leaf number, stem number, and mean tuber weight. At 12 WAP, variety Nicola produced the tallest plant of 39.29 cm, while variety Marable was the shortest (28.88 cm). Mean tuber weight was significantly affected by 1.0 mL of seaweed extract. In addition, a significant interaction between variety and seaweed extract was observed for all the parameters, indicating differential responses of varieties to different concentrations of seaweed extract. This study highlights significant varietal differences in response to treatment, identifying 1.0 mL as the optimal concentration for mitigating heat stress damage. These offer a practical strategy for enhancing crop resilience, contributing valuable insights toward sustaining potato production and ensuring food security in a warming climate.

Keywords: *Seaweed extract, Potato, Heat stress, Growth, Yield*

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is an annual herbaceous plant from the Solanaceae family that produces tubers. It is a vital component of a balanced diet, contributing to global food security. This widely cultivated crop has a tetraploid chromosome number of 2n = 48 and is thought to have originated in Peru, South America (Karak et al., 2023). Following rice and wheat, it ranks third among the most widely consumed crops worldwide. Global potato production has risen from 270 million tonnes in 1961 to 383 million tonnes in 2023 (FAOSTAT, 2023). Despite their potential for high yields per unit area, potato growth and tuber yield are affected by various biotic and abiotic stresses, including extreme temperatures, drought, pests, and diseases. Recent reports indicate that climate change has a profound impact on food security by reducing viable land, decreasing yields of numerous staple crops, and increasing both biotic and abiotic stresses (Abebaw, 2025; Arif et al., 2025).

Increasing temperatures are anticipated to hinder advancements in addressing food insecurity by diminishing agricultural yields in the upcoming decades (Kroeger, 2023). The rise in temperature demands crops to grow and produce well at temperatures above their optimal. Optimal potato development occurs in temperatures between 15 and 20°C, with yields ranging from 12 to 60 tons of tubers per hectare. However, observations show a decline in yield when the ambient temperature exceeds 24°C (Paul, 2017; Obiero *et al.,* 2019; Guatam *e al*., 2024). This reduction is attributed to a combination of independent morphological, physiological, and developmental issues (Sánchez-Correa et al., 2024). One effective strategy to enhance food production under such challenging conditions is cultivating crops with enhanced resilience to environmental stress.

Traditionally, improving crop resilience has relied on breeding programs. However, these programs often encounter difficulties due to the complex genetic basis of abiotic stress tolerance, which involves multiple genes with intricate interactions. This complexity makes identifying and incorporating these traits into new cultivars time-consuming and resource-intensive. Moreover, breeding programs require several generations to produce stable, high-yielding varieties, making them too slow to keep pace with the accelerating impact of climate-induced stresses (Lau et al., 2025). Given these constraints, plant bio stimulant have emerged as a promising alternative, attracting considerable interest from researchers for their ability to enhance plant growth, overall fitness, and resilience to abiotic stresses. Although the efficacy of seaweed extracts has been widely reported, a significant gap exists in defining the optimum concentration required to mitigate severe heat stress in different potato genotypes. Most studies focus on ambient growth conditions or moderate stress, leaving a lack of evidence on how seaweed-based bio stimulants influence tuber yield when temperatures exceed the threshold. Bio stimulants are organic compounds that enhance natural plant functions without the use of chemicals, leading to increased crop yields, improved nutritional efficiency, and greater environmental resilience (Mandal *et al*., 2023). They activate biosynthetic pathways and stimulate secondary metabolism within plants (Jmaili et al., 2025). It works by promoting nutrient uptake and supporting plant growth and development rather than directly supplying nutrients or targeting pests and pathogens (Mukherjee and Patel, 2020). They have been used extensively in land crops to mitigate abiotic and biotic stress, improve yields, and enhance overall plant vigour (Shukla et al., 2017; Frazoni et al., 2022). Its application is one of the sustainable methods for securing food security, as it has strategic potential and prospects for mitigating the adverse impacts of harsh environmental conditions on plants, while also enhancing plant resilience against climate change-linked stresses (Calvo et al., 2014; Yakhin et al., 2017). In light of this perspective, the current study assessed the effect of varying concentrations of seaweed extract on potato growth and yield.

