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Effectiveness of different methods of salicylic acid application on growth characteristics of tomato seedlings under salinity

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Abstract

Background: Soil salinity is a real challenge in nowadays crop production in many regions. Various strategies have been applied to increase plant salinity tolerance. Salicylic acid (SA) frequently has been reported to increase plant salinity tolerance; however, the comparative efficiency of soil (root) or foliar application of SA has not been well tested yet. In this study, the effects of root or leaf pretreatment, and leaf treatment with 100 mg L^{-1} salicylic acid were evaluated on growth characteristics of tomato seedlings (*Solanum lycopersicum* Mill) under salinity stress. The plants were grown 3 weeks in sand that were fed with Hoagland nutrient solution with or without 100 mM NaCl.

Results: The results showed that salinity significantly reduced tomato seedling growth and traits of plant height, leaf area, shoot fresh weight, and nutrient concentration of potassium, calcium, iron and zinc compared to control plants. However, leaf SPAD value, root fresh and dry weights, leaf concentration of sodium, proline and soluble sugars were significantly increased under 100 mM NaCl salinity compared to control plants. Application of salicylic acid particularly by foliar pretreatment increased the tomato plant growth and those traits that were reduced by NaCl salinity. Application of SA, particularly foliar pretreatment, also increased the root fresh and dry weights, leaf proline and soluble sugars concentrations as compared with salinity alone. Foliar SA pretreatment significantly increased leaf K and Fe concentrations, whereas leaf Ca was significantly increased by either root or leaf pretreatment with SA under salinity.

Conclusion: The results indicate that the most to least effective method of SA application was leaf pretreatment, root pretreatment and leaf treatment, respectively, to recover the reduced growth parameters of tomato plant under salinity stress.

Keywords: Amelioration, Growth stimulation, Nutrient uptake, Proline, Soluble sugars, Stress, Vegetable

Background

Salinity is a common environmental stress particularly in dry climates that significantly restricts plant growth and production. The resistant plants (known as halophytes) can tolerate high concentrations of salts in their root medium; however, most of plants especially economic edible crops are sensitive to high soil or water salinity conditions [1, 11, 33]. In many cases, salinity has adverse effects on general plant growth, development and quality [6, 48] that can significantly increase the production costs of agricultural crops [18, 41]. Different approaches including genetic and biotechnology methods or physiochemical treatment strategies have been applied to increase plant tolerance to salinity [22, 29, 32].

Salicylic acid is a water-soluble secondary metabolite and phenolic compound that is produced in many organisms including plants. It is a plant growth regulator with various roles in plant metabolism [10, 39]. Salicylic acid has important regulatory functions in plant growth, particularly under adverse stressful conditions [9, 25, 35, 46]. Salicylic acid has roles in flower induction, general growth and development, various enzyme biosynthesis, stomata movements, membrane protections, and cell respiration [4, 9, 21, 39, 45]. One of the most prominent roles of salicylic acid is in stress tolerance of plants, where it can act as a signaling molecule that induces resistance [18, 22, 43,

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46]. There is a positive correlation between salinity tolerance and endogenous levels of SA in halophyte plant species [14, 28]. In addition, exogenous application of salicylic acid has been shown to reduce the adverse effects of salinity stress on plant growth [5, 10, 12, 15, 24, 36]; however, the comparative efficiency of SA application has not been well tested yet. Acting as a signal molecule in plant defense responses is the best known function of SA under stress conditions [21, 22, 46]. Nevertheless, plant responses to exogenous application of SA are greatly dependent on applied concentration, plant species, growth stage and environmental conditions [2, 21, 22]. Despite SA may be applied with different methods as root or foliar application; however, there are contradictory reports on root or foliar efficiency of SA application [27, 34]. For example, it has been reported that root application of SA can inhibit maize plant growth [34]. In another study, seed soaking or foliar pretreatment of SA provided similar tolerance effect in muskmelon under drought stress conditions [26]. In tomato plant, it has been shown that foliar application of SA generally induces tolerance to salinity stress [13, 30]; however, seed soaking (priming) and root feeding of SA revealed contradictory results [8, 30, 37]. Application of 1 mM SA in nutrient solution of tomato plants reduced stomata conductance, CO_2 fixation and photosynthesis rates, resulting in the death of tomato plants [37]. Therefore, the aim of this study was to evaluate the effectiveness of foliar or root pretreatment or foliar treatment of salicylic acid on growth characteristics of tomato seedlings under salinity stress to find out which application method is more efficient and suitable.

