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Effect of Salt Stress on Germination Test and Scanning Electronic Microscope (SEM) Analysis of Tomato (*Solanum lycopersicum* L.) Seeds

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Abstract: This study investigates the responses of various tomato genotypes to different salt doses, revealing significant variations in germination outcomes. Distinct differences were observed between salt-tolerant and salt-sensitive genotypes, wherein tolerant genotypes exhibited higher germination rates and shorter germination periods. Scanning electron microscope analysis identified elemental variations, including carbon (C), oxygen (O), calcium (Ca), silicon (Si), sodium (Na), phosphorus (P), sulfur (S), chlorine (Cl), potassium (K), and magnesium (Mg), contributing to the differing responses among genotypes. In salt-sensitive genotypes, an increase in salt doses correlated with delayed germination, decreased germination rates, and notable changes in seed coat cells, including increased shrinkage and reduced cell width and seed hair. Conversely, salt-tolerant genotypes displayed potassium (K) and magnesium (Mg) elements, further emphasizing their resilience to salt stress. This study highlights the importance of selecting salt-tolerant tomato genotypes in saline environments to mitigate germination losses compared to their sensitive counterparts. The findings provide valuable insights for enhancing salt tolerance in tomato plants, contributing to sustainable agricultural practices.

1. Introduction

Crop production might grapple with diverse soil salinity levels, exerting detrimental effects on crucial stages like seed germination, emergence, seedling formation, and overall plant development. These challenges necessitate effective management for sustainable agriculture. Our study originates from the recognition that the identification of salt-tolerant genotypes is imperative for enhancing both yield and quality in saline soil conditions.

To contextualize this investigation, previous studies have underscored the intricate relationships between various crops and salinity stress. Notably, the germination and early seedling development of sweet corn were reported to decrease with increasing NaCl doses (Öztürk et al., 2021). Additionally, Soysal et al. (2021) found that grass seed parameters were not affected at 20 and 40 mM salt doses but were negatively impacted after 140 mM salt dose. Merino et al. (2021) highlighted the broader impact of soil salinity on crop productivity, visually observed under a scanning electron microscope. Dere (2021) noted decreasing parameters such as germination percentage, germination time, germination index, and germination rate in Rio Grande and H2274 tomato varieties with increasing salt doses. Furthermore, Kibar et al. (2020) reported a reduction in the germination rate and seedling development of bean seeds with increasing salt doses. Gou et al. (2020) emphasized the positive effects of silicon on cucumber seeds negatively affected by salt doses, increasing germination percentage, germination index, and seedling strength. Wu et al. (2019) demonstrated the alleviation of negative effects caused

by salt stress on seed germination parameters through the priming process in broccoli seeds. Petrovic et al. (2016) and Benlioğlu and Özkan (2015) studied peas and barley, respectively, revealing varied germination rates under different NaCl doses. Aydın (2015) explored the response of wheat, tomato, bean, and corn varieties to increasing salt doses, noting a decrease in various parameters. Uyanık et al. (2014) observed decreased germination time and rate in rapeseed varieties with increasing salt doses. Similarly, Dadaşoğlu and Ekinci (2013) noted reduced germination of bean seeds with increasing salt doses. Doğan (2008) identified salt damage thresholds in tomatoes, with tolerant genotypes affected at doses of 125-150 mM NaCl and sensitive genotypes damaged at doses of 50-75 mM NaCl. Leon et al. (2005) investigated the effects of nickel salts on a proteaceae species, revealing varying impacts on germination and root growth.

Scanning Electron Microscope (SEM) Analysis is a high-resolution imaging technique used to examine surface morphology. In SEM, a focused electron beam scans the sample, and interactions with atoms produce signals for imaging. Sample preparation involves coating with a conductive layer. The electron beam creates detailed images by detecting signals such as secondary electrons and backscattered electrons, revealing microstructures and compositions. SEM is widely applied in materials science, biology, and nanotechnology for its ability to provide microscopic insights into surface features. Scanning electron microscopy could reveal changes in the seed coat during germination (Sembada et al., 2023). These diverse studies underscore the complexity of plant responses to salinity stress, and the present study aims to contribute insights into the responses of four tomato genotypes and the H2274 variety to varying salt concentrations in the Erciş district, Van province, Turkey, including a comprehensive Scanning Electronic Microscope (SEM) Analysis of Tomato Seeds.

2. Materials and Methods

Erciş tomato genotypes and the seeds of the commercial tomato variety H2274 were subjected to germination tests and scanning electron microscope (SEM) analyses at salt doses of 0, 50, 100, and 150 mM NaCl. A 100% NaCl salt source was used to create the specified doses. Plastic petri dishes with filter paper were employed for seed planting during the trial setup. Room temperature and humidity were monitored every 2 hours using a Loyka Elite 100 device, averaging 24.75°C and 64.83%, respectively. Seeds from H2274 and ED1, ED2, ED3, and ED4 tomato genotypes were utilized. The seeds were placed on plastic petri dishes with two layers of filter paper, following Çalışkan's (2009) methodology. Twenty tomato seeds were distributed in each petri dish. Salt doses were prepared and applied to each petri dish. The experimental design involved random plots in a factorial trial with three repetitions, each comprising four petri dishes. Daily germination data were recorded, and the study concluded after 13 days of germination for tomato seeds, followed by analysis.

2.1. Germination percentage

The germination percentage for Erciş tomato genotypes subjected to various salt doses was determined using the formula:

Germination Percentage=(Total number of seeds / Number of seeds germinated)×100

This calculation method is in accordance with established protocols outlined by Jalink and Van Der Schoor (2000), Al-Maskri et al. (2004), Li et al. (2007), and Çalışkan (2009).

2.2. Germination time (days)

The average number of days to germination for the Erciş tomato genotypes, subjected to varying salt doses, is determined by the formula:

Average number of days to germination = [(number of seeds germinating on day 1×day 1)+(number of seeds germinating on day 2×day 2)+…+(number of seeds germinating on the last day×last day)] / Total number of seeds germinating

This calculation follows the methodology proposed by Jalink and Van Der Schoor (2000), Al-Maskri et al. (2004), Li et al. (2007), and Çalışkan (2009).

2.3. Germination index

Germination Index = (germination rate on day 1 / first counting day) + (germination rate on day 2 / second counting day) +…+ (germination rate on the last counting day / last counting day)

(This calculation method aligns with the approach suggested by Jalink and Van Der Schoor (2000), Al-Maskri et al. (2004), Li et al. (2007), and Çalışkan (2009).

2.4. Scanning electronic microscope (SEM) analysis

In the scanning electron microscopy (SEM) analysis for this study:

1- Seed Coat Interaction and Cell Damage:

Examined the interaction and cell damage within the seed coat.

