

Effects of salinity on germination and growth of turkish wheat cultivars: environmental and genetic interactions

Efeitos da salinidade na germinação e crescimento de cultivares de trigo turco: interações ambientais e genéticas

Efectos de la salinidad sobre la germinación y el crecimiento de los cultivares de trigo turco: interacciones ambientales y genéticas

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ABSTRACT

Salinity, a major environmental stress, affects global cereal production by decreasing yields, particularly in wheat (*Triticum aestivum* and *Triticum durum*). This study evaluated the effects of varying salinity levels on the germination and growth parameters of two Turkish wheat cultivars. Germination experiments were conducted using six salinity levels 2, 4, 8, 12, 16, and 20 dS/m with SAR values 3, 6, 9, and 12. While growth parameters were evaluated under greenhouse conditions in Tlemcen - Algeria, and Çanakkale - Türkiye, using irrigation water with EC levels of 8, 16, and 20 dS/m and SAR 9. Salinity stress negatively impacted both durum and bread wheat. Durum wheat exhibited the highest germination rates at SAR3 (78.89%) and SAR6 (75.56%), with a moderate decline at SAR12 (61.67%). In contrast, bread wheat peaked at SAR3 (67.78%) but declined more sharply under higher salinity levels. High salinity (20 dS/m) reduced durum wheat ear length from 4.7 cm (control) to 2.4 cm and decreased plant dry weight from 5.27 g to 4.14 g. In bread wheat, moderate salinity (8 dS/m) resulted in the longest ear lengths (7.21 cm) and the highest ear weight (0.84 g), while high salinity (20 dS/m) caused the lowest number of fertile tillers (FTN). Differential responses observed between the two locations; wheat grown in warmer Tlemcen (Algeria) faced greater salinity stress than in cooler Çanakkale (Türkiye), highlighting the role of environment and genetics in salinity tolerance.

Keywords: wheat, salinity stress, electrical conductivity, germination rates, yield.

RESUMO

A salinidade, um importante stress ambiental, afeta a produção global de cereais através da diminuição dos rendimentos, particularmente no trigo (*Triticum aestivum* e *Triticum durum*). Este estudo avaliou os efeitos de níveis de salinidade variáveis sobre os parâmetros de germinação e crescimento de duas cultivares de trigo turco. Foram realizados experimentos de germinação utilizando seis níveis de salinidade 2, 4, 8, 12, 16 e 20 dS/m com valores SAR 3, 6, 9 e 12. Enquanto os parâmetros de crescimento foram avaliados em condições de estufa em Tlemcen - Argélia, e Çanakkale - Türkiye, usando água de irrigação com níveis EC de 8, 16 e 20 dS/m e SAR 9. O estresse da salinidade impactou negativamente tanto o trigo duro quanto o pão. O trigo duro apresentou as maiores taxas de germinação no SAR3 (78,89%) e no SAR6 (75,56%), com um declínio moderado no SAR12 (61,67%). Em contraste, o trigo-pão atingiu o pico de SAR3 (67,78%), mas diminuiu mais acentuadamente sob níveis de salinidade mais elevados. Alta salinidade (20 dS/m) reduziu o comprimento da espiga de trigo duro de 4,7 cm (controle) para 2,4 cm e diminuiu o peso seco das plantas de 5,27 g para 4,14 g. No trigo farinhoso, a salinidade moderada (8 dS/m) resultou nos maiores comprimentos da espiga (7,21 cm) e no maior peso da espiga (0,84 g), enquanto a salinidade elevada (20 dS/m) causou o menor número de perfilhos férteis (FTN). Respostas diferenciadas observadas entre os dois locais; trigo cultivado em Tlemcen (Argélia) mais quente enfrentou maior estresse por salinidade do que no mais frio Çanakkale (Túquia), destacando o papel do ambiente e da genética na tolerância à salinidade.

Palavras-chave: trigo, salinidade stress, condutividade elétrica, taxas de germinação, rendimento.