Aim and Objectives of the Study

This study aimed to assess the effect of seaweed extract on the growth and yield of selected potato varieties.

Objectives

i) To evaluate the morphological performance of three potato varieties in response to seaweed extract applications under heat-stressed conditions.
ii) To determine the optimum concentration of seaweed extract on the growth and yield of selected potato varieties.

MATERIAL AND METHODS

Experimental site

This experiment was carried out under controlled conditions between February and June 2023 at the Federal College of Forestry, Jos, and Plateau State. The college is located at an altitude of 1,150 m above sea level at a latitude of 09.9473^{0}'E and a longitude of 08.2N. The climate of the area is generally humid and tropical, with an annual rainfall of about 136 mm to 148 mm, with approximate annual temperatures of 10$^{°C}$ to 32$^{°C}$, respectively.

Source of planting materials

Three (3) potato varieties (Diamant, Marabel, and Nicola) collected from the National Root Crops Research Institute, Potato Program, Vom, Plateau State, were used.

Experimental design

The experiment was laid out in a Completely Randomized Design (CRD) in a 3 x 4 factorial arrangement with three replications per treatment combination. The factors were variety and seaweed extract concentrations (0 mL, 0.5 mL, 1.0 mL, and 1.5 mL). A total of one hundred and eight (108) polythene bags were used, with each plot having three polythene bags filled with soil. Cow dung, sharp sand, and loamy soil were mixed at a potting ratio of 1:2:1, respectively.

Plant material and growth conditions

Healthy and uniform seed tubers of three potato varieties were planted in black polythene bags. The plants were maintained under standard agronomic practices until the commencement of the stress treatment.

Heat stress induction

At four weeks after emergence (WAE), heat stress was imposed daily for six hours and maintained for two consecutive weeks. To simulate heat-stressed conditions, all plants were enclosed within a custom-built propagator. The structure was constructed using wooden planks and draped with transparent polythene sheets, ensuring high light availability with a transmittance of (< 92%). The experimental design focused specifically on the differential response of potato varieties and seaweed extract concentrations under heat stress; consequently, a non-stressed (ambient) control group was not included. This specific focus on comparative resilience under stress is acknowledged as a limitation of the current study.

Environmental Monitoring

The internal microclimate of the propagator was monitored using a standard thermometer placed at the canopy level. Daytime temperatures within the structure were maintained between 32°C and 40°C throughout the 14-day stress period. To provide a baseline for the localized environment, daily ambient temperature data were retrieved from the college's meteorological station; these data were subsequently used to calculate the average monthly temperature for the duration of the study (Figure 1).

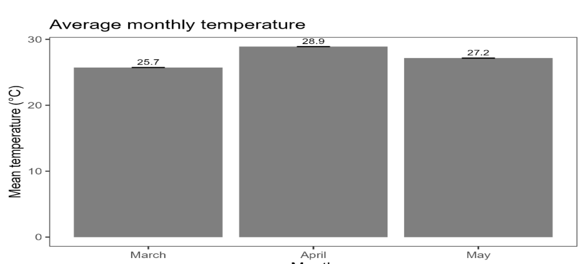

Figure 1: Mean ambient temperature at the experimental site in 2023

Seaweed preparation and application

A stock liquid seaweed extract derived from *Ascophyllum nodosum* was used to prepare three treatment solutions (0.5, 1.0 and 1.5 mL). Each solution was prepared by diluting the extract with 1000 mL of distilled water. The control group (0 mL) was established by applying only 1000 mL of distilled water. All solutions were prepared immediately before application to ensure stability and efficacy. Foliar application of the solution began four weeks after planting and was repeated at two-week intervals. Plants in the 0 mL concentration group received only distilled water and served as the treatment control under heat stress conditions (Table 1).

Table 1: Seaweed extract specification

Item	Specification
Solubility in water	100 %
Odor	Marine-like
Ph (1% solution)	7.5-8.5
Fucoidan	> 3 %
Mannitol	> 1 %
Amino acids	> 0.6 %
Total organic matter	12 – 18 %
Alginic Acid	> 3 %
Other organic compounds	>6%
Appearance	Black brown liquid

Growth and Yield parameters measured

Data were collected at two-week intervals until harvest, and the following parameters were assessed:

Plant height (cm)

Plant height was measured from the base to the tip of the plant, using a measuring tape.

