Does Seaweed Extract as a Biostimulant Ameliorate Tomato Plant's Salt Stress Tolerance？

Fatma K. Sherif [1], Hoda A. Argeaa[2] and Aly S. Mostafa[1]

ABSTRACT

Seaweed extracts are considered a promising strategy in reducing plant stress. A growth experiment was designed to study the effect of an alkali seaweed extract (SE) on the morphology, physiology, and biochemical parameters of tomato plant grown under salt stress. The experiment consisted of five salinity levels (0.6, 4, 8, 12, and 16 dSm^{-1}), and four levels of SE (0.0, 1, 3, and 6%). Salt stress decreased significantly shoot and root fresh weight, shoot and root water content, chlorophyll, fruit length, and fruit yield. Seaweed extracts significantly ameliorated tomato's growth. Sprayed SE has increased significantly morphological parameters evaluated. Indeed, salinity increased the antioxidant enzymes (superoxide dismutase) and resulted in the accumulation of proline and lycopene. The results of this study demonstrated that spraying SE ameliorate the negative effect of salt stress in tomato plants.

Key words: Marine algae - oxidative and reducing enzymes - salt stress- tomato-proline –lycopene.

INTRODUCTION

Egyptians Economy depends largely on agriculture industries; extended use of mineral fertilizers resulted in economic losses. The improper use of it caused agro-contamination that affect the environment, resulting eutrophication phenomena, reducing crop yield, and increasing in pH of the soil (Prakash *et al.,* 2018). Agricultural activity could be enhanced with new and innovative agricultural practices to overcome the negative effects of deterioration agroecosystems. Several technological have been proposed such as new plant bio-stimulants and efficient application methods. Using seaweed liquid fertilizer as a plant bio-stimulants is a promising, environmentally friendly, and alternative to mineral fertilizer (Colla and Rouphael, 2015).

Marine aquatic plants known as seaweeds are found along the coasts of oceans and seas. Seaweeds are a rich source of nutrients and active compounds that produce metabolites with various beneficial properties, such as anti-bacterial (Singh and Chaudhary, 2010), anti-fungal (De Corato *et al.,* 2017), anti-coagulant, and anti-inflammatory (Caijiao *et al.*, 2021) effects.

Recently, seaweeds have gained significant importance in organic and sustainable agriculture as an alternative to excessive applications of mineral fertilizer. Unlike, chemical fertilizers, seaweeds are bio-degradable, non-toxic, non-hazardous, and non-polluting to humans, animals and birds (Raghunandan *et al.,* 2019).

Application of seaweeds employed as biofertilizer to compensate soil nutrients deficiencies and support plant growth. Indeed, seaweeds had beneficial effects such as increased; crop yield, fruit fresh weight, fruit quality, chlorophyll levels, nutrient uptake, seed germination, and plant resistance towards stress conditions, and reduced fungal disease and insect attack (Zodape, 2001; Malaguti *et al*., 2002; Hu *et al*., 2004; Wang *et al*., 2005; El-Bakry *et al*., 2006 and Salah El Din *et al*., 2008). Seaweeds included growth promoting hormones, cytokinins, trace elements, vitamins that can be helped in improving crop productivity and maintain soil fertility (Strik *et al*., 2004 and Mamatha *et al*., 2007). Seaweeds increased germination rate and increased seedling vigor by promoting root length and density (Trivedi *et al.,* 2018). Seaweeds were applied with conventional fertilizer on maize and potato tuber and increased growth, yield, and quality had been observed in both crops (Pramanick *et al.,* 2017). Strawberry and rapeseed treated with *A. nodosum* has shown promoting in growth and nutrient uptake (Jannin *et al.,* 2013). The same trend was observed with wheat and nutrient accumulation in grain was linearly related with grain production. Moreover, *A. nodosum* had increased the root length density and the yield (Mattner *et al.,* 2018). do Rosário Rosa *et al.* (2021) reported that photosynthetic activity and chlorophyll content was increased in soybean treated with *A. nodosum* extract while enhancing the growth of root system. The application of seaweeds on tomato and pepper resulted in an increase in chlorophyll content (Ali *et al.,* 2019). Additionally, the extract derived from *Macrocystis pyrifera* has been shown to enhance the growth of tomato plants and stimulate root development in mung beans (Briceño-Domínguez *et al.,* 2014).

Seaweeds possess various mechanisms to enhance their tolerance to stress. Numerous studies have indicated that the application of seaweed extracts (SE) leads to earlier seed germination, enhanced plant performance and yield, greater resilience to both biotic

---

DOI: 10.21608/asejaiqjsae.2025.409702
[1]Soil and Water Sciences Dept., Agriculture College, Alexandria University.
[2]Higher Institute of Science and Technology, Elmerj.
Received, January 01, 2025, Accepted, January 31, 2025.

and abiotic stressors, and an extended shelf-life for fresh produce. For example, the flowering stage in tomatoes was improved by foliar spraying with *A. nodosum* seaweeds (Dookie *et al.,* 2021). Also, salt tolerance level increased in wheat plant due to application of polysaccharides extracted from brown seaweed *Lessonia nigrescens* (Zou *et al.,* 2019). The treatment minimized the oxidative damage in plants by increasing the antioxidant activity of superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) enzymes. Similarly, salt tolerance and enzymatic activities in wheat plant were increased by using *U. rigida* (Chernane *et al.,* 2015). Meanwhile, salt tolerance was mitigated in rice seedlings because of spraying polysaccharides extracted from *Grateloupia filicina* (Liu *et al.,* 2019). Indeed, Milkweed seedling tolerance was increased up 15 dSm^{-1} and the survival rate were increased by 69% by treatment with *S. angustifolium* extract (Bahmani Jafarlou *et al.,* 2023). Similarly, salt stress amelioration in chickpea and enhancement activity of SOD and ascorbate peroxidase (APX) were observed by supplementation of *S. muticum* and *Jania rubens* (Abdel Latef *et al.*, 2017).

Tomato (*Solanum lycopersicum* L.), family Solanaceae, and is one of the most important horticultural crops worldwide (Ali *et al.*, 2016 and Abu *et al.,* 2022). Currently, the main challenges facing tomato production is the development of yield in terms of productivity and fruit quality to satisfy the market demand while minimizing chemical inputs (Jones Jr, 2007; Baroud *et al.,* 2021; Hussain *et al.*, 2021 and Ma *et al.,* 2022).

Thus, the main objective of this research is to evaluate the effect of sprayed seaweeds Green Algae (*Ulva* sp.) extract on the biometric parameters and yield of tomato plants grown under salinity stress.

MATERIALS AND METHODS

Collection of Seaweeds

Green algae (*Ulva* spp.) were gathered from the coastal region of the Mediterranean Sea near Alexandria, Egypt, in June 2023. The algae were carefully handpicked and thoroughly rinsed with seawater to eliminate any impurities, including adhering particles and sand. They were then placed in new plastic bags and transported to the laboratory in an ice box filled with slush ice. Upon arrival, the samples were washed extensively with tap water to remove any residual salt from their surfaces. After draining the water, the algae were laid out on blotting paper to absorb any excess moisture.

Preparation of Seaweed Liquid Fertilizers

Seaweed powder (250 g) was extracted with 1500 ml of potassium hydroxide (KOH) solution (5 M) then the extract was put on the hot plate until it boiled. Then, it was cooled to room temperature for 3 days. The supernatant was utilized as a seaweed extract with different ratio (Mostafa, 2024).