RESUMEN

La salinidad, un importante factor de estrés ambiental, afecta a la producción mundial de cereales al disminuir los rendimientos, en particular del trigo (*Triticum aestivum* y *Triticum durum*). Este estudio evaluó los efectos de los diferentes niveles de salinidad sobre los parámetros de germinación y crecimiento de dos cultivares de trigo turco. Se realizaron experimentos de germinación utilizando seis niveles de salinidad 2, 4, 8, 12, 16 y 20 dS/m con valores SAR 3, 6, 9 y 12. Mientras que los parámetros de crecimiento se evaluaron en condiciones de invernadero en Tlemcen - Argelia, y Çanakkale - Türkiye, utilizando agua de riego con niveles EC de 8, 16 y 20 dS/m y SAR 9. El estrés por salinidad afectó negativamente tanto al trigo duro como al trigo blando. El trigo duro exhibió

las tasas más altas de germinación en SAR3 (78,89%) y SAR6 (75,56%), con una disminución moderada en SAR12 (61,67%). En contraste, el trigo blando alcanzó su punto máximo en SAR3 (67,78%), pero disminuyó más bruscamente con niveles de salinidad más altos. La salinidad elevada (20 dS/m) redujo la longitud de las orejas del trigo duro de 4,7 cm (control) a 2,4 cm y disminuyó el peso seco de la planta de 5,27 g a 4,14 g. En el trigo blando, la salinidad moderada (8 dS/m) dio lugar a las longitudes de oreja más largas (7,21 cm) y al peso de oreja más alto (0,84 g), mientras que la salinidad alta (20 dS/m) causó el menor número de topadoras fértiles (FTN). Respuestas diferentes observadas entre las dos localidades; el trigo cultivado en Tlemcen (Argelia) más caliente enfrentó un mayor estrés por salinidad que en Çanakkale (Turquía), donde se observó una mayor tolerancia a la salinidad debido al medio ambiente y a la genética.

Palabras clave: trigo, estrés de salinidad, conductividad eléctrica, tasas de germinación, rendimiento

1 INTRODUCTION

Irrigation water quality is primarily evaluated according to the risk of salinity and sodium to the soil. In evaluating the impact of irrigation water on the soil, the relationship between cations and Sodium Adsorption Rate (SAR) is important for sustainable production (Maia et.al.,2020: Vieira and Christofaro 2020: Mello and Abessa, 2021: De Sousa et.al., 2022). Salinity stress poses a danger to global food security by limiting the global agricultural productivity. Salinity describes high levels of dissolved salts in soil or water. These salts come in various forms, including minerals like calcium, potassium, and magnesium, and anions like chloride and sulphate. Some of these minerals are necessary nutrients for plants. However, high concentration of salts creates problems for plants by making it harder for them to absorb water and potentially causing toxic effects (“Thematic 1: Farmers’ Guidelines on Soil and Water Management in Salt-affected Areas,” 2023). Soil salinization is the process by which salts accumulate in the soil to harmful levels. This build-up of salts, typically measured by electrical conductivity (EC), can negatively impact agricultural production, environmental health, economic well-being, and ultimately, quality of life (Kumar & Sharma, 2020). According to Hasanuzzaman et al. (2012), salinity primarily arises from an increase in sodium (Na⁺) and chloride (Cl⁻) ions, which disrupt various plant mechanisms crucial for survival. While both Na⁺ and Cl⁻ contribute to physiological disorders, Cl⁻ is considered particularly harmful. Increased salinity has wide-ranging physiological consequences, including osmotic stress, ion-specific toxicity, imbalances in nutrients and hormones, and oxidative damage. Salinity can reduce the yield of important crops (e.g., wheat, maize, rice and barley) by up to 70% (Etesami & Beattie, 2018).

