



Crude extracts of seaweeds (*Ulva lactuca* and *Eucheuma spinosum*) as biostimulants for enhancing sweet pepper production

Charles O Joseph* and Seif Amour M

Department of Crop Sciences and Beekeeping Technology, College of Agriculture and Food Technology, University of Dar es Salaam, Box 35091, Dar es Salaam, Tanzania.

Keywords

Biostimulants;
Eucheuma spinosum;
Seaweed extracts;
Sustainable agriculture;
Ulva Lactuca.

Abstract

Sweet pepper is the world's second most important vegetable after tomato, making its production vital for economic growth and supporting livelihoods. However, growing concerns about environmental protection and sustainability make the search for eco-friendly alternatives to synthetic fertilizers inevitable. Seaweed extracts are rich in bioactive compounds that can stimulate key plant growth and defense pathways making them effective biofertilizer. A Randomized Complete Block Design was laid out to evaluate the potential of seaweed extract (*U. lactuca* and *E. spinosum*) in promoting the growth and productivity of sweet pepper (*Capsicum annuum* L.). Seaweed was applied in both liquid and in powder form. The liquid extracts were prepared by soaking 15 g, 20 g, 25 g, and 30 g of seaweed powder in 1 L of hot and cold water, while the powder was applied directly without dilution. The negative control group received no seaweed treatment. Both Nonparametric and parametric comparisons for the growth and yield parameters were performed. Results showed that seaweed significantly increased the average fruit weight (792%), fruit number (100%), number of branches (114.3%), and number of leaves (51.7%), stem girth (20%) and plant height (50.2%), with variations depending on the extraction method, seaweed species, and concentration. The optimal seaweed extract concentration was 0.6% beyond which no significant increase in growth or yield of sweet pepper was observed. Mean separation revealed that cold-water extraction had the most pronounced effect. In conclusion, this study highlights the importance of incorporating seaweed as biostimulants in a closed-system agriculture. However, further research should explore the extracts long-term effects, refine application and scalable methods for mass production and consistent quality and evaluate its efficiency in open-field agriculture.

Introduction

The sweet pepper plant (*Capsicum annuum* L.) is the third most important crop in the Solanaceae family, following tomatoes and potatoes. The fruit exhibits diverse colours, including red-orange, green, yellow, purple-

black, and brown (Zakir et al. 2024). The fruit provides substantial nutritional benefits (Khan et al. 2025, Mokgehle et al. 2025). Due to its health benefits and economic potential, efforts to increase production have included the use of synthetic fertilizers (Islam

*Corresponding author: jcharles@udsm.ac.tz

Received 10 May 2025, Revised 21st August 2025, Accepted 9th September, 2025, Published 30 October 2025

<https://doi.org/10.65085/2507-7961.1066>

© College of Natural and Applied Sciences, University of Dar es Salaam, 2025

ISSN 0856-1761, e-ISSN 2507-7961

et al. 2017, Gajc-Wolska et al. 2018). However, the indiscriminate use of fertilizers has been associated with pathogen resistance, chemical residue in food, higher production costs, and environmental damage, thus the need for alternative inputs in agriculture is inevitable (Yadav et al. 2024).

Researchers have reported that organic-based biostimulants, such as seaweed extracts, enhance seed sprouting and seed germination (Khanahmadi et al. 2025), thus promoting plant growth, increasing yield, and improving stress tolerance (De Mastro et al. 2025, Ahmed et al. 2024). Additionally, they play a role in remediating hydrocarbon-polluted soils (Ehis-Eriakha et al. 2025) improving seedling vigor, root and shoot development, photosynthesis, shelf life (Singh et al. 2019) and stimulating lateral bud growth to increase branch formation (Mokgehle et al. 2025). Seaweed extracts also promote early flowering and fruit set, leading to higher yields (Ali et al. 2019). For example, the application of extract as a foliar spray improved plant growth, increased fruit number, and extend the shelf life of sweet peppers (Ali et al. 2021). Furthermore *A. nodosum* alleviated drought damage in tomato by improving plant water relations, photosynthetic performance, and stomatal function (Ahmed et al. 2024). Similarly, the use of *Kappaphycus alvarezii* has led to significant yield increases in soybeans and maize by improvement of plant height, pod number, and nutrient uptake (Sanodiya et al. 2022).

The potential of seaweed extracts has been associated with its bioactive compounds, including plant growth regulators such as gibberellins, auxins, and cytokinins, as well as carbohydrates and essential macro- and micronutrients (Bradáčová et al. 2016, Shukla et al. 2019, Sanodiya et al. 2022, Mokgehle et al. 2025). Additionally, their antimicrobial, antifungal, anticancer, immunomodulatory, antihypertensive, and anticoagulant activities, as well as their role in human nutrition have been reported (Peedika et al., 2025, Listihani et al. 2023, Das et al. 2025). Seaweed is also envisaged as a key player in shaping key sectors such as aquaculture, hydrocolloid

production, biopesticide efficacy, biofertilizer formulation, biofuel production, and the development of biodegradable/edible bioplastics (Yong et al. 2024, Sharma et al. 2025).

Despite considerable research on seaweed primarily conducted in temperate climates or in developed countries, there is a significant knowledge gap regarding their application in Africa, where agricultural systems and environmental conditions vary widely. Furthermore, the optimal dose that could be beneficial to the farmers has been shown to vary significantly across different studies (Mohamed and Hassan 2025, Ahmed et al. 2024, Castellanos-Barriga et al. 2017, Marhoon and Abbas 2015). Therefore, localized studies are essential to assess effectiveness of seaweed extracts and determine optimum application rate especially in diverse environments of Africa which faces challenges such as drought, heat stress, disease pressure, and soil degradation. In particular, Tanzania has abundant seaweed species such as *Eucheuma spinosum*, *Ulva lactuca*, *Ulva armoricana*, and *Kappaphycus alvarezii* (TNC 2023, Msuya 2020). However, their economic potential remains largely underutilized, especially in crop production sectors. Therefore, this study assessed the potential of *U. lactuca* and *E. spinosum* in improving sweet pepper production in Tanzania.

