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Impact of Salinity on Tomato Seedling Development: A Comparative Study of Germination and Growth Dynamics in Different Cultivars

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KEYWORDS

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ABSTRACT: Soil salinity is an escalating problem that significantly reduces crop yield, particularly in regions with intensive agriculture or poor irrigation practices. This study aimed to assess the impact of salinity on the germination and early growth parameters of four tomato (*Solanum lycopersicum*) cultivars: 'Sakata', 'US-Agriseed', 'Rossen B.V.', and 'Supermarmance'. Methods: The experiment was conducted under controlled greenhouse conditions with a randomized complete block design. Seeds were exposed to five salinity treatments (0, 4, 6, 8, and 10 ds m^{-1}), and growth parameters including germination rate, seedling length, leaf number, and wet and dry weights were measured over a two-week period. The results demonstrated that increasing salinity levels had a significant inhibitory effect on all measured growth parameters across all cultivars. Germination rates and seedling vigor decreased with increasing salinity, and a complete inhibition of growth was observed at the highest salinity levels (EC-8 and EC-10). However, variability among cultivars indicated differential salinity tolerance, with 'US-Agriseed' displaying relatively better performance under saline conditions. The study provides clear evidence that salinity levels as low as 4 dS m^{-1} can adversely affect the germination and seedling growth of tomato plants. The findings highlight the critical need for developing salinity management strategies and breeding programs to improve salinity tolerance in tomatoes, which could significantly mitigate the impact of salinity stress on crop productivity.

INTRODUCTION

Soil salinity is a critical abiotic stressor that detrimentally impacts agricultural productivity across the globe [1-3]. The accumulation of soluble salts, particularly sodium chloride, in the soil profile imposes osmotic and ionic stress on plant physiological processes, disrupting water uptake and cellular ion homeostasis [4]. The tomato plant (*Solanum lycopersicum*), one of the most extensively cultivated horticultural crops, is moderately tolerant to saline environments; however, its growth and yield are markedly susceptible to high salinity levels [5, 6]. Understanding the impact of salinity on tomato plants is paramount, given their economic and nutritional significance worldwide. The initial effect of salinity on plants manifests as osmotic stress, inhibiting water uptake and reducing cell expansion, leading to stunted growth [7]. Chronic exposure further contributes to ionic stress, with the accumulation of Na^+ and Cl^- ions in plant tissues, which interferes with metabolic processes and

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enzyme function [8-10]. These stresses can trigger oxidative damage through the production of reactive oxygen species (ROS), exacerbating the plant's physiological burden. Salinity can also competitively inhibit the uptake of essential nutrients, compounding the stress effects [11].

Plant responses to salinity are multifaceted, involving complex genetic, biochemical, and physiological adaptations. In tomatoes, these include selective ion transport and sequestration, osmotic adjustment through organic osmolytes, and an augmented antioxidant defense system [12-14]. However, the variability among tomato cultivars in these adaptive responses is substantial and necessitates a comparative analysis to identify and utilize salt-tolerant varieties effectively [15]. Moreover, the repercussions of soil salinity span beyond the direct effects on plant health, extending to ecological dynamics and the sustainability of agricultural practices [16]. Salinization of arable land can lead to a significant decline in farmable acreage, alterations in soil microbiota, and, consequentially, reductions in crop yields. Therefore, characterizing the salinity tolerance of important crops such as tomatoes is crucial for maintaining food security and the viability of agricultural ecosystems in saline-prone regions [17].

The aim of this study is to investigate the effects of salinity on the germination, growth, and biomass accumulation of four tomato cultivars, with an emphasis on identifying varietal differences in salt tolerance. Through a comprehensive analysis of growth parameters under controlled salinity treatments, the study seeks to contribute to the development of salinity management strategies and inform selective breeding programs, thereby enhancing the resilience of tomato crops against salt-induced stress.