Among the various crops impacted by salinity, wheat holds a critical role in addressing global food security. Wheat, including durum wheat (*Triticum durum*) and bread wheat (*Triticum*

aestivum), has been the cornerstone of food and nutritional security and is currently the most widely grown crop in the world (“Wheat Improvement,” 2022). Fuelling billions across the globe, wheat supply a significant portion of global calorie and protein intake, with most used as food (70%), some as livestock feed (20%), and a small percentage in industrial processing (2-3%) (Shiferaw et al., 2013). While modern wheat varieties hold the potential to feed the world's growing population, their productivity can be significantly hampered by salinity stress stands out as a major constraint to global wheat production (Dutta et al., 2023). Soil salinity negatively affects wheat production globally, hindering seed germination, plant growth, development, and yield (Khalid et al., 2023; Qi & Dai, 2019).

Wheat exhibits moderate tolerance to salinity, as reported by Maas and Hoffman (1977). It can be cultivated in areas with some level of salt concentration in the soil. However, there is significant genotypic variation in salinity tolerance among different wheat varieties (Saqib et al., 2005). With approximately 20% of global arable land already affected by salt stress, and this number rising due to climate change and human actions (Arora, 2019), gaining a comprehensive understanding of morphoanatomical, physiological, biochemical, and molecular mechanisms underlying wheat's response to salinity stress across various growth stages is critical for advancing breeding strategies and engineering salt-tolerant cultivars (Sabagh, Islam, Skalický et al., 2021).

None of the waters found in nature contain only Sodium Chloride. It may definitely contain other cations such as Calcium, Magnesium, Potassium in addition to NaCl as different compounds. Both irrigation water salinity and soil salinity are among the main abiotic stresses in plant production. When the literature is examined, there are many studies on both irrigation water salinity and soil salinity. However, almost all of these studies are specific to NaCl. None of the waters found in nature contain only Sodium Chloride. It may definitely contain other cations such as Calcium, Magnesium, Potassium in addition to NaCl as different compounds (Tas et.al., 2022; Coskun et.al., 2020; Akcaman and Tas, 2020; Kunt and Tas, 2019; Coşkun and Tas, 2017; Akcaman et.al., 2017; Tas and Ozturk 2011). In this study, the research was established by considering the SAR values of irrigation water in a way that would eliminate the damage of NaCl salt in irrigation water salinity. In other words, not only the EC of irrigation water but also the SAR value was taken into account. Thus, research topics were created by considering the EC of irrigation water and the SAR value indicating sodium damage together. Thus, both Turkish and Algerian wheat varieties were examined in terms of threshold values for both irrigation water salinity and sodium damage, as in Tas et.al. (2022), Coskun et.al. (2020), Akcaman and Tas (2020), Kunt and Tas (2019), Coşkun and Tas (2017) and Akcaman et.al. (2017). Thus, useful information can be provided to all scientists working on abiotic stress in plants, especially plant breeders, scientists working on irrigation water quality

and soil salinity. This study assessed the impact of varying salinity levels (0-20 dS/m) on germination rates and growth parameters of two Turkish wheat cultivars, Harmankaya 99 and Dumlupinar. Germination experiments utilized NaCl, MgSO₄, and CaCl₂ salts with SAR values 3, 6, 9, and 12 while growth parameters were examined assessed under greenhouse conditions in Algeria and Türkiye using irrigation water with EC levels of 8, 16, and 20 dS/m and SAR 9.

2 MATERIAL AND METHODS

2.1 PLANT MATERIAL

Two wheat varieties registered and distinct from Türkiye were used in this study. Harmankaya 99 (*Triticum aestivum* L.) is a bread wheat, and Dumlupinar (*Triticum durum* Desf.) is a durum wheat. Both cultivars were registered for west of Central Anatolia, Türkiye.

2.2 EXPERIMENTAL LOCATION AND CONDITION

The germination experiments were conducted in the laboratory of Çanakkale Onsekiz Mart University Faculty of Agriculture in December 2022. The greenhouse experiments were conducted in two locations, Tlemcen - Algeria and Çanakkale - Türkiye, from the end of January 2023 to mid-May 2023. Temperature data from both locations are presented in Table 1, with consistently higher temperatures occurring at Tlemcen - Algeria.