Materials and Methods

Study site

The study was conducted in a semi-covered greenhouse at the Department of Botany demonstration farm, University of Dar es Salaam, from December 2022 to July 2023. Each plant was transplanted in a 10 L plastic bucket containing 7 kg of soil. Forest soil was dug around semi-covered greenhouse and then mix thoroughly to eliminate heterogeneity. Seaweed species, *U. lactuca* (green) and *E. spinosum* (brown) were collected from the coastline of Indian Ocean in Zanzibar. The extraneous materials such as seashells and pieces of wood were hand-picked and separated from the seaweed. The seaweeds were then packed into a cold box

container. Identification of the seaweed was further confirmed at the Institute of Marine Sciences-Zanzibar. The seaweeds were rinsed with fresh water in order to purify it from salt and sand. Thereafter the seaweeds were dried under the shade for 3 days to remove excess water, and then oven-dried to brittle at 60 °C for 15 hrs (Badmus et al. 2019). Oven-dried seaweeds were blended to powder and sieved through a fine mesh (100 mesh). The powder was then stored in airtight bottles. The Sweet peppers seeds of Indra F1 variety collected from agro-dealer shop in Dar es Salaam was used to test the potentiality of seaweed as biostimulants.

Seaweed extraction procedure

The powder obtained from each species was divided into three portions, each weighing 500g. For hot-water extractions, 500 g of powder from each species were heated to boiling in 2 L of distilled water for 30 min. In cold water extraction, 500 g of seaweed powder from each species were also dissolved in 2 L of cold water and left overnight. Then both mixtures were filtered by using muslin cloth to form a stock solution (crude seaweed extract-250g/l). The other remaining 500 g was applied in powder form.

Experimental design and layout

The experiment was conducted by using Randomized Complete Block Design (RCBD). Each species of seaweed was assigned in each block (replication). From the stock solution 15 ml, 20 ml, 25 ml and 30 ml of hot and cold-water extracts were mixed with 1 L of water to get working solutions of 3.75, 5, 6.25 and 7.5 g/L which were equivalent to 0.4%, 0.5%, 0.6% and 0.8% respectively. Working solution were applied directly on the soil around the plant (soil drenching) after every two weeks from transplanting until fruit setting (equivalent to 5 applications) using a 50 ml measuring cylinder. For the powder form treatment, 15 g, 20 g, 25 g and 30 g of seaweed powder were also applied after every two weeks from transplanting until fruit setting. For the control treatment no seaweed crude extract or

powder were applied. The treatments were replicated three times.

Data collection

From the date of transplanting (7th April 2023), the first data on plant height, number of leaves, number of branches and stem diameter (girth) was collected on 3rd week. The second data; the plant height, number of leaves, number of branches, stem diameter, fruit number and fruit weight was collected on the first harvest, on 6th June, 2023. A metre ruler was used to estimate plant height, and Vernier calliper to measure plant diameter (girth). The average weight of the first emerging two fruits were measured in gram using electronic weighing balance.

Statistical Analysis

In this study, JMP Pro 17 statistical software was used to perform statistical analysis. The normality test was computed using the goodness of fit index. Data that were not normally distributed, the Kruskal-Wallis test was used to compare means. Whenever the means differed significantly at $p < 0.05$, mean separation was performed using the Wilcoxon Signed-Rank Test for Paired samples to identify significant variations between pairs of means. For normally distributed data, a one-way ANOVA followed by Tukey's Honest Significant Difference (HSD) test was applied. Multivariate methods (multivariate correlation and discriminant analysis were carried out to evaluate correlations and compare categorical groups, respectively. Furthermore, fully factorial three-way ANOVA was performed to compare treatments interaction effects.

Results

The data for growth and yield parameters were tested for normality using goodness of fit-test (Figure 1), and it was evident that plant height, number of leaves, number of fruits and fruit weight were not normally distributed ($p < 0.05$) while, girth and number of branches were normally distributed ($p > 0.05$).

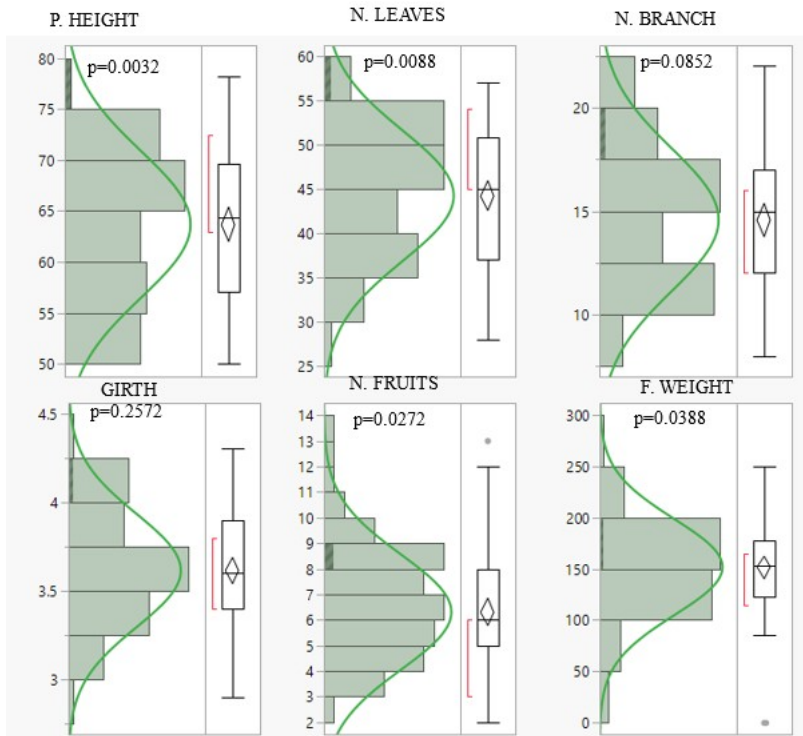


Figure 1: Normality test for growth and yield parameters. Traits with $p < 0.05$ are not normally distributed and the opposite are normally distributed.

