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Mitigation the adverse effect of salinity stress on the performance of the tomato crop by exogenous application of chitosan

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Abstract

Background: In recent years, ecofriendly compounds such as chitosan has been used to alleviate the destructive effects of salt stress. Chitosan is a natural biodegradable compound with no toxicity in nature and act as a stress tolerance inductor involved in physiological processes and prevent water loss through transpiration. Tomato cv. Rio Grande grown in pots was subjected with salinity stress in the form of 4 levels (0, 50, 100 and 150 mM) whose effect was mediated by treating it with different concentration of chitosan (0, 50, 100 and 150 mg L^{-1}).

Results: The data revealed that various application of salinity had a negative effect on almost all the studied parameters. Tomato plants treated with distilled water having no salinity (control) recorded maximum plant height (cm), average number of compound leaves $plant^{-1}$, leaf area (cm^2), stem diameter (mm), number of fruits $plant^{-1}$, fruit firmness (kg cm^{-2}), leaf chlorophyll content (SPAD), fruit juice pH, yield $plant^{-1}$ (kg) and minimum total soluble solids (Brix°). Whereas, minimum plant height (cm), average number of compound leaves $plant^{-1}$, leaf area (cm^2), stem diameter (mm), number of fruits $plant^{-1}$, fruit firmness (kg cm^{-2}), leaf chlorophyll content (SPAD), fruit juice pH, yield $plant^{-1}$ (kg) and maximum total soluble solids (Brix°) were found in plants treated with salinity level of 150 mM. Chitosan concentration of 150 mg L^{-1} significantly mediated the effect of salinity stress and recorded maximum plant height (cm), average number of compound leaves $plant^{-1}$, leaf area (cm^2), stem diameter (mm), number of fruits $plant^{-1}$, fruit firmness (kg cm^{-2}), leaf chlorophyll content (SPAD), total soluble solids (Brix°) and yield $plant^{-1}$ (kg) with minimum fruit juice pH.

Conclusion: It is concluded that foliar application of chitosan at the rate of 150 mg L^{-1} and salinity stress 150 mM could have positive impact on performance of tomato.

Keywords: Abiotic stress, Chitosan, Salinity, Tomato, Quality, Growth

Background

Salinity has become a severe threat among various abiotic stresses. It has affected around one-third of irrigated land on the earth (Akladious and Mohamed 2018) which negatively affect the performance of plants. Salinity is an extreme stress which limits plant growth (Latif and Mohamed 2016). It affects the structure of soil and nutrient availability. It also affects the water and nutrients uptake of the plants (Sofy et al. 2020b). In Pakistan, salinity is known as the main problem of the soil, which negatively affects plant growth and production (Shahid et al. 2011). Salinity decreases plant growth and yield due to increased efficacy in water use and changes the plant metabolism (Munns 2002). Salinity effects seed germination, plant growth, photosynthesis, lipid metabolism, deoxyribonucleic acid (DNA), ribonucleic acid (RNA), protein synthesis and mitosis (Niu et al. 2013). One of the

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key problems causing a drastic decrease in plant growth, production and yield is drought stress. Chitosan use helps to induce resistance to drought and increase the quality of water use (Khan et al. 2020).

Chitosan is a natural, less toxic and economical compound that is biodegradable and environmentally safe with numerous agricultural applications (Basit et al. 2020). It is healthy and nutritious for both animals and plants. Chitosan is made from D-glucosamine and N-acetyl-D-glucosamine. It is made when the acetyl group of chitins is replaced with an amino group (Sofy et al. 2020a; Sugiyama et al. 2001). It is the most commonly available basic biopolymer and has structural similarity with cellulose (de Alvarenga 2011). Chitosan is widely used for Post-harvest coating to improve shelf life and also used to improve growth and yield (Haytova 2013). It also improves plant defense mechanism against both biotic and abiotic stress (Sofy et al. 2020a). Chitosan enhances both qualitative and quantitative characteristics of crops because it promotes nutrient uptake of the plant (Malerba and Cerana 2016). Chitosan is used as both soil treatment and foliar spray and induce stress tolerance and improves performances of plants (Ortiz et al. 2007). Chitosan plays an important role inside plant body such as it activates several enzymes against many stresses. Nowadays Chitosan is mostly used as a growth promoter because of its organic nature, environment-friendly and biodegradable properties. It improves the plants resistance to stresses.

