Improvement of tomato yield and salinity tolerance by decreasing the medium pH

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Abstract

The increasing salinity of water and soil as one of the consequences of climate change has adversely affected the plant functions and reduced plant productivity, threatening future food security. Hence, we hypothesis different pH levels (unadjusted as control (~8.5-9), 5.5, and 4.5) would mitigate the salinity effects on tomato plants (*cv*. Mobil). Generally, increasing salinity stress and pH levels decreased stomatal conductance (g_s) and leaf SPAD; however, the greatest g_s was observed in pH 4.5 grown plants under control conditions (31% greater than the control pH). Stomatal conductance and leaf osmotic potential were negatively correlated. The highest leaf osmotic potential was observed at 56 days after stress (DAS) at pH 5.5. Leaf relative water content (RWC) was decreased by increasing salinity intensity in low-pH-grown plants. Plants grown at pH 5.5 had the most significant fruit fresh weight and plant dry weight. It seems that although salinity reduced the plant performance, lowering the rhizosphere pH could positively mitigate the diminishing effects of salinity on the plant yield.

Keywords: Fruit weight, Hydroponic culture, Osmotic potential, Rhizosphere acidity, Survival.

Introduction

Tomato (*Lycopersicon esculentum*) is one of the most crucial fruit vegetables that is cultivated for its edible fruits. Tomato accounts for 25% of the world's vegetable production. Tomato is labeled for its good nutritional values and is a good source of vitamins and the phytochemical lycopene [1]. The increasing salinity of water and soils throughout the world and Iran has led plants' production to reduce. Furthermore, the population growth and increasing demand for food products enhance the requirement to adopt approaches to reduce environmental stresses' harmful effects. Such circumstances have led crop producers to use unconventional irrigation waters, which threaten future food security. Besides, due to the scarcity of freshwater resources and low-quality water resources (saline and semi saline water), vegetable crop management has received a great deal of attention worldwide due to saline conditions[2].

Plant growth can be maximized through a proper acidity of nutrient solution that optimizes nutrient uptake and increases photosynthetic system efficiency [3]. The solubility of some nutrients in the water and plant access to those elements increases by decreasing the nutrient solution acidity [4]. The acidity of nutrient solutions and the plant rhizosphere is important in two respects; it affects the oxidation-reduction equilibrium, the solubility, and the ionic form, and it affects the uptake of ions by the effect of H^+ and OH^- ions on the plant root, especially the membrane of ion transporting cells. It has been found that reducing the acidity of nutrient solution is an influential factor in reducing stomatal conductance in plants, with a 29% decrease in stomatal conductance by a decrease in acidity from 5.6 to 1.8 in bean plants. With a decrease in acidity from 5.6 to 1.8, the transpiration rate was also

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decreased by 4%, which could be due to a decrease in leaf pressure potential [5]. The decrease in stomatal conductance due to the decrease in acidity can be due to reducing the compressive potential of the leaves.

Due to high salinity and high initial costs to reduce salinity, most farmers are reluctant to greenhouse cultivation and consider production to be low profitable. However, with reliable information, it is possible to evaluate the economic justification of greenhouse cultivation by saline water and provide more detailed recommendations. Therefore, it was hypothesized that decreasing the medium pH mitigates the adverse effects of salinity on the plant performance and fruit yield of tomato plants. The study was also aimed to find the most reliable physiological parameter upon which the effects of salinity can be recognized.

Materials and methods

The experiment was performed in a factorial arrangement based on a completely randomized design (CRD) with three replications at the Department of Agriculture, Ferdowsi University of Mashhad, in 2018. Tomato cultivar (*cv*. Mobil) were studied under salinity stress conditions at three acidities (pH) levels (Unadjusted Control [~8.5-9], 5.5, and 4.5) and five measurement time (before the onset of salinity stress; 0, 14, 28, 42, and 56 days after the onset of salinity stress) every 14 days.

Seeds were first sown in the seedling trays in a mist room and, after two weeks, transferred to a hydroponic system. The culture medium was perlite, and a closed hydroponic system was used. The plants were fertilized using Hoagland's nutrient solution, which was rotated continuously. One month after the plant establishment, the salinity (NaCl) stress was applied gradually (4 $dS.m^{-1}$ per week), increased to 20 $dS.m^{-1,}$ and then applied until the end of the experiment. The nutrient solution was changed weekly, and the nutrient solution acidity was adjusted daily using sulfuric acid (H_2SO_4). The photoperiod inside the greenhouse was adjusted according to the natural daylength (spring) and day and night temperatures were 25±2 and 18±2 ℃, respectively.