Materials and methods

Experimental setup

The study was carried out under greenhouse conditions during spring of 2015. Tomato seeds (*Solanum lycopersicom* var. Green Supper) were first disinfected in 0.5% sodium hypochlorite for 30 min and then washed with tap and distilled water, respectively. The seeds were then sown 1.5–2 cm deep in quartz sand and after emergence they were fed with ½ Hoagland nutrient solution [17] for 2 weeks. Thereafter, two uniform seedlings (per pot) were pull out intact from the medium and transferred to experimental conditions and into black plastic pots of 3–4 kg volume that were filled with fine sands (0.02–0.5 mm).

Treatments application

This study was done under hydroponic sand culture and in a completely randomized design with four replications, in which a pot containing two tomato seedlings was regarded as one replicate. The treatments were (1) control (without salinity and SA application), (2) salinity (100 mM NaCl), (3) salinity + foliar SA pretreatment, (4) salinity + root SA pretreatment, (5) salinity + foliar SA treatment. For all plants except in control treatment, salinity treatment was applied 1 week after transplantation. For this purpose, 100 mM NaCl was applied in Hoagland nutrient solution, and plants (in sand medium) were fed regularly by this solution for 3 weeks, and two times per day, at 8 am (500 mL) and 4 pm (700 mL). These amounts of nutrient solution were more than the pot sand capacity to retain the solution, aimed to leach out and to prevent salt accumulation in the medium.

Salicylic acid in a concentration of 100 mg L^{-1} was supplied to seedlings either by foliar or root pretreatment or by foliar treatment. At transplanting (after pulling out the seedlings for transferring to experimental salinity conditions), root pretreatment with salicylic acid was done once with immersing the seedling roots in 100 mg L^{-1} for 30 min. Foliar pretreatment of seedlings was done with two sprays of 100 mg L^{-1} salicylic acid. The first spray was done at 1 day before transplantation and another spray at 4 days after seedling transplantation and 3 days before salinity application. Foliar treatment with salicylic acid also was applied with two sprays, the first spray was on the same day of starting salinity treatment, and the another spray was on 5 days later. Foliar sprays of SA were done with a portable sprayer, at the early morning and 1 h after sunrise, and the both sides of leaf were sprayed.

Measurements

Plants were harvested 3 weeks after salinity treatment application. Different growth traits were measured just before harvest or after cutting the shoot and root tissues. Generally, the average record of two plants per pot was presented for each trait in the results. Plant height (cm) was determined using a tape and the average leaf area was measured by leaf area meter (Model CI 202, Germany), from all leaves of two plants per pot. Leaf SPAD value (The Soil and Plant Analysis Development) was measured by an average of 30 readings of two plants per pot and using a portable SPAD meter (Model SPAD-502 Plus, Illinois, USA). Middle plant leaves were used for this purpose. After cutting the shoots from pot surface, roots were precisely washed out of sand particles and after washing the shoot and root tissues with distilled water they were dewatered with tissue paper. Thereafter, their fresh and dry weights were recorded by a precise digital balance. For determination of root and shoot dry weights, plant materials were dried in an oven at 60 °C for 48 h. Leaf concentrations of sodium and potassium were determined by flame photometer, and leaf calcium, zinc and iron concentrations were determined by atomic absorption spectrophotometer [15]. Leaf proline concentration was determined using alcoholic extraction

of fresh leaf samples (2 mL), acid ninhydrin (2 mL) and glacial acetic acid (2 mL). The absorption of samples was then measured against different concentrations of standard proline of 0, 5, 10 and 20 mg L^{-1} and by spectrophotometer at 520 nm following Krantev et al. [27]. For determination of leaf soluble sugars, 0.1 g of fresh leaf samples was extracted in 2.5 mL of ethanol 80%. The anthrone reagent was used for the preparation of samples and their absorption was measured at 625 nm following Dong et al. [9]. A standard glucose curve was also used for calculation of carbohydrate content.

Statistics

The experiment was arranged in completely randomized design with four replications, in which each pot containing two seedlings represents one replication. Data were analyzed with SPSS version 16.0 (SPSS, Inc., Chicago, IL, USA). For each measured parameter, the effect of the treatments was analyzed by analysis of variance (ANOVA) and comparison of means was performed with Duncan's multiple range test.