2- Salt Interaction and Elemental Composition:

2.1. Determined the salt interaction within the seed coat.

2.2 Identified elements through SEM analysis.

2.3. Calculated the percentage element amounts of seed weight.

These SEM investigations align with prior studies conducted by Leon et al. (2005), Carvalho et al. (2011), and Merino et al. (2021).

2.5. Statistical analysis

The experimental design of the study followed a randomized factorial trial with three replications. Statistical analyses were conducted using SAS 9.0, employing analysis of variance (ANOVA) within the package program. To discern significant means, Duncan's multiple comparison test was applied, referencing the methodology outlined by Duncan (1955), Yeşilova and Denizhan (2016), and SAS (2018). This rigorous statistical approach ensured robust evaluation and interpretation of the obtained results.

3. Results and Discussion

This study comprehensively investigated the responses of tomato genotype seeds to varying salt doses, incorporating analyses of scanning electron microscope results and germination tests both within and between genotypes. The findings provide a nuanced understanding of how these tomato genotypes respond to salt stress, shedding light on potential variations in germination patterns and seed coat interactions. The integration of SEM results with germination tests enhances the depth of insight into the effects of salt doses on the examined tomato genotypes, contributing to the broader discourse on plant responses to salinity stress.

3.1. H2274 tomato genotype: germination and SEM analysis

In evaluating the response of H2274 tomato genotype seeds to varying salt doses, significant differences emerged in germination characteristics (Table 1). The germination rate exhibited a range from 91.14% at 0 mM salt to 64.41% at 150 mM salt, accompanied by corresponding fluctuations in the number of days required for germination and the germination

index. The data highlights the salt sensitivity of H2274, with higher salt concentrations correlating to reduced germination efficiency and delayed germination (Table 1).

Table 1. Germination parameters of H2274 tomato genotype

Salt doses (mM)	Germination rate	Germination time (days)	Germination index
0	91.14 a*	3.83 d	38.56 a
50	86.65 b	3.91 c	38.14 b
100	75.54 c	4,54 b	32.91 c
150	64.41 d	5.28 a	25.96 d

*Significant differences indicated by different letters ($p<0.05$).

Furthermore, scanning electron microscope (SEM) analysis provided insights into the elemental composition of H2274 tomato genotype seeds at different salt doses (Table 2). Notably, variations in carbon (C), oxygen (O), calcium (Ca), silicon (Si), sodium (Na), phosphorus (P), sulfur (S), and chlorine (Cl) levels were observed. SEM images (Figure 1 and Figure 2) visually depicted alterations in seed cell morphology, such as increased shrinkage and reduced ribbon-like hairs, particularly evident at higher salt concentrations (Figure 2).

Table 2. Nutrient element amounts in SEM of H2274 tomato genotype

Elements	% Amounts in SEM at Salt Doses			
	0 mM salt	50 mM salt	100 mM salt	150 mM salt
C	48.06	46.12	45.18	44.01
O	49.60	41.86	29.46	43.55
Ca	2.33	0.97	0.95	1.04
Si	-	0.89	0.80	0.86
Na	-	2.67	6.64	4.46
P	-	3.17	2.44	1.38
S	-	2.44	2.00	1.12
Cl	-	1.88	12.54	3.57

