

Physiological and growth attributes of salt-stressed tomato plants in response to foliar application of nano phosphorus or potassium

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Abstract

The present study aims to explore various alternatives to alleviate the detrimental effects of salinity on tomato plants subjected to salt stress. An experiment was conducted in pots during the growing seasons of 2021 and 2022. Hybrid Super Strain B of tomato (*Solanum lycopersicon*) seedlings were transplanted in pots with a diameter of 0.3 m and a capacity of 15 liters, filled with washed sand. Subsequently, fresh water was used for irrigation for two weeks, after which salinity treatments were applied. To achieve targeted EC levels (control, 2000, 3000, and 4000 ppm), saline water was mixed with fresh water. Two weeks after transplantation, foliar sprays of nano-K or nano-P were administered three times during the seasons, at two-week intervals. The findings indicate that increasing salinity levels had a significant negative impact on the growth and production aspects of all plants. However, the negative impacts were mitigated by the application of nano fertilizers, particularly nano-K. The results suggest that the mitigation effects of foliar application of nano fertilizers could be attributed to the partial recovery of nutrient imbalances caused by salinity stress.

Key words: Tomato, salinity, nano fertilizers, growth, production, potassium, phosphorus.

Introduction

Salinity buildup in agricultural soil is a major challenge to food production in many parts of the world. The increase in salinity levels in the soil is mostly due to factors such as misuse of fertilizers, and/or irrigation as well as using marginal quality water. The negative effects of salinity on crops are well documented (Tantawy *et al.*, 2015; Abdelmawgoud, 2017; Sassine *et al.*, 2022a&b). Salinity impairs plant growth and affects crop yields (Tantawy *et al.*, 2014), with some crops such as tomatoes being more sensitive to salinity than others (Shannon and Grieve, 1999). Salinity affects the plant's water uptake and transpiration, with high salt levels causing water stress and leading to physiological damage. Salinity also affects the uptake of nutrients by plants, with the concentration of certain nutrients reduced at high salt concentrations (Grattan and Grieve, 1994). Additionally, salinity disrupts the osmotic regulation of cells, leading to toxicity and causing the cell membrane to become more permeable (Flower *et al.*, 2015).

Tomato plants may respond to salinity by producing proteins that help protect against cellular damage and/or biosynthesizing osmoprotectants such as proline (Goudarzi and Pakniyat, 2009) which acts as osmotic regulators. Physiologically, salinity affects the accumulation of certain ions, with high salt concentrations leading to nutrient deficiencies (Gupta and Huang, 2014). Morphologically, tomato plant growth is reduced, with the plant displaying stunted growth and decreased shoot and root growth. As salinity stress becomes severe, the growth rate of the plant is reduced, and the quality of the fruit decreases (Abdel-Mawgoud, 2002).

Different attempts were documented to mitigate the negative

effects of salinity on tomato plants (Tantawy *et al.*, 2014; Sassine *et al.*, 2022a,b). For instance, the soil and/or foliar applications of some compounds proved to help in mitigating the negative effects of salinity on plants (Tantawy *et al.*, 2013). The use of plant growth regulators such as gibberellic acid and cytokinin has been shown to reduce the impact of salt stress on crops (Javid *et al.*, 2011). Additionally, the use of organic amendments such as humic acid can improve the plant's nutrient uptake and reduce the negative effects of salt stress (Tantawy *et al.*, 2009; Abdelmawgoud *et al.*, 2010). More recently, (Tantawy *et al.*, 2015) reported that nano compounds such as silicon have also shown potential for mitigating the negative effects of salinity on plants. The use of nano-calcium compounds has been shown to reduce the impact of salt stress on tomatoes (Tantawy *et al.*, 2014).

Therefore, this investigation aims at providing more insight into the effect of nano compounds on mitigating the negative effects of salinity on tomato plants to provide more effective alternatives for growers to overcome this abiotic stress and improve their production.