Minerals determination using ICP:

Mineral's content determined in a sample of 0.5 ml, digestion procedure was performed according to Piper (1947). Minerals determined using Inductively Coupled Argon Plasma, ICAP 6500 Duo, Thermo Scientific, England. 1000 mgL^{-1} multi-element certified standard solution, Merck, Germany was used as stock solution for instrument standardization (ASTM, 2002).

Experimental Design

A greenhouse experiment was conducted during spring season of 2024. A sandy soil was collected from Al-Bustan, Al Behira Governorate. The soil was sandy with EC 1.1 dsm^{-1}, pH 8.1, and O.M 0.62%. It was irrigated with fresh water had an EC value of 0.6 dsm^{-1} and pH 7.6.

Five salinity levels (0.6, 4.0, 8.0, 12.0, and 16 dSm^{-1}), and four treatments of tested seaweed (0.0, 1.0, 3.0, and 6.0%) were used in this experiment. A total of 20 treatments were replicated four times to study the effect of salinity, spraying SE, and the interaction on tomatoes yield and different parameters.

Tomato (*Malak* spp.) seedlings obtained from Agricultural Research Center (ARC), Nubaria, Egypt. The seedlings with uniform size, color and weight collected for the experimental purpose, and transferred to pot containing 3Kg sandy soil. Seedlings watered with half-strength modified Hoagland nutrient solution containing: 1 mM $NH_4H_2PO_4$, 5 mM KNO_3, 5.5 mM $Ca(NO_3)_2$, 0.5 mM $MgSO_4$, 10 µM H_3BO_3, 25 µM KCl, 1 µM $MnSO_4$, 1 µM $ZnSO_4$, 0.25µM $CuSO_4$, 10 µM Na_2MoO_4, and 1.87 mgL^{-1} Fe-EDDHA. Three weeks after transplanting, seedlings irrigated once each week with Hoagland solution, saline water treatments and sprayed by seaweed treatments.

Plant morphology

Samples of different treatments collected at yield stage to determine root and shoot fresh and dry weight (g $plant^{-1}$), water content, chlorophyll determined in tomatoes leaves using SPAD meter (Minolta instrument), root morphology (root length, root radius, and root surface area).

Root length measured according to Tennant method (1975).

Root radius (R_r, cm), and root surface area (RSA) were calculated according to Hallmark and Barber (1984).

Fruit number per plant and fruit length (cm), yield (g pot^{-1}) also recorded.

Fruit quality parameters estimated from firm red-ripe fruits on centrifuged tomato juice extracted from two fruits per replicates and per treatment: total soluble solids (TSS) determined according to Almasoum (2000).

Proline Content

Proline content determined in 0.20 g of dry leaves by colorimetric method described by Bates *et al.* (1973).

Lycopene content

Extraction performed according to Fish *et al.* (2002). 100 µL tomato juice dispensed into a 125 mL tube. Then, 8.0 ml of hexane: ethanol: acetone (2:1:1) added, vortex the tube immediately, and was incubated out of bright light. After 10 minutes, phases separated, and air bubbles disappeared. Determine the absorbance of the upper layers of the lycopene samples at 503 nm spectrophotometry using re-determined extinction coefficients (Perkins-Veazie and Collins, 2004).

Lycopene levels in the hexane extracts were calculated according to:

Lycopene (mg/kg fresh wt.) = $(A_{503} \times 537 \times 8 \times 0.55)/(0.30 \times 172)$ (1)

$= A_{503} \times 137.4$ (2)

Where, The lycopene MW= 537 g/mole.

Ratio of the upper layer: the mixed solvents= 0.55.

The extinction coefficient for lycopene in hexane= 172 mM^{-1}.

Peroxidase enzymes activity

Seedlings were collected from each treatment for determination of SOD activities in root and shoot separately. One gm fresh plant weighted and was homogenized in 10 ml of 0.1 M phosphate buffer. The suspension centrifuged for 15 min at 15000 rpm. The supernatant used for enzyme activity assay (Esfandiari *et al.*, 2007). Peroxidase activity assayed according to Shannnon *et al.* (1966).

Statistical Analysis

A complete randomized design with four replicates was used. Statistical analysis of experimental data carried out using CoStat Software package (CoHort, 2004). The least square difference technique of Student Newman-Keuls at 5% significance level (LDS 0.05) used to test the differences between means of treatments.

RESULTS AND DISCUSSIONS

Seaweed characterization

First, the SE composition was characterized. Table (1) represent the chemical analysis of SE from green algae. Data revealed that seaweed contains various minerals because it accumulates the minerals found in sea water. The highest element concentration was Ca while P recorded very low concentration. Moreover, Fe, Zn, and Cu were the predominant micronutrient. Overall, these results agree with the macro and micronutrients described by Espinosa-Antón *et al.* (2023). Earlier studies reported that *Ulva* species as bio-stimulants and bio-fertilizers was used for many economically crops due to their rich content of nutrients (Abu *et al.*, 2022).

Data in Table (2) presented the chemical composition of SE performed using HS GC-ISQ mass spectrophotometer (Thermo Scientific, Austin, TX, USA. Some organic acid was detected, such as butanoic, lactic, and isovaleric acid.

Table 1. Chemical characteristics of seaweed extract (SE)

Analysis	value	Analysis	Value
pH	14	Micronutrients $mgKg^{-1}$	
O.M	46.3	Fe	1.12
% CaO	0.28	Zn	0.245
% MgO	0.10	Mn	0.062
Macronutrients %		Cu	0.13
P_2O_5	0.2	B	0.45
K_2O	17.5	Si	1.27
TN	2.98	Ni	0.53
Ca $mgKg^{-1}$	6.84	Toxic elements $mgKg^{-1}$	
Mg $mgKg^{-1}$	0.177	Cd	0.007
		Pb	0.005

Table 2. Chemical composition of organic acid content in seaweed extract (SE)

Acid	
Succinic acid	Not Detected
Butanoic acid	Detected
Isovaleric acid	Detected
Ethylmalonic acid	Not Detected
Propanoic acid	Not Detected
Lactic acid	Detected
Phenylpyruvic acid	Not Detected
Evoninic acid	Not Detected
PYROACETIC ACID	Detected
Folic Acid	Not Detected
GLUTARIC ACID	Not Detected
2-PHENYLACETIC ACID	Not Detected
2-METHYLVALERIC ACID	Not Detected

These organic acids have a significant role in plant biochemical reaction and plant growth. Mun *et al.* (2024) reported that chlorophyll maintenance increased significantly by butanoic acid which reflected on plant growth. The PGPR Bacillus aryabhattai promotes soybean growth via nutrient and chlorophyll maintenance and the production of butanoic acid (Mun *et al.*, 2024). Isovaleric acid has a role as a plant metabolite. Indeed, Lactic acid had a beneficial components to ensure food safety and to prolong shelf life, and their valuable multifunctional ingredients with disinfection, descaling, exfoliating and moisturizing properties (Murindangabo *et al.*, 2023).

Data in Table (3) and Fig. (1) represent concentration of anthocyanin in SE. Pelargonidin-3-O-glycosides recorded the highest concentration. This component represents a metabolic product derived from algae, which is responsible of growth regulation, and defense mechanisms against damage. Indeed, cyanidin-3-O-glycosides recorded about 6.41 µg/gm. These anthocyanins are a group of polyphenolic pigments that have a positive effect in reproduction, seed dispersers, and in protection from various abiotic and biotic stresses. While, delphinidin-3-O-glycosides represent the less concentration, but it has a vital role in coloring such as bright red, purple, and blue colors in the plant kingdom (Dangles, 2024).