Number of leaves

The number of leaves produced on each plant was counted and recorded.

Number of stems

The number of stems produced by each plant was counted and recorded.

Mean tuber weight (g)

All tubers from each plot were weighed and divided by the total number of plants in that plot.

RESULTS

Number of leaves

No significant differences were observed among the varieties, except at 8 weeks after planting (WAP) (P <

Table 2: Main effect of variety and different concentrations of seaweed extract on the number of leaves at different growth stages

	Weeks after planting			
Variety	**6**	**8**	**10**	**12**
Diamant	58.71 ± 6.86	64.53 ± 6.42	64.61± 6.48	58.19± 6.75
Marabel	38.25 ± 6.45	40.58 ± 6.31	42.08± 6.55	36.08± 6.24
Nicola	40.75 ± 8.45	47.29 ± 7.48	51.17± 8.55	47.62 ± 8.1
Significance	NS	*	NS	NS
$LSD_{0.05}$	21.672	20.173	21.829	21.16
Concentrations of seaweed Extract				
0 mL	46.82±10.27	52.48 ± 9.47	50.87±11.5	46.31±11.4
0.5 mL	40.48 ± 7.71	46.2 ± 7.87	53.04± 7.94	42.99± 7.58
1.0 mL	53.37 ± 9.42	56 ± 9.12	57.13± 8.94	53.2 ± 8.51
1.5 mL	42.94 ± 8.32	48.52 ± 7.75	49.44± 7.53	46.69± 6.95
Significance	NS	NS	NS	NS
$LSD_{0.05}$	25.024	23.294	25.205	26.58
VXC	NS	*	NS	NS
CV (%)	61.73	51.48	52.27	58.15

* = significant, NS = Not significant, CV (%) = coefficient of variation, LSD test at 5% significance level

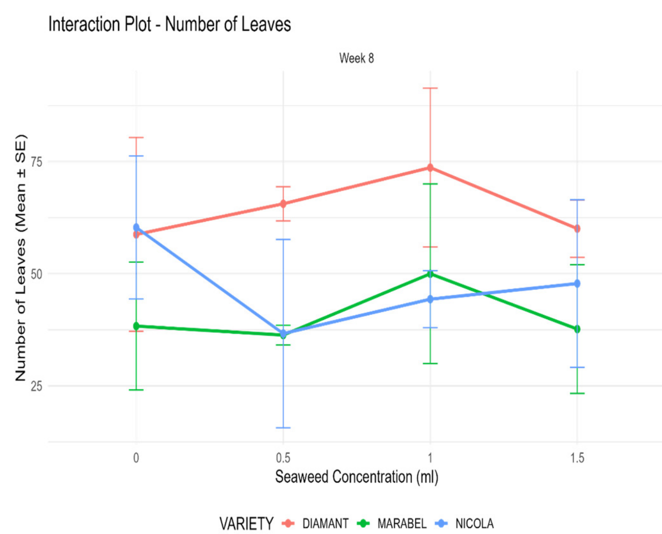

Figure 2. Interaction effects of variety and seaweed extract concentration on the number of leaves of potato at Week 8.

0.05). At this stage, the variety Diamant had the highest leaf count (64.53), while Marabel had the lowest (40.58), as shown in Table 2. Although the main effect of concentration was not significant (P > 0.05), a significant interaction was observed between variety and concentration. The variety Diamant recorded the highest number of leaves, reaching approximately 75 when treated with 1.0 mL of extract. Although this count decreased slightly at the 1.5 mL concentration, Diamant consistently maintained the highest leaf numbers (Figure 2). In contrast, Marabel generally exhibited lower leaf counts, ranging from approximately 30 to 50 leaves.

Stem number

No significant differences (P>0.05) were observed among varieties at 6, 10 and 12 WAP, however, a significant difference was observed at 8 WAP (Table 3). Variety Diamant produced the highest number of stems (3.05), while Nicola recorded the lowest stem number (1.71). A significant difference (P<0.05) was also observed among the concentrations measured at 12 WAP.

Table 3: Main effect of variety and different concentrations of seaweed extract on stem number at different growth stages.