Material and methods

Planting material and salinity treatments: Tomato (*Solanum lycopersicon*) seedlings hybrid Super Strain B were transplanted in 5.0 L pots filled with washed sand and placed in the open field on a private farm in Monsha'et El-Kanater, Giza governorate (Latitude 30.2082610 N, 30.7457860 E), in early January 2021 and 2022. Tomato plants were grown in open field conditions at a range of day/night temperatures of 25/30 ± 3 °C and 55-60% relative humidity. For two weeks after transplantation (1-14 DAT), plants were irrigated with fresh water (EC fresh water=0.4 dS m⁻¹). Saline irrigation started at 15 DAT with an interval of 2

days between consecutive irrigations and using the corresponding EC level (EC= 2000, 3000, and 4000 ppm). Saline irrigation water was prepared by mixing the water of Qaron Lake with fresh water to reach the targeted EC level.

Nano fertilizers treatments: Nano potassium and phosphorus compounds were used as a foliar spray on the plants. The applications of each of the two products were carried out three times during each of the growing seasons. The applied concentrations started at 14 DAT and were 0.0 (control); 0.5; and 1.0 cm³ L⁻¹ for both products.

Experimental design and statistical analysis: Experimental treatments were arranged in a split block design with the salinity level in the main block.

Growth measurements: Plant height and leaf area were measured at 70 DAT. A destructive sampling took place where three representative plants of each treatment were selected for determining the fresh weights of total plant parts (only aboveground parts). Plants were oven dried at 100° C until a constant weight was reached to be recorded as total dry weight.

Total harvested fruit was recorded by the end of the experiment as kg/plant. Some fruits were selected randomly and weighted, and the average weight of individual fruits was calculated (g per fruit).

Table 1. Effect of salinity levels, nano treatments, and their interactions on plant height and leaf area, total chlorophyll content, total plant fresh and dry weights of tomato plants during the two seasons

Treatments	Plant height		Leaf area (cm ² /plant)		Chlorophyll content (SPAD)		Plant fresh weight (g)		Plant dry weight (g)		
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	
Salinity (ppm)											
2000	58.26	56.92	84.2	84.84	59.86	61.3	125.68	124.75	41.82	39.97	
3000	52.80	50.92	75.42	75.6	54.87	55.15	109.13	106.83	38.66	36.68	
4000	49.91	47.59	70.1	71.04	49.04	48.5	94.58	94.39	34.59	33.28	
L.S.D at 5% level	1.01	0.9	0.74	0.71	2.34	2.42	0.39	0.38	0.19	0.17	
Nano treatments											
Control	40.66	39.5	65.55	66.97	44.44	44.13	59.18	57.87	31.03	29.66	
Nano P 0.5 cm /L	53.32	51.77	73.02	74.32	53.52	53.51	94.74	97.1	35.39	33.62	
Nano P 1 cm /L	55.59	53.78	77.1	78	56.04	56.53	101.69	103.89	37.52	35.77	
Nano K 0.5 cm /L	58.04	56.06	81.24	80.92	58.48	59.28	142.2	138.88	41.4	39.77	
Nano K 1 cm /L	60.66	57.93	85.94	85.59	60.48	61.47	151.18	145.55	46.44	44.4	
L.S.D at 5% level	0.27	0.32	0.11	0.24	0.11	0.17	0.49	0.47	0.14	0.12	
Interaction											
2000 ppm	Control	46.44	45.21	71.11	73.22	51.11	52.34	77.33	78.33	35.11	33.55
	Nano P 0.5 cm /L	57.32	56.33	80.33	82.22	58.12	60.34	106.11	108.44	38.54	36.44
	Nano P 1 cm /L	59.23	58.41	85.22	86.23	61.11	62.5	116.33	115.36	40.56	38.77
	Nano K 0.5 cm /L	62.45	61.32	90.11	89.21	63.56	64.64	161.22	158.11	45.44	43.45
	Nano K 1 cm /L	65.87	63.34	94.23	93.34	65.44	66.71	167.44	163.55	49.45	47.66
3000 ppm	Control	39.34	37.66	65.34	66.6	45.55	44.51	54.11	50.65	30.44	29.11
	Nano P 0.5 cm /L	52.54	50.44	72.33	73.43	53.34	51.73	97.66	98.54	35.32	33.32
	Nano P 1 cm /L	55.11	53.52	75.55	76.34	55.56	56.52	100.34	103.65	37.56	35.33
	Nano K 0.5 cm /L	57.44	55.67	79.44	78.34	58.45	60.55	143.12	137.76	42.33	40.43
	Nano K 1 cm /L	59.56	57.34	84.44	83.33	61.45	62.47	150.45	143.55	47.65	45.22
4000 ppm	Control	36.22	35.65	60.21	61.11	36.66	35.56	46.11	44.65	27.55	26.33
	Nano P 0.5 cm /L	50.11	48.55	66.42	67.33	49.11	48.46	80.45	84.34	32.33	31.11
	Nano P 1 cm /L	52.44	49.43	70.54	71.44	51.45	50.57	88.42	92.67	34.45	33.22
	Nano K 0.5 cm /L	54.23	51.21	74.18	75.23	53.44	52.67	122.27	120.77	36.44	35.43
	Nano K 1 cm /L	56.56	53.11	79.17	80.12	54.56	55.25	135.66	129.56	42.22	40.32
L.S.D at 5% level	0.48	0.52	0.31	0.4	0.31	0.34	0.89	0.84	0.09	0.08	