Effect of seaweed species on growth parameters at different growth stages

Figure 2 shows the data on the contribution of seaweed species on the observed number of leaves, plant height, and girth on the 3rd week (vegetative stage) after transplanting and at first harvesting time (reproduction stage). At the vegetative state the contribution of *U. lactuca* and *E. spinosum* treatments to the observed number of leaves, plant height and girth were 50% by 45%), 48% by 46% and 41% by 54% respectively. At

reproduction stage (first harvesting time), *U. lactuca* and *E. spinosum* also contributed the number of leaves (by 49% and 46%), plant height (by 47% and 48%), and girth (by 48% and 46%) respectively. The control treatment contributed only 5, 5, and 6% of the observed number of leaves, plant height and girth. However, *t*-test indicated the effects of *U. lactuca* and *E. spinosum* on the number of leaves, plant height, and girth were significantly different between growth stages.

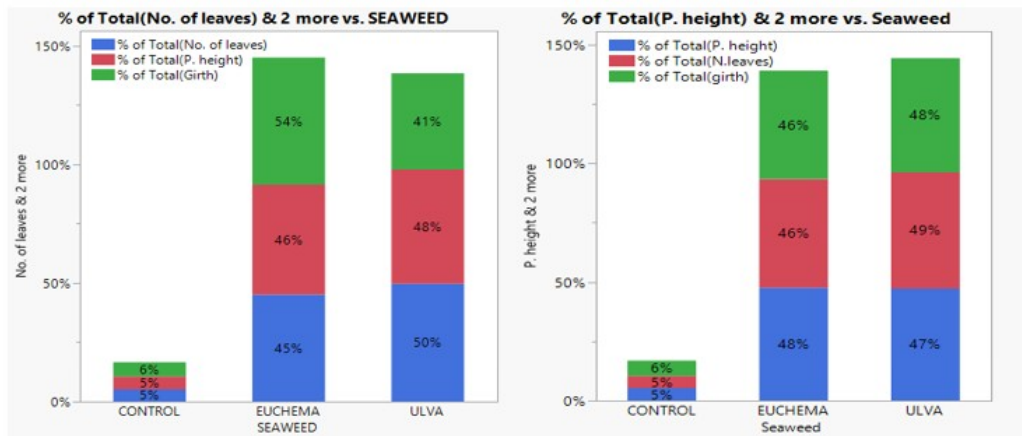


Figure 2: Effect of seaweed type on number of leaves, plant height and girth on the vegetative state (3rd week) after transplanting (left) and at first harvesting time (right) respectively.

Effects of seaweed species on sweet pepper growth and yield parameters

Plant height, number of leaves, number of fruits, and fruit weight were not normally distributed; therefore, the Kruskal-Wallis test was used to compare the means between the two groups. For stem girth and number of branches, which were normally distributed, a one-way ANOVA followed by Tukey's Honest Significant Difference (HSD) test was applied. Non-parametric pairwise

comparisons using the Wilcoxon method showed no significant differences between seaweed species for plant height, number of leaves, number of fruits, and fruit weight. Similarly, ANOVA results followed by HSD mean separation indicated no statistically significant differences between seaweed species for stem girth and number of branches (Table 1). However, the control treatment consistently exhibited significantly lower performance across all traits.

Table 1. Effect of seaweed species on sweet pepper growth and yield parameters

Level	Count	P. Height	N. Leaves	F. Number	F. Weight	Girth	N. Branch
<i>E. spinosum</i>	36	63.9±6.9a	42.8±7.6a	6.1±2.7a	152.3±47.4a	3.5±0.3a	14.7±3.6a
<i>U. lactuca</i>	36	63.5±7.5a	45.7±6.9a	6.5±1.7a	151.0±47.0a	3.7±0.3a	14.5±3.4a
Control	6	42.4±3.4b	29.2±2.9b	2.5±1.0b	17.0±26.8b	3.0±0.2b	7.2±1.6b

*Numbers with the same letter down the column are not statistically different at $p < 0.05$. P. height= Plant height, N. leaves= number of leaves, F. number= number of fruits, F. weight=fruit weight N. branch= number of branches

Effect of seaweed extract concentrations on the sweet pepper growth and yield parameters

The effect of *E. spinosum* and *U. lactuca* on fruit weight, fruit number and branches at first harvesting time increased with concentration (Figure 4). Generally, when compared to control (C0), C1 increased plant height, number of leaves, number of branches, stem girth, fruit number and fruit weight at the first harvesting by, 30.1, 20.4,

51.2, 11.0, 68.9 and 500.7%, C2 increased the same parameters by

41.7, 43.0, 82.9, 17.0, 115.6, and 750%. At C3, parameters increased by 64.7, 70.3, 130.2, 28.6, 206.7 and 906.2% respectively, while at C4 they increased by 64.7, 72.9, 149.6, 30.7, 217.8 and 1012.1%. Further analysis indicated no significant difference between the plant height, number of leaves, number of branches, stem girth, fruit number and fruit weight at C3 and C4.

Table 2. Effect of seaweed concentration on the sweet pepper growth and yield parameters.

Level	Count	P. Height	N. Leaves	N. Fruits	F. Weight	Girth	N. Branch
C0	6	42.4±3.4d	29.2±2.9d	2.5±1.0d	17.0±26.8d	3.0±0.23c	7.2±1.6d
C1	18	55.1±3.6c	35.1±3.0c	4.2±1.2c	102±42.3c	3.3±0.20b	10.8±1.6c
C2	18	60.1±3.4b	41.7±4.3b	5.4±1.5b	144.5±21.8b	3.5±0.18b	13.1±2.2b
C3	18	69.8±3.5a	49.7±4.6a	7.6±2.0a	171.1±35.1a	3.8±0.21a	16.5±2.1a
C4	18	69.8±2.7a	50.4±3.3a	7.9±1.8a	189.1±33.8a	3.9±0.25a	17.9±2.2a

*Numbers with the same letter down the column are not statistically different at $p < 0.05$. P. height = Plant height, N. leaves = number of leaves, F. number = number of fruits, F. weight = fruit weight N. branch = number of branches

Effects of extraction and application methods of seaweeds on sweet pepper growth and yield parameters

The variations in fruit number and size between different *U. lactuca* powder concentrations and the control at first harvesting time are shown in figure 3. Nonparametric comparisons for plant height, number of leaves, number of fruits and fruit

weight, using Wilcoxon method and one-way ANOVA followed by Tukey's Honest Significant Difference (HSD) test for the normally distributed number of branches and stem girth across seaweed extraction and application methods were trait specific (Table 3).