Total leaf pigments content was measured in intact leaves using a portable chlorophyll meter (CCM-200, Opti-Science, USA). At least three leaves per replicate were measured. Readings were taken from three plants per replicate in the middle of leaf lamina and averaged. Stomatal conductance (g_s) was measured using a leaf porometer (Decagon Devices, Inc., USA) from the leaves used to measure pigment content at the same time. Leaf relative water content (RWC) was measured according to Smart and Bingham [6]. The leaf Ψ_O was determined according to the freezing point depression method using an osmometer (Wogel, model OM802.D). Plant dry matter and fruit fresh weight were measured after physiological maturation. To calculate survival percentage (SU), the plant number was counted after establishment (n), the plant number was recounted (m) at the end of the experiment, and survival percentage was calculated using Eq. 1:

$$SU(\%) = \frac{m}{n} \times 100 \quad (1)$$

Statistical analysis was performed using SAS *v*. 9.1 and Excel software. The mean comparison was made using the LSD test at 5% of probability. Means were presented as ±SE.

Results and discussion

The medium pH and time of measurement interacted to affect g_s. Generally, g_s was diminished by increasing salinity stress and pH levels. The greatest g_s was observed in plants at pH 4.5 on the first day (31% greater than at control pH), but it decreased to day 56. Leaf SPAD also showed a decreasing trend to 56 DAS. The lowest SPAD was recorded at day 56 in plants grown at pH 4.5, 2.5 times lower than plants in the control pH (Table 1). The leaf Ψ_O was increased by decreasing RWC. The most significant leaf Ψ_O was recorded at 56 DAS in the plants grown at pH 5.5 by an increase of 82% compared with the control pH. Leaf RWC showed a decreasing trend either by increasing salinity or decreasing pH. The greatest decline in the leaf RWC was observed at pH 4.5 after 56 days of salinity stress by 70% compared with the control pH (Table 1). Photosynthesis is regulated by stomatal and non-stomatal factors, depending on plant species and the environmental conditions [7]. A lower g_s is an important mechanism to protect the internal tissues against stress injury [8]. Salinity stress reduces leaf RWC and water potential; both limit the stomatal aperture. Eventually, the photosynthetic process will be inhibited and resulting in changes in ΦPSII [9].

A significant negative correlation was observed between gs and Ψ_O. Reducing stomatal aperture and osmotic adjustment led to an increase in the osmotic potential of leaves. Lowering the nutrient solution acidity reduces the g_s of the plant effectively. Velikova, Yordanov, Kurteva and Tsonev [5] found a decrease in pH from 5.6 to 1.8

decreased the transpiration rate by 4% in bean (*Phaseolus vulgaris*) plants, which may have decreased the leaf pressure potential. Stomatal conductance and transpiration rate were suppressed in potato (*Solanum tuberosum*) by decreasing the pH of the growing medium from 5.6 to 3 [10].

Table 1. Physiological parameters and plant survival percentage of tomato plants during different measurement days at different pH levels

	pH	0DAS†	14DAS	28DAS	42DAS	56DAS
Stomatal conductance (mmol.m^{-2}.s^{-1})	Control‡	17.3±0.88	15.0±0.55	8.6±1.03	9.28±0.40	5.08±0.40
	5.5	22.6±1.47	16.7±1.73	8.8±1.24	9.31±0.71	5.11±0.55
	4.5	22.7±1.20	19.3±2.19	7.6±1.84	7.15±0.88	2.95±0.88
Relative water content (%)	Control	82.6±3.24	74.8±2.27	76.5±2.89	78.1±6.94	75.1±6.02
	5.5	84.3±1.30	71.5±1.20	74.6±1.87	82.6±3.56	76.8±6.27
	4.5	79.3±1.71	78.0±0.91	61.8±12.9	65.3±7.49	44.1±8.45
Osmotic potential (-Mpa)	Control	0.95±0.01	1.46±0.16	1.78±0.23	2.63±0.16	1.78±0.28
	5.5	0.95±0.02	1.28±0.05	2.11±0.25	2.07±0.13	3.25±0.27
	4.5	0.93±0.03	1.31±0.03	1.98±0.42	1.69±0.15	2.05±0.40
SPAD	Control	71.2±3.81	81.8±4.34	68.8±5.43	46.3±4.43	35.8±7.34
	5.5	75.0±4.60	74.1±5.14	67.0±1.69	52.1±5.77	39.6±3.54
	pH4.5	70.9±3.38	73.0±4.55	65.5±13.7	34±4.02	22.5±2.92
Plant survival (%)	Control	100	100	100	100	83±7.60
	5.5	100	100	100	100	66±7.55
	4.5	100	100	100	83±6.15	50±9.31

†DAS: days after stress onset. ‡Unadjusted (pH~8.5-9). Data are means of six measurements ± SE.