Results

Plant growth

The results of ANOVA for plant height and leaf area were significant at $P=0.01$. Plant height and leaf area were significantly reduced under salinity stress compared to control plants (Table 1). On the other hand, plant height and leaf area tended to increase with application of SA. All methods of SA application significantly increased plant height under salinity; however, only foliar pretreatment with SA was able to recover the reduced plant height (induced by salinity) to the levels of control plant (without NaCl treatment). Moreover, SA leaf pretreatment or SA root pretreatment (but not leaf treatment) significantly increased plant leaf area under salinity stress.

The results of ANOVA for leaf SPAD value were significant at $P=0.01$. Leaf SPAD value (Table 1) was significantly increased by salinity compared to control plants, and different application methods of SA tended to decrease leaf SPAD value under salinity treatment; however, it was the root SA pretreatment showing the best leaf greenness recovery.

The results of ANOVA for shoot fresh were significant at $P=0.05$ and for shoot dry weights were not significant. Plant shoot fresh weight was significantly reduced under salinity compared to control plants (Table 1), and application of SA increased plant shoot fresh weight under salinity treatment. However, only application of SA as leaf pretreatment was able to increase shoot fresh weight under salinity to the levels of control plants. The reduction in shoot dry weight by salinity treatment was not significant compared to control plants (Table 1). The significant lowest and highest shoot dry weight was observed in plants under salinity, and those plants under salinity that received leaf pretreatment of SA, respectively.

The results of ANOVA for root fresh and dry weights were significant at $P=0.01$. Plant root fresh and dry weights were increased under salinity treatments (Table 1), and application of SA further increased the root fresh and dry weights. The lowest and highest root fresh and dry weights were in control plants and in those plants pretreated with leaf SA application, respectively. Application of SA as leaf pretreatment was the only method that significantly increased root fresh and dry weights under NaCl salinity (Table 1).

Mineral concentrations

The results of ANOVA for leaf concentrations of Na, K, Ca and Fe were significant at $P=0.01$ and for leaf Zn concentration was significant at $P=0.05$, respectively. Application of NaCl salinity significantly increased leaf Na

Table 1 Some growth characteristics of tomato seedlings under salinity treatment and salicylic acid applications

	Plant height (cm)	Leaf area (cm^2)	Leaf SPAD value	Shoot FW (g)	Shoot DW (g)	Root FW (g)	Root DW (g)
Control	25.8 ± 1.7a	38.5 ± 3.4a	34.5 ± 1.3c	39.5 ± 4.0a	3.8 ± 0.25ab	17 ± 2.9c	1.9 ± 0.30c
Salinity	17.5 ± 1.3c	30.5 ± 2.6c	40.2 ± 2.2a	31 ± 3.6c	3.4 ± 0.50b	22 ± 3.2b	2.8 ± 0.25b
Salinity + root SA pretreatment	20 ± 1.8b	34.8 ± 2.2ab	35 ± 0.8c	35 ± 4.1ab	3.7 ± 0.47ab	24.8 ± 2ab	3.1 ± 0.26ab
Salinity + foliar SA pretreatment	24.8 ± 1.7a	36 ± 1.4ab	37.8 ± 0.9b	38.2 ± 2.2a	4.2 ± 0.30a	27.5 ± 2.1a	3.4 ± 0.22a
Salinity + foliar SA treatment	21.3 ± 1.6b	33.3 ± 2.7bc	35.7 ± 1bc	34 ± 2.9ab	3.7 ± 0.34ab	23.3 ± 1.7b	3.1 ± 0.30ab
ANOVA[a]	$F_{4,15}=46.3$**	$F_{4,15}=35.8$**	$F_{4,15}=22.3$**	$F_{4,15}=46.1$*	$F_{4,15}=0.31$ ns	$F_{4,15}=60.3$**	$F_{4,15}=1.2$**

Salinity was applied at 100 mM NaCl in nutrient solution

Salicylic acid was applied with two sprays of 100 mg L^{-1}, as pretreatment or treatment

Root pretreatment was done once with 30 min immersing in 100 mg L^{-1} salicylic acid

Comparison of means was done with Duncan's multiple range test at 5% level

0.05, 0.01 and ns mean significant effect at 5%, 1% and not significant, respectively

[a] Indicating *F* values and corresponding *P* values in which *, ** and ns mean significant effect at 5%, 1% and not significant, respectively

Table 2 Leaf nutrient concentrations in tomato seedlings under salinity treatment and salicylic acid application methods