	Weeks after planting			
Variety	**6**	**8**	**10**	**12**
Diamant	3.19 ±0.35	3.05 ±0.39	3.17± 0.33	3.31 ± 0.36
Marabel	2.5 ± 0.53	1.88 ±0.34	2.36 ±0.23	2.46 ± 0.41
Nicola	2.08± 0.27	1.71 ± .19	2.50± 0.42	2.67 ± 0.45
Significance	NS	*	NS	NS
$LSD_{0.05}$	1.188	0.94	0.97	1.07
Concentrations of seaweed Extract				
0mL	2.67 ±0.45	2.19 ±0.44	2.63 ±0.39	2.37 ± 0.47
0.5mL	2.17 ±0.29	2.11 ± 0.27	2.48 ±0.26	2.48 ± 0.26
1.0mL	2.72 ±0.75	2.04 ±0.58	2.33 ±0.51	2.41 ± 0.44
1.5ML	2.8 ± 0.32	2.5 ± 0.32	3.26 ±0.39	3.98 ± 0.53
Significance	NS	NS	NS	*
$LSD_{0.05}$	1.372	1.09	1.12	1.23
VXC	*	*	*	*
CV (%)	54.63	54.99	42.78	47.58

* = significant, NS = Not significant, CV (%) = coefficient of variation, LSD test at 5% significance level

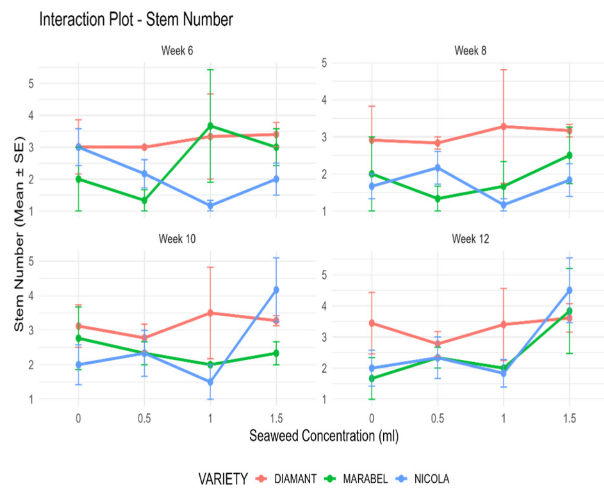

Figure 3: Interaction effects of variety and seaweed extract concentration on the number of stems of potato at Weeks 6, 8, 10 and 12.

Plants treated with 1.5 mL of seaweed extract resulted in the highest number of stems (3.98), while those treated without seaweed extract (0 mL) produced the lowest mean stem number (2.37). A significant interaction was observed between variety and concentration (Figure 3). The variety Diamant consistently produced the highest number of stems across concentrations except at 10 and 12 WAP, while Marabel produced the lowest number of stems across all concentrations.

Plant height (cm)

Significant variation ($p < 0.05$) was observed in plant height at 10 and 12 (WAP) (Table 4). The variety Nicola produced the tallest plants (37.59 cm and 39.29 cm, respectively), while Marabel produced the shortest plants (29.77 cm and 28.88 cm, respectively). The various concentrations also showed a significant effect on plant height. Plants treated with 1.0 mL extract exhibited the greatest height (36.74 cm and 36.57 cm), while untreated plants (control) had the shortest height (30.00 cm and 28.54 cm) at 10 and 12 WAP, respectively. A significant interaction was observed between concentration and variety on plant height at both 10 and 12 WAP (Figure 4). The variety Nicola consistently showed increased plant height when treated with all concentrations, whereas Diamant and Marabel produced shorter plants under all treatments.

Table 4: Main effect of variety and different concentrations of seaweed extract on plant Height at 8, 10 and 12 Weeks after Planting.