Table 3. HPLC analysis of Anthocyanin components

RT	Compound	Concentration (µg/gm)
3.0	Delphinidin-3-O-glycosides	3.12
4.0	pelargonidin-3-O-glycosides	9.25
9.8	cyanidin-3-O-glycosides	6.41

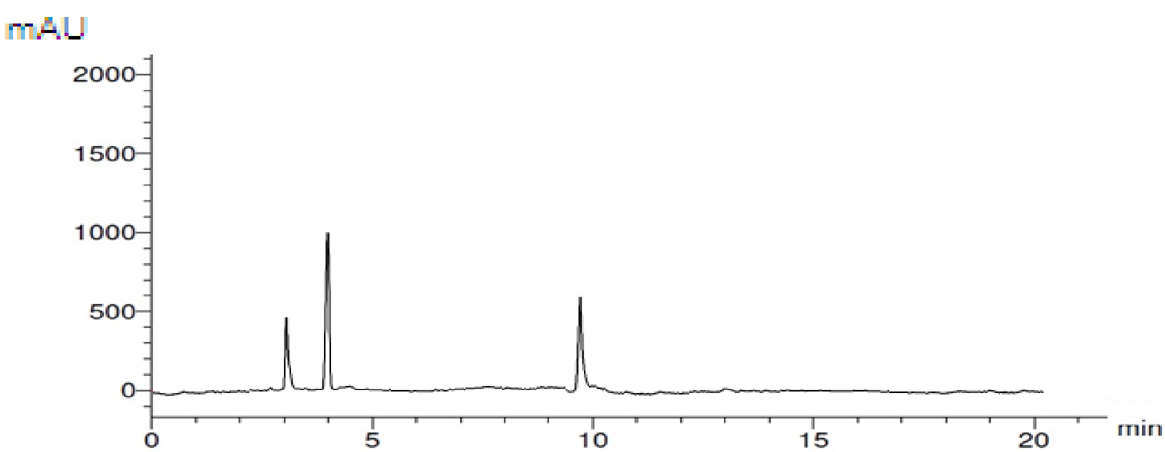

Fig. 1. HPLC Anthocyanin Chromatogram

Previous studies found that the chemical components of SEs are involved in multiple biochemical pathways that improve quality characteristics, crop production, and abiotic stress tolerance (Sharma *et al.*, 2014; Van Oosten *et al.*, 2017 and Di Stasio *et al.*, 2018).

Growth Amelioration of Tomato plants by seaweed extract

Increasing salinity decreased significantly ($p < 0.05$) shoot fresh weight, shoot water content, chlorophyll, fruit length, and finally fruit yield (Tables 4 & 5) and Fig. (2).

Seaweed extract had significantly ($p < 0.05$) ameliorated the growth of tomato plants. Sprayed SE was significantly increasing the values of all morphological parameters evaluated (Figs. 3 and 4). Relative to control, plants' shoot weight increased by 31 and 74% in plants treated by 6% SE and irrigated with fresh water (0.6 dSm^{-1}) and the highest salinity treatment (16 dSm^{-1}), respectively.

Table 4. Effect of Sprayed different concentration of seaweed extraction on water content, chlorophyll and fruit yield of tomato plants grown under salinity stress

Salinity dSm^{-1}	% SE			
	0.0	1.0	3.0	6.0
Shoot fresh weight (g)				
0.6	101.71	102.53	131.12	133.78
4.0	90.85	94.64	112.61	150.83
8.0	82.74	86.28	88.56	89.03
12.0	54.51	58.13	96.33	99.07
16.0	51.67	67.88	80.85	90.20
Shoot water content (g)				
0.6	66.38	67.10	95.49	96.97
4.0	66.13	66.56	84.14	120.7
8.0	62.15	65.18	63.56	63.76
12.0	34.22	37.78	73.8	76.31
16.0	36.84	46.73	59.44	67.95
Chlorophyll				
0.6	49.53	50.09	51.23	53.68
4.0	42.86	43.54	43.69	47.65
8.0	42.60	48.19	49.41	49.62
12.0	37.58	39.61	44.51	44.78
16.0	35.17	39.34	39.96	41.48
Fruit Yield				
0.6	72.80	240.75	241.31	244.70
4.0	162.10	237.92	238.57	242.30
8.0	121.58	205.85	228.93	229.20
12.0	89.40	185.07	187.48	240.05
16.0	52.65	57.87	78.18	96.08
Total soluble salts				
0.6	42.8	44.9	45.3	50
4	51	44	52.3	53.1
8	53.6	55	57	61
12	54	52	48	47
16	65	66.1	66.6	67.8
Fruit length				
0.6	7.77	13.07	13.42	13.92
4	5	8.75	10.7	11.22
8	4.85	11.87	13.62	14
12	4.12	15.15	16.07	10.45
16	4.27	7.07	11.3	12.35

Table 5. Analysis of variance of tomato plants grown under different salinity levels and treated with different levels of SE

Source of variance	F-Value					
	FWS	WC	Chlorophyll	Fruit Yield	TSS	Fruit length
LSD 0.05 (Salinity)	11.719	0.322	0.539	38.38	0.229	0.418
LSD 0.05 (Seaweed)	10.482	0.288	0.482	34.33	0.205	0.374
LSD 0.05(salinity*seaweed)	0.757	0.991	0.599	0.998	0.998	0.984
Salinity	***	***	***	**	***	***
Seaweed	***	***	***	***	***	***
Salinity*Seaweed	*	*	***	*	***	***

Fig. 2. Effect of different salinity levels on tomato plants after 3 months of treatment application

Fig. 3. Effect of spraying tomato plants with different concentration of SE after 3 months of treatment application

Fig. 4. Effect of spraying tomato plants with different concentration of SE under moderate salinity level after 3 months of treatment application

The same trend was obtained for shoot water content that increased by 46 and 84% by 6% SE in plants irrigated with fresh water and 16 dSm^{-1}. The observed data agree with Ali *et al.* (2022) who reported that SE affect plant stomatal conductance and photosynthesis, which could increase the ability of plant to retain water and avoid dehydration, resulting in improved water use efficiency.

Data in Table (4), showed that increasing salinity decreased chlorophyll contents significantly, in tomatoes leaves. This decreasing was promoted by sprayed plants with SE, the observed promotion was 1, 3, and 8% in plants irrigated with fresh water, while the highest salinity treatment recorded 11, 13, and 17% with 1, 3, and 6% SE, respectively. This observation means a significant and beneficial effect of sprayed SE at higher salinity level.

Unlike, previous parameter, Tomato yield was increased significantly under moderate salinity (4, and 8 dSm^{-1}). This may be referred to antioxidant molecules, ex. carotenoids, vitamin C, vitamin E, ascorbic acid, and phenolic compounds that found in tomatoes (Frusciante *et al.*, 2007), which help ROS and lipid free radicals to be effectively scavenged by antioxidants and protect biological membranes (Munné-Bosch and Alegre, 2002). Sprayed tomato plants with different concentration of SE ameliorate tomato fruit yield. Plants irrigated with fresh water recorded an increasing in fruit weight by 230, 231, and 236% when sprayed with 1, 3, and 6% SE, respectively. At highest salinity level (16 dSm^{-1}) fruit weight increased by 9, 48, and 84% at the same obvious SE concentration.