Figure 3: The variation in fruit number and size between different *U. lactuca* powder concentrations and control

Result showed that cold water *E. spinosum* increased plant height, number of leaves, fruit weight, number of branches, number of fruits and plant girth by 51.8, 26.6, 183.2, 957.8, 137.1 and 50.6% respectively. Cold water *U.*

lactuca increased the same parameters by 59.9, 24.9, 173.2, 751, 130.1 and 63.7% respectively. Hot water *E. spinosum* increased the plant parameters by 51.1, 16.8, 156.8, 728.4, 98.7 and 52.5%. Hot water *U.*

lactuca increased the plant parameters by 36.5% while *U. lactuca* by 46.5, 23.6, 160, 42.9, 26.6, 150, 855.4, 88.3 and 53.4%. For the powder forms, *E. spinosum* increased the parameters by 49.614.1, 90, 701.9, 77.8 and 758.8, 88.3 and 53.1% respectively.

Table 3. Effects of extraction and application methods of seaweeds on sweet pepper growth and yield parameters

Level	Count	P. Height	N. Leaves	N. Fruits	F. Weight	Girth	N. Branch
cold water euchema	12	64.3±7.4.ab	43.9±6.9ab	7.1.4±3.1 a	179.8±62.1a	3.7±0.38ab	17.0±3.3a
cold water ulva	12	67.8±7.4a	47.8±7.1a	6.8±1.4a	144.5±49.2ab	3.7±0.03ab	16.5±3.6a
control	6	42.4±3.4c	29.2±2.9c	2.5±1.0d	17.0±26.8b	3.0±0.20c	7.2±1.6c
hot water euchema	12	64.1±6.9ab	44.5±8.3ab	6.4±2.8ac	140.8±32.0a	3.5±0.30ab	14.3±3.3ab
hot water ulva	12	60.6±6.8b	44.8±6.9ab	6.3±1.7ac	162.4±45.2a	3.8±0.34ab	13.5±3.1ab
powder euchema	12	63.4±7.1ab	39.8±7.4b	4.8±1.5c	136.3±31.8ab	3.4±0.27bc	12.8±2.9ab
powder ulva	12	62.1±7.0ab	44.7±6.7ab	6.5±2.1a	146.0±48.5ab	3.7±0.28ab	13.8±2.7ab

*Numbers with the same letter down the column are not statistically different at $p < 0.05$. P. height =Plant height, N. leaves= number of leaves, F. number= number of fruits, F. weight=fruit weight N. branch= number of branches

Analysis of mean method by transformed rank indicated cold water extracts of *E. spinosum* and *U. lactuca* had significant effects on plant height, number of leaves, girth, and number of branches, fruits number and fruits weights (Figure 4).

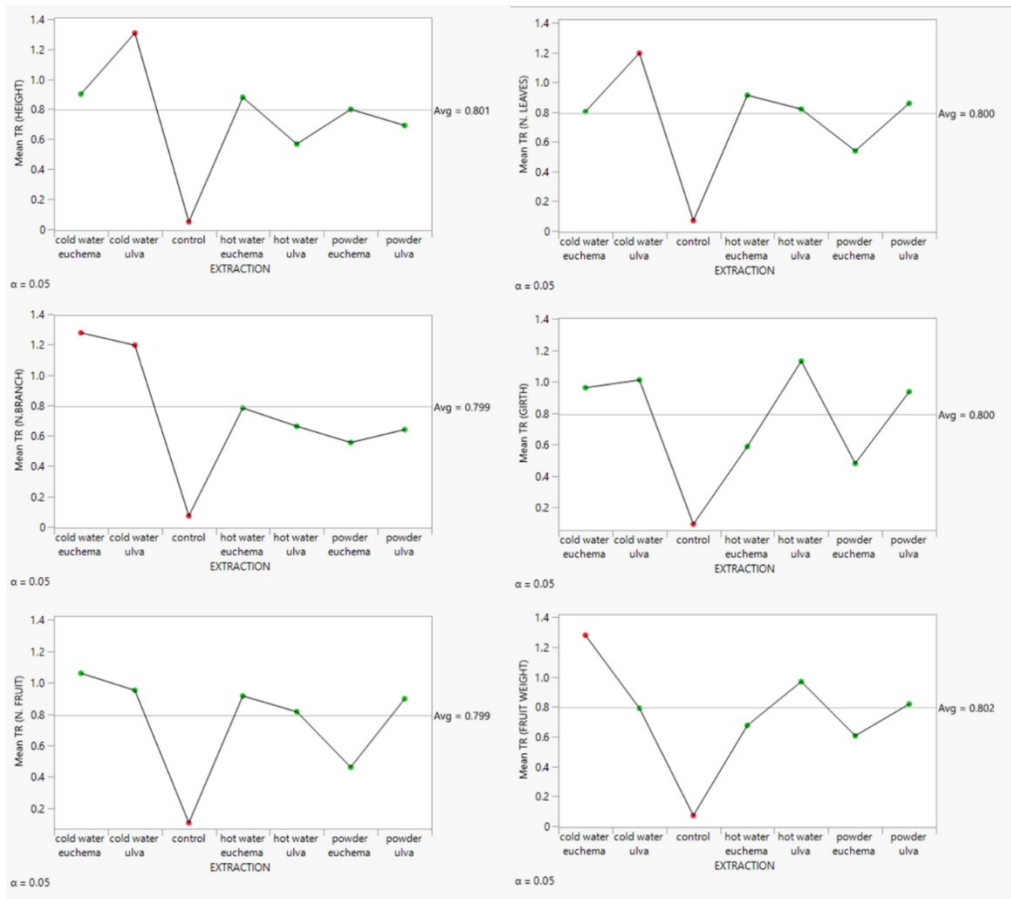


Figure 4: Analysis of mean methods by transformed rank

Interaction effects between the treatments on growth and yield parameters

Fully factorial three-way ANOVA indicated significant variations that were trait specific (Table 4).