Tomato (*Lycopersicon esculentum*) belongs to Solanaceae family (Night shaded family) mostly grown in almost all region of the world. It is grouped as the world 2nd essential vegetable crop, grown in almost all countries of the world (Megahed et al. 2013). It is cultivated in tropical and sub-tropical area of the word (Nicola et al. 2009). In Pakistan, tomato is grown on a large area and the total area under its cultivation is 60.7 thousand hectares with a production of 570.6 thousand tons. Tomatoes play a crucial role in human diet because of its taste and nutritional value. Tomatoes are hermaphrodite, susceptible to high temperature, which affect the fruit set and size. The optimum temperature for fruit set formation is 25 to 30 °C (Anonymous 1999). It performs well in sandy and heavy clay soil with soil pH of 5.5 to 7.5. Tomato is mostly consumed in fresh form and also used in processed form (Beutner et al. 2001). Tomato yield is affected due to many problems such as biotic, abiotic stress, use of low yielding varieties, improper use of fertilizers, insects and pest management that causes serious damage to the crop. Tomato plants require proper nutrition during its growth period for attaining optimum yield. Its plant requires relative cool climate with proper sunshine for better growth and development. Flowers abortion might occur when temperature is increased (Sofy et al. 2012; Srinivasan 2010).

The goal of this study was to determine the role of chitosan on tomato performance, growth and yield under salinity stress condition.

Methods

Plant material

Seeds of tomato cultivar (Rio Grande) were taken from breeding section at Agriculture Research Institute Tarnab, Peshawar.

Experimental procedures

The experiment was conducted in plastic pots laid out in Complete Randomized Design (CRD) with factorial arrangement and size of plastic bags was (11 × 14 inches) containing 4 kg soil comprise of farmyard manure, clay and sand mixed in equal ratio (1:1:1). The pots were divided into four main irrigation groups with different saline solution levels using NaCl solutions at 0, 50,100 and 150 mM. Each of the previous groups was split into four subgroups and foliar sprayed with distinct chitosan concentrations (0.0, 50, 100 and 150 mg L^{-1}). There were five replicates distributed in a fully randomized design for each treatment. Total number of plants in each treatment was 12. After 7 days of transplantation, the pots were irrigated 2 weeks with the four levels of NaCl (0, 50.100 and 150 mM). Foliar application of chitosan was sprayed after 14 days of transplantation and it was sprayed 3 times during research. Samples were taken at the end of experiment to determine the morphological measurements and biochemical analysis. The morphological measurements were plant height (cm), average number of compound leaves $plant^{-1}$, leaf area (cm^2), stem diameter (mm), No of fruits $plant^{-1}$, average fruit weight (g), fruit firmness (kg cm^{-2}) and yield $plant^{-1}$ (kg). In addition, some biochemical parameters such as leaf chlorophyll content, total soluble solids (Brix0) and fruit juice pH.

Soil analysis

A soil sample of 10 g was collected from the media and brought to Department of Soil and Environmental Sciences, The University of Agriculture Peshawar, Pakistan. The sampled soil was poured into 50 ml distill water, mixed for 50 min through shaker and then was filtered through Whatman filter paper. After the filtration the salinity was determined through electrical conductivity meter, the probe of electrical conductivity was putted in the sample and the reading was noted which was 0.67 dsm^{-1}. The soil pH was also determined with help of pH meter which was 8.1 (Table 1).

Table 1 Soil physical and chemical properties

No	Properties	Values	Method applied
1	Sand	22%	Hydrometer
2	Silt	33%	Hydrometer
3	Clay	45%	Hydrometer
4	pH	8.01	pH Meter
5	Electrical conductivity	0.67 dsm^{-1}	5:1 (water: soil)

Fruit firmness ($kg\ cm^{-2}$)

Usage of a penetrometer (Model-Wagner FT-327, fruit firmness analyzer) to test the firmness of tomato fruits (Basit et al. 2020). Five fruits from each plant in each treatment were randomly picked for determining firmness.

Biochemical parameters

Leaf chlorophyll content

Chlorophyll content was determined using a spade meter. In each treatment, three randomly leaves were chosen and their average was determined. Total soluble solids ($Brix^0$).

It was determined with help of hand refractometer. Fruit juice was extracted and passed from mesh to remove the seeds and then juice drop were poured on hand refractometer and the TSS were measured.

Statistical analysis

The experimental recorded data were subjected to analysis of variance (ANOVA) method to find the difference between different treatments and their interactions, while least significant difference (LSD) was used to determine the mean difference at 1 and 5% level of significance (Steel and Torrie 1997). Statistical software STATISTIX 8.1 was used for calculating ANOVA and LSD.

Results

Plant height (cm)

Average plant height data are shown in Figs. 1 and 2. The data in (Tables 2, 3) regarding plant height of tomato was significantly affected by various levels of salinity and different foliar application of chitosan and their interaction was found significant effect. Plant height of tomato was significantly decreased with increasing salinity level as compared with unstressed plants. The maximum value of plant height (64.81 cm) was found in control plants, while the minimum value of plant height (55.750 cm) was noted in plants treated with the high concentrations of salinity (150 mM). Regarding chitosan foliar application, maximum value of plant height (63.75 cm) was noted in plants treated with 150 mg L^{-1} of chitosan concentration, while minimum value (57.10 cm) was found in plants treated with control treatment of chitosan. All concentrations of chitosan can alleviate the adverse effect of salinity levels (Table 2). The most pronounced increases were detected in plants treated with 150 mg L^{-1} of chitosan at all salinity level as compared with salt stressed plants.

