

Salinity-Induced Changes in Germination and Early Seedling Growth of Triticale (*x Triticosecale* Wittmack) Genotypes

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Abstract

Soil salinity is a major constraint limiting cereal production worldwide, particularly during early developmental stages. This study evaluated the effects of increasing NaCl concentrations (0, 50, 100, 150, and 200 mM) on germination and early seedling growth of five triticale (*xTriticosecale* Wittmack) genotypes under controlled conditions. Significant reductions were observed in germination percentage, coleoptile length, root length, shoot length, and fresh and dry biomass as salinity levels increased. Severe inhibition occurred at 150 and 200 mM NaCl, indicating pronounced osmotic and ionic stress effects. Genotypic variation was evident, particularly under moderate and high salinity, with DZ9-09 and Vardem maintaining relatively greater root development and biomass accumulation, whereas genotype 44 exhibited higher sensitivity. Root length and shoot dry weight emerged as reliable and discriminative traits for early-stage salinity screening. The results demonstrate substantial genetic variability in salt tolerance among triticale genotypes and highlight the value of early morphological traits as practical selection criteria. These findings provide a framework for improving salinity tolerance in triticale breeding programs targeting salt-affected agroecosystems

Triticale (*x Triticosecale* Wittmack) Genotiplerinin Çimlenmesinde ve Erken Fide Gelişiminde Tuzluluğun Neden Olduğu Değişiklikler

Özet

Toprak tuzluluğu, özellikle erken gelişim dönemlerinde tahıl üretimini dünya genelinde sınırlayan başlıca stres faktörlerinden biridir. Bu çalışmada, kontrollü koşullar altında beş tritikale (*x Triticosecale* Wittmack) genotipinin çimlenme ve erken fide gelişimi üzerine artan NaCl konsantrasyonlarının (0, 50, 100, 150 ve 200 mM) etkileri değerlendirilmiştir. Tuzluluk düzeyi arttıkça çimlenme yüzdesi, koleoptil uzunluğu, kök uzunluğu, fide uzunluğu ile yaş ve kuru biyokütlede önemli azalmalar gözlenmiştir. Özellikle 150 ve 200 mM NaCl uygulamalarında şiddetli inhibisyon meydana gelmiş olup, bu durum belirgin ozmotik ve iyonik stres etkilerini göstermektedir. Orta ve yüksek tuzluluk düzeylerinde genotipler arasında farklılıklar belirginleşmiş; DZ9-09 ve Vardem genotipleri kök gelişimi ve biyokütle birikimi açısından göreceli olarak daha yüksek performans sergilerken, 44 numaralı genotip daha duyarlı bulunmuştur. Kök uzunluğu ve fide kuru ağırlığı, erken dönemde tuzluluğa dayanıklılık taraması için güvenilir ve ayırt edici özellikler olarak öne çıkmıştır. Sonuçlar, tritikale genotipleri arasında tuzluluğa dayanıklılık bakımından önemli genetik varyasyon bulunduğunu göstermekte ve erken dönem morfolojik özelliklerin pratik seleksiyon kriterleri olarak değerini ortaya koymaktadır. Bu bulgular, tuzdan etkilenmiş agroekosistemler için tritikale ıslah programlarında tuzluluğa dayanıklılığın geliştirilmesine yönelik bir çerçeve sunmaktadır.