	Weeks after planting			
Variety	**6**	**8**	**10**	**12**
Diamant	15.39 ± 1.36	24.61 ± 1.92	31.75 ± 1.78	31.55±1.77
Marabel	15.15 ± 1.53	22.9 ± 2.24	29.77 ± 2.59	28.88 ± 3.2
Nicola	14.79 ± 3.33	26.32 ± 2.2	37.59 ± 1.98	39.29±2.57
Significance	NS	NS	*	*
$LSD_{0.05}$	6.58	6.06	6.09	7.33
Concentrations of Seaweed Extract				
0 mL	17.73 ± 4.25	23.19 ± 1.93	30 ± 2.93	28.54±3.98
0.5 mL	12.5 ± 1.8	21.77 ± 3.09	31.89 ± 2.69	33.36 ± 4
1.0 mL	16.42 ± 1.62	28.07 ± 2.16	36.74 ± 2.53	36.57±2.58
1.5 mL	13.81 ± 1.45	25.41 ± 2.25	33.51 ± 2.35	34.49±1.88
Significance	NS	NS	*	*
$LSD_{0.05}$	7.60	6.9	7.03	8.47
VXC	NS	NS	*	*
CV (%)	48.39	30.99	22.56	26.23

* = significant, NS = Not significant, CV (%) = coefficient of variation, LSD test at 5% significance level.

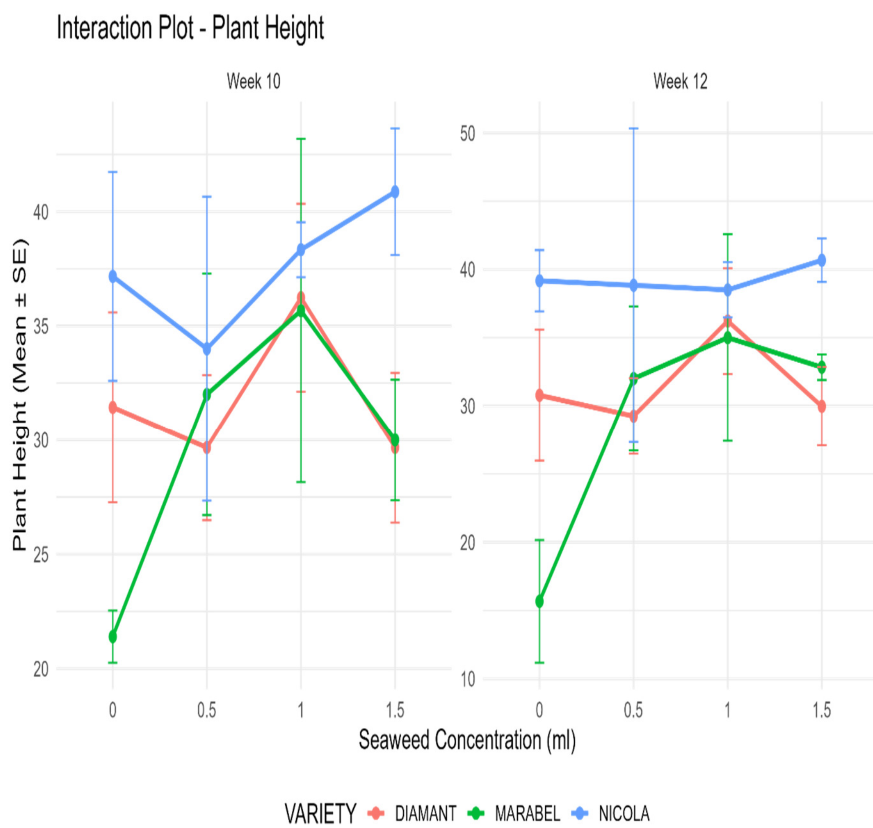

Figure 4: Interaction effects of variety and seaweed concentration on plant height of potato at Weeks 10 and 12.

Mean weight of tuber

The main effect of variety on mean tuber weight was significant ($P < 0.05$) (Table 5). Marabel recorded the highest tuber weight (55.69 g), whereas Nicola produced the lowest (34.21 g). Furthermore, the concentration of seaweed extract significantly affected yield. Plants treated with 1.0 mL of extract produced the highest tuber weight (56.74 g), while those treated with 1.5 mL resulted in the lowest weight (33.67 g).

Figure 5 illustrates the interaction between variety and concentration. Marabel recorded the highest tuber weights

Table 5: Main effect of variety and different concentrations of seaweed extract on mean tuber weight at harvest.