Average number of compound leaves $plant^{-1}$

The data in Tables 2 and 3 regarding average number of leaves $plant^{-1}$ of tomato was significantly affected by different salinity levels and foliar application of chitosan and interaction of salinity stress levels and sprayed with chitosan was found significant at $p \leq 0.05$. The maximum average number of leaves $plant^{-1}$ (21.99) was found in unstressed plants, while the minimum average number of leaves $plant^{-1}$ (11.99) were noted in plants treated with the high concentrations of salinity level of 150 mM. In addition, maximum average number of leaves $plant^{-1}$ (20.07) were recorded in plants treated with 150 mg L^{-1} chitosan concentration, while minimum average number of leaves $plant^{-1}$ (11.91) were found in control plants (Figs. 1, 2). Foliar spray with 150 mg L^{-1} chitosan caused significantly increased in the average number of leaves $plant^{-1}$ as compared with salt stressed plants (Table 2).

Leaf area (cm^2)

Leaf area of tomato was significantly affected by various levels of salinity and foliar sprayed with chitosan and their interaction was found significant at $p \leq 0.05$. The leaf area was decreased significantly with increasing salinity level, for example at 150 mM which showed minimum value (15.96 cm^2) as compared with control plants which showed high value (19.19 cm^2). In addition, foliar application with 150 mg L^{-1} chitosan showed the maximum leaf area value (18.53 c m^2) as compared with control plants which recorded minimum leaf area (16.87 cm^2) an (Table 2 and Figs. 1, 2). In comparison to salt-stressed plants, all chitosan concentrations induced a substantial increase in the leaf area (Table 2).

Stem diameter (mm)

Data in Tables 2 and 3 show that the maximum value of stem diameter (10.37 mm) were recorded in control plants, while the minimum value of stem diameter (9.09 mm) was noted in plants treated with the high salinity level of 150 mM. Moreover, chitosan foliar application showed significantly increased in stem diameter as compared to salt stressed plants. The most pronounced increases have been observed in plants treated with chitosan 150 mg L^{-1} (Figs. 1, 2).

Number of fruits $plant^{-1}$ and average fruit weight (g)

The data in Tables 2 and 3 showed the highest number of fruits $plant^{-1}$ (23.00) and fruit weight (64.31 g) were