Table 1. Monthly Maximum and Minimum Temperature Means for Tlemcen (Algeria) and Çanakkale (Türkiye) in the trial season

Months	Maximum temperature means °C		Minimum temperature means °C	
	Tlemcen (Algeria)	Çanakkale (Türkiye)	Tlemcen (Algeria)	Çanakkale (Türkiye)
January	16	9	6	3
February	17	10	7	4
March	19	12	8	5
April	22	17	10	9
May	25	22	13	13

Source: Prepared by the authors

2.3 EXPERIMENTAL DESIGN

Germination experiments: According to the experimental design of a "random blocks-factorial" with 3 replications, 10 wheat seeds were placed in glass Petri dishes (6 cm in diameter) lined with filter paper. Before placement, the seeds were disinfected in 2.5% sodium hypochlorite for 5 minutes, washed twice with sterile distilled water, and then soaked in sterile distilled water for 24 hours to swell and activate. Irrigation solutions with salinity levels of 0 (control), 4, 8, 12, 16,

and 20 dS m⁻¹ were prepared by using NaCl, MgSO₄, and CaCl₂, sodium adsorption ratio (SAR) values 3, 6, 9, and 12. Each Petri dish received 10 ml of the appropriate saline solution. The Petri dishes were sealed with paraffin film to prevent evaporation and placed in a growth cabinet with controlled conditions (70% humidity, 22-24°C) for germination.

Greenhouse experiments were conducted according to the experimental design of a "random blocks-factorial" with 3 replications fungicide-treated wheat seeds were sown in pots at a density of 20 seeds per pot and a seeding depth of 2 cm. The wheat plants were grown in pots measuring 45 cm x 45 cm x 30 cm, filled with sandy loam soil with a pH of 6.4, moderate organic matter content (2.63%), and sufficient levels of nitrogen (2.22%) and potassium (385.5 mg/kg). The pots were rinsed to field capacity four times from the seeding date to February 14. After 12 days, seedlings were thinned to 10 healthy plants per pot, and regular weeding was done. Six weeks after emergence, a complete fertilizer [growth 20:20:10] corresponding to N:P₂O₅:K₂O as powder was split applied at a rate of 30 kg/ha.

2.4 EVALUATION OF GERMINATION AND AGRONOMIC CHARACTERISTICS

Germination rate was assessed after 8 days and calculated as the percentage of seeds that germinated out of the total sown. In the greenhouse experiment, plants were harvested at maturity, and agronomic traits were measured, including ear length (cm), ear weight (g), grain weight per ear (g), fertile tillers per plant, total tillers per plant, tiller height (cm), and plant dry weight (g) after oven-drying at 70°C for 48 hours.

2.5 STATISTICAL ANALYSIS

The data obtained from both experiments were analysed by one-way analysis for variance (ANOVA) test using GenStat Discovery Edition 3 software, with Duncan's pairwise comparison between means at a level of significance $\alpha = 0.05$.

3 RESULTS AND DISCUSSION

3.1 RESULTS

Salinity stress, a significant challenge to crop productivity, disrupts both the initial stages of growth and the final yield in wheat. Our goal was to understand how different salinity levels (represented by electrical conductivity, EC) affects early germination rates and essential yield components at maturity responded to these challenging conditions across two distinct regions, Algeria and Türkiye.

3.1.1 Effects of Salinity (SAR and EC Levels) on Germination rate in Bread and Durum Wheats

The ANOVA results illustrate the highly significant effects of salinity treatments (EC), and wheat taxa (durum and bread wheat) on germination percentages at Day 8 (Table 2). A highly significant difference ($p < 0.001$) was observed in germination percentage between durum wheat (72.64%) and bread wheat (65.14%). Germination rates were affected by both salinity levels (EC) and Taxa ($p < 0.001$). Durum wheat reveals the highest percentage 78.89% at EC 3 and 75.56% at EC 6 while EC 12 reduces the rate of germination to 61.67% indicating strong tolerance to moderate salinity conditions, while high salinity levels (EC 12) significantly inhibit germination. Bread wheat, however, was more sensitive to increasing salinity levels. Its germination rate decreased from 67.78% to 65% as salinity increased from EC 3 to EC 12. The impact of high EC levels, indicative of high salinity levels, had a highly significant ($p < 0.01$) negative impact on germination. Durum wheat maintain higher germination percentages under all conditions. At EC 12, durum wheat achieves a germination rate of 58.33%, beating bread wheat at 45.00%. In contrast, bread wheat experiences a more pronounced decline in germination as EC levels rise, with rates dropping from 87.50% at EC 12 to 33.33% at EC 20 (Table 2).