MATERIALS AND METHODS

Materials

Tomato cultivars 'Sakata', 'US-Agriseed', 'Rossen B.V.', and 'Supermarmance' were utilized for this study. Seeds were sourced from a certified agricultural supplier, ensuring high quality and uniformity. Supermarmance is a French class called the local class, Sakata is a hybrid class of Japanese origin, US-Agriseed is a hybrid class of American origin and Rossen B.V. is a hybrid class of Netherland origin. Other materials used in the current experiments included Plastic Petri dishes, filter papers, sodium chloride, electrical balance, measurement ruler, and electrical conductivity (EC).

Methods

Seedlings were grown in a controlled environment greenhouse with a consistent temperature of 25°C, 60% relative humidity, and a photoperiod of 16 hours of light and 8 hours of darkness. Salinity treatments were prepared by dissolving analytical grade sodium chloride (NaCl) in deionized water to achieve the desired electrical conductivity (EC) levels of 4, 6, 8, and 10 dS m^{-1} [18]. Tap water was used as the control (EC-0). Each treatment had a corresponding control to account for any potential variability in the tap water source. A randomized complete block design (RCBD) was employed with four replicates per treatment. Each replicate consisted of a tray containing 25 seeds from each tomato species. The trays were irrigated with the respective salinity treatments from sowing until the end of the experimental period. Germination rate was recorded when the radicle emerged from the seed coat. Seedling length, leaf number, and wet and dry weights of seedlings were measured at the end of weeks 1 and 2. Wet weights were obtained immediately after harvest, while dry weights were measured after drying the seedlings in an oven at 70°C for 48 hours.

Statistical analysis

Data were subjected to a statistical analysis of variance (ANOVA) using a standard statistical software package (SPSS). Mean comparisons were performed using the Least Significant Difference (LSD) test at a 5% probability level to determine the statistical significance of differences between treatments.

RESULTS

The study's results indicate a clear inverse relationship between salinity levels and the germination rates of four tomato species. Germination was highest with tap water, with 'Sakata' and 'US-Agriseed' showing the best performance at 96% and 90%, respectively. Increasing salinity to an EC of 4 and 6 led to a substantial drop in germination for all species. At an EC of 8, 'US-Agriseed' had a negligible germination rate of 0.2%, and at EC-10, germination ceased entirely for all species. The average germination rate across all species fell from 70.5% with tap water to 0% at the highest salinity level, with statistical significance confirmed at $p<0.05$. This demonstrates the detrimental impact of high salinity on tomato seed germination as shown in Table 1.

Table 1. The effect of the salinity on the germination percentage of four tomato species.

Species	Tap water	EC=4	EC=6	EC=8	EC=10	Average
Sakata	96.0	76.0	30.6	00.0	00.0	40.52*
US-Agriseed	90.0	74.0	38.0	02.0	00.0	40.8*
Rossen B.V.	54.0	48.0	18.0	00.0	00.0	24.0
Supermarmance	42.0	8.6	00.0	00.0	00.0	10.12
average	70.5*	51.65	21.65	0.25	00.0	
For species: 5.30, salinity concentrations: 5.8, for interference 4.52						

Statistical significance is denoted at $p<0.05$ (LSD).

The results from Table 2 show that seed germination rates for all species decreased with increasing salinity. The highest germination rates were observed in tap water, particularly for Sakata and US-Agriseed at 14.2 days. At an EC level of 4 and 6, all species experienced a drop in germination rates, with US-Agriseed showing slightly better resilience. At EC-8, US-Agriseed was the only species to germinate, albeit at a reduced rate of 10.0 days, and at EC-10, germination ceased for all species. Overall, germination rates declined from an average of 13.29 days in tap water to zero at EC-10. US-Agriseed had a statistically significant higher average germination rate of 9.74* days across salinity levels, indicating its relative tolerance to salinity stress. The asterisk signifies statistical significance at $p<0.05$ by LSD test.