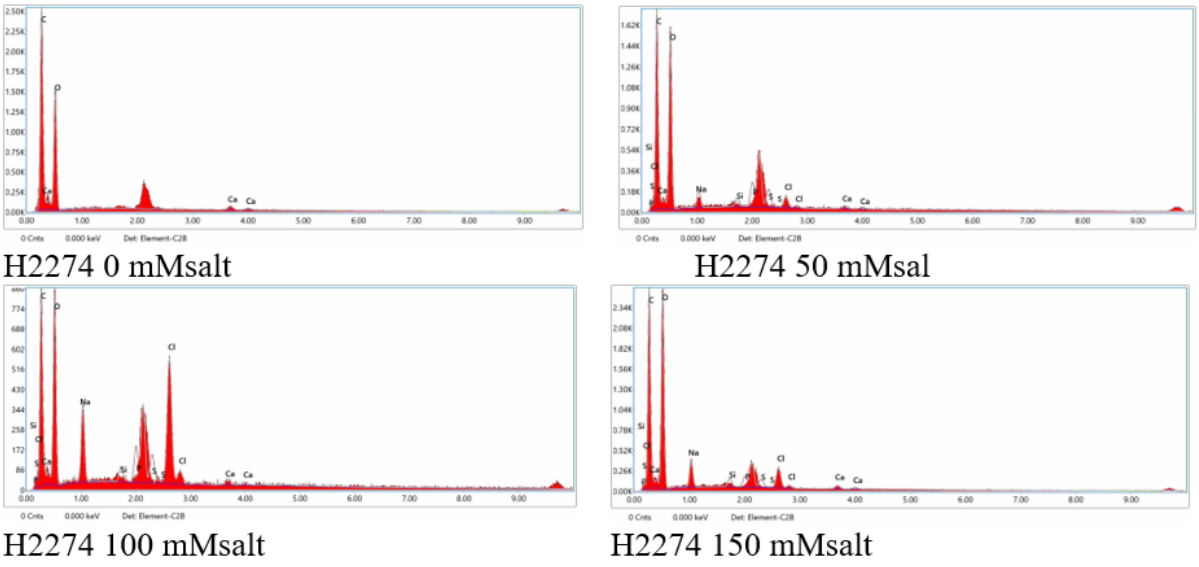

Figure 1. Nutrient elements in SEM at salt doses of H2274 tomato genotype

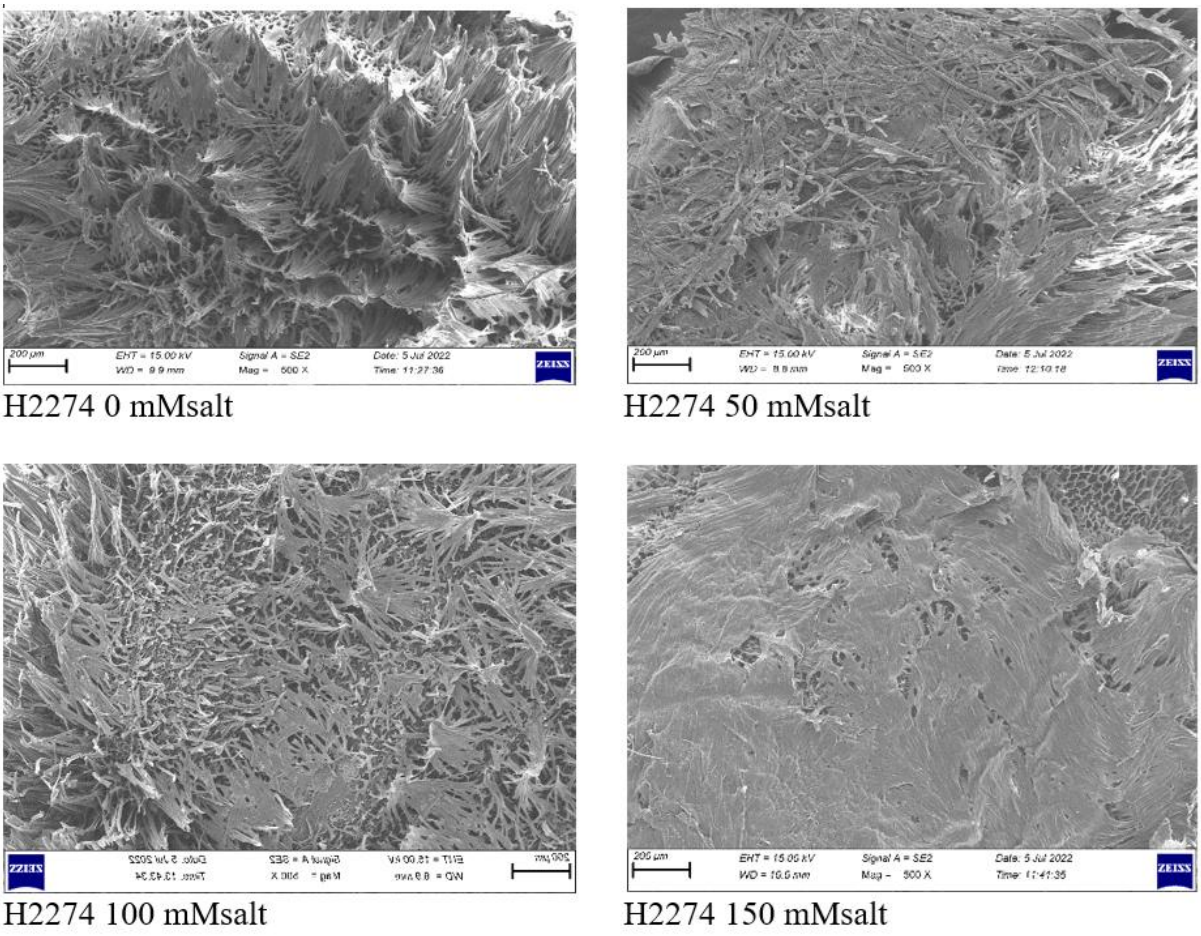

Figure 2. Seed images of H2274 tomato genotype in SEM at salt doses

These findings underscore the intricate interplay between salt stress, germination dynamics, and seed morphology in H2274 tomato genotype, contributing valuable insights for future agricultural practices in saline conditions.

3.2. ED1 and ED2 tomato genotypes: germination and SEM analysis

The germination dynamics and scanning electron microscope (SEM) analysis of ED1 and ED2 tomato genotypes under varying salt concentrations revealed distinct responses (Table 3, Table 4, Table 5, Figure 3, Figure 4, Figure 5, Figure 6).

3.2.1 ED1 tomato genotype

Table 3 demonstrates that ED1 exhibited statistically significant variations in germination parameters across salt doses. At 0 mM salt, the highest germination rate was 91.13%, declining to 57.66% at 150 mM salt. Similarly, the germination index ranged from 44.92 at 0 mM to 23.35 at 150 mM. SEM analysis (Table 4, Figure 3, Figure 4) revealed changes in elemental composition and seed morphology, with increased shrinkage and reduced ribbon-like hairs at higher salt doses.

Table 3. Germination parameters of ED1 and ED2 tomato genotype

Salt doses (mM)	ED1			ED2		
	Germination rate	Germination time (days)	Germination index	Germination rate	Germination time (days)	Germination index
0	91.13 a*	4.23 d	44.92 a	97.73 a	3.93 d	40.53 a
50	77.74 b	4.84 c	36.35 b	93.27 b	4.07 c	40.35 a
100	64.43 c	6.03 b	30.06 c	77.73 c	4.46 b	31.87 b
150	57.66 d	6.75 a	23.35 d	64.44 d	5.79 a	27.68 c

*Significant differences indicated by different letters ($p<0.05$)

Table 1. Nutrient element amounts in SEM of ED1 tomato genotype

Elements	% Amounts in SEM at Salt Doses			
	0 mM salt	50 mM salt	100 mM salt	150 mM salt
C	49.50	45.55	45.64	44.77
O	42.69	40.22	42.53	37.36
Ca	1.55	1.25	0.90	2.22
Si	1.17	0.53	0.79	0.78
Na	1.16	5.13	3.92	4.95
P	1.89	0.77	1.80	0.53
S	1.87	0.72	1.40	0.88
Cl	0.18	5.84	3.02	8.52

