Saudi Journal of Biological Sciences 30 (2023) 103810

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Response of *Moringa oleifera* trees to salinity stress conditions in Tabuk region, Kingdom of Saudi Arabia

Hala M. Bayomy [a,*], Eman S. Alamri [a], Basmah M. Alharbi [b], Shaden H. Foudah [a], Esmail A. Genaidy [c], Amira K. Atteya [d]

[a] *Food Science and Nutrition Department, Faculty of Science, University of Tabuk, Tabuk 71491, Saudi Arabia*
[b] *Biology Department, Faculty of Science, University of Tabuk, Tabuk 71491, Saudi Arabia*
[c] *Pomology Department, Agricultural and Biology Research Institute, National Research Centre, Giza 12622, Egypt*
[d] *Horticulture Department, Damanhour University, Damanhour 22516, Egypt*

ARTICLE INFO

Article history:
Received 30 July 2023
Revised 22 August 2023
Accepted 9 September 2023
Available online 14 September 2023

Keywords:
Moringa oleifera
Seaweed
Growth
Flowering
Yield
Salinity

ABSTRACT

Moringa oleifera is an amazing tree with various applications. Salinity is a world major barrier to crop productivity. This study was conducted to investigate salinity and seaweed extract's effect on *Moringa oleifera*'s growth and yields. Measurements were made of growth characteristics, fresh and dried leaf, inflorescence, mature pod and seed weight, and yield per tree, as well as chemical parameters. Seasons had no substantial effect on any of these traits. In terms of seaweed concentrations, the treatment containing 20% seaweed outperformed the treatment containing 0% seaweed in all measurements. Concerning the salinity levels, the maximum level of all studied attributes was at 18.75 mmol/L NaCl, while the level of 70.31 mmol/L NaCl has the lowest values. The interaction between salinity levels and seaweed revealed that T4 (18.75 mmol/L NaCl plus 20 % seaweed) was the highest for all traits and T9 (70.31 mmol/L NaCl plus 0 % seaweed) was the lowest for all traits except for the potassium content. Concerning potassium content, T7 (54.69 mmol/L NaCl plus 0 % seaweed) was the lowest. These findings could help to develop efficient breeding methods for *Moringa oleifera* in the future.

1. Introduction

Moringa oleifera is a marvel tree with enormous uses such as vegetable farming, alley cropping, medicinal, water purification, gardening, etc. It is typically found in a variety of environments at an altitude of 600–1800 m (Jama et al., 1989). It comes from Pakistan and India and belongs to the Moringaceae family, but it is now grown all over the worldsuch as African, South American, and Southeast Asian countries (Olson and Carlquist, 2001; Anwar and Bhanger, 2003).

The entire moringa plant, including the flowers, fruits, and leaves, is used to make highly nutritious foods (Anwar and Bhanger, 2003). Moringa leaves have a high percentage of protein (28.2%) and also have a feasible amount of vital amino acids in comparison to soybean (Melsse and Berihun, 2013). A significant amount of macro and micronutrients have been in Moringa leaves and pods (Aslam et al., 2005). Moringa has recently been recognized for numerous uses, and farmers are taking steps to produce it as a forage crop or food production, as well as for farm forestry.

Salinity is one of the main issues affecting crop productivity globally. The majority of dry and semi-arid regions are affected by the global problem of soil salinity. Due to poor drainage, irrigation methods, little rainfall, and high rates of transpiration, it is significantly growing on irrigated lands. Salinity is regarded as a severe threat to agriculture because it has already negatively impacted around 1,125 million hectares of agricultural lands (Islam et al., 2019; Sanower-Hossain, 2019). Consequently, our agricultural economy is being decreased by soil salinity by persistently decreasing the territory of crop cultivation. So, if this heavily influenced area is effectively utilized, it will be of significant economic benefit. Salinity is an old, critical abiotic problem that

* Corresponding author.
E-mail addresses: hm.mohamed@ut.edu.sa (H.M. Bayomy), ialamri@ut.edu.sa (E. S. Alamri), b.alharbi@ut.edu.sa (B.M. Alharbi), sfouda@ut.edu.sa (S.H. Foudah), ea.genaidy@nrc.sci.eg (E.A. Genaidy), amira.khames@agr.dmu.edu.eg (A.K. Atteya).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2023.103810
1319-562X/

accords baleful effects on farming is practiced in many regions of the world (Abdel Latef, 2010). According to Ramoliya and Pandey (2003), excessively salty soils have detrimental impacts on seed germination, seedling development, and plant growth. According to studies, higher amounts of Cl- and Na + in the soil reduce the nutrient selectivity of root membranes and cause ionic imponderables in plants, like a deficiency in calcium or potassium (Chow et al., 1990), which can cause damage to plant growth.

Salinity is related to a disorder of plant water relationship that ends with physiological drought and a disorder of homeostasis (Munns, 2002; Rady, 2011). Despite the *Moringa oleifera* tree's enormous potential, many studies, like those by Sanchez et al. (2006) and Ghazali and Yasin (2016), have handled it as an herbal plant rather than a tree. On the mature tree, however, as well as its pods and seeds, little research has been done. This study was done in order to find out how salinity affected the *Moringa oleifera* plant's productivity and quality.

Using seaweed in either soil or foliar treatments improves the plant's physiological state and adaptability under stress conditions (Ali et al., 2022). The use of seaweed extracts as an organic biostimulant has become more common in the horticulture and crop industries, is obtainable as an extract and powder system, helps the plant to be more disease and stress resistant and helps supply rapid root growth. Blue-green seaweed is free-living and a fixer of photosynthetic nitrogen. Green algae can breakdown a variety of toxins and have huge advantages as it can biodegrade microorganisms (Subramanian & Uma, 1996). Secretion of substances that encourage growth like hormones, amino acids, and vitamins (Rodrguez et al., 2006). Following their decomposition and death, soil biomass increased (Saadatnia and Riahi, 2009). Therefore it prevents the growth of weeds and boosting soil phosphate through the release of organic acids (Sahu et al., 2012). Significant searches have identified some well-known biostimulants, including fulvic acid, protein hydrolysates, and seaweed extracts (Van Oosten et al., 2017). By maintaining tissue water equilibrium, the combination of proline, glycine, soluble protein, soluble sugar, and total free amino acids reduces the detrimental effects of stress (Abdel Latef and Tran, 2016; Ahmad et al., 2016).

But in salt stress regimes, nutrient screening absorption and the subsequent build-up of Na+, Cl-, and K + ions play a significant part in osmoregulation. The researchers Layek et al., 2018 and Mzibra et al., 2018 showed that seaweed had a favourable impact on plant output and quality. Seaweed extracts have health benefits in addition to their vitamin, polyamine, betaine, and amino acid content (Lötze and Hoffman, 2016; Singh et al., 2016). Arioli et al. (2015) and Mansori et al. (2015) looked at the effects of seaweed extracts on plants that could withstand stress, such as biotic and abiotic difficulties. Therefore, the primary objectives of this inquiry were to: (1) identify the impact of salinity on the *Moringa oleifera* tree's leaves, inflorescences, and seeds yield and quality. (3) Look into how applying seaweed extract and salinity interact. The anticipated outcomes might help in the future development of efficient methods for breeding *Moringa oleifera.*

2. Materials and methods

2.1. Moringa oleifera pots management

In the open air, a pot experiment was conducted throughout the 2020–2021 and 2021–2022 seasons at the University of Tabuk's main campus in Tabuk, Saudi Arabia. Split-plot designs with three replicates in randomized complete block designs made up the experiment. It was done the combination analysis. In the main plot, there were five irrigation water salinity levels (Tap water, 18.75, 39.06, 54.69, and 70.31 mmol/LNaCl) and two concentrations of seaweed foliar spray (0 and 20%) (Table 1). In plastic pots with a 30 cm diameter and 20 cm height (14 cm^3), three *Moringa oleifera* seeds were manually planted in them in the months of February 2020 and 2021. One plant per pot was preserved after 20 days. As a result, 900 pots containing 900 plants were left after the allocation of 10 experimental units (pots) per replication and per treatment. Tables 1 and 2 exhibited the physical and chemical characteristics of water irrigation and soil samples, according to Jackson (1973) and Cottenie et al. (1982). The field where the cultivation took place was open. The growing season's temperatures and rainfall totals are displayed in Table 3.

2.2. Plant material

Moringa oleifera seeds were obtained from a single tree planted alone in an isolated area of the study site. Its seed had previously been obtained from the national research center - Egypt.

2.3. Irrigation treatments

Moringa oleifera seeds were watered with tap water. Once seedlings were established, irrigation was applied every three days until 50 days after sowing, when salt treatments were applied. After that, irrigation was applied once or twice a week. Around twice a week, irrigation with (tap water or control, 18.75, 39.06, 54.69, and 70.31 mmol/L NaCl) was utilized (Table 3). After every four irrigations with salt water, pot soil was given one irrigation with tap water to prevent the buildup of salt. Up until the field's capacity, irrigation was used around 750 mL of water per pot.