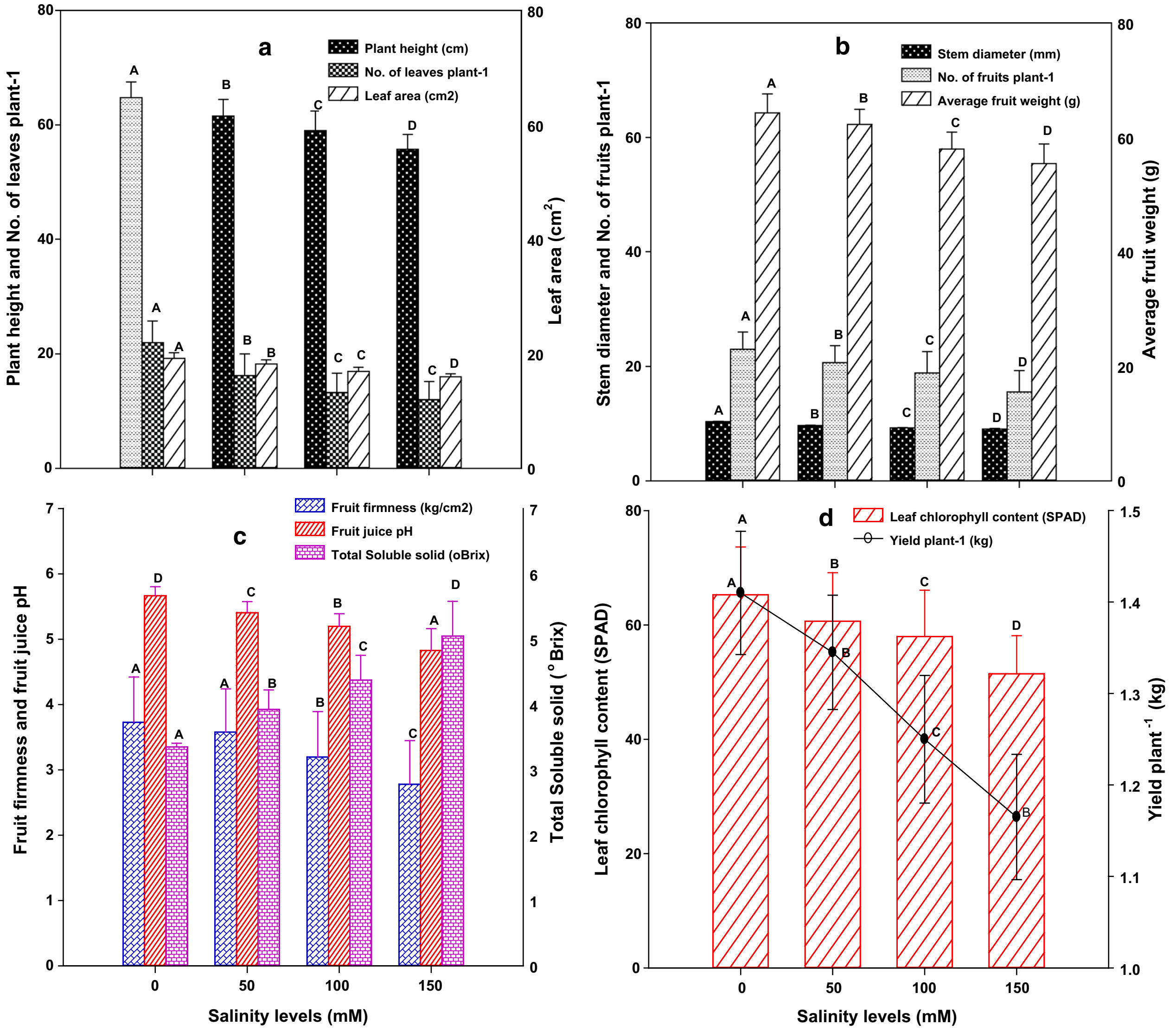

Fig. 1 Changes in morphological, yield and quality related attributes of tomato as affected by different salinity levels. Each value is a mean (± SE) of 3 replications, and the different letters in each bar indicate a significant difference (LSD $p \leq 0.05$)

found in control plants while the least fruits plant^{-1} (15.83) and fruit weight (55.43 g) were noted in plants grown under high salinity stress level (150 mM). Also, chitosan foliar application showed the highest fruits plant^{-1} (23.58) and fruit weight (64.35 g) were noted in 150 mg L^{-1}, while the minimum number of fruits plant^{-1} (15.66) and fruit weight (57.26 g) was found in control treatment of chitosan (Figs. 1, 2). All concentrations of chitosan caused significantly increased in number of fruits plant^{-1} and fruit weight as compared to salt stressed plants (Table 2).

Fruit firmness (kg cm^{-2}) and fruit juice pH

Fruit firmness of tomato was significantly affected by various levels of salinity and chitosan alone and/or interaction between salinity and chitosan. The maximum average fruit firmness (3.73 kg cm^{-2}) and fruit juice pH (5.66) was found in untreated plants, while the minimum fruit firmness (2.78 kg cm^{-2}) and