Data in Table (4) showed that relative to control, the 6% SE treatment increased fruit yield by 238, 49, 89, and 84% at different levels of salinity 0.6, 4, 8, 12, and 16 dSm^{-1} respectively. Also, it was noticed that after 5 weeks of treatments application, the highest salinity level combined with the highest SE (16 dSm^{-1}+ 6% SE) started to have tomato fruits. This may be due to salt stress that accelerate plant life cycle.

In this study, increased vegetative growth due to SE spraying resulted in greater overall production. Similarly, Rao (1991) reported that foliar applications with SE increased yield and improved in the quality of *Zizyphus mauritiana L.* Further, these findings also coincided with Rathore *et al*. (2009) they found that applications of SE (prepared from *Kappaphycus alvarezii*) increased plant height, number of branches, number of pods, number of grains per plant, and yield of soybean plant.

Total soluble solid concentration (TSS) is known as the most common flavor index associated directly with sugar and organic acid concentrations in tomatoes juice (Stevens *et al.*, 1977). Data in Table (4) showed that TSS concentrations in tomatoes juice was increased by salinity. High saline treatments have increased TSS of fruits at all SE levels. Meanwhile, SE did not affect salinity stress. Relative to control the highest salinity level increase TSS by 51% and the highest level of SE caused an increase by 19%. While a gradual increase with increasing salinity levels. The results have indicated that accumulation of TSS in fruit may be due to decreasing water flux to the fruit under high salinity levels as previously reported. The same trend was obtained by Wu and Kubota (2008).

Root Morphology

Increasing salinity decreased significantly, fresh and water root content (Tables 6 & 7). Meanwhile, sprayed tomato plants with SE ameliorated both. The highest fresh weight and water content of roots were recorded in tomato plants treated with 0.6 % SE. Relative to control, 0.6% SE increased root fresh weight by 27, 47, 38, 12, and 51% at the various salinity treatments 0.6, 4, 8, 12, and 16 dSm^{-1} respectively, the same trend was observed in water content.

While SE increased significantly root length, moderate salinity (4 dSm^{-1}) recorded higher root length relative to control. This may be one of the plant strategies towards high salinity. At the highest salinity level 12, and 16 dSm^{-1}, root length decreased significantly, but spraying plants with SE recover this decline. Sherif *et al.* (2024) found that salt stress decreased germination percent, root length, root surface area, and water content. Moreover, increased root radius, Na influx and SOD enzyme.

On the other hand, plant used root radius as another mechanism to increase plant tolerance towards stress. Data in Table (6) showed that root radius increased significantly by increasing salinity levels. The largest root diameter was observed in the highest salinity treatment 16 dSm^{-1} (0.058 mm), followed by 12 dSm^{-1} (0.044 mm). These results agree with Sherif (1996) who found that root go through increasing thickness of intercellular in stressed conditions. The same trend was observed for root surface area.

Our results agree with those investigated by Aremu *et al.* (2015) who reported that eckol and phloroglucinol isolated from seaweed increased auxin level which resulted increasement in the root length of the treated plant.

Table 6. Effect of Sprayed different concentration of seaweed extraction on root morphology of tomato plants grown under salinity stress

Salinity dSm^{-1}	% SE			
	0.0	**1.0**	**3.0**	**6.0**
Root fresh weight(gm)				
0.6	35.85	101.71 / 36.8	102.53 / 42.1	131.4[illegible] / [illegible].75
4.0	31.18	90.85 / 43.45	94.64 / 45.23	112.[illegible] / [illegible].33
8.0	26.75	82.74 / 31.5	86.28 / 34.9	88.56 / 36.58
12.0	26.08	54.51 / 27.85	58.13 / 29.03	96.32 / 29.43
16.0	22.49	51.67 / 32.85	67.88 / 33.05	80.85 / 33.95
Root water content (gm).				
0.6	27.86	28.45	30.85	34.23
4.0	24.54	32.96	34.14	34.18
8.0	19.99	24.73	27.76	28.36
12.0	21.49	22.77	19.18	23.67
16.0	18.01	26.95	27.42	28.8
Root length (m)				
0.6	111.03	198.62	249.65	344.83
4.0	142.00	216.04	261.35	283.35
8.0	133.12	161.34	162.06	168.79
12.0	68.11	87.38	98.96	102.91
16.0	40.32	70.54	71.02	71.38
Root radius (mm)				
0.6	0.035	0.026	0.023	0.020
4.0	0.031	0.025	0.023	0.022
8.0	0.031	0.029	0.029	0.028
12.0	0.044	0.039	0.037	0.036
16.0	0.058	0.044	0.043	0.043
Root surface area (m^2)				
0.6	24.2	32.37	36.29	42.65
4.0	27.37	33.76	37.17	38.66
8.0	27.48	29.17	29.24	29.84
12.0	18.96	21.47	22.85	23.3
16.0	14.58	19.29	19.36	19.4

Table 7. Analysis of variance of tomato plants grown under different salinity levels and treated with different levels of SE

Source of variance	F-Value				
	RFW	**WC**	**RL**	**Rr**	**RSA**
LSD 0.05 (Salinity)	0.434	2.814	11.719	0.596	0.539
LSD 0.05 (Seaweed)	0.388	2.517	10.482	0.5334	0.482
LSD 0.05(salinity*seaweed)	0.995	0.827	0.757	0.9866	0.991
Salinity	***	***	***	***	***
Seaweed	***	***	***	***	***
Salinity*Seaweed	***	*	*	***	***

These compounds influence auxin's root-lengthening activity by preventing decarboxylation and acting as a cofactor which promotes the breakdown of the IAA oxidase.

Peroxidase enzyme (SOD)

Plants experience internal oxidative stress as an initial response to abiotic stress, characterized by the excessive generation of reactive oxygen species (ROS). The photosynthetic electron transport chain within chloroplasts is responsible for the production of ROS (Mittler, 2002). Figs. (5 and 6) illustrate the impact of salt stress on the protective enzyme superoxide dismutase (SOD) in tomato plants. The presence of salt stress led to an increase in SOD enzymatic activity, likely due to the disruption between ROS generation and the plant's capacity to detoxify and eliminate intermediate compounds. The heightened levels of ROS can result in structural damage to DNA and proteins, suppression of antioxidant enzymes, and the initiation of programmed cell death (Huang *et al.*, 2019). It has been noted that SOD plays a significant role in enhancing the tolerance of plants to salt stress (Bates *et al.*, 1973). However, root plants treated with 8 dSm^{-1} presented the highest SOD values relative to control or saline treatments plants (Fig. 5). Similar findings were noted in shoot plants, where the activity of the antioxidant enzyme superoxide dismutase (SOD) was variably influenced by salt stress and the application of SE (Figs. 5 and 6). Under challenging environmental conditions, tomato plants developed an antioxidant defense mechanism to alleviate ROS stress, which comprises both enzymatic and non-enzymatic antioxidants (Hao *et al.*, 2021). The enzymatic antioxidants include SOD, APX, and CAT. SOD serves as the most efficient scavenger of ROS, converting superoxide (O2−) into hydrogen peroxide (H_2O_2), which is subsequently detoxified to water (H_2O) (Yang and Guo, 2018).