	Leaf Na (% DW)	Leaf K (% DW)	Leaf Ca (% DW)	leaf Zn (mg kg^{-1} DW)	Leaf Fe (mg kg^{-1} DW)
Control	0.073 ± 0.03c	2.2 ± 0.27a	1.5 ± 0.25a	46.5 ± 6.4a	78.3 ± 2.7a
Salinity	1.38 ± 0.21a	1.5 ± 0.25c	0.95 ± 0.21c	35.7 ± 3.8b	53.7 ± 5.5c
Salinity + root SA pretreatment	0.95 ± 0.26b	1.60 ± 0.29bc	1.3 ± 0.18ab	38 ± 3.6b	59.8 ± 4.1bc
Salinity + foliar SA pretreatment	0.9 ± 0.24b	2 ± 0.26ab	1.4 ± 0.08ab	42.8 ± 3.7ab	62.3 ± 6.6b
Salinity + foliar SA treatment	1.17 ± 0.17ab	1.5 ± 0.15c	1.2 ± 0.15bc	36.2 ± 3.8b	58.2 ± 5.4bc
ANOVA[a]	$F_{4,15} = 0.99^{**}$	$F_{4,15} = 0.41^{**}$	$F_{4,15} = 0.17^{**}$	$F_{4,15} = 85.8^{*}$	$F_{4,15} = 350^{**}$

Salinity was applied at 100 mM NaCl in nutrient solution

Salicylic acid was applied with two sprays of 100 mg L^{-1}, as pretreatment or treatment

Root pretreatment was done once with 30 min immersing in 100 mg L^{-1} salicylic acid

Comparison of means was done with Duncan's multiple range test at 5% level

[a] Indicating *F* values and corresponding *P* values in which *, ** and ns mean significant effect at 5%, 1% and not significant, respectively

concentration compared to control plants (Table 2). On the other hand, application of SA tended to decrease the leaf concentration of Na under salinity treatment, as root or leaf pretreatment with SA significantly reduced leaf Na levels under NaCl treatment. Leaf concentration of mineral nutrients (Table 2) including potassium, calcium, zinc and iron was significantly reduced by NaCl salinity treatment compared to control plants. Application of SA, however, tended to increase the leaf concentration of these nutrients under salinity. Nevertheless, leaf K and Fe concentrations were significantly increased by only leaf SA pretreatment under salinity, whereas leaf Ca concentration was significantly increased by either root or leaf pretreatment with SA under salinity treatment (Table 2). The increase in leaf Zn by SA application methods was not significant under salinity.

Proline and soluble sugars concentrations

The results of ANOVA for leaf concentrations of proline and soluble sugars were significant at $P = 0.01$. Treatment with NaCl salinity resulted in significantly higher leaf concentrations of proline (Fig. 1) and soluble sugars (Fig. 2) as compared to control plants. Application of salicylic acid as foliar or root pretreatment also significantly increased further leaf proline concentration under salinity treatment (Fig. 1). Different methods of SA significantly increased leaf soluble sugars under salinity (Fig. 2); however, the highest leaf proline and soluble sugars were in SA foliar pretreatments under salinity.

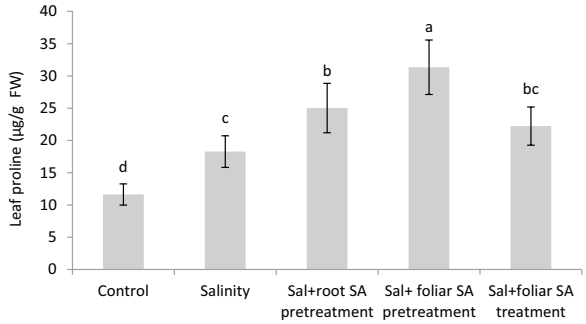

Fig. 1 Leaf proline concentration in tomato seedlings under salinity treatment and different application methods of salicylic acid. Treatments were control (without salinity and SA application), salinity (application of NaCl but without SA), salinity + root pretreatment with SA; salinity + foliar pretreatment with SA, salinity + foliar treatment with SA. Data are average of 4 replicates ± SD ($F_{4,15} = 217.7^{**}$). Comparison of means was done at 5% level of Duncan's multiple range test