Table 2. Germination Percentage of Bread and Durum Wheat at Day 8 Under Different Salinity (SAR) and Electrical Conductivity (EC) Levels

Factor	Germination %								p-value
TAXA***	Bread wheat				Durum wheat				<
	65.14 b				72.64 a				0.001
TAXA.SAR***	Bread wheat				Durum wheat				<
	SAR3	SAR6	SAR9	SAR12	SAR3	SAR6	SAR9	SAR12	0.001
	67.78	66.67	61.11	65.00	78.89	75.56	74.44	61.67 c	
	b	bc	c	bc	a	a	a		
TAXA.EC**	Bread wheat				Durum wheat				<0.01
	0	95.00 a			95.83 a				
	4	90.00 ab			92.50 ab				
	8	87.50 b			89.17 ab				
	12	45.00 d			58.33 c				
	16	40.00 d			56.67 c				
	20	33.33 e			43.33 d				

Source: Prepared by the authors

***: Highly significant statistical test ($P\text{-value} < 0.001$).

**: Very significant statistical test ($P\text{-value} < 0.01$).

Means with distinct letters are significantly distinct at the critical value $\alpha = 5\%$.

3.1.2 Durum Wheat Response to Salinity Levels

The effect of salinity on certain yield components of durum wheat was significant ($p < 0.05$) and increased with increasing salinity levels of irrigation water.

Ear length exhibited distinct patterns in response to salinity levels. Compared to control ears at 4.7 cm, high salinity (20 dS/m) reduced durum wheat ear length to just 2.4 cm. Even moderate

salinity (8 dS/m) caused a slight decrease to 4.2 cm, the differences observed were statistically ($p < 0.001$) highly significant (Table 3).

Ear weight, however, wasn't significantly ($p > 0.05$) affected by salinity levels, ranging from (0.53 to 0.66 g) across all treatments (Table 3).

While the control group exhibited the lowest average grain weight per ear (0.34 ± 0.11 g), moderate salinity (EC = 8 dS/m) induced a significant ($p < 0.001$) increase, culminating in a peak of 0.49 ± 0.22 g at EC = 16 dS/m. Notably, despite a slight decline at the highest salinity (EC = 20 dS/m) (Table 3).

The number of fertile tillers per plant demonstrated notable trends in response to varying salinity levels. While the control plants averaged 1.71 ± 0.15 fertile tillers, high salinity conditions (20 dS/m) significantly reduced this number to 0.70 ± 0.31 . Moderate salinity (8 dS/m) also caused a decrease to 1.45 ± 0.19 , with differences observed being statistically ($p < 0.001$) highly significant (Table 3).

The total number of tillers per plant remained relatively stable across treatments, with values ranging from 3.36 ± 0.36 to 4.36 ± 1.13 , and not statistically significant ($p > 0.05$) differences observed (Table 3).

Tiller height, however, showed significant ($p < 0.001$) variation with salinity levels, decreasing from 50.42 ± 11.63 cm in control plants to 39.79 ± 12.51 cm under the highest salinity level 20 dS/m (Table 3).

Plant dry weight showed a significant ($p < 0.05$) reduction under high salinity (20 dS/m), decreasing from 5.27 ± 0.71 g in control plants to 4.14 ± 1.41 g (Table 3).

Table 3. The Effect of saline irrigation water on yield components of durum wheat in comparison to control treatment.