1. Introduction

Soil salinity is one of the most severe abiotic stresses limiting agricultural productivity worldwide, particularly in arid and semi-arid regions where low precipitation and high evaporation promote salt accumulation in the root zone. It is estimated that more than 20% of irrigated agricultural lands are affected by salinity, and this proportion is expected to increase due to climate change, improper irrigation practices, and poor drainage systems (Munns and Tester, 2008). High salt concentrations in the soil solution increase osmotic pressure, thereby reducing water availability to plants and inducing physiological drought. In addition to osmotic stress, excessive accumulation of Na⁺ and Cl⁻ ions leads to ionic toxicity, nutrient imbalance (particularly reduced K⁺ and Ca²⁺ uptake), membrane instability, and oxidative stress (Hasanuzzaman et al., 2018). Salinity stress is particularly critical during germination and early seedling stages, which are highly sensitive phases in the plant life cycle. Successful germination and uniform seedling establishment are prerequisites for optimal plant density and final yield. Numerous studies have reported that increasing salinity levels significantly reduce germination rate, root and shoot elongation, fresh and dry biomass accumulation, and overall seedling vigor in cereal crops (Saddiq et al., 2019; Kizilgeci et al., 2020; El Sabagh et al., 2021; Yılmaz et al., 2022). The inhibitory effects of salinity at early growth stages are mainly associated with reduced water uptake, delayed enzyme activation, impaired mobilization of seed reserves, and increased production of reactive oxygen species (ROS) (Zhu, et al., 2008; Hasanuzzaman et al., 2018). Triticale (*x Triticosecale* Wittmack), an artificial hybrid between wheat (*Triticum* spp.) and rye (*Secale cereale* L.), was developed to combine the high yield potential and grain quality of wheat with the environmental adaptability and stress tolerance of rye. Due to its relatively higher tolerance to abiotic stresses compared to wheat, triticale has gained importance as an alternative cereal for marginal and salt-affected soils (Blum, 2014). However, significant genotypic variation exists among triticale cultivars in terms of salinity tolerance (Atak et al., 2023; Ramadan et al., 2023). Some genotypes exhibit better ionic regulation, osmotic adjustment, and antioxidant defense mechanisms, enabling them to maintain higher growth performance under saline conditions. Early-stage screening under controlled salinity conditions is widely accepted as an efficient approach for identifying salt-tolerant genotypes. Morphological parameters such as germination percentage, root length, coleoptile length, and shoot dry weight are considered reliable indicators of salt tolerance during the seedling phase (Kızılgöçü, 2021; Fellahi et al., 2024). Identifying tolerant genotypes at this stage is particularly valuable for breeding programs aimed at improving salinity tolerance in cereal crops. Therefore, the objective of this study was to evaluate the effects of different NaCl concentrations on germination and early seedling development of selected triticale genotypes and to identify potential salt-tolerant genotypes suitable for cultivation in saline environments.

2. Materials and Methods

2.1. Plant Material

Five triticale (*x Triticosecale* Wittmack) genotypes were used as plant material, including two commercial cultivars (Esin and Vardem) and three advanced breeding lines (44, DZ23-3, and DZ9-09). The genotypes were obtained from Teknobiltar R&D Company. Uniform, healthy, and undamaged seeds were selected prior to the experiment to ensure homogeneity.

2.2. Experimental Design and Salinity Treatments

The experiment was conducted under controlled laboratory conditions using a completely randomized design (CRD) with a factorial arrangement. The factors consisted of five genotypes and five salinity levels (0, 50, 100, 150, and 200 mM NaCl). Each treatment combination was replicated four times. Salinity solutions were prepared by dissolving analytical-grade sodium chloride (NaCl) in distilled water to obtain the desired concentrations. The 0 mM NaCl treatment served as the control.

2.3. Seed Sterilization and Germination Conditions

All experimental materials and equipment were prepared under sterile conditions to prevent contamination. Work surfaces and tools were disinfected with 80% ethanol solution prior to use. Before sowing, seeds were surface-sterilized by immersion in 80% ethanol for 60 seconds and subsequently rinsed three times with sterile distilled water to remove chemical residues. After rinsing, seeds were dried between sterile paper towels under aseptic conditions. Germination tests were conducted in sterile 9 cm diameter plastic petri dishes. For each replication, 10 seeds were placed evenly between double layers of filter paper. The filter papers were moistened with the respective NaCl solutions

according to treatment. Petri dishes were sealed with parafilm to prevent moisture loss and contamination. The experiment was carried out in a germination chamber at a constant temperature of 24 ± 2 °C for 8 days. Moisture levels were checked periodically and maintained using the corresponding treatment solutions to ensure uniform germination conditions.

2.4. Measured Parameters

Germination percentage (GP) was determined on the 8th day and calculated as the percentage of germinated seeds relative to the total number of seeds sown. On the 8th day, seedling growth parameters were measured using a digital caliper and a precision balance. The following morphological traits were evaluated: coleoptile length (mm), shoot length (mm), root length (cm), root fresh weight (mg), shoot fresh weight (g). For dry weight determination, root and shoot samples were separated and oven-dried at 180 °C for 2 hours, and subsequently weighed using a precision balance.

2.5. Statistical Analysis

All data were analyzed according to the completely randomized design. Statistical analyses were performed using JMP Clinical 18 statistical software. Analysis of variance (ANOVA) was conducted to determine the significance of genotype, salinity level, and genotype \times salinity interaction effects. When significant differences were detected, means were compared using the Least Significant Difference (LSD) test at the 5% probability level.