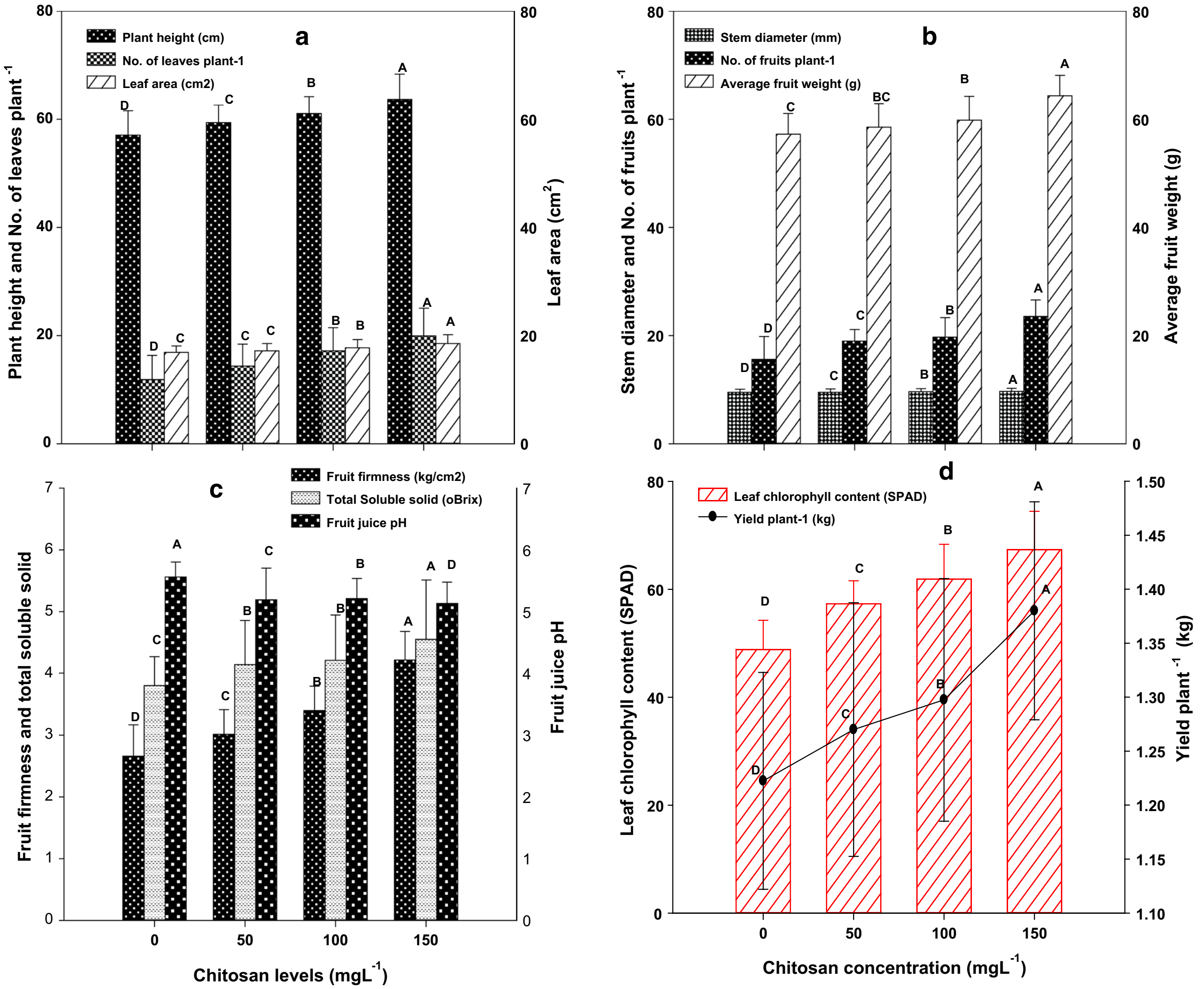

Fig. 2 Changes in morphological, yield and quality related attributes of tomato as affected by different levels of chitosan. Each value is a mean (± SE) of 3 replications, and the different letters in each bar indicate a significant difference (LSD $p \leq 0.05$)

fruit juice pH (4.93) was noted in plants treated with 150 mM salinity level (Figs. 1, 2). Moreover, foliar application with 150 mg L^{-1} chitosan caused significantly increased in fruit firmness and pH as compared with plants untreated and salt stressed plants (Tables 2, 3).

The interactive result between salinity and chitosan treatments showed that fruit juice pH was affected significantly. The maximum value of fruit juice pH (5.84) was recorded in plants treated with control treatment of salinity and control treatment of chitosan. The minimum value of fruit juice pH (4.71) was recorded in plants treated with 150 mM salinity level and 0 mM chitosan.

Yield plant^{-1} (kg)

Data regarding yield plant^{-1} are represented in Tables 2 and 3. Yield plant^{-1} of tomato was significantly affected by different salinity levels and different foliar application of chitosan and interaction of salinity stress levels and foliar application of chitosan was found significant effect. The maximum yield plant^{-1} (1.41 kg) was found in plants with control plants, while the minimum yield plant^{-1} (1.16 kg) was noted in salinity level of 150 mM. In addition, foliar application with 150 mg L^{-1} chitosan showed maximum yield plant^{-1} (1.38 kg) as compared with untreated plants which showed minimum yield plant^{-1} (1.22 kg) (Figs. 1, 2). All concentrations

Table 2 Effect of different salinity levels and foliar application of chitosan on morphological criteria and chlorophyll content

Salinity levels (mM)	Chitosan Levels (mg L^{-1})	Plant height (cm)	Average number of compound leaves ($plant^{-1}$)	Leaf area (cm^2)	Stem diameter (mm)	No of fruit ($plant^{-1}$)	Fruit weight (g)	Fruit firmnes (s)	Yield $plant^{-1}$ (kg)	pH	TSS	Chl content
0	0	62.4	17.9	18.2	10.27	20.7	61.1	3.1	1.34	5.8	3.2	55.1
	50	63.5	20.2	18.6	10.34	21.3	62.9	3.3	1.39	5.7	3.5	62.8
	100	64.8	23.3	19.4	10.42	22.7	64.4	3.9	1.43	5.6	3.3	68.5
	150	68.5	26.6	20.5	10.48	27.3	68.9	4.7	1.49	5.5	3.4	74.7
50	0	58.7	12.7	17.5	9.64	17.0	59.5	3.1	1.28	5.7	3.7	50.4
	50	60.2	14.0	17.9	9.65	20.0	61.3	3.2	1.33	5.4	3.9	57.5
	100	62.3	16.9	18.5	9.71	21.7	62.6	3.5	1.34	5.3	4.0	64.5
	150	65.3	21.9	19.1	9.76	24.0	65.8	4.5	1.43	5.3	4.3	70.0
100	0	55.2	9.2	16.1	9.25	14.0	55.8	2.3	1.17	5.5	4.0	47.5
	50	58.2	12.2	16.7	9.21	18.3	56.4	3.1	1.24	5.2	4.3	56.5
	100	59.3	14.3	17.2	9.28	20.0	57.5	3.3	1.26	5.1	4.5	61.2
	150	63.5	17.2	17.8	9.35	23.0	62.3	4.0	1.35	5.0	4.8	66.7
150	0	52.1	7.9	15.7	8.99	11.0	52.7	2.1	1.11	5.3	4.4	42.1
	50	55.7	11.2	15.5	9.07	16.3	53.8	2.4	1.13	4.9	5.1	52.5
	100	57.8	14.2	15.9	9.10	14.7	54.9	2.9	1.17	4.8	5.0	53.3
	150	57.4	14.7	16.7	9.21	20.0	60.4	3.6	1.26	4.7	5.7	57.9
L.S.D at 0.05		1.2	0.6	0.8	0.2	0.4	1.5	0.05	0.02	0.1	0.2	1.7