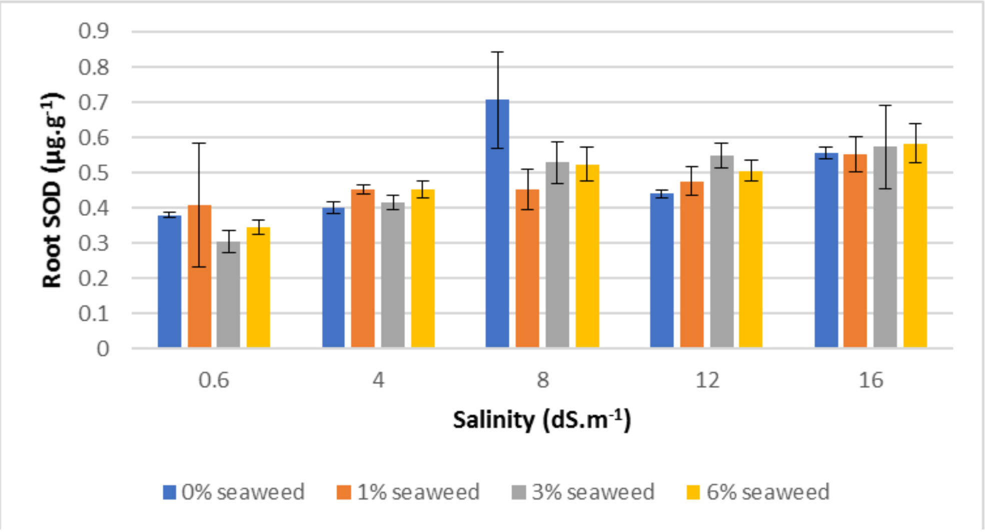

Fig. 5. Effect of salinity and seaweed extract on root peroxidase content of tomato plants

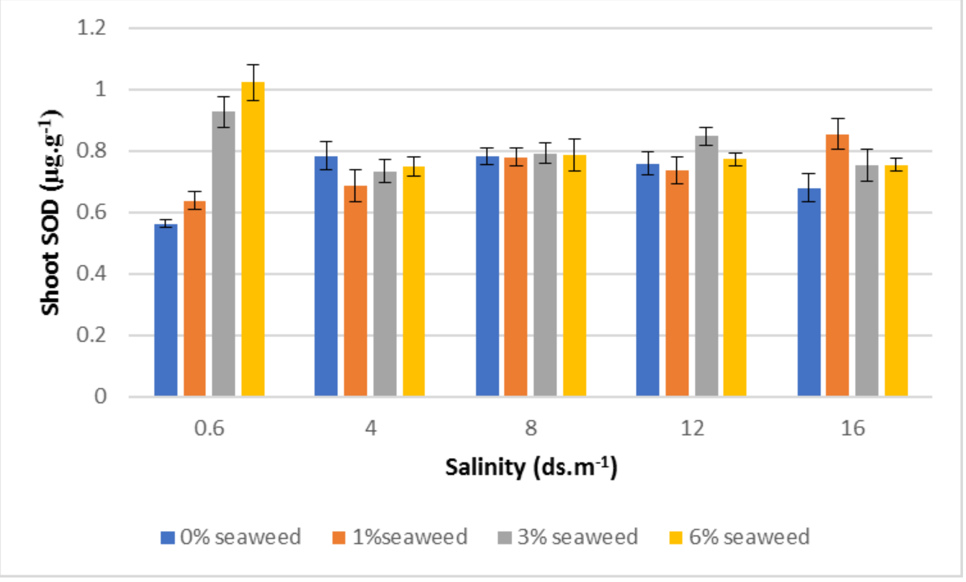

Fig. 6. Effect of salinity and seaweed extract on shoot peroxidase content of tomato plants

SOD activity was significantly altered in control tomato shoot treated with SE. This may be due to foliar spray with SE, which increased the antioxidant potential in stressed plants when compared to control plant (untreated). Patel *et al.* (2018) observed that the use of seaweed liquid fertilizer enhanced the antioxidant activity of different vegetables seeds. Our result can be explicated by the effect of SE on the reduction of the cells damage caused by ROS. The application of SE increased plant's tolerance to oxidative stress (Benzie and Strain, 1996).

Proline

Interestingly, the proline concentration can also be used as a negative indicator of tolerance. Proline is a metabolite solute that increases when plants are subjected to adverse environmental conditions. Salinity increases proline accumulation (Fig. 7); plants treated with the highest salinity levels (16 dSm^{-1}) recorded the highest level of proline (1.52 µmol/gm Dw), this may be due to increase production of proline by plants which is responsible of scavenging free radicals and inhibited lipid peroxidation (Lopez-Delacalle *et al.*, 2021). Proline levels decreased in plants treated with SE under salt stress. Proline levels were declined among the control treated with different concentration of SE. The same trend was obtained by Hernández-Herrera *et al.* (2024). In tomato plants, proline content has been significantly increased by salinity, higher levels were observed in leaves than roots (Gharsallah *et al.*, 2016 and De la Torre-González *et al.*, 2018).

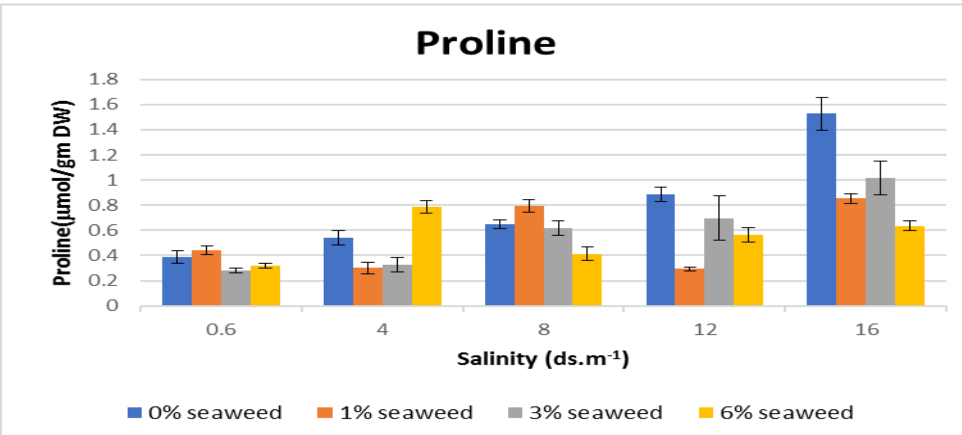

Fig. 7. Effect of salinity and seaweed extract on proline content of tomato plants