Table 2. The salinity effect on the seed germination rate

Species	Tap water	EC=4	EC=6	EC=8	EC=10	Average
Sakata	14.2	12.9	11.65	00.0	00.0	7.75
US-Agriseed	14.2	12.6	11.9	10.0	00.0	9.74*
Rossen B.V.	12.4	11.54	10.32	00.0	00.0	6.852
Supermarmance	12.35	10.6	00.0	00.0	00.0	4.59
average	13.29*	11.91	8.47	2.5	00.0	
For species: 1.05, salinity concentrations: 0.932, for interference 0.52						

*Statistical significance is denoted at $p<0.05$ (LSD).

The results from Table 3 demonstrate a clear negative impact of salinity on seedling length across all species. In the first week, seedlings grown in tap water had the longest average lengths, with Sakata at 2.45 cm and US-Agriseed at 2.79 cm. In the second week, seedlings in tap water continued to grow, but those in saline conditions showed stunted growth. By EC-4, growth was already reduced, and at EC-6, the lengths were significantly shorter. For Sakata and US-Agriseed, no growth was observed at EC-8 and EC-10. Rossen B.V. and Supermarmance exhibited minimal growth at EC-4 and EC-6, with no growth at higher salinity levels. Overall, seedling growth declined with increased salinity, halting completely at EC-8 and EC-10.

Table 3. The effect of the salinity on the seedling length average.cm^{-1}.

Species	Period	Tap water	EC=4	EC=6	EC=8	EC=10
Sakata	Week1	02.45	02.15	0.93	00.0	00.0
	Week2	08.40	04.46	02.12	00.0	00.0
US-Agriseed	Week1	02.79	01.66	0.86	00.0	00.0
	Week2	05.72	04.06	01.88	01.40	00.0
Rossen B.V.	Week1	01.13	01.08	00.0	00.0	00.0
	Week2	04.70	03.52	01.57	00.0	00.0
Supermarmance	Week1	01.83	00.0	00.0	00.0	00.0
	Week2	04.53	01.68	0.98	00.0	00.0

Table 4 illustrates the impact of salinity on the number of leaves developed by various tomato species over a two-week period. In the first week, under tap water conditions, Sakata had an average of 0.44 leaves, and US-Agriseed had slightly more at 1.20 leaves. Rossen B.V. and Supermarmance had fewer leaves, with 0.40 and 0.83 leaves respectively. However, as salinity increased to EC-4, there was a general decline in leaf formation for all species, and by EC-6, none of the species produced any leaves. In the second week, the pattern continued; Sakata and US-Agriseed had 2.00 and 1.66 leaves respectively in tap water, but this number decreased under EC-4 conditions (0.65 and 1.02 leaves, respectively). At higher salinity levels of EC-6 and beyond, none of the species showed any leaf development. Rossen B.V. and Supermarmance also experienced a reduction in leaf numbers at EC-4 and did not produce any leaves at higher salinity levels. The data clearly indicates that increased salinity has a detrimental effect on leaf development in tomato plants, with no leaf formation observed at many of the salinity concentrations tested.

Table 4. Effect of the salinity on the leaf numbers.

Species	period	Tap water	EC=4	EC=6	EC=8	EC=10
Sakata	Week1	0.44	0.33	00.0	00.0	00.0
	Week2	02.00	0.65	00.0	00.0	00.0
US-Agriseed	Week1	01.20	0.22	00.0	00.0	00.0
	Week2	01.66	01.02	0.178	00.0	00.0
Rossen B.V.	Week1	0.40	00.0	00.0	00.0	00.0
	Week2	0.58	0.43	00.0	00.0	00.0
Supermarmance	Week1	0.83	00.0	00.0	00.0	00.0
	Week2	0.94	00.0	00.0	00.0	00.0