2.4. Seaweed treatments

Ulva lactuca seaweed was collected from three selected coast zones in the regions of Tabuk including Sharma (27° 55′ 48.4320′' N and 35° 16′ 38.3808′' E), Alkhuraybah (28°03′24.0″N 35°09′50.9″E) and Gayal (28°07′33.5″N 35°01′40.1″E). Drying seaweed material at 70 °C for 72 h resulted in the creation of *Ulva lactuca* aqueous extract solutions. The dried product was processed for filtration using a 40-mesh screen after being ground in a grinder. To make the extracts, 400 g of each pulverized plant material was macerated in 1000 mL of distilled water. Solutions were shaken in an orbital shaker at room temperature for 24 h. Using Whatman filter paper No. 1, the extracts were filtered. The concentrations could only be achieved by diluting the dried extracts. Table 4 displays the findings of the *Ulva lactuca* seaweed extract study's various analyses. Table 5 *Ulva lactuca* seaweed extract chemical properties lists the treatments that used this extract. The foliar spray with seaweed extract solution was applied to every plant at 15-day intervals until the pods were ripped (around 15 month from planting) with a manual sprayer until fell off at a true two-leaf growth stage (around 9 day from sowing). The control plants had an equal amount of distilled water sprayed on them. The soil of the pot was covered with plastic during spraying.

2.5. Measurements

The respective data was gathered each season:

2.5.1. Parameters of development, leaves and inflorescences yield

The following growth characteristics were examined at the end of the experiment: plant height (cm), stem diameter (mm), number of leaves per tree, fresh and dry leaf weight (g), fresh leaf yield (g $tree^{-1}$), dry leaf yield (g $tree^{-1}$), number of inflorescences per tree, fresh and dry inflorescence weight (g), fresh and dry inflorescence yield (g $tree^{-1}$). Five plants were randomly chosen from each block and fifteen plants from each treatment.

Table 1
The experimental soil's physical and chemical properties.

Characteristic							
O.M.	**1.25**	**Clay%**	31	**Soluble ions (mg kg^{-1})**			
Sand	31	**pH***	7.9	HCO_3^-	2.33	Ca^{2+}	6.00
Silt %	36	**EC* (mS cm^{-1})**	2.24	K^+	0.30	Na^+	4.38

* EC: Electrical Conductivity.

Table 2
This study's irrigation water's chemical properties.

Parameters	**pH***	**EC* dS m^{-1}**	**Ca^{2+} meq L^{-1}**	**Mg^{2+}**	**Na^+**	**K^+**	**HCO^{3-}**	**Cl^-**	**$SO4^{-2}$**
Values	7.64	0.45	1.12	0.54	2.53	0.22	0.13	2.87	1.23

* EC: Electrical Conductivity.
* pH: Potential of Hydrogen.

Table 3
The maximum, minimum air temperatures (C°), and rain (mm day^{-1}) in Tabuk region during two growing seasons of 2020/2021 and 2021/2022.

Growing Seasons	Temperature (°C)		Rain
	Max	Min	(mm day^{-1})
February 2020	20.9	4.4	1.73
March 2020	24.8	6.4	3.9
April 2020	28.7	10	1.2
May 2020	30.5	14.3	1.8
June 2020	37.9	22	0
July 2020	39.2	24	0
August 2020	39.5	24.2	0.7
September 2020	37.2	21.4	0
October 2020	32.2	16.9	4.8
November 2020	25	10.8	4.1
December 2020	19.9	5.9	4.17
January 2021	18.9	4.4	4.4
February 2021	27.5	3.6	33.4
March 2021	25.2	10.2	4.4
April 2021	30.5	14.8	1.2
May 2021	34.8	19.2	1.8
June 2021	37.9	22	0
July 2021	39.2	24	0
August 2021	39.5	24.2	0.7
September 2021	29.4	21	0
October 2021	24.6	16.1	2.9
November 2021	17.6	10.4	3.3
December 2021	19.9	5.8	1.7
January 2022	18.3	4.5	9.1
February 2022	21	6.5	2.2
March 2022	25.2	10.2	4.4
April 2022	30.5	14.8	1.2

Source: Saudi National Center of Meterology.
https://ncm.gov.sa/Ar/MediaCenter/Reports/Pages/SeasonClimate.aspx.

Table 4
Ulva lactuca dried seaweed extracts chemical characteristics.

Parameters	**Units**	**Values**
Amino acids	%	8.9
Lipid	%	5.6
Zn	ppm	3
Mg	ppm	46
Fe	ppm	2
K	ppm	13
Ca	ppm	43

2.5.2. The characteristics and yield of pods and seeds

After around 15 months of sowing, Five plants at random were chosen from each block and fifteen plants from each treatment to evaluate the characteristics of the pods per inflorescence, pods per tree, mature pod weight (g), mature pod yield (g tree^{-1}), seeds per pod, mature seed weight, and mature seeds yield (g tree^{-1}).

Table 5
All different combinations of salinity and seaweed treatments were used with the following.

Treatments	
T1	Tap water plus 0 % seaweed
T2	Tap water plus 20 % seaweed
T3	18.75 mmol/L NaCl plus 0 % seaweed
T4	18.75 mmol/L NaCl plus 20 % seaweed
T5	39.06 mmol/L NaCl plus 0 % seaweed
T6	39.06 mmol/L NaCl plus 20 % seaweed
T7	54.69 mmol/L NaCl plus 0 % seaweed
T8	54.69 mmol/L NaCl plus 20 % seaweed
T9	70.31 mmol/L NaCl plus 0 % seaweed
T10	70.31 mmol/L NaCl plus 20 % seaweed

2.5.3. Content of total chlorophyll

The amount of total chlorophyll (measured in SPAD units) was determined using a SPAD-502 Chlorophyll Meter from Minolta Camera Co. in Ramsey, New Jersey.

2.5.4. Vitamin C (mg/g dry weight), phosphorus percentage (P_2O_5) and potassium percentage (K_2O)

Using a titration approach and the indicator dye 2,6-dichloroindophenol, the vitamin C content of moringa leaves was determined (Nielsen and Nielsen, 2017). Moringa leaves' phosphorus content was measured using a colorimetric technique and the Murphy and Riley reagent at a wavelength of 660 nm (Ward, R. E.; Legako, 2017). According to Harris et al.'s (2017) description, the amount of potassium in leaves was determined using atomic absorption spectrophotometry.

2.6. Statistical analysis

Using SAS v9.1 and a split-plot design, the analyzed ANOVA and variance analysis were performed on the data. It was done the combination analysis. All attributes were put through a homogeneity test. The Duncan test was used to compare the means within treatments at a 5% level of probability**.** Using R v3.5.1, the Pearson's correlation coefficient between the various parameters was determined.

3. Results

3.1. Growth characteristics

The height, diameter of the stem, and number of major branches per tree of the plant were all assessed under the two seaweed concentrations and salinity stress conditions. Seasons had no discernible impact on any of the growth features, according to an ANOVA study, but salinity levels, seaweed concentrations, and the impacts of their interactions did. All growth traits responded differently to different salinity levels and seaweed treatments. In comparison to other seaweed treatments, the salinity level (18.75 mmol/L NaCl) produced the highest average plant height (142.81), leaf number per tree (16.35), and stem diameter (36.07 mm). But for plant height (98.83), the number of leaves per tree (8.00), and stem diameter (18.53 mm), the salinity level (70.31 mmol/L NaCl) was the lowest (Fig. 1). When compared to the seaweed concentration (0%), which produced the following results (plant height 114.25, number of leaves per tree 11.26, and stem diameter 26.42 mm), the seaweed treatment (20%) had the highest results for all traits (plant height, number of leaves per tree, and stem diameter), as follows: (124.53, 12.98, and 29.35 mm, respectively) (Fig. 1). When salinity levels and seaweed treatment were combined, T4 treatment produced plants with the highest height (156.15), number of leaves per tree (17.79), and stem diameter (39.33 mm), while T9 treatment produced plants with the lowest height (97.84), number of leaves per tree (7.9), and stem diameter (17.79 mm) (Fig. 1).

Plant height, leaves per tree, fresh leaves per tree, and stem diameter were all significantly correlated (P 0.01) with one another (Table 6). All defining characteristics revealed a significant association. The diameter of the tree's trunk and leaves, however, had the most significant association (r = 0.98; P 0.001).

3.2. Fresh and dried leaf yield and weight

We measured the fresh leaf weight, dry leaf weight, fresh leaf yield per tree, dry leaf yield per tree under salinity stress conditions, and the two concentrations of seaweed. An ANOVA study revealed that none of these traits were significantly influenced by seasons, but that salinity levels, seaweed concentrations, and their interactions were all highly significant (P 0.01) for all traits. Depending on the amount of salt and how the seaweed was treated, each feature responded differently. The maximum salinity (18.75 mmol/L NaCl) was observed for the fresh weight of leaf trait (6.43), dry weight of leaf (2.06), fresh leaf yield per tree (107.25), and dry leaf yield per tree (34.32 mm) in the seaweed treatments (Fig. 3). The fresh weight of a leaf was 4.98, the dry weight of a leaf was 1.58, fresh leaves yield per tree was 72.33, and dry leaves yield per tree was 23.14 compared to the seaweed concentration (0%) that produced its results (fresh weight of leaf was 4.48, dry weight of leaf was 1.43, fresh leaves yield per tree was 54.74, and dry leaves yield was 23.14). The concentration (20%) of seaweed was the highest across all traits in the seaweed treatments. The results of the interaction between the seaweed treatment and salt levels showed that T4 had the greatest leaf fresh weight, leaf dry weight, yield of fresh leaves per tree, and dry leaves per tree values, which were, in order, 6.91, 2.21, 124.53, and 39.84, respectively. T9 had the lowest fresh leaf weight, dry leaf weight, fresh leaf to tree ratio, and dry leaf to tree ratio as follows: 2.96, 0.94, 23.72, and 7.59, respectively (Fig. 2).