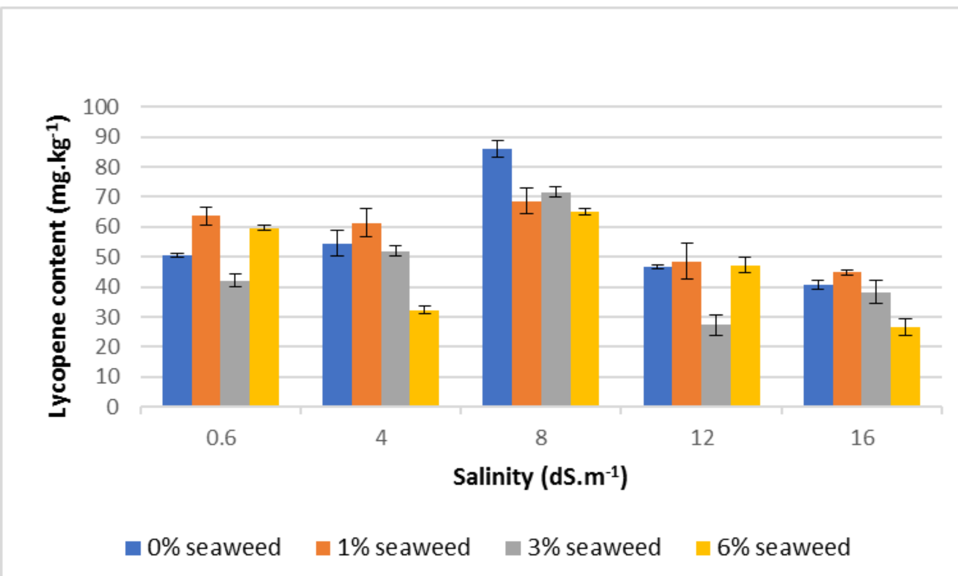

Fig. 8. Effect of salinity and seaweed extract on lycopene content of tomato plants

Lycopene

Lycopene are important pigments found in photosynthetic pigment-protein complexes in plants. They are responsible for the bright colors of fruits and vegetables and perform various functions in photosynthesis. It is a powerful antioxidant, which can prevent the initiation or propagation of oxidizing chain reaction (Riso *et al.,* 1999). Our results (Fig. 8) showed that the application of moderate salt stress on tomato plants increased lycopene concentrations in tomato fruits. The same trend was observed by De Pascale *et al.* (2001) and Wu & Kubota (2008) who reported that lycopene concentration in tomato fruit increased by increasing level of salinity in the nutrient solution. Lycopene concentrations gradually increased up to 8.0 dSm^{-1} and decreased at higher salinity levels. Spraying plants with different concentration of SE decreased significantly lycopene content.

CONCLUSION

Application of SE can be considered a promising strategy in reducing salinity stress. The antioxidant activity observed, along with the elevated levels of metabolites induced by the application of the SE to plants experiencing salt stress, contributed to enhanced survival rates and increased yields. Also, using SE as a bio-stimulant can influence morphological, physiological and biochemical characteristics which would be reflected in the growth, nutrient uptake efficiency, and assimilation of tomato plants and increased tomato plants tolerance towards salinity. Additionally, the SEs are environmentally sustainable and play a significant role in enhancing the innate immunity of plants. When utilized alongside other bio-fertilizers, SEs can optimize yield while minimizing the reliance on chemical fertilizers.

REFERENCES

Abdel Latef, A.A.H., A.K. Srivastava, H. Saber, E.A. Alwaleed and L.S.P. Tran. 2017. *Sargassum muticum* and *Jania rubens* regulate amino acid metabolism to improve growth and alleviate salinity in chickpea. Sci. Rep. 7, 10537.

Abu, N.J., J.S. Bujang, M.H. Zakaria and S. Zulkifly. 2022. Use of *Ulva reticulata* as a growth supplement for tomato (*Solanum lycopersicum*). PloS one 17, e0270604.

Ali, N., A. Farrell, A. Ramsubhag and J. Jayaraman. 2016. The effect of *Ascophyllum nodosum* extract on the growth, yield and fruit quality of tomato grown under tropical conditions. J. Appl. Phycol. 28: 1353-1362.

Ali, O., A. Ramsubhag and J. Jayaraman. 2019. Biostimulatory activities of *Ascophyllum nodosum* extract in tomato and sweet pepper crops in a tropical environment. PLoS One 14, e0216710.

Ali, S., Y.S. Moon, M. Hamayun, M.A. Khan, K. Bibi and I.J. Lee. 2022. Pragmatic role of microbial plant biostimulants in abiotic stress relief in crop plants. J. Plant Interact. 17: 705-718.

Almasoum, A.A. 2000. Effect of planting depth on growth and productivity of tomatoes using drip irrigation with semi saline water. Acta Hort. 537: 773-778.

Aremu, A.O., N.A. Masondo, K.R. Rengasamy, S.O. Amoo, J. Gruz, O. Bíba, M. Šubrtová, A. Pěnčík, O. Novák, K. Doležal and J. Van Staden. 2015. Physiological role of phenolic biostimulants isolated from brown seaweed *Ecklonia maxima* on plant growth and development. Planta 241: 1313-1324.

ASTM (American Society for Testing and Materials). 2002. Annual book of ASTM standards, Baltimore, MD, USA, 11, 939.

Bahmani Jafarlou, M., B. Pilehvar, M. Modaresi and M. Mohammadi. 2023. Seaweed liquid extract as an alternative biostimulant for the amelioration of salt-stress effects in *Calotropis procera* (Aiton) WT. J. Plant Growth Regul. 42: 449-464.

Baroud, S., S. Tahrouch, K. El Mehrach, I. Sadki, F. Fahmi and A. Hatimi. 2021. Effect of brown algae on germination, growth and biochemical composition of tomato leaves (*Solanum lycopersicum*). J. Saudi Soc. Agric. Sci. 20: 337-343.

Bates, L.S., R.P.A. Waldren and I.D. Teare. 1973. Rapid determination of free proline for water-stress studies. Plant Soil 39: 205-207.

Benzie, I.F. and J.J. Strain. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Anal. Biochem. 239: 70-76.

Briceño-Domínguez, D., G. Hernández-Carmona, M. Moyo, W. Stirk and J. van Staden. 2014. Plant growth promoting activity of seaweed liquid extracts produced from *Macrocystis pyrifera* under different pH and temperature conditions. J. Appl. Phycol. 26: 2203-2210.

Caijiao, C., H. Leshan, Y. Mengke, S. Lei, Z. Miansong, S. Yaping, L. Changheng, B. Xinfeng, L. Xue, L. Xin and J. Airong. 2021. Comparative studies on antioxidant, angiotensin-converting enzyme inhibitory and anticoagulant activities of the methanol extracts from two brown algae (*Sargassum horneri* and *Sargassum thunbergii*). Russ. J. Mar. Biol. 47: 380-387.

Chernane, H., S. Latique, M. Mansori and M. El Kaoua. 2015. Salt stress tolerance and antioxidative mechanisms in wheat plants (*Triticum durum* L.) by seaweed extracts application. J. Agric. Vet. Sci. 8: 36-44.

CoHort. 2004. Statistical analysis package, Version 6.303. CoHort Software, Monterey, CA, 93940, USA.

Colla, G. and Y. Rouphael. 2015. Biostimulants in horticulture. Sci. Hortic. 196: 1–2.

Dangles, O. 2024. Anthocyanins as natural food colorings: the chemistry behind and challenges still ahead. J. Agric. Food Chem. 72: 12356-12373.

De Corato, U., R. Salimbeni, A. De Pretis, N. Avella and G. Patruno. 2017. Antifungal activity of crude extracts from brown and red seaweeds by a supercritical carbon dioxide technique against fruit postharvest fungal diseases. Postharvest Biol. Technol. 131: 16-30.

De la Torre-González, A., D. Montesinos-Pereira, B. Blasco and J.M. Ruiz. 2018. Influence of the proline metabolism and glycine betaine on tolerance to salt stress in tomato (*Solanum lycopersicum* L.) commercial genotypes. J. Plant Physiol. 231: 329-336.

De Pascale, S., A. Maggio, V. Fogliano, P. Ambrosino and A. Ritieni. 2001. Irrigation with saline water improves carotenoids content and antioxidant activity of tomato. J. Hort. Sci. Biotechnol. 76: 447–453.