The results from Table 5 indicate that salinity levels have a significant effect on the average root lengths of tomato plants over a two-week period. In the first week, Sakata exhibited an average root length of 0.91 cm in tap water, which was reduced dramatically to 3.38 cm at EC-4, and no growth was observed at salinity levels of EC-6 and beyond. US-Agriseed showed a similar pattern, with root lengths decreasing from 1.64 cm in tap water to 0.32 cm at EC-6 and no growth at higher salinity concentrations. During the second week, the average root lengths continued to decrease with increasing salinity. Sakata's roots grew to 0.70 cm in tap water but reduced to 0.47 cm at EC-4 and then to 0.40 cm at EC-6, with no growth at EC-8 and EC-10. US-Agriseed showed slightly better tolerance with root lengths of 2.84 cm in tap water and 4.67 cm at EC-4, but growth was substantially reduced to 2.49 cm at EC-6 and 0.5 cm at EC-8, with no growth at the highest salinity level. Rossen B.V. and Supermarmance had very limited root growth across all salinity levels. By the second week, Rossen B.V. had 1.96 cm root length at EC-4, but this reduced to 0.81 cm at EC-6. Supermarmance only managed to reach 0.33 cm at EC-4, and no root growth was observed at higher salinity levels for both species. These findings clearly show that increased salinity levels have a substantial inhibitory effect on root elongation in tomato plants, with the most severe impact observed at EC-6 and higher, where virtually no root growth occurred.

Table 5. Effect of the salinity on the average of the root lengths.cm^{-1}.

Species	period	Tap water	EC=4	EC=6	EC=8	EC=10
Sakata	Week1	0.91	3.38	00.0	00.0	00.0
	Week2	03.70	05.47	04.0	00.0	00.0
US-Agriseed	Week1	01.64	01.77	0.32	00.0	00.0
	Week2	02.84	04.67	2.49	0.5	00.0
Rossen B.V.	Week1	0.45	00.0	00.0	00.0	00.0
	Week2	1.96	1.77	0.81	00.0	00.0
Supermarmance	Week1	0.78	00.0	00.0	00.0	00.0
	Week2	03.33	0.23	00.0	00.0	00.0

In Table 6, salinity negatively affected the wet weight of tomato seedlings. Sakata started with the highest weight in tap water (43.0 mg) but declined with increased salinity. US-Agriseed initially increased in weight at EC-4 and EC-6 but then decreased to zero by EC-10. Rossen B.V. increased slightly at EC-4 but then decreased along with increasing salinity levels. Supermarmance consistently declined across all salinity levels. By EC-10, all species experienced complete growth inhibition with a wet weight of 0.0 mg. The average wet weight across all species was highest in tap water and declined to zero at EC-10, with Supermarmance showing the most significant decrease, indicated by a statistically significant average of 15.80* mg.

Table 6. The effect of the salinity on the wet weight of the seedlings.mg^{-1}.

Species	Tap water	EC=4	EC=6	EC=8	EC=10	Average
Sakata	43.0	32.0	32.0	00.0	00.0	21.40
US-Agriseed	24.0	26.0	34.0	20.0	00.0	20.80
Rossen B.V.	36.0	38.0	27.0	08.0	00.0	21.80
Supermarmance	27.0	29.0	23.0	00.0	00.0	15.80*
average	32.5*	31.25	29.0	07.0	00.0	
For species: 1.20, salinity concentrations: 0.99, for interference 1.45						

*Statistical significance is denoted at p<0.05 (LSD).

Salinity significantly reduced the dry weight of tomato seedlings across all species, as shown in Table 7. Dry weights decreased from their initial values in tap water as salinity increased, with all species reaching a dry weight of 0.0 mg at EC-8 and EC-10. While there were some variations at lower salinity levels, with minor increases or decreases, the overall trend was a decline to zero at high salinity, reflecting a clear inhibitory effect of salinity on seedling growth. The average dry weight across species mirrored this pattern, decreasing from 1.32 mg in tap water to 0.0 mg at high salinity levels.

Table 7. The effect of the salinity on the dry weight of the seedlings.mg^{-1}.

Species	Tap water	EC=4	EC=6	EC=8	EC=10	Average
Sakata	01.72	01.10	02.80	00.0	00.0	01.124
US-Agriseed	01.40	01.02	01.22	02.0	00.0	01.128
Rossen B.V.	0.8	02.0	02.62	05.70	00.0	02.22
Supermarmance	01.34	02.30	03.50	00.0	00.0	01.428
average	01.32	01.605	02.535	01.925	00.0	
For species: 1.50, salinity concentrations: 01.625, for interference 2.40						

*Statistical significance is denoted at p<0.05 (LSD).