The fresh leaf weight, dry leaf weight, fresh leaf yield per tree, and dry leaf yield per tree attributes all showed a highly significant connection (P 0.01) (Table 7). All traits revealed a very strong association. The weight of fresh leaf and the weight of dried leaf, as well as the yield of fresh and dry leaves per tree, were shown to be significantly correlated (r = 1) and to be positively correlated (P 0.01) with one another.

3.3. Parameters of inflorescences

The flowering of moringa plant in this experiment began after nine month of sowing. Salinity levels, seaweed concentrations, and their interaction effects were highly significant (P 0.01) for all inflorescence parameters (fresh weight of inflorescence, dry weight of inflorescence, fresh inflorescences per tree, and dry inflorescences per tree), whereas seasons had no significant influence on any of the traits. The greatest number of characteristics were seen in the 20% seaweed concentration (3 Figures). Salinity levels for the four characteristics—fresh weight of inflorescence, dry weight of inflorescence, fresh inflorescences per tree, and dry inflorescences per tree—ranged from the highest (18.75 mmol/L NaCl) to the lowest (70.31 mmol/L NaCl) (Fig. 3). The greatest of the four traits, T4, had the following values for the fresh weight of an inflorescence, the dry weight of an inflorescence, the number of fresh inflorescences per tree, and the number of dry inflorescences per tree, respectively: 4.07, 1.41, 58.5, and 20.37. T4 had values for fresh weight of inflorescence, dry weight of inflorescence, fresh inflorescences per tree, and dry inflorescences per tree that were respectively 1.78, 0.67, 7.77, and 2.95, making it the least significant of the four traits (Fig. 3).

The correlation between the fresh weight of inflorescence and dry inflorescence per tree was the lowest (r = 0.93) (P < 0.01), whereas the correlation between fresh inflorescence per tree and dry inflorescence per tree exhibited the strongest significant correlation (r = 0.99) (P < 0.01) (Table 8).

3.4. Parameters of mature pods and seeds

All of these variables were assessed, including the number of mature pods per inflorescence, the weight of mature pods, the number of mature pods per tree, the weight of mature pods per tree, the number of seeds per pod, the weight of seeds, and the yield of seeds per tree. For every feature, there was a very significant relationship (P 0.01) between the amounts of seaweed present, the salt levels present, and their interaction. The largest amount of all traits was present at the 20% seaweed concentration (Fig. 4). The lowest salinity level was 70.31 mmol/L NaCl, while the highest salt level across all seaweed treatments was 18.75 mmol/L NaCl (Fig. 4). Seasons have no discernible impact on any of the traits of mature pods and seeds. The results of the interaction between the treatment of seaweed and salinity levels were as follows: 1.92, 7.43, 27.68, and 205.39. T4 was the highest of all traits (pods number per inflorescence, weight of mature pod, pods number per tree, mature pods weight per tree, seeds number per pod, seed weight, and yield of seeds per tree) (Fig. 4). Of all the mature pods and seeds attributes, T9 was the least desirable (Fig. 4).

Table 9 revealed that the correlation between all traits was very strong. In addition to the correlation between the weight of a mature pod and the seeds number per pod, the correlation between the pod's number per inflorescence and the pod's number per tree also demonstrated a very high significant correlation (r = 0.99; P < 0.01).

3.5. Physical and chemical parameters

The physical and chemical parameters (total chlorophyll, vitamin c content, potassium content, and phosphorus content) were greatly influenced by salinity levels, seaweed concentrations, and their interactions. For all these traits, the effect of the seasons was not significant. Except for the antioxidant activity trait, the

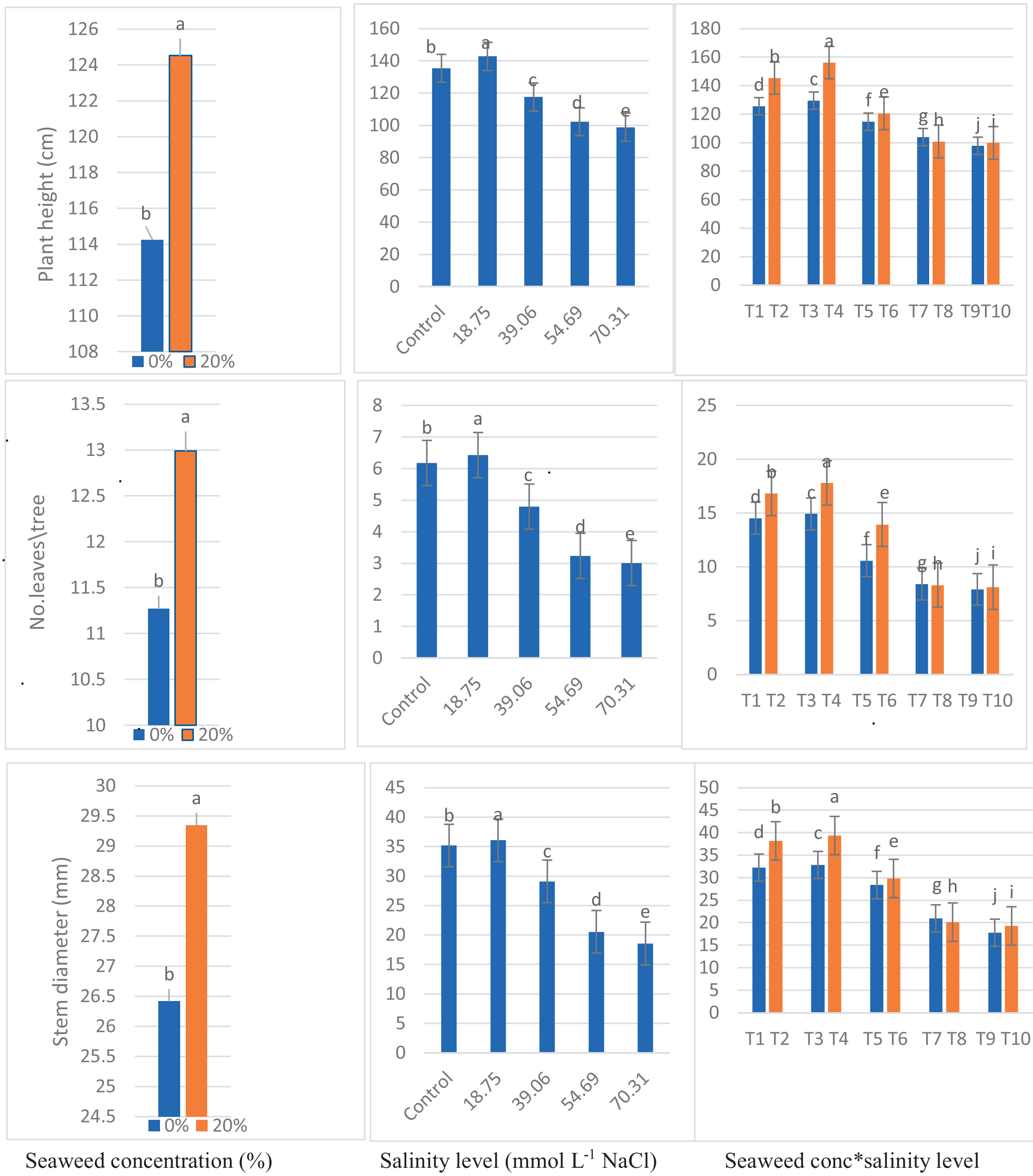

Fig. 1. Effect of seaweed concentrations, salinity levels and their interactions on plant height, no. leaves\tree, fresh leaves\tree and stem diameter (mm).

Table 6
The relationships between plant height (in cm), number of leaves, tree diameter (in mm), and seaweed concentrations.

	Plant height	No.leaves\ tree	Stem diameter
Plant height	1		
No.leaves\ tree	0.965626**	1	
Stem diameter	0.973461**	0.982085**	1

20% seaweed concentration was the greatest for all these traits (Fig. 5). Regarding the total chlorophyll, vitamin C content, potassium content, and phosphorus content among the seaweed treatments, the salinity level (18.75 mmol/L NaCl) was the highest and the salinity level (70.31 mmol/L NaCl) was the lowest (Fig. 5). With the exception of potassium content, which was treated with T7, the attributes of total chlorophyll, vitamin C, potassium content, and phosphorus content were all highest with T4. However, T9 of salinity was the lowest on these features.

The association between all chemical and physical properties was extremely significant ($P < 0.01$). The strongest correlation was between vitamin c content and phosphorus content ($r = 1.00$) whereas the correlation between potassium content and phosphorus content was the lowest (Table 10).