Di Stasio, E., M.J. Van Oosten, S. Silletti, G. Raimondi, E. Dell'Aversana, P. Carillo and A. Maggio. 2018. *Ascophyllum nodosum*-based algal extracts act as enhancers of growth, fruit quality, and adaptation to stress in salinized tomato plants. J. Appl. Phycol. 30: 2675-2686.

do Rosário Rosa, V., A.L.F. Dos Santos, A.A. da Silva, M.P.V. Sab, G.H. Germino, F.B. Cardoso and M. de Almeida Silva. 2021. Increased soybean tolerance to water deficiency through biostimulant based on fulvic acids and *Ascophyllum nodosum* (L.) seaweed extract. Plant Physiol. Biochem. 158: 228-243.

Dookie, M., O. Ali, A. Ramsubhag and J. Jayaraman. 2021. Flowering gene regulation in tomato plants treated with brown seaweed extracts. Sci. Hortic. 276: 109715.

El-Bakry, A.A., R.A. Salah El Din, S.M. Ghazi and O.M. Abdel Hamid. 2006. Effect of some seaweed extracts on the growth and yield of wheat (*Triticum vulgare* L.). Egypt. J. Biotech. 24: 195-209.

Esfandiari, E., M.R. Shakiba, S.A. Mahboob, H. Alyari and M. Toorchi. 2007. Water stress, antioxidant enzyme activity and lipid peroxidation in wheat seedling. J. Food Agric. Environ. 5, 149.

Espinosa-Antón, A.A., J.F. Zamora-Natera, P. Zarazúa-Villaseñor, F. Santacruz-Ruvalcaba, C.V. Sánchez-Hernández, E. Águila Alcántara, M.I. Torres-Morán, A.P. Velasco-Ramírez and R.M. Hernández-Herrera. 2023. Application of seaweed generates changes in the substrate and stimulates the growth of tomato plants. Plants 12, 1520.

Fish, W.W., P. Perkins-Veazie and J.K. Collins. 2002. A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. J. Food Compos. Anal. 15: 309-317.

Frusciante, L., P. Carli, M.R. Ercolano, R. Pernice, A. Di Matteo, V. Fogliano and N. Pellegrini. 2007. Antioxidant nutritional quality of tomato. Mol. Nutr. Food Res. 51: 609-617.

Gharsallah, C., H. Fakhfakh, D. Grubb and F. Gorsane. 2016. Effect of salt stress on ion concentration, proline content, antioxidant enzyme activities and gene expression in tomato cultivars. AoB Plants 8, plw055.

Hallmark, W.B. and S.A. Barber. 1984. Root growth and morphology, nutrient uptake, and nutrient status of early growth of soybeans as affected by soil P and K 1. Agron. J. 76: 209-212.

Hao, S., Y. Wang, Y. Yan, Y. Liu, J. Wang and S. Chen. 2021. A review on plant responses to salt stress and their mechanisms of salt resistance. Hortic. 7, 132.

Hernández-Herrera, R.M., J.F. Gómez-Leyva, C.V. Sánchez-Hernández, H. Ocampo-Álvarez, R. Ramírez-Romero and P.A. Palmeros-Suárez. 2024. Seaweed extract ameliorates salt stress in tomato plants by enhancing the antioxidant system and expression of stress-responsive genes. J. Appl. Phycol. 36: 2269–2282.

Hu, X., X. Jiang, H. Hwang, S. Liu and H. Guan. 2004. Promotive effects of alginate-derived oligosaccharide on maize seed germination. J. Appl. Phycol. 16: 73-76.

Huang, H., F. Ullah, D.X. Zhou, M. Yi and Y. Zhao. 2019. Mechanisms of ROS regulation of plant development and stress responses. Front. Plant Sci.10, 800.

Hussain, H.I., N. Kasinadhuni and T. Arioli. 2021. The effect of seaweed extract on tomato plant growth, productivity and soil. J. Appl. Phycol. 33: 1305-1314.

Jannin, L., M. Arkoun, P. Etienne, P. Laîné, D. Goux, M. Garnica, M. Fuentes, S.S. Francisco, R. Baigorri, F. Cruz and F. Houdusse. 2013. *Brassica napus* growth is promoted by *Ascophyllum nodosum* (L.) Le Jol. Seaweed extract: microarray analysis and physiological characterization of N, C, and S metabolisms. J. Plant Growth Regul. 32: 31-52.

Jones Jr, J.B. 2007. Tomato plant culture: In the Field, Greenhouse, and Home Garden, Second Edition (2nd ed.). CRC Press.

Liu, H., X. Chen, L. Song, K. Li, X. Zhang, S. Liu, Y. Qin and P. Li. 2019. Polysaccharides from *Grateloupia filicina* enhance tolerance of rice seeds (*Oryza sativa* L.) under salt stress. Int. J. Biol. Macromol. 124: 1197-1204.

Lopez-Delacalle, M., C.J. Silva, T.C. Mestre, V. Martinez, B. Blanco-Ulate and R.M. Rivero. 2021. Synchronization of proline, ascorbate and oxidative stress pathways under the combination of salinity and heat in tomato plants. Environ. Exp. Bot. 183, 104351.

Ma, C., W. Song, J. Yang, C. Ren, H. Du, T. Tang, S. Qin, Z. Liu and H. Cui. 2022. The role and mechanism of commercial macroalgae for soil conditioner and nutrient uptake catalyzer. Plant Growth Regul. 97: 455-476.

Malaguti, D., A.D. Rombolà, M. Gerin, G. Simoni, M. Tagliavini and B. Marangoni. 2002. Effect of seaweed extracts-based leaf sprays on the mineral status, yield and fruit quality of apple. Acta Hortic. 594: 357–359.

Mamatha, B.S., K.K. Namitha, A. Senthil, J. Smitha and G.A. Ravishankar. 2007. Studies on use of *Enteromorpha* in snack food. Food Chem. 101: 1707-1713.

Mattner, S.W., M. Milinkovic and T. Arioli. 2018. Increased growth response of strawberry roots to a commercial extract from *Durvillaea potatorum* and *Ascophyllum nodosum*. J. Appl. Phycol. 30: 2943-2951.

Mittler, R. 2002. Oxidative stress, antioxidants and stress tolerance. Trends Plant Sci. 7: 405-410.

Mostafa, A.S. 2024. Simple and economical methods for producing a nano-algae fertilizer and its efficacy for germination of cucumber seeds. Alex. Sci. Exch. J. 45: 563-570.

Mun, B.G., A. Hussain, Y.G. Park, S.M. Kang, I.J. Lee and B.W. Yun. 2024. The PGPR *Bacillus aryabhattai* promotes soybean growth via nutrient and chlorophyll maintenance and the production of butanoic acid. Front. Plant Sci. 15, 1341993.

Munné-Bosch, S. and L. Alegre. 2002. The function of tocopherols and tocotrienols in plants. Crit. Rev. Plant Sci. 21: 31–57.

Murindangabo, Y.T., M. Kopecký, K. Perná, T.G. Nguyen, P. Konvalina and M. Kavková. 2023. Prominent use of lactic acid bacteria in soil-plant systems. Appl. Soil Ecol. 189, 104955.

Patel, R.V., N. Brahmbhatt and K.Y. Pandya. 2018. Effect of seaweed liquid fertilizer on antioxidant and enzyme activity of different vegetables seeds. Annu. Res. Rev. Biol. 30: 1-8.