Table 4 Interaction effects between treatments on the growth and yield parameters. * indicate significant variations

Source	DF	P. Height	N. Leaves	N. Branch	Girth	N. Fruit	F. Weight
Seaweed species	1	0.4930	0.0002*	0.5925	<.0001*	0.2244	0.8653
Extraction/form	2	<.0001*	0.0008*	<.0001*	0.0053*	0.0155*	0.0904
Concentration	3	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
Seaweed x Extraction	2	0.0003*	0.0339*	0.1164	0.0122*	0.0465*	0.0099*
Seaweed x conc.	3	0.7660	0.3510	0.8476	0.9843	0.1754	0.7450
Extraction x conc.	6	0.8962	0.1304	0.1888	0.7183	0.6814	0.6246
Extraction x conc x seaweed	6	0.8184	0.8023	0.6915	0.8507	0.6446	0.4518

*Indicate significant interactions at $p < 0.05$. P. height = Plant height, N. leaves = number of leaves, F. number = number of fruits, F. weight = fruit weight N. branch = number of branches

Multivariate analysis of growth and yield parameters

Multivariate correlation analysis showed that all growth and yield parameters had strong and positive relationships. Coefficient of correlations (r) ranged between 0.64 and

0.87 (Figure 5). This suggests that the relationship between the variables is consistent and that changes in one variable are likely associated with similar changes in the others.

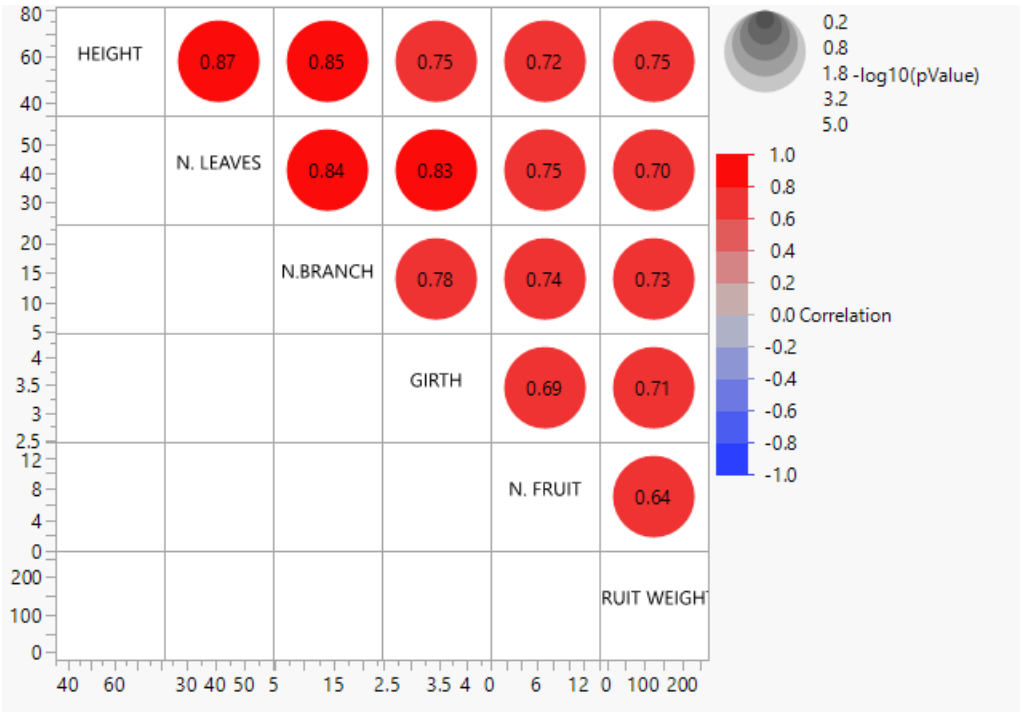


Figure 5: Correlation analysis between growth and yield parameters

Discussion

The findings from this study indicate that the application of both *U. lactuca* and *E. spinosum* extracts positively influenced the growth and development of sweet pepper plants. Plants treated with *U. lactuca* and *E. spinosum* extracts generally exhibited higher values in all parameters compared to the control group, which did not receive any seaweed treatment. These findings suggest that seaweed extracts can enhance the growth and productivity of sweet pepper plants. However, the response of the sweet pepper to the seaweed treatments at vegetative stage

and the harvesting stage were not statistically different.

When the performance of *U. lactuca* and *E. spinosum* were compared against plant height, number of leaves, girth, number of branches, fruit number, and fruit weight, there were no significant differences across all parameters. However, according to Mutavski et al. (2024), a comprehensive phytochemical profiling of *U. lactuca* from the Adriatic Sea revealed the presence of 54 volatile compounds, 11 fatty acids, 4 carotenoids, 18 amino acids, and 48 non-volatile compounds. On the other hand, while detailed chemical profiling of *E. spinosum*

was not available, Labiaga et al. (2021) reported the presence of alkaloids, carbohydrates, phenols, flavonoids, tannins, terpenoids, saponins, proteins, lipids, sterols, steroids, and cardiac glycosides in decreasing order.