Chlorophyll content: Chlorophyll content was measured in individual fully grown leaves as SPAD using Minolta SPAD (model 501) (1.0 SPAD = 10.0 mg chlorophyll).

Nutrient content in shoots: The aboveground parts were dried in the oven at 100°C, then ground separately. Samples were digested in a mixture of sulphuric and perchloric acids, and each element was determined as: N was determined in % using kjeldahl method (Brenner, 1965), P was determined calorimetrically (Trouw and Meyer, 1939), whereas K was determined by flame photometry as described by Brown and Lilleland (1946).

Statistical analysis: All data were subjected to ANOVA by using Statistical Package for Social Sciences (SPSS) software version 25® software. Least significant difference (LSD) was calculated at $P \leq 0.05$ to differentiate between means. Regression analysis was carried out using Excel spreadsheet tool pack.

Results

Effects of salinity: Vegetative parameters such as plant height and leaf area are shown in Table 1. Both parameters were negatively affected by salinity. The effect was linear in both seasons and had a slope of -0.004 and -0.006 for plant height and leaf area, respectively. Increasing salinity levels significantly increased the

negative impact on chlorophyll content compared to the control. The negative impact showed a linear relationship between salinity levels and chlorophyll contents with a slope of -0.0064. Similar trends were recorded on fresh and dry weights as shown in where salinity negatively affected both parameters compared to the control. The regression analysis revealed a negative linear trend as salinity increased with a slope of -0.0152 and -0.0033 for fresh and dry weights respectively. Fruit yield and its attributes such as average fruit weight decreased significantly as the salinity level increased (Table 2). The reduction continued linearly in a slope of -0.067 and 0.007 for fruit yield and average individual fruit weight respectively. Plant chemical contents in terms of total nitrogen, phosphorus, and potassium responded negatively and significantly to the increment in salinity levels (Table 2). The responses showed negative linear relationships with slopes of -0.0004; -0.00006; and -0.0003 for N, P, and K, respectively.

Effects of nano applications: In Both seasons, plant height and leaf area (Table 1) responded positively and significantly to the application of nano fertilizers compared to the control. The effect increased as the concentration of either nano-P or nano-K increased with a higher effect recorded with K compared to P. Chlorophyll content showed a significantly positive response to

the applied nano fertilizers compared to the control treatment. The positive effect increased as the applied concentration of any of the applied nano-fertilizer increased. Nano-K showed a clearer significant positive effect than that of nano-P at the same applied concentration. Similarly, applications of both nano fertilizers showed significant positive effects on both fresh and dry weights parameters compared to the control (Table 1). The positive effects of nano-K were significantly higher than that recorded with nano-P application, especially at a similar concentration. Fruit yield and average individual fruit weight increased significantly in response to the applied nano-fertilizers (Table 2). The positive effect on both parameters increased as the concentration of the applied fertilizer increased. Nano-K showed a higher positive significant effect compared to all other treatments. Likewise, plant chemical contents of N, P, and K significantly increased as the applied concentration of nano-P and nano-K increased (Table 2). The observed effects showed the highest significant positive impact under the treatment of nano-K at a concentration of 1.0 cm³ L⁻¹.