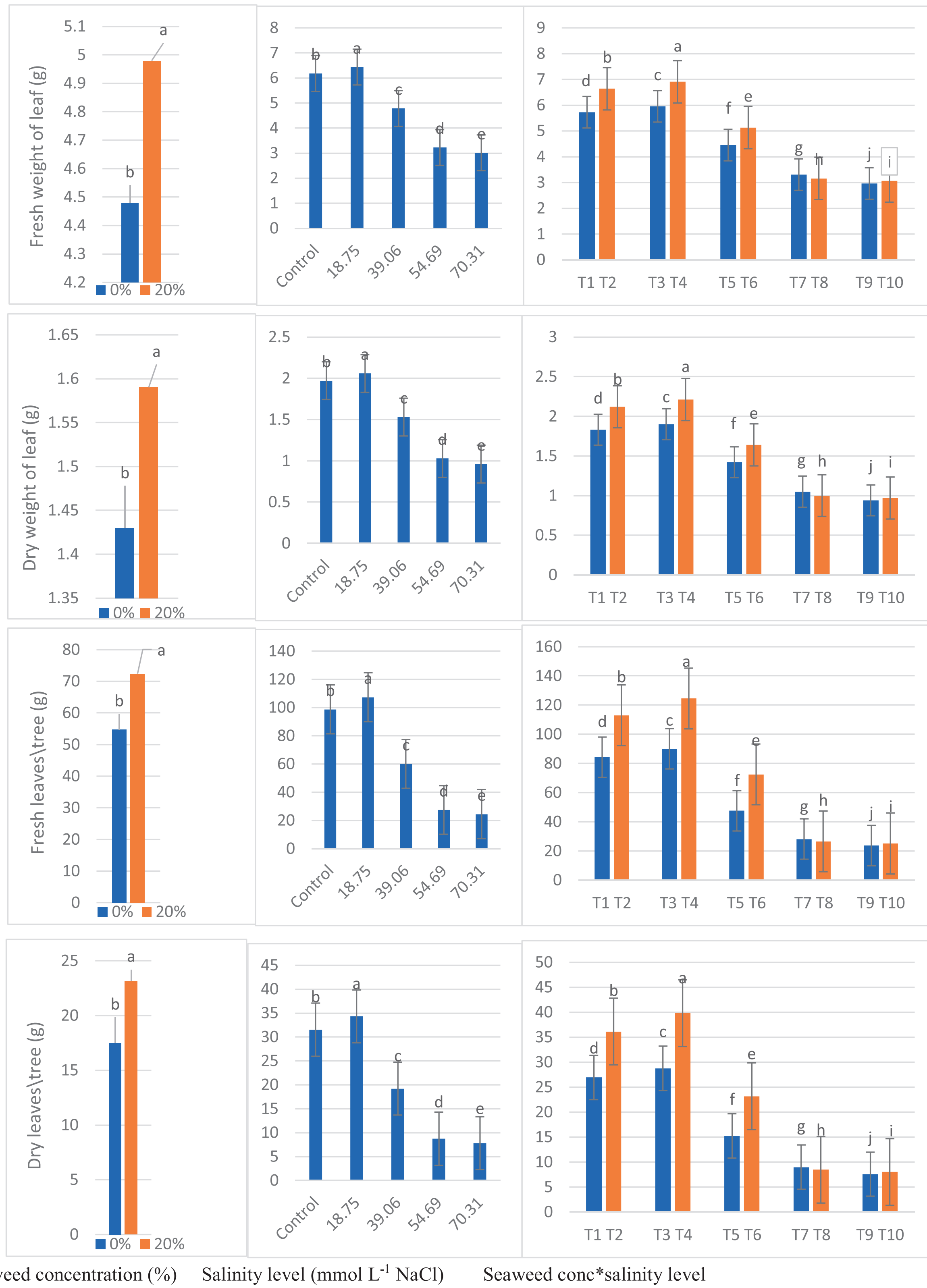

Fig. 2. Effect of seaweed concentrations, salinity levels, and their interactions on the fresh and dry weights of leaves, as well as the weights of fresh and dry leaves of trees.

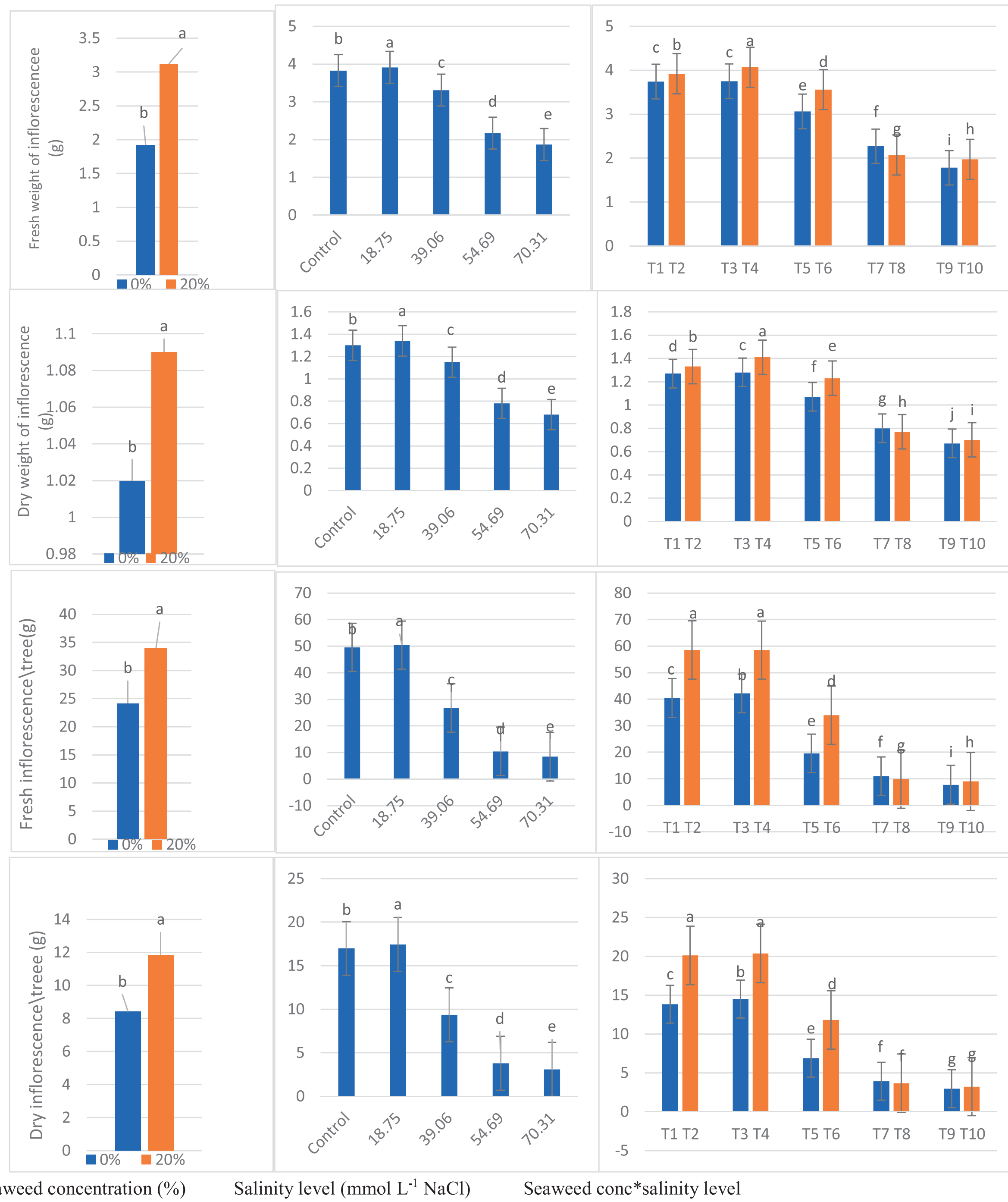

Fig. 3. Effects of seaweed concentrations, salinity concentrations, and their interactions on the fresh weight (g), dry weight (g), fresh inflorescence-tree (g), and dry inflorescence-tree (g) characteristics.

Table 7
The correlations between the fresh leaf weight (g), dry leaf weight (g), fresh leaf yield per tree (g), and dry leaf yield per tree (g) at different salinity levels and seaweed concentrations.

	fresh weight of leaf	dry weight of leaf	fresh leaves/tree	dry leaves/tree
fresh weight of leaf	1			
dry weight of leaf	0.999993***	1		
fresh leaves/tree	0.991155***	0.991218***	1	
dry leaves/tree	0.991163***	0.991225***	1***	1

Table 8
The correlations between the fresh weight of inflorescence (g), dry weight of inflorescence (g), fresh inflorescence\tree (g) and dry inflorescence\tree (g) across the salinity levels and seaweed concentrations.

	fresh weight of inflorescence	dry weight of inflorescence	fresh inflorescences/tree	dry inflorescences/tree
fresh weight of inflorescence	1			
dry weight of inflorescence	0.961217***	1		
fresh inflorescences/tree	0.932144***	0.930317***	1	
dry inflorescences/tree	0.909076***	0.93967***	0.99243***	1