	Control	8	16	20	
Ear length (cm)	4.70 ± 0.24 a	4.20 ± 0.42 b	2.66 ± 1.18 c	2.41 ± 1.08 c	<0.001***
Ear weight(g)	0.53 ± 0.16 a	0.62 ± 0.25 a	0.66 ± 0.31 a	0.52 ± 0.23 a	0,424NS
Grain weight per ear (g)	0.34 ± 0.11 a	0.45 ± 0.20 b	0.49 ± 0.22 b	0.46 ± 0.21 b	<0.001***
Fertile tillers per plant	1.71 ± 0.15 a	1.45 ± 0.19 a	0.72 ± 0.31 b	0.70 ± 0.31 b	<0.001***
Tillers per plant	4.36 ± 1.13 a	3.36 ± 0.36 a	3.72 ± 0.65 a	3.48 ± 0.61 a	0,290NS
Plant dry weight (g)	5.27 ± 0.71 a	5.31 ± 1.18 a	5.11 ± 1.40 a	4.14 ± 1.41 b	0,012*
Tiller height (cm)	50.42 ± 11.63 a	46.47 ± 11.18 a	33.71 ± 13.13 b	39.79 ± 12.51 c	<0.001***

Source: Prepared by the authors

NS: Non-significant statistical test ($P > 0.05$).

***: Highly significant statistical test ($P < 0.001$).

*: significant statistical test ($P < 0.05$).

Means with distinct letters are significantly distinct at the critical value $\alpha = 5\%$

3.1.3 Bread Wheat Response to Salinity Levels

The effect of salinity on specific yield components of bread wheat was significant ($p < 0.05$) and intensified with higher salinity levels in the irrigation water. Plants irrigated with the highest salinity (EC = 20 dS/m) displayed significantly ($p < 0.001$) shorter ear lengths (4.26 cm) compared

to the control and those at EC = 16 dS/m. Interestingly, moderate salinity (EC = 8 dS/m) resulted in the longest ear lengths (7.21 cm,) and the highest ear weight (0.84 g) compared to the control (0.58 g). Ear weights under moderate (EC = 16 dS/m; 0.75 g) and slightly higher salinity (EC = 20 dS/m; 0.66 g) were also higher (Table 4). The grain weight per ear was relatively ($p>0.05$) stable among the control and other EC values (Table 4).

Compared to the control group with the highest tiller number (4.53) and fertile tiller number (2.25), moderate salinity (EC = 8 dS/m) resulted in a significant reduction in tillers per plant (2.15). Plants exposed to the highest salinity (EC = 20 dS/m) displayed the lowest number of fertile tillers, with statistically highly significant ($P < 0.001$) differences observed across all treatments (Table 4). Moderate salinity (EC = 16 dS/m) resulted in the highest dry weight (5.08 g), exceeding the control group slightly. However, the highest salinity (EC = 20 dS/m) caused a significant ($p > 0.01$). decrease to 4.22 g (Table 4). Tiller height exhibited no significant response ($p>0.05$) across the salinity treatments (Table 4).

Table 4. The Effect of saline irrigation water on yield components of bread wheat in comparison to control treatment.

	Control	8	16	20	
Ear length (cm)	5.83 ± 0.73 a	7.21 ± 0.44 c	5.16 ± 1.32 bc	4.26 ± 1.51 ab	<0.001***
Ear weight (g)	0.58 ± 0.19 a	0.84 ± 0.25 a	0.75 ± 0.31 a	0.66 ± 0.29 a	<0.001***
Grain weight per ear (g)	0.41 ± 0.11 a	0.42 ± 0.18 a	0.40 ± 0.19 a	0.29 ± 0.13 a	0.375NS
Fertile tillers per plant	2.25 ± 0.27 a	1.26 ± 0.13 b	0.97 ± 0.19 bc	0.78 ± 0.25 c	<0.001***
Tillers per plant	4.53 ± 1.11 a	2.15 ± 0.26 b	2.86 ± 0.52 b	2.75 ± 0.36 b	<0.001***
Plant dry weight (g)	4.92 ± 0.73 a	4.55 ± 0.92 ab	5.08 ± 1.34 a	4.22 ± 1.22b	0.040*
Tiller height (cm)	39.60 ± 7.43 a	43.30 ± 8.96 a	38.80 ± 11.14 a	35.90 ± 10.94 a	0.140NS

Source: Prepared by the authors

NS : Non-significant statistical test ($P > 0.05$).