Furthermore, in this study, all concentrations of seaweed extract tested had a significant effect on plant characteristics. However, the optimal concentration was 0.6% (6 g/L), beyond which no further significant improvements in growth or yield parameters were observed. It is important to note that the optimal concentration may vary depending on factors such as plant species, soil conditions (Zhao et al. 2025, Moora et al. 2025), extraction techniques (Chadwick et al. 2025), or the interaction between concentration, seaweed species, and extraction method, as demonstrated in this study. According to Renata et al. (2020), all dosages of *U. lactuca* increased the germination rates of tomato, however, highest total germination percentage was observed with the *U. lactuca* powder treatment, at 2 gL⁻¹. In another study by Mohamed and Hassan (2025), the seaweed extract treatment at 4 mL/L produced the highest percentages of agronomic, yield and trace elements of hot pepper plants. Moreover, seaweed extract at 6 mL/L recorded the highest values for most of the measured characters of sweet pepper (*Capsicum annuum* L.) in comparison with control (Marhoon and Abbas 2015). Castellanos-Barriga et al. (2017), who conducted a study on *E. spinosum* extract and its effect on the growth of mung bean plants reported that treatment with the seaweed extract at 0.2% significantly increased shoot and root length, fresh and dry weight, and chlorophyll content in the treated plants. Furthermore, an integrated program comprising *Ascophyllum nodosum* seaweed extract (ASE) at 5 mL L⁻¹ and K (100 kg K₂O ha⁻¹) significantly alleviated drought stress in tomato cultivation in water-scarce areas (Ahmed et al. 2024). These findings suggest that the available quantities of nutrients, growth regulators, and bioactive compounds in the seaweeds, which stimulate plant growth and developments, have

concentrations threshold beyond which may lead to nutrient imbalances (Idris et al. 2025).

Other treatments tested were the extraction and application methods. The findings showed that the seaweed extraction and application methods influenced their effectiveness. Cold water of both *U. lactuca* and *E. spinosum* treatments demonstrated the most significant effects on the growth and yield parameters of sweet pepper plants compared to hot water and powder forms. The observation that cold-water seaweed extract performs better than hot-water extract in the growth and yield parameters of sweet pepper (*Capsicum annuum*) might be associated with several factors. For example, cold-water extraction could preserve reported growth promoting compounds such as cytokinins, auxins, and gibberellins (Sanna et al. 2022), minerals like nitrogen, phosphorus, potassium, and magnesium (Craigie 2011, Khan et al. 2009), vitamins (A, C, E, and K, as well as B-group vitamins (B1, B2, B6, B12) and salts (Pereira 2025). Additionally, cold water extract could mimic the natural environment of the plant more closely and thus reduce plant stress, less damaging to beneficial soil microbes, maintained polysaccharides such as alginic acid and laminarin antioxidants and phenolic compounds that stimulate plant immunity, improve stress resistance and enhance water and nutrients uptakes (Ummat et al. 2025).

The observed effects of seaweed on sweet pepper growth and yield parameters might be attributed to several mechanisms. Reports by Craigie (2011) and Sanna et al. (2022) indicated that *U. lactuca* extract enhanced cell division, elongation, and differentiation in lettuce seedlings. Moreover, *U. lactuca* extract enhanced nutrient uptake by tomatoes (Khan et al. 2009) and number of tillers and branching in rice (Hussain et al. 2021). Other literatures have indicated that algal biostimulants improved flower cluster number, fruit number, shoot dry weight, and root dry weight in tomato (James et al. 2025). Furthermore, *Ascophyllum nodosum* and *Sargassum wightii* enhanced the number of fruits and fruit weight in chili, bell and hot

pepper (Yaseen et al. 2024), shoot and root length, leaf area, and grain yield in wheat (Ali et al. 2019) and plant height, fruit weight, and yield of okra (Divya et al. 2015). The reported findings suggest that the application of seaweed extracts could be a sustainable approach for enhancing productivity of various crops.

According to Quitério et al. (2022) and Sharma et al. (2025), advanced “green extraction” technologies have notable advantages over the conventional methods. However, the findings from this study, for examples, the average increase of fruit weight (792%), fruit number (100%), number of branches (114.3%), number of leaves (51.7%), stem girth (20%) and plant height (50.2%) still highlight the importance of incorporating seaweed as biostimulants into African farming systems which is predominantly small-scale farming. Moreover, incorporating seaweed into urban and peri-urban agriculture (especially in coastal cities where seaweed is readily available) can promote an eco-friendly source of fresh, high-quality horticultural crops. This would eventually enhance food availability and provide employment opportunities for low-income families, whose numbers are growing daily in urban areas. Multivariate correlation analysis showed that all growth and yield parameters had strong and positive relationships with coefficient of correlation (r) ranging from 0.64 to 0.87. The findings align with Jadhao et al. (2025), Putri et al. (2025) who observed significant positive correlations between fruit yield per plant with growth parameters, suggesting that the variables could be selected when considering to further improve the fruit yields per plant.

This study was conducted under greenhouse conditions, which might not fully reflect field conditions. Future research should assess performance across diverse agroecological zones to ensure broader applicability of the findings. Furthermore, to understand the underlying mechanisms for the observed changes, further study on the molecular characterization of the extract is recommended.

Conclusion

Findings from this study provide preliminary evidence that seaweed extracts derived from *U. lactuca* and *E. spinosum* can significantly enhance sweet pepper production. Treated plants showed increased plant height, leaf number, fruit count, and fruit weight. These results suggest that incorporating seaweed extracts into agricultural practices may boost crop productivity, reduce dependence on synthetic inputs, and support sustainable farming systems. The optimal application rate identified in this study was 0.6%. To fully realize the benefits of seaweed-based inputs in agriculture, further research is needed to assess their long-term effects and to refine application methods. Additionally, exploring the potential of other locally abundant seaweed species could help identify those with greater agricultural value. A comprehensive cost-benefit analysis, factoring in production and application costs of seaweed extracts, along with gains in yield and fruit quality, is also crucial to ensure the sustainable and economically viable use of seaweed in crop production. Future studies should also focus on scalability and conduct long-term field trials to validate these findings under real-world farming conditions and to reinforce their relevance for sustainable agriculture.

Acknowledgements

The authors would like to acknowledge the University of Dar es Salaam for providing the research facilities used in this study.