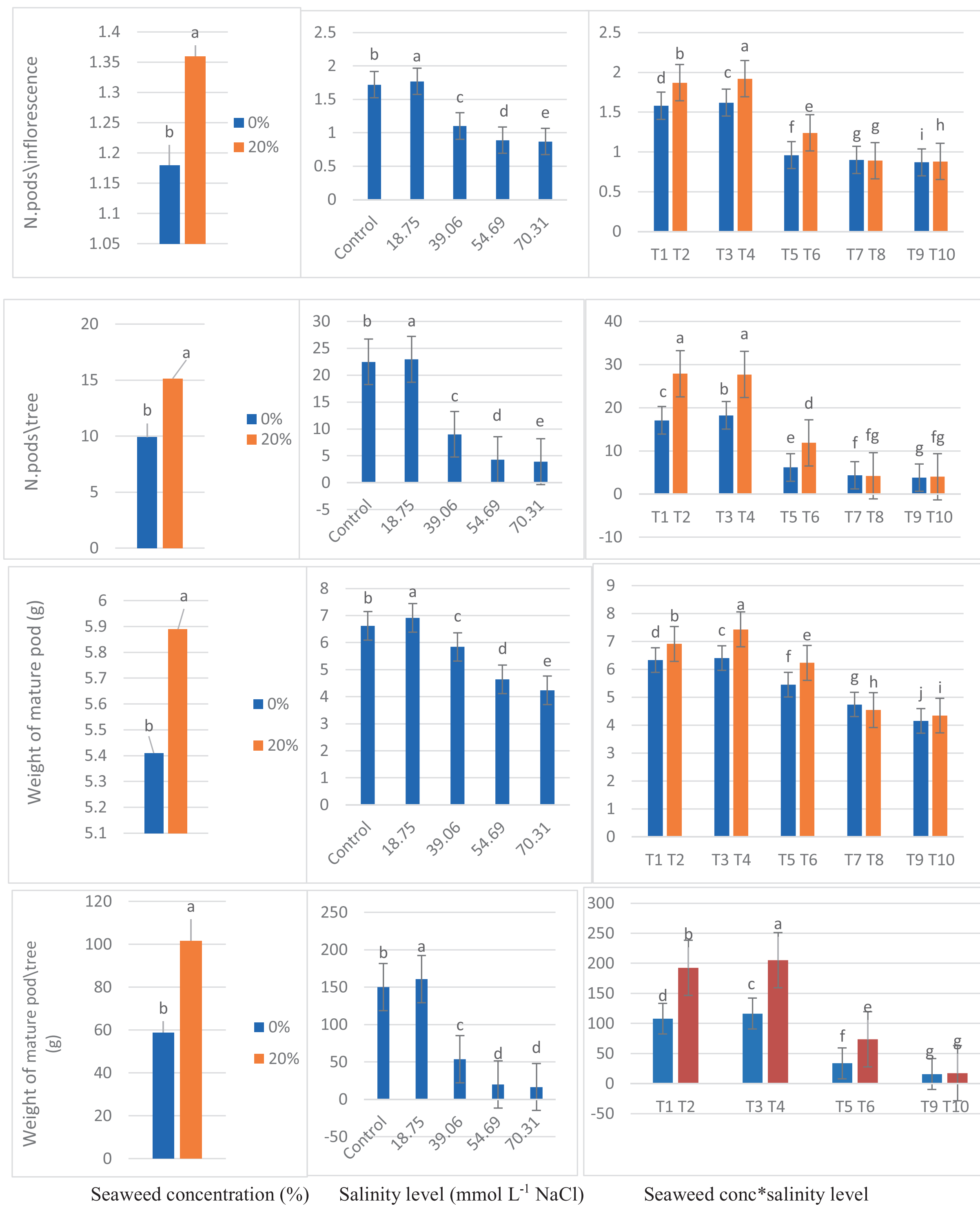

Fig. 4. Effect of seaweed concentrations, salinity levels and their interactions on pods number per inflorescence, the mature pod's weight (g), pods number per tree, the mature pod's weight per tree (g), seed's number per pod, seed weight (g) and seed yield per tree (g) traits.

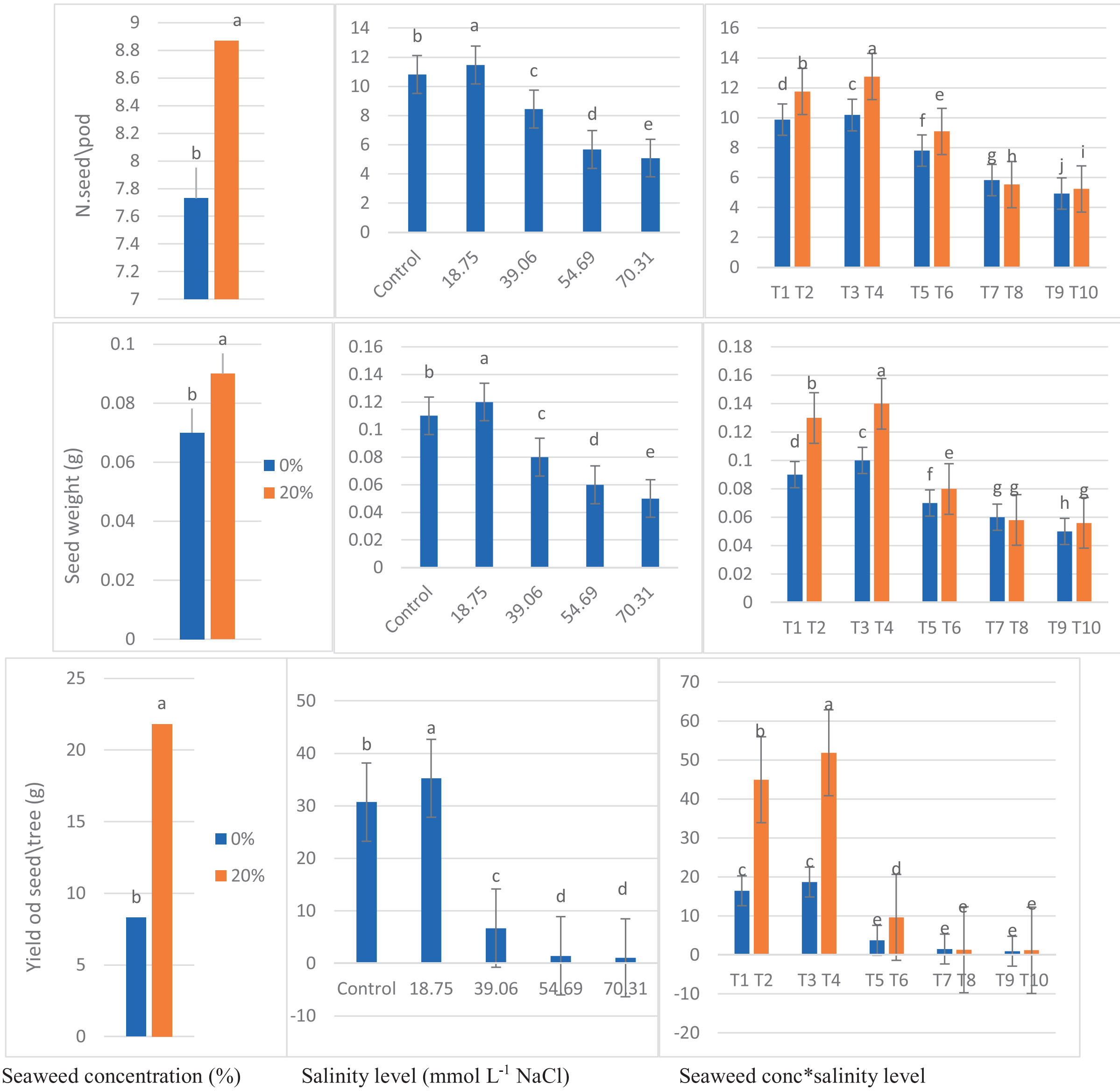

Fig. 4 (*continued*)

Table 9
The correlations between pod number per inflorescence, the mature pod's weight (g), pod number per tree, the mature pod weight per tree (g), seed number per pod, seed weight (g), and seed yield per tree (g) across the salinity levels and seaweed concentrations.

	N. pods/ inflorescenes	N. pods/ tree	Weight of mature pod	Weight of mature pod/ tree	N. seed / pod	Seed weight	Yield of seed/ tree
N. pods/inflorescenes	1						
N. pods/tree	0.987393***	1					
Weight of mature pod	0.947338***	0.929941***	1				
Weight of mature pod/ tree	0.982233***	0.995821***	0.931639***	1			
N. seed / pod	0.968706***	0.961322***	0.991997***	0.960086***	1		
Seed weight	0.961344***	0.97856***	0.956239***	0.984753***	0.977804***	1	
Yield of seed/tree	0.931165***	0.962552***	0.872383***	0.980248***	0.907231***	0.966691***	1

4. Discussion

4.1. Growth characteristics

Most trees, including moringa, have varying levels of salt tolerance, as do different plants (Farooq et al., 2022). According to Nouman et al. (2012), moringa plants have a fair amount of tolerance for salinity. The findings of the present study were in agreement with those of Elhag and Abdalla (2012), who found that moringa's development was hindered when exposed to high salt concentrations. Salinity stress is detrimental to the growth and development of moringa. According to Arif et al. (2020), this adverse effect of salt on moringa growth may be brought about by blocking K + and Ca2 + uptake as well as increasing Na + toxicity