Variety	Mean tuber weight (g)
Diamant	37.91 ± 3.57
Marabel	55.69 ± 10.38
Nicola	34.21 ± 4.06
Significant	*
$LSD_{0.05}$	18.59
Concentration of Seaweed Extract	
0 mL	34.59 ± 7.9
0.5 mL	45.41 ± 4.41
1.0 mL	56.74 ± 12.49
1.5 mL	33.67 ± 3.65
Significance	*
$LSD_{0.05}$	21.47
VXC	*
CV (%)	46.42

* = significant, NS = Not significant, CV (%) = coefficient of variation, LSD test at 5% significance level

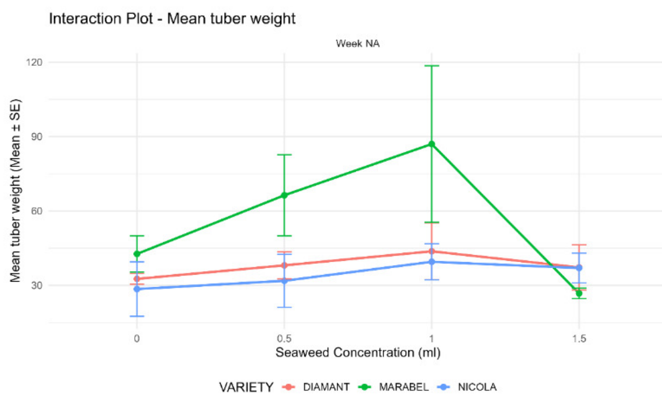

Figure 5: Interaction effects of variety and seaweed extract concentration on mean tuber weight (MTW)

with the 1.0 mL extract, while Nicola had the lowest. Overall, the 1.0 mL concentration was the most effective, yielding the highest tuber weights for Marabel (Figure 5).

DISCUSSION

The results demonstrate varied responses among potato varieties under heat stress. Significant variation was observed in the number of leaves per plant (Table 3), with Diamant recording the highest value (64.53) and Marabel the lowest (40.58). This trend was consistent across other vegetative parameters, including stem number and plant height. The vigorous vegetative growth observed in Diamant and Nicola suggests that these varieties allocated resources primarily toward source organ development. However, their substantially lower tuber weights indicate inefficiency in dry matter partitioning, based solely on morphological outcomes. The inhibition of tuber yield by high temperature is due to the limited translocation of carbohydrates from leaves to the tubers, following the reduction of leaf nitrate reductase activity and the expense of carbohydrates for dark respiration (Ghosh et al., 2000; Sánchez-Correa et al., 2024). Despite moderate vegetative growth, Marabel achieved the highest tuber weight (55.69 g), indicating it as a sink-efficient variety at least in terms of morphological yield traits. It is important to note that only morphological parameters were assessed under heat stress in this study. While these parameters provide valuable insights into varietal performance, they do not capture the underlying physiological responses, such as photosynthetic efficiency, stomatal conductance, or carbohydrate assimilation rates, which are critical for understanding stress adaptation mechanisms.

The role of seaweed extract was pivotal in managing the source–sink balance. The optimum concentration of 1.0 mL extract increased both vegetative and yield parameters. This suggests that applying an optimal proportion of seaweed extract can promote tuber development by enhancing nutrient absorption and resilience to stress. Luwangch et al. (2025) found that the use of seaweed extract at a 60 ml concentration acts as a significant catalyst for growth in spinach. This specific dosage was reported to markedly improve key parameters, including plant height, leaf count, and overall agricultural yield. Seaweed extract is widely recognized for its effectiveness in yield optimization and stress mitigation (Souza et al., 2019; Umanzor et al., 2019; Abdelkader et al., 2026). Our findings are consistent with those of Avendaño et al. (2024), who also reported significant yield increases following seaweed application.

Conclusion

This study reveals that vegetative growth alone is not a reliable indicator of yield in heat-stressed potato production. Although Diamant exhibited the highest leaf counts, stem numbers, and plant height, these traits did not translate into greater tuber yield. In contrast, Marabel produced the highest tuber weight despite only moderate vegetative growth, highlighting the importance of genotype-specific responses and the balance between source and sink strength. The application of 1.0 mL seaweed extract was optimal for increasing tuber yield under heat stress by balancing growth and yield. Key limitations of the research include the exclusive measurement of morphological parameters and the lack of a non-stressed control, which restricts broader conclusions about physiological mechanisms and generalizability. Future research should include physiological assessments and non-stressed comparisons to better understand varietal performance and improve breeding strategies for heat tolerance and yield.

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