3. Results and Discussion

3.1. Germination Percentage (%)

Salinity treatments significantly reduced germination percentage at the 1% significance level, and the decline became more pronounced as NaCl concentration increased (Table 1). While germination remained relatively high under control conditions, severe inhibition was observed at 150 and 200 mM NaCl. The reduction in germination under saline conditions is primarily associated with osmotic stress, which limits water uptake during seed imbibition, and with ionic toxicity that interferes with enzyme activation and mobilization of seed reserves. Similar inhibitory effects of increasing salinity on cereal germination have been reported in wheat and triticale (Kizilgeci et al., 2020; Köseoğlu and Doğru, 2021). Kaur and Gupta (2020) also demonstrated that germination declines sharply at salt concentrations exceeding 100 mM NaCl. Genotypic differences became more apparent at higher salinity levels, suggesting variation in osmotic adjustment capacity and membrane stability among genotypes.

Table 1. Effects of different salinity levels on germination percentage (%) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	90.0	72.5	65.0	32.5	0.0	52.0
DZ9-09	92.5	82.5	65.0	50.0	32.5	64.5
DZ23-3	80.0	72.5	55.0	30.0	32.5	54.0
Esin	90.0	70.0	60.0	32.5	20.0	54.5
Vardem	85.0	72.5	60.0	37.5	40.0	59.0
Means	87.5A	74.0B	61.0C	36.5D	25.0E	

Salinity**, Genotype^{ns}, Salinity \times Genotype^{ns}

** is significant at 1%, ns: non significant, Means followed by the same letter do not differ significantly according to the LSD test ($P < 0.05$).

3.2. Coleoptile Length (mm)

Coleoptile length was significantly influenced by salinity level, genotype, and their interaction (1%), indicating that genotypes responded differentially to increasing NaCl concentrations. Mean separation according to the LSD test confirmed clear statistical groupings among treatments (Table 2). The longest coleoptiles were recorded under non-saline conditions, whereas 200 mM NaCl resulted in severe reduction. Salt stress restricts cell elongation by decreasing turgor pressure and disrupting hormonal balance, particularly gibberellin-mediated growth regulation. Kutlu et al. (2009), reported

comparable reductions in shoot elongation in triticale genotypes exposed to increasing NaCl levels. Similarly, Mohammadi Alagoz et al. (2023) observed that triticale shoot growth declines progressively as soil salinity increases. Among genotypes, DZ23-3 and Vardem maintained relatively higher coleoptile length under moderate salinity, indicating potential morphological adaptation at early growth stages.

Table 2. Effects of different salinity levels on coleoptile length (mm) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	23.69def	28.65bcd	20.52fg	20.90efg	0.000k	18.75 ^b
DZ9-09	23.45def	32.19abc	33.69abc	22.07def	12.5lij	24.78 ^a
DZ23-3	27.82cd	33.94abc	27.29cde	23.59def	19.42fgh	26.41 ^a
Esin	35.25ab	27.61cd	17.98fghi	14.86g-j	9.49j	21.04 ^b
Vardem	37.10a	30.66abc	33.66abc	17.49f-i	13.15hij	26.41 ^a
Means	29.49AB	30.61A	26.63B	19.78C	10.91D	

Salinity**, Genotype**, Salinity × Genotype**

** is significant at 1%, Means followed by the same letter do not differ significantly according to the LSD test

3.3. Shoot Length (mm)

Shoot length was significantly affected by salinity level, genotype, and genotype × salinity interaction (1%). Increasing NaCl concentration led to a sharp decline in overall shoot growth (Table 3). The highest mean shoot length was recorded under control conditions (111.81 mm), whereas the lowest value was observed at 200 mM NaCl (10.54 mm), indicating a severe suppression of growth at high salinity. Among genotypes, Vardem exhibited the highest overall mean (66.29 mm), distinguishing it as the best-performing genotype across treatments. In contrast, genotype 44 had the lowest overall mean (39.81 mm), reflecting greater sensitivity to salt stress. Under severe salinity (200 mM), DZ23-3 (15.94 mm) maintained the greatest shoot length, followed by Vardem (13.48 mm), whereas genotype 44 showed complete growth inhibition (0.00 mm) (Table 3). These results highlight clear genotypic differences in tolerance, particularly under high stress conditions. The significant interaction effect confirms that shoot development under salinity is genotype-dependent. Reduced shoot length under salt stress may be attributed to impaired photosynthetic efficiency, reduced carbon assimilation, and metabolic disturbances caused by ionic imbalance. Hasanuzzaman et al. (2018) emphasized that excessive Na⁺ accumulation disrupts chloroplast function and induces oxidative stress, limiting vegetative growth. Similar findings have been reported in triticale and wheat, where shoot growth was significantly suppressed at NaCl levels above 100 mM (Kizilgeci et al., 2020; Atak et al., 2023).