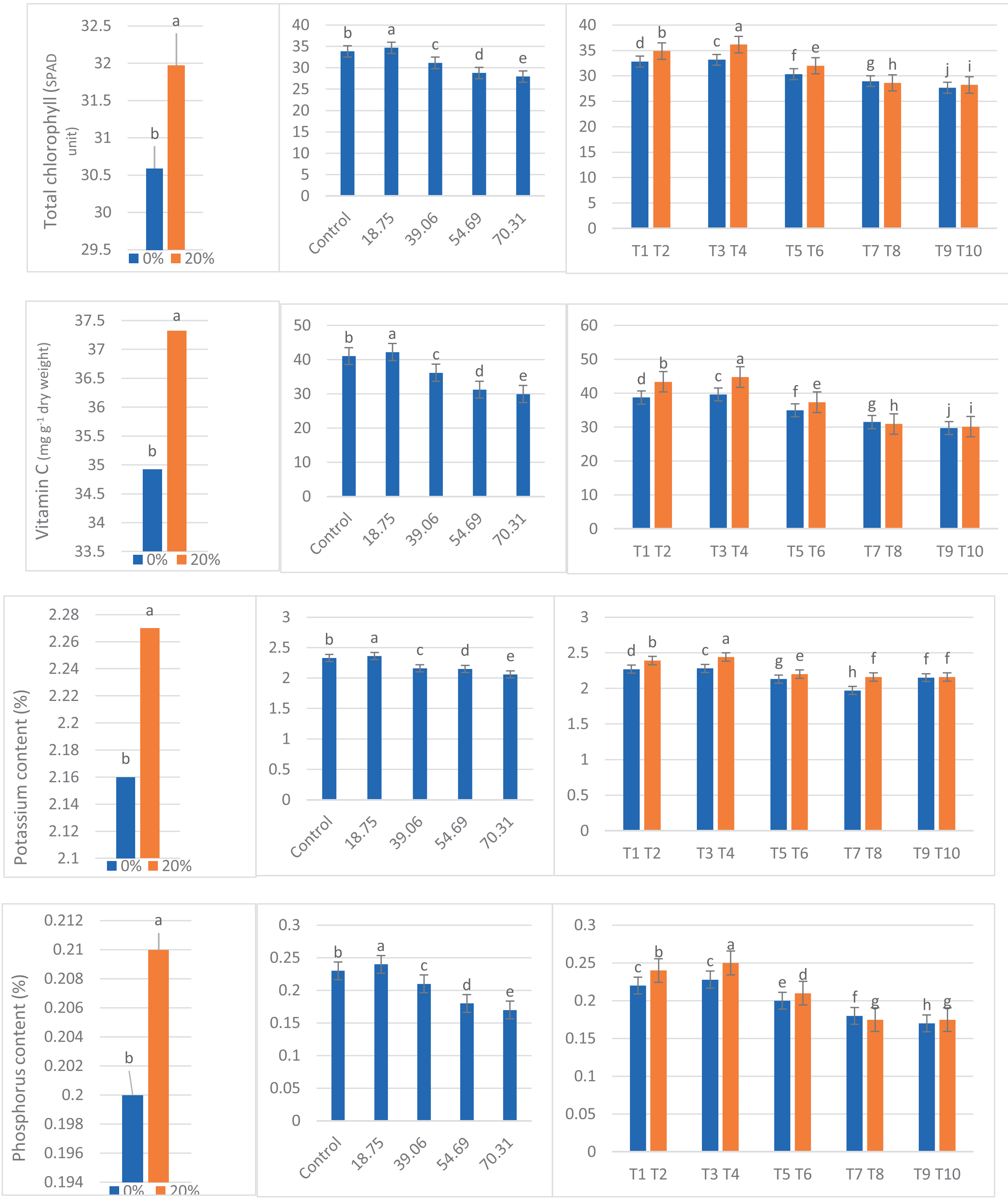

Fig. 5. Effect of seaweed concentrations, salinity levels and their interactions on total chlorophyll (SPAD unit), vitamin C content (mg/g dry weight), potassium content (%K_2O) and phosphorus content (% P_2O_5) traits.

Table 10
The correlations between total chlorophyll (SPAD unit), vitamin c content (mg/g dry weight), potassium content (%K_2O) and phosphorus content (% P_2O_5) across the salinity levels and seaweed concentrations.

	Chlorophyll	Vitamin c	Potassium	Phosphorus
Chlorophyll	1			
Vitamin c	0.987145***	1		
Potassium	0.879676***	0.838181***	1	
Phosphorus	0.984469***	0.996312***	0.833962***	1

at the high salinity level, which obstructs the plant's crucial function. Plant length and fresh and dry biomass are thus impacted (Fatima et al., 2018). Osmotic stress is exacerbated by salinity, which prevents water from being absorbed and transported. According to Sarker and Oba (2020), this inhibition results in hormone-induced sequential reactions that can lower the rate of photosynthetic activity, CO_2 assimilation, and stomatal opening. According to Atkin and Macherel (2009) and Sarker and Oba (2020), two other factors for the decline in growth could be the divergence of energy from growth to the homeostasis of salinity stress and a decrease in carbon gains. The current study's phenotypic findings all point to the possibility that salinity's detrimental effects on cell division and elongation are to blame for the decline in growth and biomass. Additionally, salinity results in nutritional imbalance, excessive ROS formation, and inhibition of enzymatic activities, all of which have a negative impact on biological membranes and cellular components, resulting in a reduction in biomass production (Ali et al., 2017; Alzahrani et al., 2019).

4.2. Physical and chemical parameters

Salinity is known to significantly reduce photosynthetic (chlorophyll *a*, b) activity, as reported in our work. High salt concentration reduced plant development and output by disrupting the photosynthetic machinery and altering the fine structure of cellular components by increasing reactive oxygen species (ROS) (Hasanuzzaman et al., 2014). A high NaCl concentration impacts photosynthesis, and prolonged salt stress reduces the production of the chlorophyll protein-lipid complex (Akbari Ghogdi et al., 2012). High salt levels resulted in a reduction in chlorophyll, which was in line with the findings of Soliman et al. (2015). Effective food uptake and consequent ion accumulations such sodium (Na +), chloride (Cl-), and potassium (K +) play a bigger role in osmoregulation during salinity stress (Liu et al., 2016). Numerous studies have shown that potassium and sodium have antagonistic relationships with a variety of other important ions (Abd-Allah et al., 2015). According to the latest findings, sodium absorption has improved, which has a negative impact on the uptake of other ions like potassium and phosphorus. The findings are consistent with those made by Yasmeen et al. (2013) and Iqbal et al. (2015) for Brassica juncea, which found decreased absorption of some important minerals including potassium and phosphorus for wheat.

4.3. Parameters of mature pods (dark brown pods) and seeds

The findings of the current study showed that high salt levels affected the characteristics of pods and seed. The similar result was found by Fatima et al. (2018). Due to ion toxicity and an instantaneous rise in anion and cation levels, high salt concentrations have a detrimental effect on plant growth (Panuccio et al., 2014). Furthermore, salinity stress results in an ion imbalance that makes Na and chloride hazardous, slowing the growth of seeds and pods and decrease they yield (Khajeh-Hosseini et al., 2003; Atteya et al., 2022).

4.4. Seaweed effect on yield, physical and chemical parameters of moringa

Because salt stress hinders root water uptake and results in a water deficit, it inhibits plant growth and production through its osmotic action (Pardo, 2010; Roy et al., 2014; Meng et al., 2020). This is because an increase in soil salt concentration coincides with a decrease in soil water potential. (Munns, 2005; Munns and Tester, 2008) Salt stress suppresses intracellular turgor and reduces cell growth. In addition to negatively affecting stomatal conductance, water scarcity also lowers biomass production and carbon fixation and absorption (Almeida et al., 2017). Because salt stress hinders root water uptake and results in a water deficit, it inhibits plant growth and production through its osmotic action (Pardo, 2010; Roy et al., 2014; Meng et al., 2020). This is because an increase in soil salt concentration coincides with a decrease in soil water potential. (Munns, 2005; Munns and Tester, 2008) Salt stress suppresses intracellular turgor and reduces cell growth. In addition to negatively affecting stomatal conductance, water scarcity also lowers biomass production and carbon fixation and absorption (Almeida et al., 2017). In actuality, the exogenous application of minerals or amino acids to increase plants' tolerance to salt. This was in connection with the advantageous benefits of seaweed extracts, which also contain polysaccharides, betaines, vitamins, and amino acids (Singh et al., 2016). Amino acids reduced the amount of Na in plant cells while increasing the concentration of macronutrients during salt stress (Abd El-Samad et al., 2010). By increasing biomass conversion per plant nitrogen, carbon produced from amino acids stimulates plant development (Franklin et al., 2017). Proline as one of these amino acids control the osmotic potential. By maintaining the osmotic strength of the cytosol with that of the vacuole and the surrounding environment, proline accumulation under stress situations protects the cell. Proline plays an important role in the protection of enzymes from damage and the stabilization of their structural integrity in addition to its role in osmoprotection (Rahneshan et al., 2018; Alzahrani et al., 2019). Semida et al. (2020) found that, exogenously administered proline improves photosynthetic efficiency, water consumption efficiency, and up-regulates osmoprotectants to increase growth and yield. From Table 4 in this study the used seaweed extract had a percentage of minirals in in its composition which have agreat role in increasing plants' tolerance to salinity such as Zn, Ca, and Mg. Through controlling the absorption of Na + and K + and influencing photosynthetic rate, zinc plays a significant role in regulating the nutritional balance (Jan et al., 2019). According to studies (Tobe et al., 2003; Zehra et al., 2012), calcium has been shown to diminish Na +'s negative effects and enhance plant development by inhibiting its uptake. By enhancing the activity of antioxidant enzymes that are directly engaged in the processing of active oxygen species and calcium catalyzes the interactions of these enzymes, calcium ions detoxified the oxidative molecules (Rental and Knight, 2004). The fundamental structural and metabolic components of plants require a significant amount of magnesium. With 75% of leaf Mg used in protein synthesis and 15–20% of all Mg being linked to chlorophyll pigments, Mg is the main constituent of chlorophyll molecules and is particularly important to plants (White et al., 2009). The structural stabilization of tissues, including nucleic acids, proteins, cell membranes, and walls, as well as several enzyme activities, are other functions of this element (Sreedhara and Cowan, 2002).