Table 3 Mean Square value of morphological, yield and quality related attributes of tomato as influenced by different salinity stress and foliar application of chitosan

SOV	*df*	Means Square (MS)										
		PH	NOCLPP	LA	SD	NOFPP	AFW	FF	LChlC	TSS	FJpH	YPP
Salinity (S)	3	174.0***	238.557***	24.1818***	3.8892***	109.889***	195.123***	2.157***	401.05***	6.271***	1.152***	0.1395***
Chitosan (C)	3	54.8***	149.002***	6.3578***	0.0603***	127.722***	113.769***	5.3395***	737.96***	1.154***	0.417***	0.0513***
S × C	9	3.25*	2.479*	0.2113*	0.0028*	2.907*	0.804*	0.0615*	6.3*	0.129*	0.008*	0.0005*
Error	32	1.59	1.505	0.105	0.0021	1.521	1.616	0.0398	3.454	0.066	0.001	0.0003
Total	47											

PH, Plant height; NOCLPP, Number of Compound leaves plant^{-1}; LA, Leaf area; SD, Stem diameter; NOFPP, Number of fruits plant^{-1}; AFW, Average fruit weight; FF, Fruit firmness; LChlC, Leaf Chlorophyll content; TSS, Total Soluble Solid; FJpH, Fruit Juice pH; YPP, Yield plant^{-1}

*Significant at $p \leq 0.05$; ***highly significant at $p \leq 0.01$

of chitosan caused significantly increased in number of yield plant^{-1} as compared to salt stressed plants (Table 2).

Total soluble solids (Brix°)

Data regarding total soluble solids are represented in Tables 2 and 3. Total soluble solids of tomato were significantly affected by different salinity levels and different foliar application of chitosan and their interaction was found significant effect. Maximum value of total soluble solids (5.05 Brix°) were found in plants treated with 150 mM salinity level, while minimum value of total soluble solids (3.34 Brix°) was noted in control plants. Also, foliar application of 150 mg L^{-1}chitosan exhibited maximum value of total soluble solids (4.56 Brix°) as compared with control plants which exhibited minimum value of total soluble solids (3.80 Brix°) (Figs. 1, 2).

Leaf chlorophyll content (SPAD)

Chlorophyll content of tomato was significantly affected by various levels of salinity and chitosan alone or in combination together (Tables 2, 3). The content of chlorophyll was substantially reduced compared to unstressed plants with rising salinity levels. Maximum value of chlorophyll content (SPAD) (65.29) was found in plants treated with control treatment of salinity and minimum value (51.45) was noted in plants treated with salinity level of 150 mM. Moreover, the maximum chlorophyll content (SPAD) (67.33) was recorded in plants treated with 150 mg L^{-1} chitosan concentration, while minimum value (48.80) was found in control treatment of chitosan (Figs. 1, 2). Foliar application with chitosan alleviates the adverse effect of salinity stress by increasing chlorophyll content.

Discussion

Salinity levels significantly reduced plant height of tomato plants which might be due to salinity that reduced the growth of roots, effects its morphology and physiology that in turn change water and ion uptake which led to decrease in plants growth and production (Tejera et al. 2006) or reducing the absorption of water and the activity of metabolic processes (Mohamed et al. 2018a). Mohamed et al. (2018b) who reported that wheat plants negatively affected by salinity stress by reduction in growth. In addition, Akladious and Mohamed (2018) who reported that under salt stress, morphological criteria were significantly suppressed in pepper plants.

Chitosan concentration positively improved the plant height of tomato, which might be due to the fact that chitosan contains the amino group which enhance the photosynthetic area of the plants which maximize the photosynthesis and finally it increased the plant height (Sofy et al. 2020a). The increment in plant growth after treatment with chitosan may be due to its impact on enhancing uptake and transport of minerals such as nitrogen, phosphorus and potassium. Chitosan have positive effect on plant height of sweet pepper, cucumber and radish plants (Farouk et al. 2008). The outcomes are similar with finding of Guan et al. (2009) they examined that chitosan concentration showed positive effect on plant height of maize.