Effects of interactions: The interactive effects of salinity and nano fertilizer applications on plant height and leaf area show clearly that the application of nano fertilizers mitigated

Table 2. Effect of salinity levels, nano treatments, and their interactions on total fruit yield per plant and average individual fruit weight, total nitrogen (N), phosphorus (P) and potassium (K) contents in tomato plants during the two seasons of 2021 and 2022

Treatments	Yield (g/plant)		Avg. fruit weight (g)		Total N content		Total P content		Total K content		
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	
Salinity (ppm)											
2000	638.22	635.14	68.67	66.8	3.52	3.42	0.53	0.50	2.94	3.05	
3000	540.12	537.42	60.53	58.33	2.84	2.74	0.49	0.47	2.78	2.78	
4000	504	501.54	55.61	53.52	2.56	2.55	0.40	0.38	2.38	2.44	
L.S.D at 5% level	6.32	5.81	1.56	1.19	0.02	0.01	0.02	0.01	0.01	0.02	
Nano treatments											
Control	518.46	516.1	50.25	48.54	2.45	2.31	0.37	0.35	1.91	2.03	
Nano P 0.5 cm /L	555.18	552.73	58.77	56.36	2.92	2.84	0.51	0.49	2.57	2.64	
Nano P 1 cm /L	565.36	562.3	62.13	59.97	3.06	2.95	0.54	0.51	2.71	2.75	
Nano K 0.5 cm /L	578.36	575.22	66.33	64.27	3.20	3.16	0.45	0.43	3.08	3.13	
Nano K 1 cm /L	586.55	583.84	70.55	68.63	3.26	3.24	0.49	0.47	3.22	3.24	
L.S.D at 5% level	1.34	2.12	1.09	1.06	0.04	0.03	0.02	0.02	0.13	0.21	
Interaction											
2000 ppm	Control	565.8	562.88	58.87	56.04	3.12	3.08	0.44	0.42	2.21	2.31
	Nano P 0.5 cm /L	641.46	638.55	67.17	65.31	3.41	3.33	0.57	0.54	2.72	2.85
	Nano P 1 cm /L	654.71	651.69	69.87	68.19	3.53	3.38	0.59	0.55	2.93	3.11
	Nano K 0.5 cm /L	659.49	656.73	72.28	70.95	3.75	3.62	0.5	0.48	3.38	3.49
	Nano K 1 cm /L	669.65	665.89	75.20	73.55	3.82	3.7	0.55	0.53	3.47	3.51
3000 ppm	Control	514.13	511.66	48.35	47.62	2.29	2.01	0.38	0.36	1.90	2.06
	Nano P 0.5 cm /L	535.45	533.79	56.52	53.23	2.83	2.7	0.53	0.51	2.70	2.68
	Nano P 1 cm /L	540.97	537.44	60.77	58.67	2.9	2.75	0.57	0.55	2.75	2.71
	Nano K 0.5 cm /L	550.63	547.46	66.33	63.42	3.07	3.06	0.48	0.46	3.22	3.18
	Nano K 1 cm /L	559.46	556.79	70.69	68.74	3.14	3.19	0.52	0.50	3.33	3.30
4000 ppm	Control	475.45	473.76	43.54	41.97	1.95	1.86	0.30	0.29	1.64	1.72
	Nano P 0.5 cm /L	488.65	485.85	52.63	50.54	2.52	2.5	0.44	0.42	2.31	2.41
	Nano P 1 cm /L	500.41	497.78	55.76	53.05	2.75	2.73	0.46	0.45	2.45	2.44
	Nano K 0.5 cm /L	524.96	521.49	60.4	58.45	2.8	2.82	0.39	0.37	2.65	2.73
	Nano K 1 cm /L	530.56	528.85	65.76	63.62	2.82	2.85	0.42	0.4	2.87	2.91
L.S.D at 5% level	1.51	1.62	0.48	0.42	0.05	0.04	0.03	0.01	0.11	0.14	

the negative effects of salinity conditions with the same trend observed under all salinity levels (Table 1). The applications of nano-K showed higher and more significant effects on mitigating the negative effect of salinity compared to similar concentrations of nano-P. The application of nano-P and nano-K mitigated the negative effects of salinity on chlorophyll content as shown in Table 1. Nano-K was superior in its mitigating effects particularly at a concentration of 1.0 mg/L compared to all other applied treatments under all salinity level treatments. Total plant growth expressed as fresh and dry weights showed mitigating effects of applications of non-fertilizers on the negative effects of salinity on those parameters. Although both nano-applications showed a similar trend of mitigation, noticeable higher significant mitigating effects of nano-K were observed compared to that of nano-P. The interaction effects of the treatments on fruit yield and average weight of individual fruits showed a similar trend to what has been observed before. Nano-fertilizer applications significantly mitigated the negative impacts of salinity on tomato fruit yield and average individual fruit weight with the superiority of nano-K at a concentration of 1.0 mg/L compared to all other treatments. Plant mineral contents in terms of N, P, and K improved in response to the application of nano fertilizers under each salinity level indicating mitigating effects of such treatments (Table 2).