References

- Ali O, Ramsubhag A and Jayaraman J 2019 Biostimulatory activities of *Ascophyllum nodosum* extract in tomato and sweet pepper crops in a tropical environment. *PLoS ONE*. 14(5): e0216710.
- Ali O, Ramsubhag A and Jayaraman J 2021 Biostimulant properties of seaweed extracts in plants: Implications towards sustainable crop production. *Plants*. 10(3): 1–27.
- Bradáčová K, Weber NF, Morad-Talab N, Asim M, Imran M, Weinmann M and Neumann G 2016 Micronutrients (Zn/Mn), seaweed extracts, and plant growth-

- promoting bacteria as cold-stress protectants in maize. *Chem. Biol. Techno. Agric.* 3(1): 1–11.
- Castellanos-Barriga LG, Santacruz-Ruvalcaba F, Hernández-Carmona G, Ramírez-Briones E and Hernández-Herrera MR 2017 Effect of seaweed liquid extracts from *Ulva lactuca* on seedling growth of mung bean (*Vigna radiata*). *J. Appl. Phycol.* 29(5), 1-10
- Chadwick M, Carvalho LG, Vanegas C and Dimartino SA 2025 Comparative Review of Alternative Fucoidan Extraction Techniques from Seaweed. *Mar. Drugs.* 23(27):1-36
- Craigie JS 2011 Seaweed extract stimuli in plant science and agriculture. *J. Appl. Phycol.* 371-393.
- Das S, Maheshwari B, Das SR, Kanhu CB and Lakshmi S 2025 Green Seaweeds as a Potential Source of Biomolecules and Bioactive Peptides: Recent Progress and Applications – A Review *Chem.Biod.* 22(2): e202401695.
- De Mastro F, Brunetti G, Farrag K and Zang H 2025 Sustainable Horticulture: Advancements and Challenges in Organic Fertilizer Applications. *Horticulturae.* 11(3):307.
- Divya K, Roja NM and Padal SB 2015 Influence of seaweed liquid fertilizer of *Ulva lactuca* on the seed germination, growth, productivity of *Abelmoschus esculentus* (L.). *Int. J. Pharmacol. Res.* 5 (12): 344–346.
- Ehis-Eriakha, C.B., Chikere, C.B., Akaranta, O and Akiemu SE 2025 A comparative assessment of biostimulants in microbiome-based ecorestoration of polycyclic aromatic hydrocarbon polluted soil. *Braz J. Microbiol.* 56, 203–224.
- Hussain HI, Kasinadhuni N and Arioli T 2021 The effect of seaweed extract on tomato plant growth, productivity and soil. *J. Appl. Phycol.* 33:1305–1314
- Idris FM, Urga K, Admassu H, Fentie EG, Kwon SM and Shin JH 2025 Profiling the Nutritional, Phytochemical, and Functional Properties of Mung Bean Varieties. *Foods.* 14(4):571.
- Jadhao DR, Khandare VS, Valvate SS and Awasarmol AB 2025 Genetic Studies of F4 Generation in Chilli (*Capsicum Annum* L.) *Plant Arch.* 25(1): 1539-1544.
- James VCX, Arokya GPT, Munirah AAD, Ashraf AHA, Najat AB, Selvaraj A, Moni K 2025 Evaluation of Nutrient Composition and Biostimulant Properties of Seaweeds for Improving Soil Microbial Population and Tomato Plant Growth. *Bioresources* 20(1): 1431-1451. DOI:10.15376/biores.20.1.1431-1451.
- Khan N, Kashif K and Muhammad JA 2025 Genetic diversity exploration in (*Capsicum annum* L.) sweet pepper germplasm through chemical and morphological characterization *Pure Appl. Biol.* 14(2):692-709.
- Khan W, Rayirath UP, Subramanian S, Jithesh MN, Rayorath P, Hodges DM, Critchley AT, Craigie JS, Norrie J and Prithiviraj B 2009 Seaweed extracts as biostimulants of plant growth and development. *J. Plant Growth Regul.* 28:386-399.
- Khanahmadi S, Böhmer M and Rafieerad A 2025 Sustainable extraction of personalized plant nano-stimulants from conspecific donor plants to induce mirror biostimulant activity in identical host plants, *Advanced Agrochem.* ISSN 2773-2371.
- Labiaga AS, Marco NEM, Adrian PY and Michael BP 2021 Phytochemical profiling of *Eucheuma denticulatum* (N.L. Burman) Collins and Hervey, 1917 and *Padina minor* (Yamada, 1925) seaweeds for compounds of potential biomedical and pharmaceutical applications. DLSU Research Congress De La Salle University, Manila, Philippines July 7 to 9, 2021
- Listihani L, Gusti ADY, Putu LYS, NiPutu P and Dewa GWS 2023 The antiviral potential of macroalgae in suppressing Sweet potato leaf curl virus (SPLCV) infection in sweet potatoes. *Biodiversitas.* 24(7):4079-4086.
- Marhoon IA and Majeed KA 2015 Effect of Foliar Application of Seaweed Extract and Amino Acids on Some Vegetative and Anatomical Characters of Two Sweet