The decreased in number of compound leaves might be due to the high concentrations of salinity which cause the osmotic effect which reduce the availability of water and nutrients to the roots which disturb the plant tissue leading to decreased in meristematic activity and cell expansion. Uddin et al. (2005) stated that No of leaves was declined with increasing NaCl ratio in Brassica species. These results are also supported by (Akladious and Mohamed 2018) showed that salt stress caused reduction in peeper plant growth. Chitosan significantly increased the number of compound leaves plant^{-1} which might be due to the role of chitosan that enhance the phosphorous and potash level to plants that ultimately increases the number of cells, cell size, chloroplasts development, and synthesis of chlorophyll (Latif and Mohamed 2016).

The result of these finding is also similar with Jian et al. (2002) they reported that chitosan application improved number of branches, plant height, and No of leaves in rice plant. The results are also supported by Khan et al. (2002) who used chitosan as a foliar spray on soybean and maize and reported that chitosan concentration positively improved the number of leaves in soya bean and maize. Also, Islam et al. (2018) reported that treatment of chitosan on tomato increased internodes per plant which resulted in increased leaf numbers.

Salinity stress has significant effect on leaf area of tomato plant at higher concentrations which is due to the salinity that effect the nitrogen levels which lead to decrease in rate of photosynthesis and hence decrease leaf area (Kashem et al. 2000). The tomato leaf area has been significantly enhanced by different chitosan concentrations, which may be due to an increase in the availability and consumption of water and essential nutrients, resulting in an increase in key nitrogen metabolism enzyme activities and improved nitrogen transport, which has increased the rate of photosynthesis, growth and plant development (Guan et al. 2009). Results are similar to Sofy et al. (2020a) who found that different chitosan concentration positively improved plant height and other growth parameters of cucumber plants.

Uptake of nitrogen and potassium that eventually increases plant growth and development leading to increase in stem thickness (Ibraheim and Mohsen 2015). Various concentrations of salinity significantly minimize the number of fruits plant^{-1} as it reduces the availability of essential nutrients which are required for the growth and development of the plants. Due to salinity, hyper osmotic stress and ion imbalance disturbed the metabolic pathway of the plant (Foolad 2004).

Chitosan significantly stimulated No of fruits per plant in tomato which might be due to chitosan that enhanced the photosynthetic pigments and biochemical activities in plants that resulted in increasing photosynthates that were directed towards the fruits and resulted in a greater number of fruits per plant (El-Tantawy 2009). Our results are similar with Mondal et al. (2013) who indicated that the foliar administration of chitosan up to 75 mg L^{-1} had a good improvement in the number of tomato fruits. Our findings are also in line with Chibu et al. (2002), who reported that rice and soybeans treated with chitosan significantly increased the number of soybean pods at early growth stages. Fruit weight were significantly reduced with an increase of salt concentration because salinity effect the chlorophyll pigments and decrease the rate of photosynthesis that led to decreased in photosynthates and ultimately decreased the fruit weight. Similar results are recorded by (El-Beltagi et al. 2013, 2020; El-Mashad and Mohamed 2012). Chitosan positively improved the number of fruits of per plant of tomato which might be due to chitosan that improves the supply of water and the absorption of important nutrients by adjustment of osmotic pressure at the cellular level and enhance the enzymatic and antioxidant activities in fruit plant. The outcome of our experiment matched with Rahman et al. (2018), who reported that fruit weight of strawberry plant increased when treated with foliar application of chitosan.

Fruit firmness of tomato fruit was significantly reduced with salinity which might be due to salinity that it decreases the deposition of calcium pectate and calcium phosphate in tissue which limit the cell wall development and hence reduced the fruit firmness (Islam et al. 2018). Chitosan positively improved the fruit firmness of tomato plants which might due to chitosan that promotes the cell wall thickness because it promotes the calcium to tissues which ultimately results in higher fruit firmness. The outcome of our experiment is in line with the results of Ali et al. (2015) they reported that papaya fruits when treated with higher concentrations of chitosan resulted in maximum firmness than untreated fruits. Also, Gayed et al. (2017) they described that peach fruit treated with chitosan reduced swelling of fruits in early stages and also maintained fruit firmness and freshness as well as decreased percentage of weight loss.

Salinity significantly reduced the fruit juice pH of tomato which might be due reduce CO_2 incorporation, transpiration rate, photosynthetic activity and stomatal conductance that lead to decrease production of carbohydrates and tends to pH decrease. Fruit juice pH decrease with increased in salinity because salinity increased respiration rate, ethylene production and disturb plant turgor pressure. Chitosan foliar application has significantly impacted pH of tomato fruit juice which might be due to more water availability to the plant as well as inside the cells through production of osmotic pressure and enzymatic activities (Guan et al. 2009). In addition, Islam et al. (2018) who reported that chitosan decreased fruit juice pH of tomato.