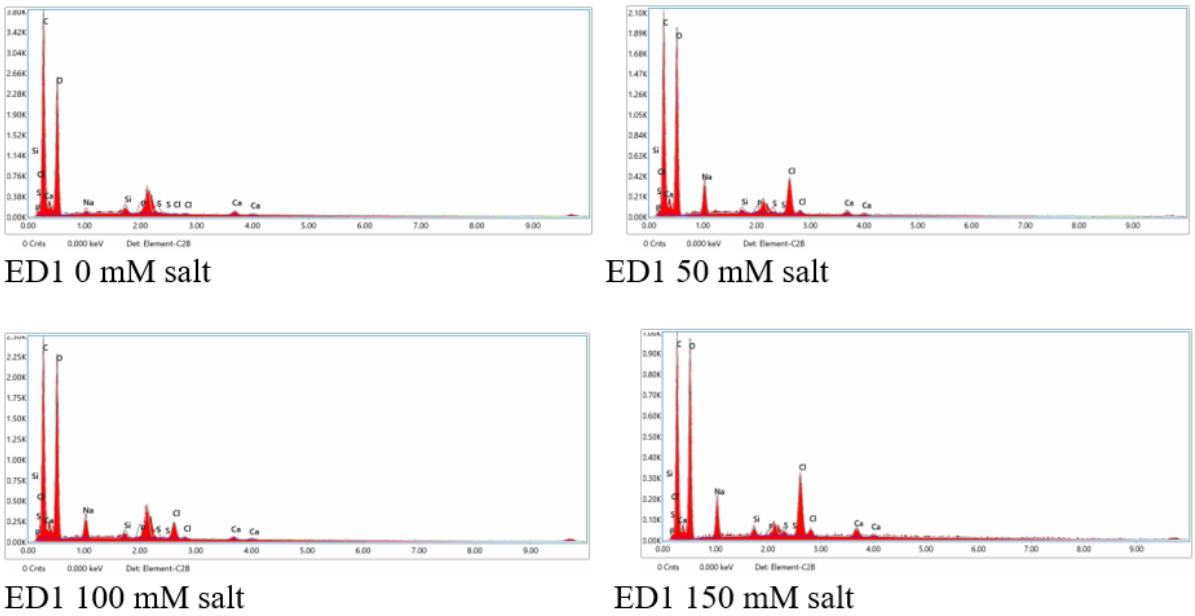

Figure 3. Nutrient elements in SEM at salt doses of ED1 tomato genotype

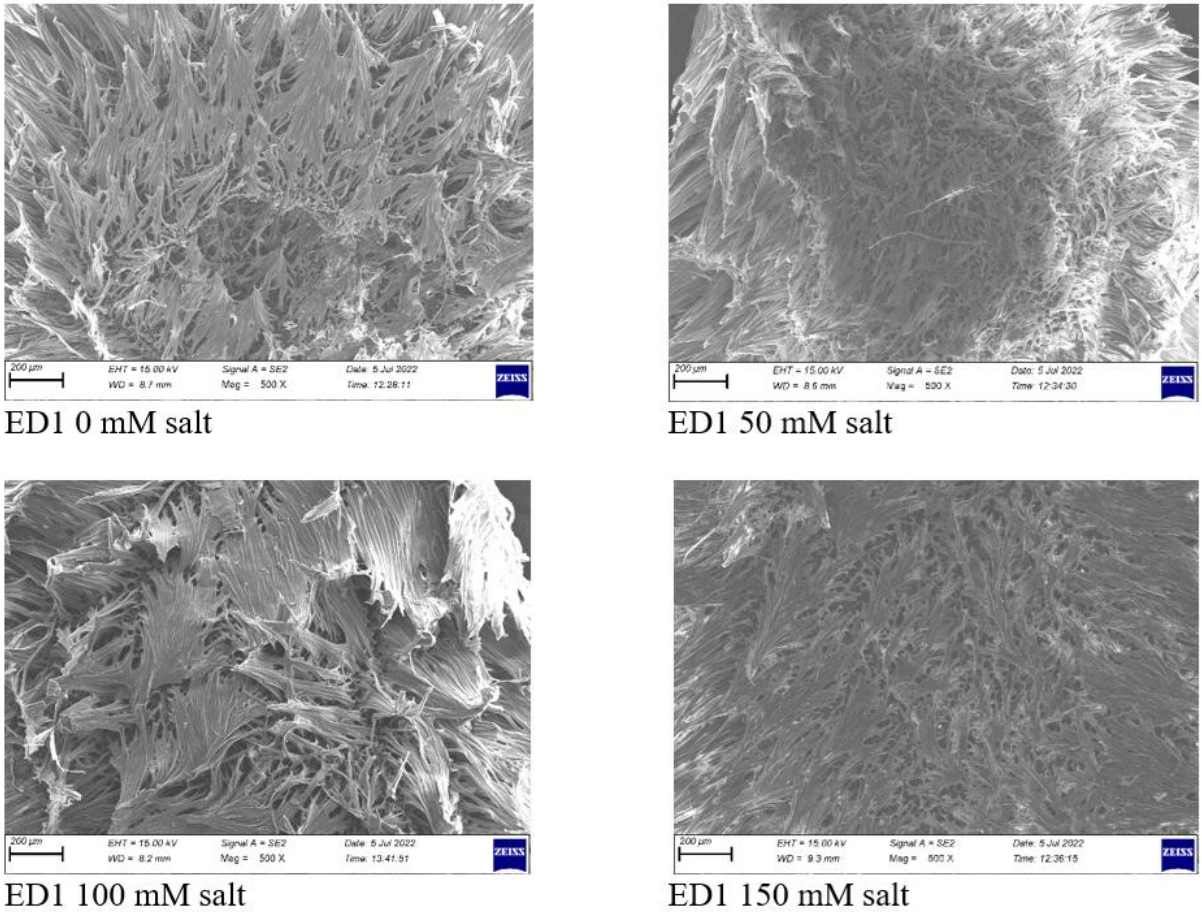

Figure 4. Seed images of ED1 tomato genotype in SEM at salt doses

3.2.2. ED2 tomato genotype

Similar trends were observed in ED2, as depicted in Table 3. ED2 showcased significant differences in germination parameters across salt doses, with the highest germination rate at 97.73% (0 mM) and the lowest at 64.44% (150 mM). The germination index ranged from 40.53 to 27.68, indicating a decline with increasing salt concentration. SEM analysis (Table 5, Figure 5, Figure 6) demonstrated alterations in elemental composition and seed morphology, further supporting the sensitivity of ED2 to salt stress.

Table 5. Nutrient element amounts in SEM of ED2 tomato genotype

Elements	% Amounts in SEM at Salt Doses			
	0 mM salt	50 mM salt	100 mM salt	150 mM salt
C	50.42	47.43	48.39	47.28
O	35.44	35.11	38.16	43.07
Ca	1.70	1.52	1.32	0.97
Si	1.45	1.81	1.24	0.69
Na	1.24	2.60	2.36	3.91
P	5.20	4.33	3.81	0.45
S	4.27	3.87	2.95	0.53
Cl	0.29	3.32	1.77	3.09