Table 3. Effects of different salinity levels on shoot length (mm) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	89.39c	59.34ef	30.68h-k	19.64ij	0.000m	39.81 ^c
DZ9-09	111.18b	65.10e	65.59e	37.64gh	12.51lm	58.41 ^b
DZ23-3	113.58b	81.19cd	50.26fg	30.92hij	15.94kl	58.38 ^b
Esin	111.26b	92.71c	43.34gh	16.50jkl	10.79lm	54.92 ^b
Vardem	133.65a	81.30cd	70.70de	32.32hi	13.48lm	66.29 ^a
Means	111.81A	75.93B	52.12C	27.40D	10.54E	

Salinity**, Genotype**, Salinity × Genotype**

** is significant at 1%, Means followed by the same letter do not differ significantly according to the LSD test

3.4. Root Length (cm)

Root length was significantly affected by salinity level (1%), genotype (1%), and their interaction (1%). Increasing NaCl concentration led to a pronounced decline in root growth, particularly at 150 and 200 mM (Table 4). The highest root length was recorded under control conditions (111.51 cm), whereas the lowest mean value was observed at 200 mM NaCl (11.66 cm), indicating a drastic reduction under severe salinity. Among genotypes, Vardem exhibited the highest overall mean root length (51.93 cm),

while genotype 44 showed the lowest performance (36.80 cm). Under severe stress (200 mM), Esin maintained the greatest root length (18.10 cm), standing out as the most tolerant genotype at this level, whereas genotype 44 showed complete inhibition (0.00 cm), indicating high sensitivity. Vardem also demonstrated relatively strong performance under moderate salinity (50–100 mM), supporting its overall superior ranking. Roots are directly exposed to saline conditions and are therefore highly sensitive to ionic toxicity. Salinity inhibits root meristem activity, reduces cell division, and disrupts ion homeostasis. However, certain genotypes maintained relatively greater root length under moderate salinity, suggesting adaptive mechanisms such as improved Na⁺ exclusion or osmotic adjustment. Rasouli et al. (2024) reported that tolerant triticale genotypes exhibit enhanced ion regulation and maintain better root growth under saline environments. Root length is widely recognized as a reliable selection criterion for early-stage salt tolerance (Fellahi et al., 2024), as it directly reflects the plant's ability to access water under osmotic stress.

Table 4. Effects of different salinity levels on root length (cm) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	107.20bc	34.37f-i	21.02ijk	21.393ijk	0.000l	36.80 ^c
DZ9-09	94.58c	43.28d-g	37.10e-h	25.016h-k	12.74kl	42.54 ^{bc}
DZ23-3	101.88c	44.11def	29.88g-j	20.821ijk	13.48kl	42.03 ^{bc}
Esin	119.84b	53.06d	29.83g-j	19.361jk	18.10jk	48.04 ^{ab}
Vardem	134.05a	49.36de	43.66d-g	18.603jk	13.97kl	51.93 ^a
Means	111.51A	44.84B	32.30C	21.04D	11.66	

Salinity**, Genotype**, Salinity × Genotype**

** is significant at 1%, Means followed by the same letter do not differ significantly according to the LSD test

3.5. Shoot Fresh Weight (g)

Shoot fresh weight was significantly affected by salinity (1%), genotype (1%), and their interaction (5%). Fresh biomass declined progressively with increasing NaCl concentration. The highest mean fresh weight was obtained under control conditions (0.949 g), whereas the lowest mean values were recorded at 150 mM (0.131 g) and 200 mM (0.057 g), both statistically grouped in the lowest category (Table 5). This sharp reduction indicates substantial biomass loss under severe salinity. Among genotypes, DZ9-09 exhibited the highest overall mean fresh weight (0.529 g), distinguishing it as the best-performing genotype across treatments. In contrast, DZ23-3 showed the lowest overall mean (0.328 g). Under high salinity (200 mM), DZ9-09 (0.091 g) maintained the highest fresh weight, while genotype 44 exhibited complete inhibition (0.000 g), indicating extreme sensitivity. The reduction in fresh biomass reflects limited water uptake, reduced cell expansion, and impaired metabolic activity under osmotic stress. García-Caparros et al. (2025) similarly reported significant decreases in biomass production in cereals exposed to saline irrigation. DZ9-09 maintained relatively higher fresh weight under saline conditions, indicating a stronger ability to preserve cellular hydration and metabolic integrity.