Plant survival was significantly decreased at 56 DAS in all pH levels, although there was no significant difference between the pH levels and time of measurement to 42 DAS. The survival on day 56 for plants grown in control pH, pH 5.5, and pH 4.5, was 84, 67, and 50%, respectively (Table 1). Tomato fruit yield and plant dry matter were affected by pH treatments (Figure 1). Plants grown at pH 5.5 had the greatest fruit yield and plant dry matter than the other pH levels. However, decreasing pH to 4.5 decreased both fruit yield and plant dry matter by 36% compared with the pH 5.5. Proper acidity of the nutrient solution optimizes the absorption of nutrients and increases plant growth [3]. The optimum pH of the nutrient solution can maximize photosynthesis and plant growth by affecting the optimal uptake of nutrients [3]. Decreasing the nutrient solution acidity increases the water solubility of some nutrients and plant access to those elements [4]. In the present study, decreasing the medium pH mitigated the adverse effects of salinity on tomato plants. Lower medium pH possibly provided the plants with higher nutrients. Some of the nutrients (*e.g.*, micronutrients) are less available when soil pH is above 7.5. Soil pH becomes alkaline as the salinity increases. Therefore, reducing pH would make some nutrients more available for plants.

Decreasing the growing medium pH to 5.5 increased plant dry matter and fruit yield of tomato plants. Zhang et al. [11] showed that by increasing the nutrient solution electrical conductivity, the total yield, average fruit weight, and leaf area index decreased, while the percentage of fruit dry matter increased. The tuber production in the potato plant increased by decreasing the nutrient solution pH to 5.5 compared to the control [4]. With the temporary and intermittent decrease in the nutrient solution pH, the tuber production rate in potato plants increased by pH 5.5 compared with the control Keshmiri, Kafi, Parsa, Nabati and Zare Mehjerdi [10]. Greater availability of the nutrients at the acidic pH might stimulate the allocation of photoassimilates to the physiological sinks and plant productivity.

Conclusion

Overall, Salinity stress gradually decreased stomatal conductance over time, suggesting a sensitivity of g_s to salinity. A decrease in g_s was occurred by a decrease in the leaf RWC and an increase in Ψ_O. Reducing stomatal aperture and osmotic adjustment increased the leaf osmotic potential, helping maintain more water in the plant. Although salinity adversely affected plant performance, lowering the rhizosphere pH could alleviate the negative impacts of salinity. It seems that the tomato variety (Mobil) has a salinity tolerance, which was stimulated by decreasing the rhizosphere pH.

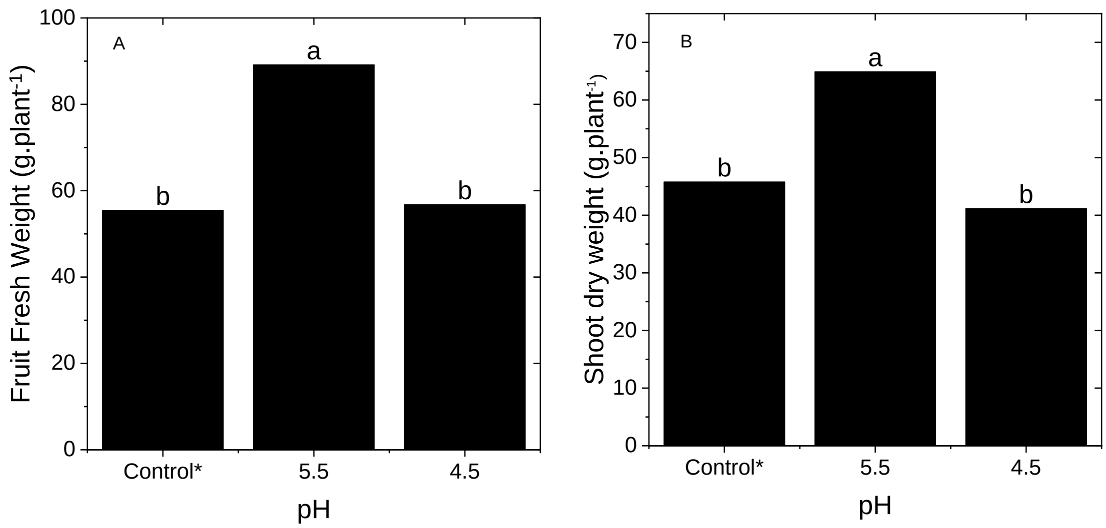

Figure 1. Fruit fresh weight and plant dry matter of tomato plants at different pH levels. * Unadjusted pH~8.5-9. Different letters denote significant differences between pH levels at $p \leq 0.05$ using LSD. Data are means of six measurements ± SE.

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