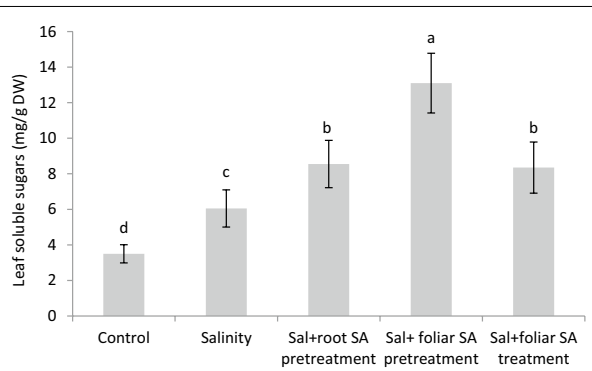

Fig. 2 Leaf soluble sugars concentration in tomato seedlings under salinity treatment and different application methods of salicylic acid. Treatments were control (without salinity and SA application), salinity (application of NaCl but without SA), salinity + root pretreatment with SA, salinity + foliar pretreatment with SA, salinity + foliar treatment with SA. Data are average of 4 replicates ± SD ($F_{4,15} = 50.4^{**}$). Comparison of means was done at 5% level of Duncan's multiple range test

Discussion

The impact of salt in tomato growth

In this study, different growth traits of tomato were significantly reduced by 100 mM NaCl treatment compared to control plants. Reduction in plant growth and biomass production is a common physiological impact of NaCl salinity in many glycophyte plants [12, 14, 39]. Strength of NaCl salinity, exposure period, climatic conditions and plant genetic variations are important factors

regarding salinity damages in plants [3, 11]. Nevertheless, sometimes a mild salinity in the soil or moderate higher EC of nutrient solution may even promote plant growth and/or quality [3, 31]. In this study, 100 mM NaCl salinity increased leaf SPAD value of tomato seedlings. Similar results of higher leaf SPAD value were obtained under mild soil salinity in coriander plants [3]. This can partly be due to reduced leaf area and smaller cells induced by salinity that may result in concentrated chlorophyll content, quite similar to ammonium toxicity effects on tomato plants [40].

Plant biomass production is directly associated with leaf photosynthetic characteristics and influenced by many environmental factors [16, 31]. The significant reduction in shoot fresh weight but not dry weight in the present study could be mainly due to the adverse effect of NaCl salinity on water relation of plants rather than merely on leaf photosynthesis [3, 33, 42]. Osmotic stress is a common secondary stress of NaCl salinity in many plants that can negatively influence many aspects of plant metabolisms [1].

In the present study, root growth was more affected by salinity and SA application than shoot growth, and root and shoot responses were quite different. Increase in root biomass due to salinity treatment has been also reported in other studies [3, 12]. This may be associated with the osmotic adjustment of root cells exposed to secondary osmotic stress by high salinity. Roots are the first organ subjected to the soil or medium salinity, and root allocations of more photo assimilates are a general plant response to salinity [31]. Moreover, for deactivation or excrete of harmful ions of salinity, root cells need more energy and associated metabolites to counter salinity effects.

Growth improvement due to SA application

In the present study, application of SA improved tomato growth and many related traits under salinity. Application of SA reversed the enhanced leaf SPAD value under salinity, and this is probably due to increased leaf area induced by application of SA. In the present study, optimization of plant nutrients uptake, hormonal activity, leaf photosynthesis and biochemical processes by SA application under salinity may contributed in improved growth traits of tomato plant under salinity [14, 18, 20, 23, 44]. Induction of resistance genes and consequent increase in the cell osmolites and antioxidants by SA signaling could also play a role in improved plant growth under salinity [11, 35, 47]. This task is mainly achieved via adequate protection of cell membranes from depolarization induced by high concentrations of Na or Cl ions [1, 10, 41]. In addition, SA application generally mitigates salinity by a reduction in root uptake of Na and Cl ions. Depending on plant species, root cell membranes have the ability to restrict the entrance of harmful ions such as Na and Cl [38, 41]. This ability is enhanced under SA application probably via its signaling effect, although other SA functions may be also involved in this phenomenon.

Application of salicylic acid, particularly via foliar pretreatment, significantly increased nutrient uptake and leaf concentrations of K, Ca, Zn and Fe, whereas it significantly reduced leaf Na concentration under salinity. Increase in nutrient uptake due to SA application has been widely reported under salinity [15, 47]. This can be achieved probably by protection and supporting effect of SA on cell membrane and nutrient uptake systems of roots [24, 39, 47]. SA may influence various physiological traits that minimize the Na/K ratios mainly through reducing Na entry into roots and its translocation into shoots, enhancing H^+-ATPase activity in roots, preventing salinity-induced K leakage from roots, and increased K concentration in shoots under salt and oxidative stresses [9, 11, 22].