Table 5. Effects of different salinity levels on shoot fresh weight (g) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	0.969b	0.436ef	0.327fgh	0.105hij	0.000j	0.367 ^b
DZ9-09	0.944bc	0.723cd	0.606de	0.279f-i	0.091ij	0.529 ^a
DZ23-3	0.771bcd	0.409ef	0.340fg	0.052ij	0.066ij	0.328 ^b
Esin	1.212a	0.350fg	0.250f-i	0.076ij	0.064ij	0.390 ^b
Vardem	0.849bc	0.439ef	0.465ef	0.144g-j	0.066ij	0.393 ^b
Means	0.949A	0.471B	0.398B	0.131C	0.057C	

Salinity**, Genotype**, Salinity × Genotype*

***, are significant at 5%, 1%, Means followed by the same letter do not differ significantly according to the LSD test

3.6. Root Fresh Weight (mg)

Root fresh weight was significantly affected by salinity (1%), genotype (1%), and their interaction (1%). (Table 6) Increasing NaCl concentration resulted in a pronounced reduction in root biomass. The highest mean root fresh weight was observed under control conditions (0.844 mg), whereas the lowest mean values were recorded at 150 mM (0.149 mg) and 200 mM NaCl (0.110 mg), both statistically

grouped in the lowest category. This trend confirms a substantial decline in root biomass under severe salinity stress. Among genotypes, DZ9-09 exhibited the highest overall mean (0.496 mg), set apart it as the most stable genotype across treatments. In contrast, DZ23-3 had the lowest overall mean (0.254 mg). Under 200 mM NaCl, Esin (0.206 mg) maintained the highest root fresh weight, whereas genotype 44 showed complete inhibition (0.000 mg), indicating high sensitivity. Root fresh weight declined markedly with increasing NaCl concentration. This reduction may be linked to decreased assimilate allocation to roots and stress-induced metabolic suppression. Salt stress enhances the production of reactive oxygen species (ROS), which can damage cell membranes and reduce root biomass accumulation (Zhu et al., 2008). Comparable trends have been documented in wheat and oat under laboratory salinity treatments (Kaur & Gupta, 2020; Köseoğlu & Doğru, 2021). The ability of certain genotypes to maintain higher root biomass suggests variability in antioxidant defense systems and ionic balance.

Table 6. Effects of different salinity levels on root fresh weight (mg) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	0.959a	0.436def	0.328e-i	0.158i-m	0.000m	0.376 ^b
DZ9-09	0.926a	0.633bc	0.482cde	0.289f-j	0.148i-m	0.496 ^a
DZ23-3	0.501cde	0.407d-g	0.240g-k	0.044lm	0.077klm	0.254 ^c
Esin	1.094a	0.375d-h	0.239g-k	0.104klm	0.206h-l	0.403 ^b
Vardem	0.738b	0.359d-h	0.515cd	0.150i-m	0.121j-m	0.376 ^b
Means	0.844A	0.442B	0.361B	0.149C	0.110C	