Perkins-Veazie, P. and J.K. Collins. 2004. Flesh quality and lycopene stability of fresh-cut watermelon. Postharvest Biol. Technol. 31: 159-166.

Piper, C.S. 1947. Soil and plant analysis. The University of Adelaide, Adelaide, Australia. 258 – 275.

Prakash, P., A. Mitra, R. Nag and S. Sunkar. 2018. Short communication effect of seaweed liquid fertilizer and humic acid formulation on the growth and nutritional quality of *Abelmoschus esculentus.* Asian J. Crop Sci. 10: 48–52.

Pramanick, B., K. Brahmachari, B.S. Mahapatra, A. Ghosh, D. Ghosh and S. Kar. 2017. Growth, yield and quality improvement of potato tubers through the application of seaweed sap derived from the marine alga *Kappaphycus alvarezii*. J. Appl. Phycol. 29: 3253-3260.

Raghunandan, B.L., R.V. Vyas, H.K. Patel and Y.K. Jhala. 2019. Perspectives of Seaweed as organic fertilizer in agriculture. In: Panpatte, D., Jhala, Y. (eds) Soil Fertility Management for Sustainable Development. Springer, Singapore.

Rao, K.R. 1991. Effect of seaweed extract on *Zizyphus mauratiana* Lamk. J. Indian Bot. Soc. 71: 19–21.

Rathore, S.S., D.R. Chaudhary, G.N. Boricha, A. Ghosh, B.P. Bhatt, S.T. Zodape and J.S. Patolia. 2009. Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions. S. Afr. J. Bot. 75: 351-355.

Riso, P., A. Pinder, A. Santangelo and M. Porrini. 1999. Does tomato consumption effectively increase the resistance of lymphocyte DNA to oxidative damage?. Am. J. Clin. Nutr. 69: 712-718.

Salah El Din, R.A., A.A. Elbakry, S.M. Ghazi and O.M. Abdel Hamid. 2008. Effect of seaweed extract on the growth and yield of faba bean (*Vicia faba* L.). Egypt. J. Phycol. 9: 25-38.

Shannon, L.M., E. Kay and J.Y. Lew. 1966. Peroxidase isozymes from horseradish roots. I. Isolation and physical properties. J. Biol. Chem. 241: 66-72.

Sharma, H.S., C. Fleming, C. Selby, J.R. Rao and T. Martin. 2014. Plant biostimulants: a review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. J. Appl. Phycol. 26: 465-490.

Sherif, F.K. 1996. Phytoavailability of zinc and copper by soybean and wheat growing in sand culture and sewage sludge amended soil in relation to growth and metal mobility in sandy soil. Ph.D thesis. Faculty of Agriculture, Alexandria University, Egypt.

Sherif, F.K., H.A. Argeaa and A.S. Mostafa. 2024. Green-synthesized nanocellulose enhanced germination, morphology roots, nutrients influx of wheat seedlings under salinity stress. Alex. Sci. Exch. J. 45: 251-261.

Singh, A. and B. Chaudhary. 2010. Preliminary phycochemical analysis and in vitro antibacterial screening of *Pithophora oedogonia* (Mont.) Wittrock: A freshwater green alga forming mats in the water bodies. J. Algal Biomass Util. 1: 33-41.

Stevens, M.A., A.A. Kader, M. Albright-Holton and M. Algazi. 1977. Genotypic variation for flavor and composition in fresh market tomatoes. J. Am. Soc. Hortic. Sci. 102: 680-689.

Stirk, W.A., G.D. Arthur, A.F. Lourens, O. Novak, M. Strnad and J. Van Staden. 2004. Changes in cytokinin and auxin concentrations in seaweed concentrates when stored at an elevated temperature. J. Appl. Phycol. 16: 31-39.

Tennant, D. 1975. A test of a modified line intersect method of estimating root length. J. Ecol. 63: 995-1001.

Trivedi, K., K.V., Anand, P. Vaghela and A. Ghosh. 2018. Differential growth, yield and biochemical responses of maize to the exogenous application of *Kappaphycus alvarezii* seaweed extract, at grain-filling stage under normal and drought conditions. Algal Res. 35: 236-244.

Van Oosten, M.J., O. Pepe, S. De Pascale, S. Silletti and A. Maggio. 2017. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. Chem. Biol. Tech. Agric. 4: 1-12.

Wang, Q., W.Y. Shi, F.J. Rong, J.W. Ma, C.H. Guan and L.N. Jiang. 2005. The effect of the liquid seaweed extract on resisting salinity stress of cucumber. Acta-Agric. Zhejiangensis 17: 268-272.

Wu, M. and C. Kubota. 2008. Effects of high electrical conductivity of nutrient solution and its application timing on lycopene, chlorophyll and sugar concentrations of hydroponic tomatoes during ripening. Sci. Hortic. 116: 122-129.

Yang, Y. and Y. Guo. 2018. Elucidating the molecular mechanisms mediating plant salt-stress responses. New Phytol. 217: 523-539.

Zodape, S.T. 2001. Seaweeds as a biofertilizer. J. Sci. Ind. Res. New Delhi 60: 378-382.

Zou, P., X. Lu, H. Zhao, Y. Yuan, L. Meng, C. Zhang and Y. Li. 2019. Polysaccharides derived from the brown algae *Lessonia nigrescens* enhance salt stress tolerance to wheat seedlings by enhancing the antioxidant system and modulating intracellular ion concentration. Front. Plant Sci. 10, 48.

الملخص العربي

هل مستخلص الأعشاب البحرية كمحفز حيوي يحسن من قدرة نبات الطماطم على تحمل الإجهاد الملحي؟

فاطمة كمال شريف، هدى أحمد أرجيعة، على سعيد مصطفى

تعتبر مستخلصات الأعشاب البحرية استراتيجية واعدة في تحسين آثار الإجهاد اللاأحيائي على أداء النبات. لذلك تم إجراء تجربة نمو لتقييم تأثيرات المستخلص القلوي من الأعشاب البحرية (SE) على الخصائص المورفولوجية والفسيولوجية والحيوية لنبات الطماطم تحت الإجهاد الملحى. تضمنت التجربة خمسة معاملات للملوحة (٠,٦، ٤، ٨، ١٢، و ١٦ d.S/m) وأربعة مستويات من مستخلص SE (٠,٠، ١، ٣، ٦%). أدى الإجهاد الملحي إلى انخفاض كبير في الوزن الطازج للمجموع الخضري والجذري، ومحتوى الماء فى المجموع الخضري والجذري، والكلوروفيل، وطول الثمار، وإنتاج الثمار. عملت مستخلصات الأعشاب البحرية على تحسين نمو نباتات الطماطم بشكل كبير، حيث أدى رش SE إلى زيادة كبيرة في المعايير المورفولوجية التي تم تقييمها. في الواقع، أدت الملوحة إلى زيادة إنزيمات مضادات الأكسدة (سوبر أكسيد ديسميوتاز) وأدت إلى تراكم البرولين والليكوبين. أظهرت نتائج هذه الدراسة أن رش SE يخفف من التأثير السلبي للإجهاد الملحي في نباتات الطماطم.

الكلمات المفتاحية: الطحالب البحرية – إنزيمات الأكسدة والإختزال – الإجهاد الملحي– الطماطم– البرولين – الليكوبين.