In the present study, application of SA further increased leaf soluble sugars and proline concentration under salinity. These compounds are important components of defense reactions of plants to salinity [2, 4, 23]. Compatible solutes at high concentrations can reduce inhibitory effects of saline ions on enzymes activity and metabolic reactions [12, 41]. Pretreatment with SA probably contributes to early biosynthesis and accumulation of proline before and during stress. SA can maintain an enhanced level of ABA in seedlings resulting in higher proline content [18, 19]. Exogenous application of proline has been shown to enhance plant growth by improving physiological and biochemical attributes under salt stress [7]. Increase in plant's ability to achieve osmotic adjustment by increasing de novo synthesis of compatible solutes may also be a result of SA application under salinity or drought stresses [9, 22, 31].

Comparison of the different modes of SA application

In the present study and under salinity, the method of SA application was a significant factor regarding SA ameliorating effects on salinity stress. The method of application of chemicals can significantly influence their tissue concentration of plants [31, 41]. Foliar pretreatment with SA was the most effective method of SA application to recover plant growth under salinity. Similar results indicating the better effect of leaf pretreatment with SA have been also reported [13, 27, 32, 36]. Despite roots are the first organ to face saline ions; however, leaves are the main and final target of toxic ions of salinity. The majority of biochemical reactions in plants generally occur in leaves. The adverse effect of Na and Cl is largely due to their toxicity on leaf biochemical processes [1, 6, 31]. Therefore, pretreatment of leaves with SA than other methods could be more effective, giving adequate time

to leaves to predict stress conditions and to synthesize/mobilize defense effectors [28, 41]. With leaf SA pretreatment, all proposed protective and positive functions of SA are probably expressed, to complete plant defense when the salinity stress starts. On the other hand, leaf SA treatment probably cannot activate or mobilize effective components to counter salinity damages at the time of stress application, despite our results showed some ameliorating effect of this method as well.

Root SA pretreatment also resulted in improved growth of tomato seedlings under salinity in our study. Similarly, root application of SA has been reported to improve the growth of tomato and wheat plants under salinity [5, 42]. SA may influence the root metabolism; however, its translocation to the leaves or more evidently its task as signaling molecules makes the leave as the main target point to induce the associated changes [2, 35, 42]. It has been shown that application of 0.1 mM SA to tomato plants via root drenching provided protection against 150 mM or 200 mM NaCl stress [42]. In contrast, exogenous application of SA through the root medium has been reported to inhibit plant growth in maize [34] and tomato [37]. In muskmelon and under drought stress, there was no difference between SA application methods of seed soaking or foliar pretreatment, indicating that both methods provided similar levels of protection [26]. Moreover, with transgenic Arabidopsis plants, it has been shown that SA cannot induce abiotic stress tolerance in all types of plants, and the effectiveness of SA in inducing stress tolerance depends on plant species and applied SA concentration [18, 21, 24, 36].

Conclusion

In the present study, tomato seedlings growth was significantly reduced by 100 mM NaCl salinity and application of SA showed ameliorating effects on reduced growth traits induced by salinity. Application of SA tended to decrease the leaf concentration of Na under salinity. Foliar SA pretreatment significantly increased leaf K, Ca and Fe concentrations, whereas root SA pretreatment significantly increased leaf Ca under salinity treatment. The results of this study indicate that beside plant species and SA concentration (shown by previous studies), the method of SA application is also an important factor regarding effectiveness of SA under salinity stress. The most effective method of SA application to recover the reduced tomato plant growth under salinity was foliar SA pretreatment and then root SA pretreatment. Leaf SA treatment showed the lowest effectiveness in this regard.

Abbreviations

ppm: parts per million; SA: salicylic acid; FW: fresh weight; SPAD: The Soil and Plant Analysis Development; ABA: abscisic acid.

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Authors' contributions

MKS has planned and prepared the manuscript and GT conducted the experiment and made the analytical analysis of the data. Both authors read and approved the final manuscript.

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Ethics approval and consent to participate

All Authors listed have contributed significantly to the work and agree to be in the author list.

Consent for publication

All authors agree to publish the work.

Competing interests

The authors declare that they have no competing interests.

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