***: Highly significant statistical test ($P < 0.001$).

*: significant statistical test ($P < 0.05$).

Means with distinct letters are significantly distinct at the critical value $\alpha = 5\%$.

3.1.4 Effects of Saline Water Irrigation on Various Growth Parameters of Durum Wheat in Algeria and Türkiye

Durum wheat grown in Algeria and Türkiye exhibited significant variation ($p<0.05$) in several growth parameters under increasing salinity levels of irrigation water (Table 5). The data demonstrate significant regional differences in the response of durum wheat to saline water irrigation. In Algeria, increasing salinity resulted in substantial reductions in ear length, ear weight, grain weight per ear, the number of fertile tillers, and plant dry weight, indicating high sensitivity to salinity stress. Conversely, in Türkiye, moderate salinity (EC 8 and EC 16 dS/m) appeared to enhance ear weight, grain weight per ear, and plant dry weight, with relatively stable ear lengths and number of fertile tillers. It was remarkable that durum wheat grown in Türkiye possess remarkable resilience to saline conditions compared to those grown in Algeria.

3.1.5 Effects of Saline Water Irrigation on Various Growth Parameters of Bread Wheat in Algeria and Türkiye

Bread wheat grown in Algeria and Türkiye exhibited significant variation ($p < 0.05$) in several growth parameters under increasing salinity levels of irrigation water (Table 6). Like durum wheat, bread wheat exhibited distinct regional responses to increasing salinity in irrigation water between Algeria and Türkiye. In Algeria, bread wheat experienced significant reductions in most yield components with increasing salinity. Ear length dropped from 4.26 cm in the control to 0.92 cm at EC 20 dS/m, while ear weight decreased from 0.16 g to 0.02 g. Grain weight per ear displayed a similar trend. Additionally, the number of fertile tillers and tillers per plant, along with plant dry weight, all exhibited significant reductions in Algeria. Conversely, in Türkiye, ear length showed minimal variation across treatments, and both ear weight and grain weight per ear even increased with moderate salinity (EC 16 dS/m). While these components decreased slightly at the highest salinity, the impact was far less severe compared to Algeria. Similarly, the number of fertile tillers, tillers per plant, and plant dry weight remained more stable in Turkish wheat. Interestingly, tiller height, although decreasing slightly at higher salinity, remained significantly higher than observed in Algeria at all treatment levels.

Table 5. Effects of Saline Water Irrigation on Various Growth Parameters of Durum Wheat in Algeria and Türkiye

Country	Algeria				Türkiye				
EC values	Control	8	16	20	Control	8	16	20	
Ear length (cm)	4.60±0.30a	3.27±0.02b	0.05±0.05c	0.00±0.00c	4.80±0.42a	5.13±0.08a	5.27±0.34a	4.82±0.18a	<0.001***
Ear weight (g)	0.19±0.03a	0.07±0.01a	0.00±0.00a	0.00±0.00a	0.88±0.04b	1.16±0.12bc	1.31±0.22c	1.03±0.09bc	0.035*
Grain weight per ear (g)	0.10±0.02a	0.00±0.00b	0.00±0.00b	0.00±0.00b	0.57±0.02c	0.89±0.03d	0.98±0.04e	0.92±0.04de	<0.001***
Fertile tillers per plant	1.88±0.18a	1.10±0.12b	0.03±0.03c	0.00±0.00c	1.53±0.23ad	1.80±0.21ad	1.42±0.10bd	1.39±0.09bd	<0.001***
Tillers per plant	6.55±1.16a	3.97±0.38a	5.07±0.52a	4.80±0.26a	2.17±0.47b	2.75±0.38b	2.38±0.19b	2.17±0.29b	0.068NS
Plant dry weight (g)	3.81±0.56a	2.71±0.18b	2.00±0.21bc	1.01±0.29c	6.72±0.33d	7.90±0.47e	8.22±0.39e	7.27±0.09de	<0.001***
Tiller height (cm)	24.51±1.27a	21.72±0.67a	10.47±0.61a	6.42±0.62a	76.33±1.68b	71.22±3.46b	69.11±1.56b	61.00±6.08b	0.384NS

Source: Prepared by the authors

NS : Non-significant statistical test ($P > 0.05$).