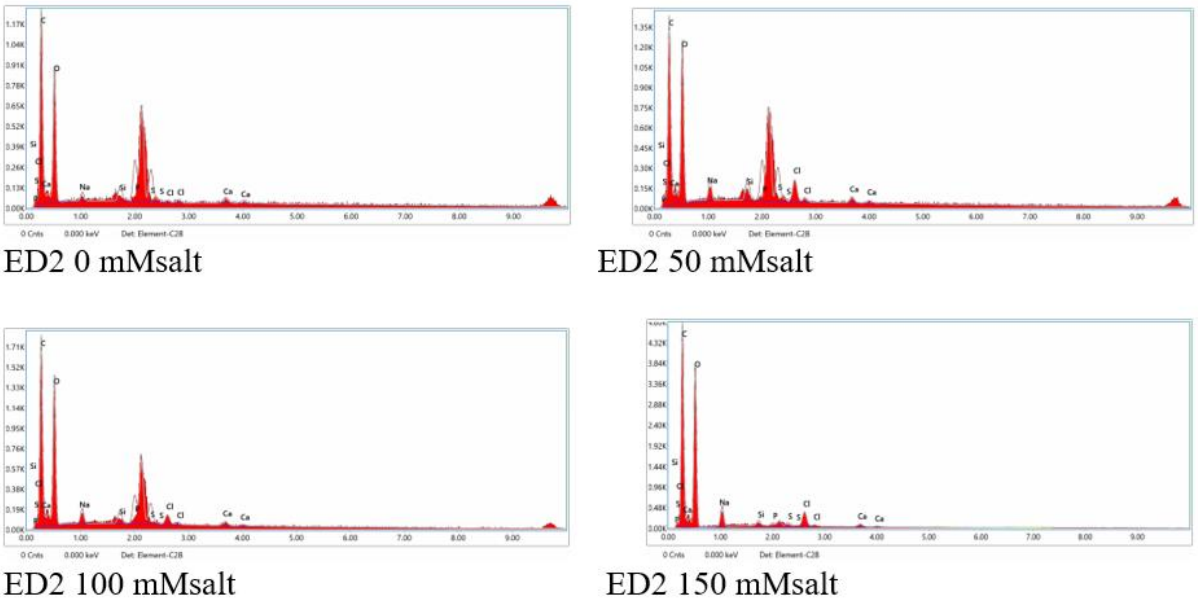

Figure 5. Nutrient elements in SEM at salt doses of ED2 tomato genotype

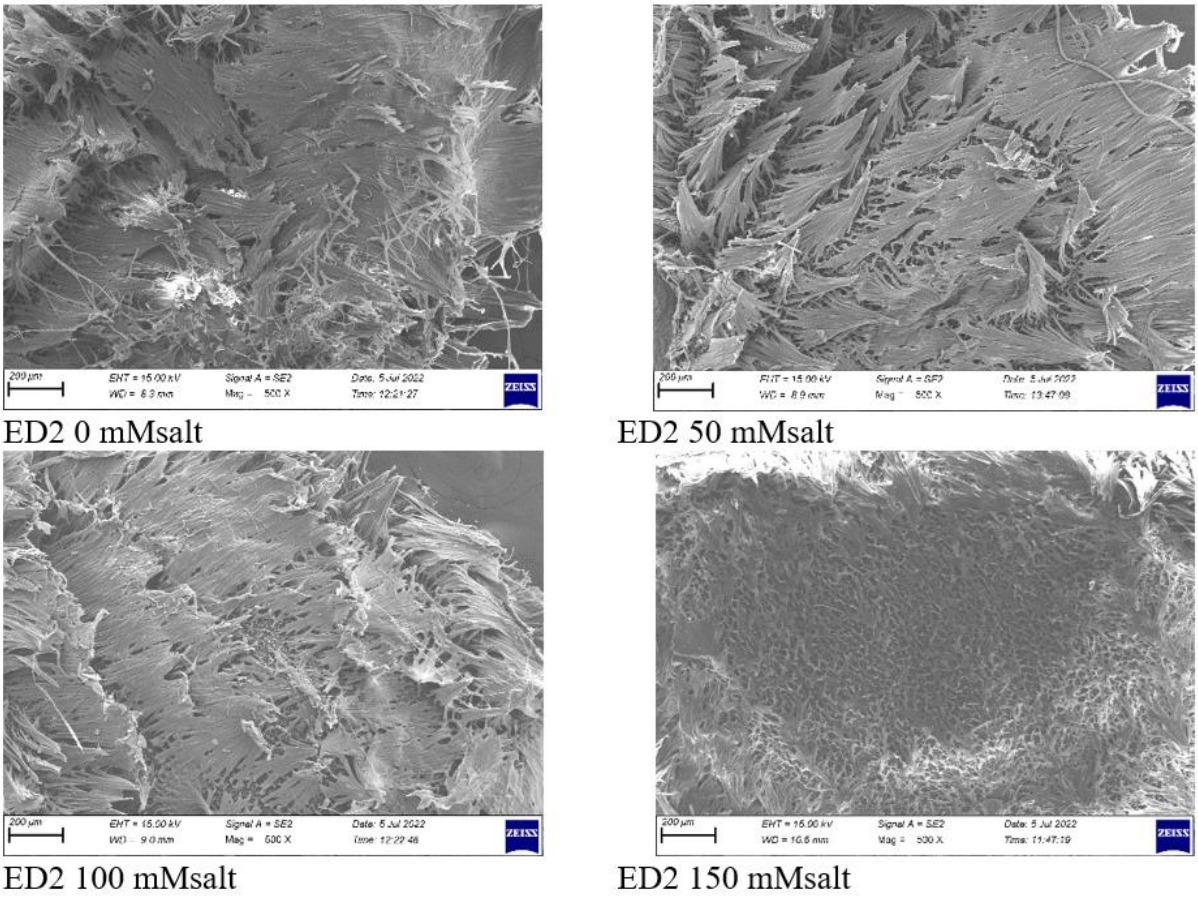

Figure 6. Seed images of ED2 tomato genotype in SEM at salt doses

3.3. ED3 and ED4 tomato genotypes germination and SEM analysis

The germination characteristics and scanning electron microscope (SEM) observations of the ED3 and ED4 tomato genotypes under varying salt concentrations demonstrate statistically significant responses (Table 6, Table 7, Table 8, Figures 7, 8, 9, 10).

3.3.1. ED3 tomato genotype germination

In Table 6, the germination parameters of the ED3 tomato genotype exhibit substantial differences across salt doses. The highest germination rate was 91.09% at 0 mM salt, while the lowest rate was 48.87% at 150 mM. The germination index ranged from 44.68 at 0 mM to 17.76 at 150 mM. SEM analysis (Table 7, Figures 7, 8) reveals changes in elemental composition and seed morphology, indicating the impact of varying salt concentrations on the structure of the seeds.

Table 6. Germination parameters of ED3 tomato genotype

salt doses (mM)	ED3			ED4		
	Germination rate	Germination time (days)	Germination index	Germination rate	Germination time (days)	Germination index
0	91.09 a*	4.09 d	44.68 a	68.85 a	4.95 d	31.08 a
50	77.72 b	4.99 c	37.74 b	57.75 b	5.89 c	21.08 b
100	66.66 c	5.64 b	29.73 c	44.43 c	7.66 b	18.71 c
150	48.87 d	7.65 a	17.76 d	35.56 d	9.04 a	13.86 d

*Significant differences indicated by different letters ($p<0.05$)

Table 7. Nutrient element amounts in SEM of ED3 tomato genotype

Elements	% Amounts in SEM at Salt Doses			
	0 mM salt	50 mM salt	100 mM salt	150 mM salt
C	49.59	46.35	44.93	44.30
O	42.76	45.00	41.99	36.22
Ca	1.47	1.37	1.74	0.70
Si	1.10	1.26	1.35	0.83
Na	0.85	1.57	2.74	5.33
P	1.75	1.05	3.00	2.43
S	1.57	0.94	2.55	2.08
Cl	0.15	1.40	1.71	8.11
K	-	1.06	-	-