According to Bulgari et al (2019), seaweed extracts have been shown to help plants retain water and minimize water loss. A decrease in chlorophyll concentration, a slower rate of photosynthetic respiration, and decreased plant health and production were all effects of salinity stress, which also activated the enzymes that break down chlorophyllase and lowered nitrogen uptake (Krishnamurthy et al., 2007; Paul and Lade, 2014). Our research showed that seaweed has positive effects on plant productivity and quality attributes, supporting the findings of Mzibra et al. (2018) and Pramanick et al. (2017). Enhancing plant development, agricultural production, and tolerance to biotic challenges like salinity and drought are some benefits of seaweed, claim Arioli et al. (2015). In accordance with the results of our investigation, Mansori et al. (2015) found that seaweed extract increased a number of biochemical and physiological indicators as well as growth metrics in bean plants under both drought-stressed and non-stress circumstances.

5. Conclusion

Salinity levels had an effect on the growth, physical, chemical, and inflorescence parameters of *Moringa oleifera* in the current study. It might be argued that growing moringa with seaweed can improve plant development and yield when salinity stress is present. Future research might examine this component to determine the maximal survival potential of moringa under abiotic challenges, notably salt stress. Therefore, we support increased interest in Moringa planting and financial investments.

Funding

The Saudi Arabian Ministry of Education's Deputyship for study & Innovation, which provided money for this study work under the project number S-1443-0012, is acknowledged by the authors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abd El-Samad, H.M., Shaddad, M.A.K., Barakat, N., 2010. The role of amino acids in improvement in salt tolerance of crop plants. J. Stress Physiol. Biochem. 6, 25–37.

Abd_Allah, E. F., Hashem, A., Alqarawi, A. A., Bahkali, A. H., Alwhibi, M. S. 2015. Enhancing growth performance and systemic acquired resistance of medicinal plant *Sesbania Sesban* (L.) Merr Using Arbuscular Mycorrhizal Fungi under Salt Stress. Saudi J. Biol. Sci. 22 (3), 274–283.

Abdel Latef, A., 2010. Changes of antioxidative enzymes in salinity tolerance among different wheat cultivars. Cereal Res. Commun. 38 (1), 43–55.

Abdel Latef, A.A., Tran, L.S.P., 2016. Impacts of priming with silicon on the growth and tolerance of maize plants to alkaline stress. Front. Plant Sci. 7 (MAR2016), 1–10. https://doi.org/10.3389/fpls.2016.00243.

Ahmad, P., Latef, A. A. A., Hashem, A., Abd Allah, E. F., Gucel, S., Tran, L. S. P. 2016. Nitric oxide mitigates salt stress by regulating levels of osmolytes and antioxidant enzymes in chickpea. Front. Plant Sci. 7 (MAR2016), 1–11. https://doi.org/10.3389/fpls.2016.00347.

Akbari Ghogdi, E., Izadi-Darbandi, A., Borzouei, A., 2012. Effects of salinity on some physiological traits in wheat (Triticum aestivum L.) cultivars. Indian J. Sci. Technol. 5, 1–6. https://doi.org/10.17485/ijst/2012/v5i1.23.

Ali, Q., Daud, M.K., Zulqurnain, M., Ali, S., 2017. Seed priming by sodium nitroprusside improves salt tolerance in wheat (Triticum aestivum L.) by enhancing physiological and biochemical parameters. Plant Physiol. Biochem. 119, 50–58. https://doi.org/10.1016/j.plaphy.2017.08.010.

Ali, A.H., Said, E.M., Abdelgawad, Z.A., 2022. The Role of seaweed extract on improvement drought tolerance of wheat revealed by osmoprotectants and DNA (CpDNA) Markers. Rev. Bras. Bot. 45 (3), 857–867. https://doi.org/10.1007/s40415-022-00820-5.

Almeida, D.M., Oliveira, M.M., Saibo, N.J.M. 2017. Regulation of Na+ and K+ homeostasis in plants: Towards improved salt stress tolerance in crop plants. Genet. Mol. Biol. 40, 326–345. [CrossRef].

Alzahrani, S.M., Alaraidh, I.A., Migdadi, H., Alghamdi, S., Altaf Khan, M., Ahmad, P., 2019. Physiological, biochemical, and antioxidant properties of two genotypes of *Vicia faba* grown under salinity stress. Pak. J. Bot. 51, 786–798. https://doi.org/10.30848/PJB2019-3(3).

Anwar, F., Bhanger, M.I., 2003. Analytical Characterization of *Moringa Oleifera* seed oil grown in temperate regions of pakistan. J. Agric. Food Chem. 51 (22), 6558–6563. https://doi.org/10.1021/jf0209894.

Arif, Y., Singh, P., Siddiqui, H., Bajguz, A., Hayat, S., 2020. Salinity induced physiological and biochemical changes in plants: an omic approach towards salt stress tolerance. plant physiol. Biochem. 156, 64–77.

Arioli, T., Mattner, S.W., Winberg, P.C., 2015. Applications of seaweed extracts in australian agriculture: past, present and future. J. Appl. Phycol. 27 (5), 2007–2015.

Aslam, M., Anwar, F., Nadeem, R., Rashid, U., Kazi, T.G., Nadeem, M., 2005. Mineral composition of *Moringa Oleifera* leaves and pods from different regions of Punjab, Pakistan. Asian J. Plant Sci. 4, 417–421.

Atkin, O.K., Macherel, D., 2009. The crucial role of plant mitochondria in orchestrating drought tolerance. Ann. Bot. 103, 581–597. https://doi.org/10.1093/aob/mcn094.

Atteya, A.K.G., El-Serafy, R.S., El-Zabalawy, K.M., Elhakem, A., Genaidy, E.A.E., 2022. Exogenously supplemented proline and phenylalanine improve growth, productivity, and oil composition of salted moringa by up-regulating osmoprotectants and stimulating antioxidant machinery. Plants 11 (12), 1553.

Bulgari, R., Franzoni, G., Ferrante, A. 2019. Biostimulants application in horticultural crops under abiotic stress conditions. Agronomy. 9, 306. [CrossRef].

Chow, W.S., Ball, M.C., Anderson, J.M., 1990. Growth and photosynthetic responses of spinach to salinity: Implications of K+ Nutrition for Salt Tolerance. Funct. Plant Biol. 17 (5), 563–578.

Cottenie, A., Verloo, M., Kikens, L., Velghe, G., Camerlynck, R. 1982. Analytical problems and method in chemical plant and soil analysis. Hand B. Ed. A. Cottenie, Gent, Belgium. 190.

Elhag, A.Z., Abdalla, M.H., 2012. Effect of sodium chloride on germination and emergence of moringa (Moringa Oleifera L.) seeds. J. Sci. Tech. 13, 62–67.

Farooq, F., Rashid, N., Ibrar, D., Hasnain, Z., Ullah, R., Nawaz, M., Irshad, S., Basra, S.M.A., Alwahibi, M.S., Elshikh, M.S., 2022. Impact of varying levels of soil salinity on emergence, growth and biochemical attributes of four *Moringa Oleifera* Landraces. PLoS One 17 (2), e0263978.

Fatima, N., Akram, M., Shahid, M., Abbas, G., Hussain, M., Nafees, M., Wasaya, A., Tahir, M., Amjad, M., 2018. Germination, growth and ions uptake of moringa (Moringa Oleifera L.) grown under saline condition. J. Plant Nutr. 41 (12), 1555–1565.

Franklin, O., Cambui, C.A., Gruffman, L., Palmroth, S., Oren, R., Näsholm, T. 2017. The carbon bonus of organic nitrogen enhances nitrogen use efficiency of plants. Plant Cell Environ. 40, 25–35. [CrossRef].

Ghazali, Q., Yasin, N.H.M., 2016. The effect of organic solvent, temperature and mixing time on the production of oil from *Moringa oleifera* seeds. IOP Conf. Ser. Earth Environ. Sci. 36 (1). https://doi.org/10.1088/1755-1315/36/1/012053.

Harris, G.K., and Marshall, M.R. 2017. Ash Analysis. Ch. 16, in Food Analysis, 5th ed. S.S. Nielsen (Ed.), Springer, New York.

Hasanuzzaman, M., Alam, M., Rahman, A., Hasanuzzaman, M., Nahar, K., Fujita, M. 2014. Exogenous proline and glycine betaine mediated upregulation of antioxidant defense and glyoxalase systems provides better protection against salt-induced oxidative stress in two rice (*Oryza Sativa* L.) varieties. Biomed Res. Int. 2014.

Iqbal, N., Umar, S., Khan, N.A., 2015. Nitrogen availability regulates proline and ethylene production and alleviates salinity stress in mustard (Brassica Juncea). J. Plant Physiol. 178, 84–91.

Islam, F., Wang, J., Farooq, M. A., Yang, C., Jan, M., Mwamba, T. M., et al. 2019. Rice responses and tolerance to salt stress," in Advances in Rice Research for Abiotic Stress Tolerance. eds. M. Hasanuzzaman, M. Fujita, K. Nahar and J. Biswas (Cambridge: Woodhead Publishing), 791–819.

Jackson, M.L., 1973. Vanadomolybdo phosphoric yellow colour method for determination of phosphorus. Soil Chem. Anal., 151–154

Jama, B., Nair, P.K.R., Kurira, P.W., 1989. Comparative growth performance of some multipurpose trees and shrubs grown at machakos, Kenya. Agrofor. Syst. 9 (1), 17–27.