Salinity**, Genotype**, Salinity × Genotype**

** is significant at 1%, Means followed by the same letter do not differ significantly according to the LSD test

3.7. Shoot Dry Weight (g)

Shoot dry weight was significantly influenced by salinity (1%), genotype (1%), and their interaction (1%) (Table 7). Increasing NaCl concentration caused a marked and progressive decline in dry matter accumulation. The highest mean dry weight was recorded under control conditions (0.098 g), while the lowest value was observed at 200 mM NaCl (0.007 g), indicating severe inhibition of biomass production at high salinity levels. Among genotypes, DZ9-09 exhibited the highest overall mean dry weight (0.059 g), it as the best-performing genotype across treatments. In contrast, genotypes 44 (0.041 g), DZ23-3 (0.045 g), Esin (0.045 g), and Vardem (0.040 g) were grouped in the lower statistical category. Under severe stress (200 mM), DZ9-09 (0.012 g) maintained the highest dry weight, whereas genotype 44 showed complete inhibition (0.000 g), indicating high sensitivity. Dry weight is considered a stable indicator of stress tolerance because it reflects net carbon assimilation rather than transient water content. The decline in dry biomass may result from reduced photosynthetic activity, impaired nutrient uptake, and energy imbalance under salt stress (Hasanuzzaman et al., 2018). Consistent with our findings, Atak et al. (2023) and Rasouli et al. (2024) reported significant decreases in dry matter production in triticale under high salinity. However, DZ9-09 and Vardem showed relatively better preservation of dry biomass, suggesting improved physiological resilience.

Table 7. Effects of different salinity levels on shoot dry weight (g) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	0.094bc	0.052d-i	0.046g-j	0.013klm	0.000m	0.041 ^b
DZ9-09	0.115ab	0.076cd	0.060d-g	0.030l	0.012klm	0.059 ^a
DZ23-3	0.073c-f	0.059d-g	0.031h-k	0.052e-i	0.009klm	0.045 ^b
Esin	0.133a	0.055d-h	0.023j-m	0.008lm	0.006m	0.045 ^b
Vardem	0.075cde	0.050f-i	0.045g-j	0.021klm	0.008klm	0.040 ^b
Means	0.098A	0.058B	0.041C	0.025D	0.007E	

Salinity**, Genotype** Salinity × Genotype**

** is significant at 1%, Means followed by the same letter do not differ significantly according to the LSD test

3.8. Root Dry Weight (g)

Root dry weight was significantly affected by salinity (1%), genotype (1%), and their interaction (1%) (Table 8). A systematic and progressive decline was observed with increasing NaCl concentration. The highest mean root dry weight was recorded under control conditions (0.073 g), while the lowest

value was obtained at 200 mM NaCl (0.009 g), indicating severe suppression of root biomass under extreme salinity. Among genotypes, DZ9-09 exhibited the highest overall mean (0.041), distinguishing it as the most stable genotype across treatments. The lowest overall mean was observed in DZ23-3 (0.030 g). Under 200 mM NaCl, DZ9-09 (0.014 g) maintained the highest root dry weight, whereas genotype 44 showed complete inhibition (0.000 g), reflecting high sensitivity. Reduced dry matter accumulation in roots is likely associated with ionic toxicity, oxidative damage, and disruption of membrane integrity. Wang et al. (2025) emphasized that tolerant cereal genotypes maintain more stable root biomass through enhanced ion compartmentalization and antioxidant activity. Root dry weight, together with root length, proved to be one of the most discriminative parameters for identifying salt-tolerant genotypes in this study.

Table 8. Effects of different salinity levels on root dry weight (g) of triticale genotypes: mean comparisons and analysis of variance

Genotypes	NaCl Concentrations (mM)					Means
	0 (Control)	50	100	150	200	
44	0.079b	0.035fg	0.036fg	0.017ijk	0.000l	0.033 ^b
DZ9-09	0.072bc	0.054de	0.042ef	0.024g-j	0.014jkl	0.041 ^a
DZ23-3	0.061cd	0.032fgh	0.017ijk	0.030f-i	0.012jkl	0.030 ^b
Esin	0.094a	0.033fg	0.018h-k	0.011jkl	0.008kl	0.033 ^b
Vardem	0.057d	0.037fg	0.035fg	0.018h-k	0.012jkl	0.032 ^b
Means	0.073A	0.038B	0.030C	0.020D	0.009E	

Salinity**, Genotype**, Salinity × Genotype**

** are significant at 1%. Means followed by the same letter do not differ significantly according to the LSD test

4. Conclusion

Salinity stress significantly suppressed germination and early seedling growth in triticale, with progressive reductions observed as NaCl concentration increased. Severe inhibition occurred at 150 and 200 mM NaCl, confirming the high sensitivity of early developmental stages to osmotic and ionic stress. Genotypic variation in salinity tolerance was evident. DZ9-09 and Vardem maintained comparatively higher root growth and biomass accumulation under saline conditions, whereas genotype 44 exhibited greater sensitivity. Root length and shoot dry weight proved to be reliable indicators for early-stage salt tolerance screening. These findings highlight the importance of genotype selection for improving triticale performance in salt-affected environments and provide a practical basis for breeding programs targeting enhanced salinity tolerance.

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