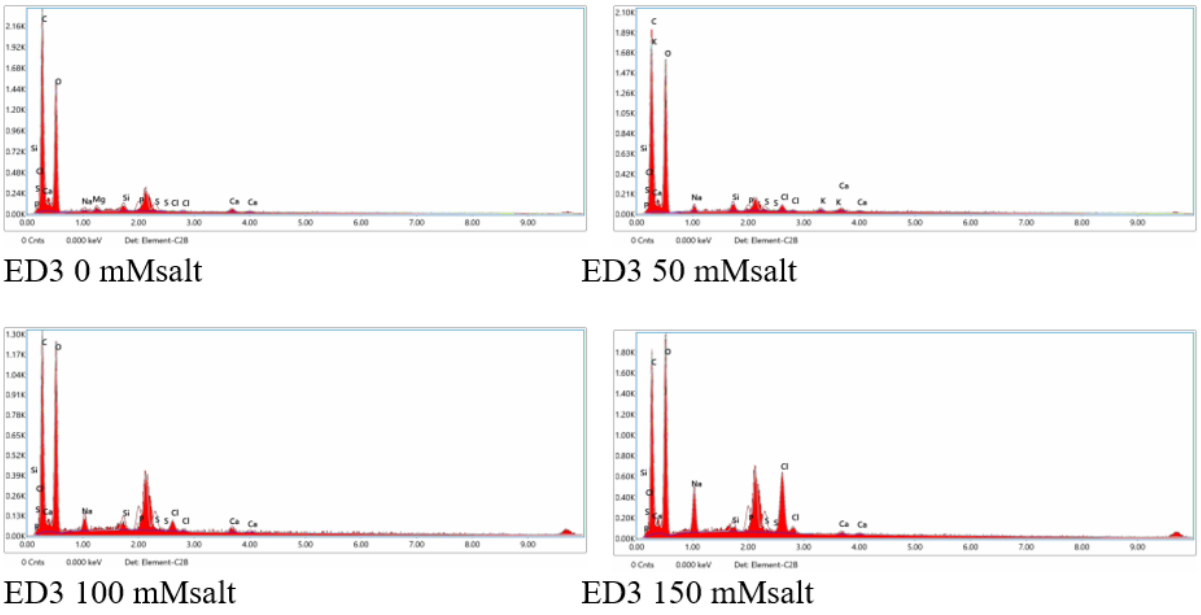

Figure 7. Nutrient elements in SEM at salt doses of ED3 tomato genotype

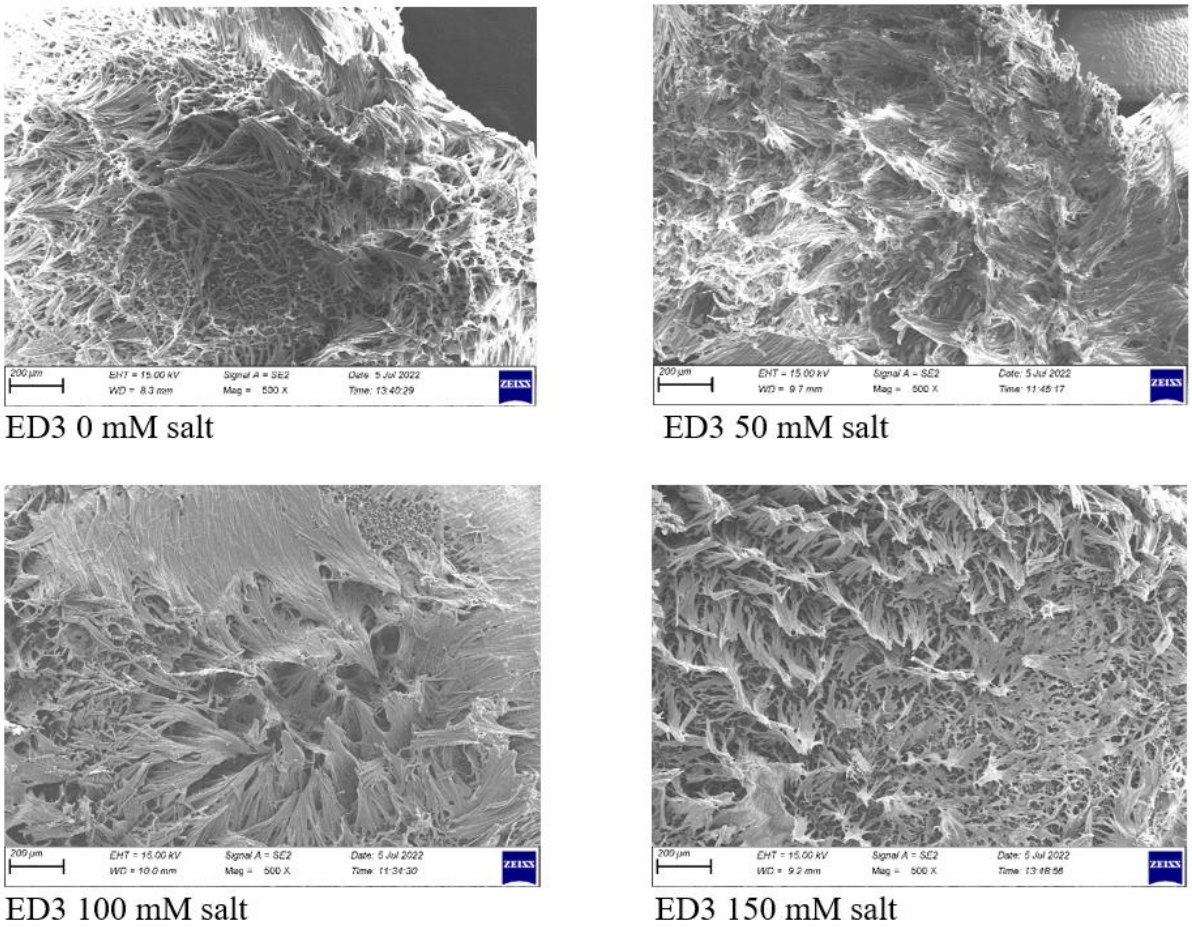

Figure 8. Seed images of ED3 tomato genotype in SEM at salt doses

3.3.2. ED4 tomato genotype germination

Table 6 illustrates variations in germination parameters across salt doses for the ED4 tomato genotype. The highest germination rate was 68.85% at 0 mM salt, while the lowest rate was 35.56% at 150 mM. The germination index ranged from 31.08 at 0 mM to 13.86 at 150 mM. SEM analysis (Table 8, Figures 9, 10) showcases changes in elemental composition and seed morphology, emphasizing the effects of different salt concentrations on seed structure.

Table 8. Nutrient element amounts in SEM of ED4 tomato genotype

Elements	% Amounts in SEM at Salt Doses			
	0 mM salt	50 mM salt	100 mM salt	150 mM salt
C	50.41	46.88	47.33	45.18
O	37.54	46.16	40.09	29.46
Ca	1.66	1.94	1.33	0.95
Si	1.28	-	1.49	0.80
Na	0.98	2.90	2.36	6.64
P	4.36	-	2.46	2.44
S	3.43	-	2.37	2.00
Cl	0.33	2.12	1.83	12.54