High level of salt in the plant disrupts numerous physiological properties which may lead to decrease the yield and size of fruit (Munns 2002); Shereen et al. (2005). Present results were also supported by Maggio et al. (2010) who reported that salinity stress decrease the yield might be due to both the osmotic stress in the root growing medium resulted from relatively high concentrations of solute and unique toxicity due to the addition of high concentrations of Na and Cl to the plant, resulting in physiological and biochemical changes that have limited the growth and development of the plant. The reduction in yield may be due to low water and essential nutrient absorption, as well as to the unique impact of the ion.

Chitosan concentration positively improved the yield of tomato that might be due to physiological processes such as improved uptake of nitrogen that eventually increases plant growth and development leading to increase in yield and yield contributing parameters (Ibraheim and Mohsen 2015). These findings are similar with Mondal et al. (2013) who reported that chitosan application caused enhancement in mung bean yield. Our results are matched with Bittelli et al. (2001) who investigated that under water stress condition pepper plants treated with foliar application of chitosan, transpiration and water use were reduced while the production and yield of biomass was maintained. Salinity has positively improved the total soluble solids which might be due to more accumulation of sodium (Na^+), potassium (K^+) and chorine (Cl^-) ions in the fruit (Mizrahi et al. 1988).The findings are supported by Islam et al. (2018) who found that TSS of tomato was increased with increased in salinity. Foliar application of chitosan increases the TSS of tomato which might be due to higher accumulation of metabolites and immediate alteration of starch into soluble sugar during fruit growth and development in response to growth regulators. In our experiment we found significant increase in total soluble solids (TSS) in tomato fruits with concentrations of chitosan especially at 100 and 150 mg L^{-1}. These results are in line with those of Abdel-Mawgoud et al. (2010), who found that in response to the application of chitosan, TSS showed a positive trend.

Meanwhile, in comparison to these untreated plants, foliar spray of tomato plants with different chitosan concentrations significantly increased all the studied growth characteristics (Table 2). Chitosan has a positive effect on plant growth on tomato and eggplant plants (Sultana et al. (2017) and on strawberry plant (Rahman et al. 2018). These increases were reflected in the rise in nitrogen metabolism enzyme activities, which increased nitrogen translocation in the leaves, improving growth (Chibu and Shibayama 2003).

Salinity significantly decreased the leaf chlorophyll content of tomato which might be due to the harmful effect of salinity stress at higher concentration which causes the induction of early maturing of leaves and diminished chlorophyll pigments that finally cause reduction in chlorophyll content (Kashem et al. 2000). Similar observations were found by Agastian et al. (2000) who stated that maximum level of salt created an imbalance in ion, leading to decreased in chlorophyll synthesis. Chitosan concentration positively improved the leaf chlorophyll content which might due to more nitrogen, phosphorus and potassium uptake and also promotes the transportation of nitrogen to leaves which enhance chlorophyll pigments that leads to increase in chlorophyll content Abd EL-Gawad and Bondok (2015). The finding is similar with Farouk et al. (2008) who found that different chitosan concentration increased leaf chlorophyll content and also enhanced starch content in cucumber and radish. The outcome is also in line with the result of Sofy et al. (2020a) who noted that plant treated with foliar application of chitosan have positively improved the chlorophyll content of cucumber plant.

In addition, the results of the interaction between different levels of salt stress and different concentrations of chitosan on tomato plant chlorophyll content indicate substantial changes, either under normal or stressed conditions. These results are in line with those obtained by Bakhoum et al. (2020), who found that the highest growth characteristics and photosynthetic pigments in sunflower plants were recorded by the interaction effect in plants treated with chitosan concentration (50 mg L^{-1}) below salinity level (4000 mg L^{-1}).

Conclusion

This study highlights the importance of foliar spray with natural chitosan compound, especially in soils affected by salt. Applying proper chitosan concentrations could effectively reduce the dangerous effect of higher salinity levels and improve the growth and yield of tomato plants by improving the different morphological aspects and the quality of chlorophyll. Based on this research, chitosan at 150 mg L^{-1} is recommended for better growth and production of tomato grown under saline condition.

Abbreviations

SPAD: Soil Plant Analysis Development; DNA: Deoxyribonucleic acid; RNA: Ribonucleic acid.

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Authors' contributions

N.U. and A.B.: conceived and designed the experiments, N. U. and A.B.: performed the experiments, I. R., I. U.: analyzed the data, S. T. U., M. S. and S.J.: contributed in materials/ analysis/ tools, N.U., A.B., and H.I.M.: wrote the paper, N.U., H.I.M. and A. B.: reviewed the manuscript: S. T. U., M. S. and S.J Supervised the experiment. All authors read and approved the final manuscript.

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Competing interests

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