Jan, R., Khan, M.A., Asaf, S., Lubna, Lee, I.J. and Kim, K.M. 2019. Metal resistant endophytic bacteria reduces cadmium, nickel toxicity and enhances expression of metal stress related gene with improved growth of *Oryza sativa* via regulating its antioxidant machinery and endogenous hormones. Plants, 8, Article No. 363. https://doi.org/10.3390/plants8100363 https://pubmed.ncbi.nlm.nih.gov/31547575/.

Khajeh-Hosseini, M., Powell, A.A., Bingham, I.J., 2003. The interaction between salinity stress and seed vigour during germination of soyabean seeds. Seed Sci. Technol. 31 (3), 715–725.

Krishnamurthy, L., Serraj, R., Hash, C.T., Dakheel, A.J., Reddy, B.V.S., 2007. Screening sorghum genotypes for salinity tolerant biomass production. Euphytica 156, 15–24 [CrossRef].

Layek, J., Das, A., Idapuganti, R.G., Sarkar, D., Ghosh, A., Zodape, S.T., Lal, R., Yadav, G.S., Panwar, A.S., Ngachan, S., 2018. Seaweed extract as organic bio-stimulant improves productivity and quality of rice in eastern himalayas. J. Appl. Phycol. 30 (1), 547–558.

Liu, W., Zhang, Y., Yuan, X., Xuan, Y., Gao, Y., Yan, Y., 2016. Exogenous salicylic acid improves salinity tolerance of *Nitraria Tangutorum*. Russ. J. Plant Physiol. 63 (1), 132–142. https://doi.org/10.1134/S1021443716010118.

Lötze, E., Hoffman, E.W., 2016. Nutrient composition and content of various biological active compounds of three south african-based commercial seaweed biostimulants. J. Appl. Phycol. 28 (2), 1379–1386.

Mansori, M., Chernane, H., Latique, S., Benaliat, A., Hsissou, D., El Kaoua, M., 2015. Seaweed extract effect on water deficit and antioxidative mechanisms in bean plants (Phaseolus Vulgaris L.). J. Appl. Phycol. 27 (4), 1689–1698.

Melsse, A., Berihun, K., 2013. Chemical and mineral compositions of pods of *Moringa Stenopetala* and *Moringa Oleifera* cultivated in the Lowland of Gamogofa Zone. J. Environ. Occup. Sci. 2 (1), 33–38.

Meng, Y., Yin, Q., Yan, Z., Wang, Y., Niu, J., Zhang, J., Fan, K., 2020. Exogenous silicon enhanced salt resistance by maintaining K+/Na+ homeostasis and antioxidant performance in alfalfa leaves. Front. Plant Sci. 11, 1183 [CrossRef] [PubMed].

Munns, R., 2002. Comparative physiology of salt and water stress. Plant Cell Environ. 25 (2), 239–250.

Munns, R., 2005. Genes and salt tolerance: Bringing them together. New Phytol. 167, 645–663 [CrossRef] [PubMed].

Munns, R., Tester, M. 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol. 59, 651–681. [CrossRef].

Mzibra, A., Aasfar, A., El Arroussi, H., Khouloud, M., Dhiba, D., Kadmiri, I.M., Bamouh, A., 2018. Polysaccharides extracted from moroccan seaweed: a promising source of tomato plant growth promoters. J. Appl. Phycol. 30 (5), 2953–2962.

Nielsen, S.S., Nielsen, S.S., 2017. Vitamin C determination by indophenol method. Food Anal. Lab. Manual, 143–146.
Nouman, W., Siddiqui, M.T., Basra, S.M.A., Khan, R.A., Gull, T., Olson, M.E., Hassan, M., 2012. Response of *Moringa Oleifera* to saline conditions. Int. J. Agric. Biol. 14 (5).
Olson, M.E., Carlquist, S., 2001. Stem and root anatomical correlations with life form diversity, ecology, and systematics in moringa (Moringaceae). Bot. J. Linn. Soc. 135 (4), 315–348.
Panuccio, M.R., Jacobsen, S.E., Akhtar, S.S., Muscolo, A., 2014. Effect of saline water on seed germination and early seedling growth of the halophyte quinoa. AoB Plants 6, plu047.
Pardo, J.M., 2010. Biotechnology of water and salinity stress tolerance. Curr. Opin. Biotechnol. 21, 185–196.
Paul, D., Lade, H., 2014. Plant-growth-promoting rhizobacteria to improve crop growth in saline soils: A review. Agron. Sustain. Dev. 34, 737–752.
Pramanick, B., Brahmachari, K., Mahapatra, B.S., Ghosh, A., Ghosh, D., Kar, S., 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 (6), 3253–3260.
Rady, M.M., 2011. Effect of 24-Epibrassinolide on growth, yield, antioxidant system and cadmium content of bean (Phaseolus Vulgaris L.) plants under salinity and cadmium stress. Sci. Hortic. 129 (2), 232–237.
Rahneshan, Z., Nasibi, F., Moghadam, A.A., 2018. Effects of salinity stress on some growth, physiological, biochemical parameters and nutrients in two pistachio (Pistacia vera L.) rootstocks. J. Plant Interact. 13, 73–82. https://doi.org/10.1080/17429145.2018.1424355.
Ramoliya, P.J., Pandey, A.N., 2003. Effect of salinization of soil on emergence, growth and survival of seedlings of *Cordia Rothii*. For. Ecol. Manage. 176 (1–3), 185–194.
Rental, M.C., Knight, M.R., 2004. Oxidative stress-induced calcium signaling in Arabidopsis. Plant Physiol. 135, 1471–1479.
Rodríguez, A., Stella, A., Storni, M., Zulpa, G., Zaccaro, M. 2006. Effects of cyanobacterial extracellular products and gibberellic acid on salinity tolerance in *Oryza Sativa* L. saline systems. 2 (1), 1–4. https://doi.org/10.1186/1746-1448-2-7.
Roy, S.J., Negrão, S., Tester, M., 2014. Salt resistant crop plants. Curr. Opin. Biotechnol. 26, 115–124 [CrossRef] [PubMed].
Saadatnia, H., Riahi, H., 2009. Cyanobacteria from paddy fields in Iran as a biofertilizer in rice plants. Plant Soil Environ. 55 (5), 207–212. https://doi.org/10.17221/384-pse.
Sahu, D., Priyadarshani, I., Rath, B., 2012. Cyanobacteria -as potential biofertilizer. CIBTech J. Microbiol. 1 (2–3), 20–26.
Sánchez, N.R., Ledin, S., Ledin, I., 2006. Biomass production and chemical composition of *moringa oleifera* under different management regimes in Nicaragua. Agrofor. Syst. 66 (3), 231–242. https://doi.org/10.1007/s10457-005-8847-y.
Sanower-Hossain, M., 2019. Present scenario of global salt affected soils, its management and importance of salinity research. Int. Res. J. Biol. Sci. 1, 1–3.
Sarker, U., Oba, S., 2020. The response of salinity stress-induced A. tricolor to growth, anatomy, physiology, non-enzymatic and enzymatic antioxidants. Front. Plant Sci. 11,. https://doi.org/10.3389/fpls.2020.559876 559876.
Semida, W.M., Abdelkhalik, A., Rady, M.O., Marey, R.A., Abd El-Mageed, T.A., 2020. Exogenously applied proline enhances growth and productivity of drought stressed onion by improving photosynthetic efficiency, water use efficiency and up-regulating osmoprotectants. Sci. Hortic. 272, [CrossRef] 109580.
Singh, S., Singh, M.K., Pal, S.K., Trivedi, K., Yesuraj, D., Singh, C.S., Anand, K.G.V., Chandramohan, M., Patidar, R., Kubavat, D., 2016. Sustainable enhancement in yield and quality of rain-fed maize through gracilaria edulis and kappaphycus alvarezii seaweed sap. J. Appl. Phycol. 28 (3), 2099–2112.
Soliman, A.S., El-feky, S.A., Darwish, E., 2015. Alleviation of salt stress on *Moringa Peregrina* using foliar application of nanofertilizers. J. Hortic. For. 7 (2), 36–47.
Sreedhara, A., Cowan, J.A., 2002. Structural and catalytic roles for divalent magnesium in nucleic acid biochemistry. Biometals 15, 211–223 [CrossRef].
Subramanian, G., Uma, L., 1996. Cyanobacteria in pollution control. J. Sci. Ind. Res. 55, 685–692.
Tobe, K., Zhang, L., Omasa, K., 2003. Alleviatory effects of calcium on the toxicity of sodium, potassium and magnesium chlorides to seed germination in three non-halophytes. Seed Sci. Res. 13, 47–54.
Van Oosten, M.J., Pepe, O., De Pascale, S., Silletti, S., Maggio, A., 2017. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. Chem. Biol. Technol. Agric. 4 (1), 1–12.
Ward, R.E., Legako, J.F. 2017. Traditional methods for mineral analysis. Ch. 21, in Food Analysis, 5th ed. S.S. Nielsen (Ed.), Springer, New York.
White, P.J., Broadley, M.R., 2009. Biofortification of crops with seven mineral elements often lacking in human diets—Iron, zinc, copper, calcium, magnesium, selenium and iodine. New Phytol. 182, 49–84.
Yasmeen, A., Basra, S.M.A., Farooq, M., Hussain, N., 2013. Exogenous application of moringa leaf extract modulates the antioxidant enzyme system to improve wheat performance under saline conditions. Plant Growth Regul. 69 (3), 225–233.
Zehra, B., Gul, R., Ansari, M.A.K., 2012. Role of calcium in alleviating effect of salinity on germination of Phragmites karka seeds. S. Afr. J. Bot. 78, 122–128.