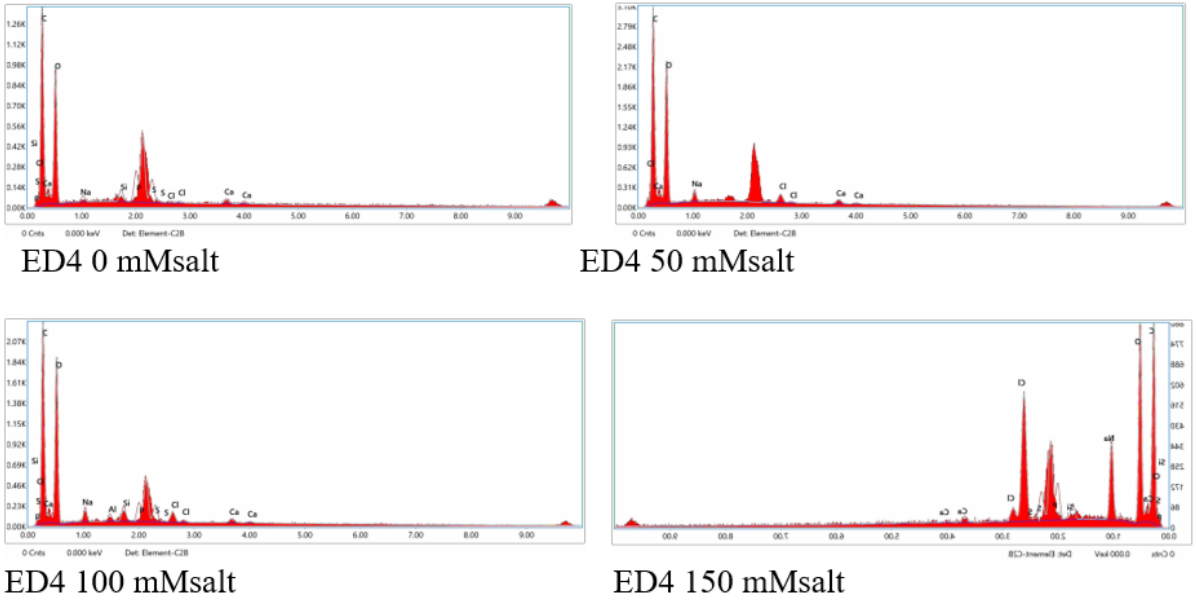

Figure 9. Nutrient elements in SEM at salt doses of ED4 tomato genotype

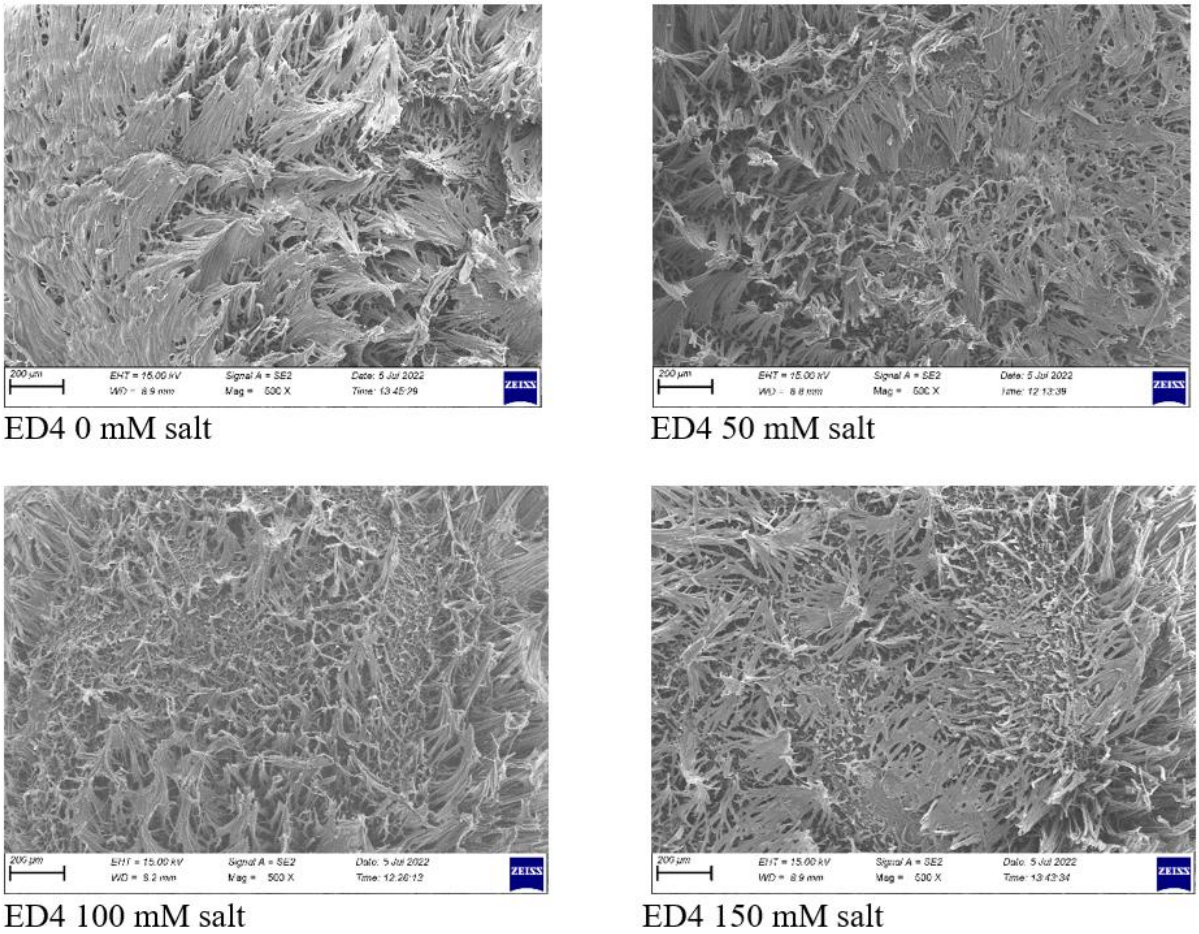

Figure 10. Seed images of ED4 tomato genotype in SEM at salt doses

3.4 Tomato inter-genotype germination test

The germination characteristics of various tomato genotypes under different salt concentrations are presented in Table 9, revealing statistically significant differences in germination rates, germination days, and germination indices.

The highest germination rate was observed in the ED2 genotype at 0 mM salt dose (97.73%), while the lowest was in the ED4 genotype at 150 mM salt dose (35.56%). The shortest germination period was recorded for the H2274 genotype and ED2 genotype at 0 mM (3.83 and 3.93 days, respectively), while the longest was for the ED4 genotype at 150 mM (9.04 days). The highest germination indices were found in the ED1 and ED3 genotypes at 0 mM salt dose (44.92 and 44.68, respectively). The lowest germination index was observed in the ED4 genotype at 150 mM (13.86). The significant differences in these parameters underscore the genotype-specific responses to salt concentrations, providing valuable insights for understanding the impact on germination in different tomato genotypes.