- Pepper (*Capsicum Annuum* L.) Cultivars. *Int. J. Res. Studies Agri. Sci.* 1(1):35-44
- Mohamed ML and Hassan AS 2025 Influence of Seaweed Extract, Fulvic Acid and Poly Amino Acid on the Growth and Productivity of *Capsicum annuum* L. "Super Nar" Cultivar. *J. Plant Product.* 16 (1):7 – 11. Mokgehle SN, Masondo NA., Araya NA, Araya HT, Kutu FR, Makgato MJ, Serote B Mofokeng MM, Bairu MW, Du Plooy CP and Amoo SO 2025 Chapter six - Application of biostimulants for vegetative reproduction of plants with special reference to bulbs, corms, tubers, rhizomes, and stolons, Editor(s): Shubhpriya Gupta, Karel Doležal, Johannes Van Staden, Biostimulants for Improving Reproductive Growth and Crop Yield, Academic Press, pp 147-167.
- Moora M, Davison J, Kohout P and Zobel M 2025 The importance of the plant mycorrhizal collaboration niche across scales. *Nat. Rev. Biodivers.* 1: 262–273
- Msuya F 2020 Seaweed resources of Tanzania: status, potential species, challenges and development potentials. *Bot. Mar.* 63(4): 371-380.
- Mutavski Z, Jerković I, Nikolić NĆ, Radman S, Flanjak I, Aladić K, Šubarić D, Vulić J and Jokić S 2024 Comprehensive Phytochemical Profiling of *Ulva lactuca* from the Adriatic Sea. *Int J. Mol. Sci.* 25(21):11711.
- Peedika P, Hafish M, Kamath AH, Velappan MN, Manohar CS, Edavalath J P and Thottingal, NM 2025 Exploration of the *in-vitro* antibacterial-antioxidant potentials and GC-MS metabolite profiling of seaweeds from the southwest coast of India *Bot. Mar.* 68(2): 175-191.
- Pereira L 2025 Role of Seaweed as Functional Ingredients in Nutraceuticals, Pharmaceuticals, Cosmetics, and Edible Salts. In: Trivedi, N., Reddy, C., Critchley, A.T. (eds) Recent Advances in Seaweed Biotechnology. *Springer*, Singapore.
- Putri DRM, Muhamad S and Arya WR 2025 Variability of yield and yield components of 23 hybrid cayenne pepper (*Capsicum frutescens*) genotypes under shaded and unshaded conditions. *Biodiversitas.* 26 (1): 396-406.
- Quitério E, Grosso C, Ferraz R, Delerue-Matos C and Soares C 2022 A Critical Comparison of the Advanced Extraction Techniques Applied to Obtain Health-Promoting Compounds from Seaweeds. *Marine Drugs.* 20(11):677.
- Renata PR, Antônio CSA, Ana CC, Jéssica CO and Beatriz C 2020 Effects of extracts of two *Ulva* spp. seaweeds on tomato germination and seedling growth. *Res. Soc. Dev.* 9(11): e61691110174-e61691110174.
- Sanna A, Ahmed F, Ala A and Awais K 2022 Status, challenges and opportunities for apple production in Eastern Algeria. *Horticult. Sci.* 49(3):147–153.
- Sanodiya LK, Kevat P, Tiwari M and Kumar L 2022 Seaweed Extract: Usable for Plants Growth and Yield. *Vigyan Varta* 3: 80–84.
- Sharma R, Mondal AS and Trivedi N 2025 Bioplastic from Seaweeds: Current Status and Future Perspectives. In: Trivedi, N., Reddy, C., Critchley, A.T. (eds) Recent Advances in Seaweed Biotechnology. *Springer*, Singapore.
- Shukla PS, Mantin EG, Adil M, Bajpai S, Critchley AT and Prithiviraj B 2019 *Ascophyllum nodosum*-based biostimulants: Sustainable applications in agriculture for the stimulation of plant growth, stress tolerance, and disease management. *Front. Plant Sci.* 10:1–22
- Singh S, Tiwari D, Gautam SS, Singh MK and Pal SK 2019 Seaweed: An Alternative Liquid Fertilizer for Plant Growth. *Int J Curr Microbiol. Appl. Sci.* 8(12):772–781
- TNC (The Nature Conservancy) 2023 Tanzania seaweed guide: Opportunities for increased productivity, traceability, and sustainability. Arlington, VA. Available at https://www.aquaculturescience.org/content/dam/tnc/nature/en/documents/aquaculture/TNC_Tanzania_Seaweed_Guide_FINAL.pdf.
- Ummat V, Sivagnanam SP, Rameshkumar S, Pednekar M, Fitzpatrick S, Rai DK, Padamati RB, O'Donnell C and Tiwari BK 2024 Sequential extraction of fucoidan, laminarin, mannitol, alginate and protein

- from brown macroalgae *Ascophyllum nodosum* and *Fucus vesiculosus*. *Int. J. Biol. Macromol.* 256 (1):128195.
- Yadav DS, Alichen A, Bhagiya BK and Mantri VA 2025 Analysis of Three-Decade Change in Global Seaweed Statistics Revealed Its Emergence as a Major Aquaculture Commodity. In: Rathore MS, Mantri VA (eds) *Biotechnological Interventions to Aid Commercial Seaweed Farming*. Springer, Singapore.
- Yaseen AA, Ahmed SJ and Bakr TD 2024 Effect of biofertilizers in improving production of hot pepper (*Capsicum annuum* L.), and tolerating drought stress. *Zanco J. Pure Appl. Sci.* 36(6):104–117.
- Yong WTL, Vun YT, Mailin M, Grace JWLC, Siti NISH, Harry LHC, Nur AY, Nyuk LM and Kenneth FR 2024 Seaweed: A bioindustrial game-changer for the green revolution, *Biomass and Bioenergy*. 183:107122 ISSN 0961-9534.
- Zakir I, Ahmad S, Haider STA, Ahmed T, Hussain S, Saleem MS and Khalid MF 2024 Sweet Pepper Farming Strategies in Response to Climate Change: Enhancing Yield and Shelf Life through Planting Time and Cultivar Selection. *Sustainability*. 16(15):6338.
- Zhao X, Peng T, François M, Shengen L, Zhaolin S, Qingkui W and Nadejda AS 2025 Mycorrhiza-dependent drivers of the positive rhizosphere effects on the temperature sensitivity of soil microbial respiration in subtropical forests. *Funct. Ecol.* 39:506–519.
- Islam MM, Islam MK, Proshad R, Islam MS, Kormoker T and Billah KMM 2017 Effect of inorganic and organic fertilizers on soil properties with vegetative growth and yield quality of sweet pepper (*Capsicum annuum* L.) in Bangladesh. *Int. J. Agron. Agri. R.* 11(5): 37-46
- Gajc-Wolska J, Mazur K, Niedzińska M, Kowalczyk K and Żołnierczyk P 2018 The influence of foliar fertilizers on the quality and yield of sweet pepper (*Capsicum annuum* L.). *Folia Hort.* 30(2), 183-190.
- Ahmed M, Ullah H, Himanshu SK, García-Caparrós P, Tisarum R, Cha-um S and Datta A 2024 *Ascophyllum nodosum* seaweed extract and potassium alleviate drought damage in tomato by improving plant water relations, photosynthetic performance, and stomatal function. *J. Appl. Phycol.* 36: 2255–2268.
- Badmus UO, Taggart MA and Boyd KG 2019 The effect of different drying methods on certain nutritionally important chemical constituents in edible brown seaweeds. *J. Appl. Phycol.* 31: 3883–3897.