Discussion

Salinity is a major abiotic stress factor that affects plant growth and yields in various agricultural lands worldwide. As one of the most widely cultivated crops, tomatoes are also susceptible to the negative impacts of salinity. The negative effects of salinity observed in this study have been reported earlier (Guo *et al.*, 2022). Salinity significantly affects tomato plants' growth and development, resulting in an overall reduction in plant height. This reduction is attributed to the disruption of various physiological processes, such as water absorption, nutrient uptake, and photosynthesis. These negative impacts may be due to salinity-induced osmotic stress causing water deficit within the plant cells, leading to stunted growth and limited expansion of shoot and root systems. This may also be reflected on other vegetative parameters such as leaf area which was recorded in this study.

Hasegawa *et al.* (2000) reported that severe salt stress leads to leaf chlorosis, wilting, and ultimately leaf drop. The observed reduction in leaf area due to salinity stress hampered the plant's ability to perform photosynthesis efficiently. The reduction in leaf area limits the plant's capacity to capture sunlight and produce energy, thus negatively affecting overall plant total fresh and dry weights as has been observed in this study. These negative responses are reflected in fruit yield production. As in this study, the reduction in crop yield was also reported earlier (Tantawy *et al.*, 2014; 2015; Zhang *et al.*, 2016). The latter mentioned that salinity stress affects several yield-related factors, including flower and fruit development, pollination, and embryo development leading to a reduction in total fruit yield. The positive effects of nano fertilizers have been reported on many crops (Tantawy *et al.*, 2014; 2015; 2016) and those positive effects may be due to the kinetic characteristics of the nutrients in the nano-forms (Castiglione and Cremonini, 2009). The latter mentioned that nanostructured fertilizers can increase nutrient use

efficiency through mechanisms such as targeted delivery, and slow or controlled release due to their high reactivity because of more specific surface area, and more density of reactive areas. Earlier, Ashok and Raykar, (2008) mentioned that when nanoparticles are added to liquids, their chemical, physiological, and transport characteristics are changed compared to their base fluids such as enhancement of thermal conductivity.

The interactive effects of salinity and nano fertilizers in this study showed that the salinity negative effects can be mitigated by the application of nano fertilizers such as nano-P and nano-K. The observed overall improvement due to the mitigation of salinity effects may be due to the partial recovery of the nutrient imbalance caused by salinity as nutrient contents improved by nano fertilizers applications. Rameeh (2019) mentioned that the application of nano potassium can alleviate the negative effects of salinity on tomato plants by improving their water retention capacity, maintaining hormonal balance, and enhancing photosynthetic activity. In addition, nano potassium promotes the synthesis of osmolytes such as proline, which helps in osmotic adjustment and protects cellular structures against salt stress. Moreover, El-Moghazy *et al.* (2018) mentioned that nano phosphorus improves root hair development, allowing tomato plants to enhance their water and nutrient uptake capacity. Nano-P also increases the activity of antioxidant enzymes, reducing oxidative stress caused by salinity. Furthermore, nano phosphorus aids in maintaining higher chlorophyll content, leading to improved photosynthetic efficiency and overall plant growth (Abbas *et al.*, 2020).

Salinity stress exerts numerous detrimental effects on tomato plant growth and yield, including a reduction in plant size and leaf area, as well as yield limitations. However, the application of nano potassium and nano phosphorus has shown promising results in mitigating the negative impacts of salinity on tomato crops. The improved mineral contents observed in this study indicate that the application of nano-P and nano-K may compensate for the nutrient imbalances caused by salinity stress. This study can also help in developing sustainable strategies to enhance tomato tolerance to this abiotic stress.

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