Table 9. Germination parameters of tomato genotypes at different salt doses

Genotypes	Salt doses	Germination rate	Germination time (days)	Germination index
H2274	0 mM	91.14 b*	3.83 f	38.56 b
	50 mM	86.65 cb	3.91 f	38.14 b
	100 mM	75.54 c	4,54 e	32.91 c
	150 mM	64.41 f	5.28 cd	25.96 d
ED1	0 mM	91.13 a	4.23 de	44.92 a
	50 mM	77.74 c	4.84 ef	36.35 b
	100 mM	64.43 f	6.03 bc	30.06 c
	150 mM	57.66 e	6.75 c	23.35 d
ED2	0 mM	97.73 a	3.93 f	40.53 ab
	50 mM	93.27 ab	4.07 de	40.35 ab
	100 mM	77.73 c	4.46 e	31.87 c
	150 mM	64.44 f	5.79 d	27.68 cd
ED3	0 mM	91.09 b	4.09 de	44.68 a
	50 mM	77.72 c	4.99 ef	37.74 b
	100 mM	66.66 d	5.64 d	29.73 c
	150 mM	48.87 f	7.65 b	17.76 e
ED4	0 mM	68.85 d	4.95 ef	31.08 c
	50 mM	57.75 e	5.89 d	21.08 de
	100 mM	44.43 f	7.66 b	18.71 e
	150 mM	35.56 g	9.04 a	13.86 f

*Significant differences indicated by different letters ($p<0.05$).

In our investigation, we delved into the inter-genotype germination test of tomato genotypes under varying salt doses, shedding light on significant variations in germination

rates, days to germination, and germination indices. Our findings align with several studies that have explored the impact of salt stress on different plant species.

A study by Leon et al. (2005) examining the effects of nickel salts on *Grevillea exul* var *rubiginosa* seeds demonstrated that Ni chloride led to a substantial decrease in germination and root growth. Interestingly, SEM images revealed distinct observations in the seed coat, showcasing the varied distribution of Mn in Ni-treated samples. This underlines the importance of understanding the intricate effects of specific salts on seed germination. In a germination study involving chickpea varieties, Bittle and Parbat, Ali et al. (2023) highlighted the importance of the germination environment. The use of scanning electron microscopy (SEM) revealed that Bittle chickpea seeds exhibited enhanced tolerance to salt stress when germinated in salicylic acid and biochar media during the vegetative period. This underscores the role of environmental factors in influencing seed germination and early plant development. Dutta et al. (2023) reported tissue degradation in rice seeds under salt stress, as observed through scanning electron microscopy. This aligns with our findings of decreasing germination rates in tomato genotypes under higher salt doses.

Öztürk et al. (2021) emphasized the negative impact of increasing NaCl doses on sweet corn seeds, leading to a decline in germination and early seedling development. Similarly, Soysal et al. (2021) noted adverse effects on annual Caramba grass seeds at higher salt doses. Merino et al. (2021) visualized the reduction in crop productivity due to soil salinity, reinforcing the significance of understanding the impact of salt stress on plant development. Dere (2021) observed a decrease in germination parameters in Rio Grande and H2274 tomato varieties with increasing salt doses. Kibar et al. (2020) reported a decline in germination rate and seedling development in beans with increasing salt doses. Gou et al. (2020) demonstrated the positive effect of silicon application on cucumber seeds, mitigating the negative impact of salt doses and enhancing germination percentage, germination index, and seedling strength. Arslan and Aydınoğlu (2019) found that damson seeds exhibited varying germination rates at different salt doses, germinating up to 150 mM salt doses. Petrovic et al. (2016) observed differences in germination rates in pea varieties under different NaCl doses. Benlioğlu and Özkan (2015) highlighted the varying salt tolerance of barley varieties at different NaCl doses, with Tarm-92 showing higher tolerance. Aydın (2015) emphasized the general decrease in germination rates in wheat, tomato, bean, and corn varieties with increasing salt doses. Uyanık et al. (2014) reported that rapeseed varieties tolerated 100 mM salt dose but not 125 mM, resulting in a subsequent decrease in germination time and rate. Dadaşoğlu and Ekinci (2013) found that increasing salt doses reduced the germination of bean seeds. In a study determining salt tolerance levels in tomatoes, Doğan (2008) highlighted that genotypes sensitive to salt doses began to show damage at doses of 50-75 mM NaCl, while tolerant genotypes started to be affected at doses of 125-150 mM NaCl.

Adding to this body of knowledge, our study specifically focuses on the inter-genotype variation in tomato genotypes, highlighting the impact of different salt doses on germination parameters. Additionally, in alignment with the broader literature, our findings suggest that understanding the specific responses of different plant varieties to salt stress is crucial for developing strategies to enhance salt tolerance. Furthermore, studies by Amjad et al. (2016), Faizan et al. (2021), and Abeed et al. (2023) provide valuable insights into the potential roles of potassium, zinc oxide nanoparticles, and calcium nanoparticles, respectively, in mitigating salt-induced stress and promoting resilience in tomato plants. These studies collectively contribute to our understanding of the complex interplay between salt stress and plant responses, offering avenues for future research and practical applications in agriculture.

4. Conclusion

Our comprehensive investigation into the responses of tomato genotype seeds to varying salt doses revealed compelling evidence of significant genotypic variations. The statistical differences observed highlight the critical importance of understanding the unique characteristics and tolerances of different tomato genotypes to salt stress.

Salt-tolerant tomato genotypes exhibited higher germination rates and shorter germination periods, indicative of their resilience to salt-induced stress. Remarkably, scanning electron microscope results unveiled distinct elemental compositions in the seeds of salt-tolerant and salt-sensitive genotypes. Elements such as C, O, Ca, Si, Na, P, S, Cl, K, and Mg were detected in the seeds of tolerant genotypes, while sensitive genotypes showed a different elemental profile.

Notably, in scanning electron microscope images, an intriguing correlation emerged between salt doses and cellular changes in the seed coat. As salt doses increased, a discernible shrinkage in cells was observed, accompanied by a reduction in cell width and alterations in seed hair structures. This visual evidence underscores the dynamic impact of salt stress on seed morphology, providing valuable insights into the intricate responses of tomato genotypes.

Crucially, our findings highlight the presence of K and Mg elements in the seeds of salt-tolerant genotypes, further emphasizing their adaptive mechanisms. In contrast, these elements were notably absent in the seeds of salt-sensitive genotypes, indicating potential deficiencies in adaptive strategies.

The practical implications of these findings are profound. Opting for the cultivation of tomato genotypes with inherent tolerance to salt stress in saline environments can significantly mitigate germination losses compared to sensitive genotypes. This strategic approach aligns with the broader goal of sustainable agriculture, where understanding and leveraging the natural resilience of certain genotypes can contribute to enhanced crop productivity in challenging environmental conditions.

In conclusion, our study not only provides valuable insights into the nuanced responses of tomato genotypes to salt stress but also underscores the potential for targeted genotype selection to address the challenges posed by salinity in agriculture. The intricate interplay between elemental compositions, cellular morphology, and germination outcomes uncovered in this research contributes to the growing body of knowledge aimed at developing resilient crop varieties for a more sustainable and productive agricultural future.

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