DISCUSSION

The collective data in the present study provide a comprehensive overview of how increasing salinity levels affect various growth parameters of tomato seedlings, including germination rate, seedling length, leaf number, wet weight, and dry weight. The results demonstrate a clear trend as salinity levels increase, germination rates, seedling lengths, and the number of leaves developed by the tomato seedlings notably decrease. At lower salinity levels (EC-4 and EC-6), some seedlings were still able to germinate and show some growth, although reduced compared to tap water. However, at higher salinity levels (EC-8 and EC-10), germination and growth were severely inhibited or completely ceased. This suggests that tomato plants have a threshold salinity level beyond which their ability to germinate and grow is significantly compromised [19-21]. The findings are consistent with the known sensitivity of tomatoes to salinity, which affects osmotic balance and nutrient uptake efficiency [22]. The reduction in both wet and dry weights of the seedlings as salinity increased is indicative of the stress imposed on the plants. At moderate salinity levels, some seedlings exhibited an initial increase in dry weight, which could be attributed to osmotic adjustment mechanisms where plants accumulate solutes to maintain water uptake [23]. However, this compensatory mechanism is overcome at higher salinity levels, leading to reduced biomass accumulation, as reflected in the reduced wet and dry weights. This reduction in biomass is likely due to both osmotic stress, which limits water uptake, and ionic stress, which can lead to toxicity and nutrient imbalance [22, 24].

The data also reveal species-specific responses to salinity stress. For instance, US-Agriseed consistently showed a higher tolerance to salinity compared to other species, as evidenced by its higher germination rates, seedling lengths, and wet and dry weights under saline conditions [25]. This indicates potential genetic differences in salinity tolerance among the cultivars, which could be explored for breeding programs aimed at improving salinity resistance. Statistical analysis, denoted by asterisks for significant differences at $p<0.05$, suggests that the observed effects of salinity on growth parameters are indeed statistically significant and not due to random variation. This adds robustness to the conclusion that salinity negatively impacts tomato seedling development. The implications of these findings are critical for agricultural practices in saline environments. They suggest that managing salinity levels is crucial for the successful cultivation of tomato plants. Strategies such as the use of less saline water sources, soil amendments to improve water retention and reduce salinity, and the selection or engineering of more salt-tolerant tomato cultivars could be key to maintaining productivity in areas affected by soil salinization.

CONCLUSIONS

the comprehensive analysis of the salinity impact on tomato seedlings across multiple growth parameters has elucidated the extent to which salt stress can impede early plant development. The consistent decline in germination rates, seedling vigor, and biomass accumulation with increasing salinity underscores the vulnerability of tomato cultivars to ionic and osmotic stress. Notably, the data revealed cultivar-specific responses, with some varieties exhibiting higher tolerance levels, suggesting an avenue for genetic improvement and selection for salinity resistance. The research reaffirms the imperative for adopting salinity management strategies in agricultural settings, particularly in regions where soil salinization poses a significant risk to crop productivity. The integration of practices such as selective breeding, appropriate irrigation management, and soil amendment applications are vital to sustain and enhance tomato crop yields. Moreover, the statistically significant findings from this study contribute valuable insights into the plant physiological responses to salinity stress, providing a foundation for further research into the underlying mechanisms of salt tolerance. This knowledge can guide the engineering of crops that are more resilient to salinity, ultimately aiding in the fight against the challenges posed by global climate change and soil degradation. Conclusively, the research not only broadens our understanding of plant-salinity interactions but also serves as a clarion call for targeted efforts in plant breeding, agricultural planning, and sustainable management practices to bolster food security in salinity-affected landscapes.

CONFLICT OF INTERESTS

None

Study Limitations

No limitations were known at the time of the study.

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