***: Highly significant statistical test ($P < 0.001$).

*: significant statistical test ($P < 0.05$).

Means with distinct letters are significantly distinct at the critical value $\alpha = 5\%$.

Table 6. Effects of Saline Water Irrigation on Various Growth Parameters of Bread Wheat in Algeria and Türkiye.

Source: Prepared by the authors

Country	Algeria				Türkiye				
EC values	Control	8	16	20	Control	8	16	20	
Ear length (cm)	4.26±0.38a	6.53±0.54b	2.43±1.08c	0.92±0.41d	7.40±0.18b	7.90±0.44b	7.89±0.14b	7.59±0.42b	<0.001***
Ear weight (g)	0.16±0.02ab	0.30±0.07a	0.06±0.03b	0.02±0.00b	1.00±0.04c	1.38±0.10d	1.44±0.02d	1.31±0.06d	<0.001***
Grain weight per ear (g)	0.21±0.15a	0.03±0.02a	0.00±0.00a	0.00±0.00a	0.60±0.03b	0.82±0.04b	0.80±0.16b	0.57±0.08b	0.071NS
Fertile tillers per plant	2.77±0.23a	1.17±0.03be	0.71±0.31bc	0.23±0.09c	1.73±0.19e	1.35±0.27be	1.24±0.09be	1.33±0.07be	<0.001***
Tillers per plant	6.97±0.30a	2.67±0.15b	3.73±0.76c	3.47±0.38c	2.08±0.29d	1.62±0.19d	2.00±0.13d	2.04±0.04d	<0.001***
Plant dry weight (g)	3.36±0.24a	2.50±0.12ab	2.16±0.52bc	1.50±0.11c	6.49±0.36d	6.61±0.04d	8.00±0.41e	6.94±0.12d	<0.001***
Tiller height (cm)	23.40±1.73ab	23.60±1.51a	14.50±2.43bc	11.7±1.74c	55.80±3.38d	63.00±3.18d	63.10±4.95d	60.00±3.27d	0.042*

NS : Non-significant statistical test ($P > 0.05$).

***: Highly significant statistical test ($P < 0.001$).

*: significant statistical test ($P < 0.05$).

Means with distinct letters are significantly distinct at the critical value $\alpha = 5\%$.

3.2 DISCUSSION

The present research evaluated the impact of varying salinity levels on the germination rates and the agronomic performance of two Turkish wheat cultivars, Harmankaya 99 (bread wheat) and Dumlupinar (durum wheat), in two distinct environments: Algeria and Türkiye. Specifically, high salinity negatively affects plants throughout their life cycle, as it begins by reducing germination rates and subsequently hinders growth and survival at later stages. Moreover, these detrimental effects have been consistently reported in the literature, including by Kamran et al. (2019), Shannon (1997), and Bessai et al. (2023).

The findings from the germination experiment clearly highlight the substantial impact of salinity stress on the growth and development of durum and bread wheat, with germination being notably more sensitive to salt stress compared to the three-leaf stage of growth, as observed by Francois et al. (1986). Specifically, germination percentages begin to decline significantly at an electrical conductivity (EC) level of 12 dS/m. Moreover, as salinity intensifies to an EC level of 20 dS/m, this reduction becomes increasingly severe, with losses in germination rates reaching up to 40%. This pattern has been extensively documented in the literature, as reported by Feghhenabi et al. (2020), Rossini et al. (2024), Pastuszak et al. (2022), and Akgün et al. (2011). Additionally, the adverse effects of salinity during the early stages of plant development are known to strongly inhibit germination, as further corroborated by Hmissi et al. (2023) and Bagwasi et al. (2020).

This study showed as well that salinity stress can negatively affect wheat growth and productivity. It has been widely reported by Abbas et al. (2013) and Sorour et al. (2019) that salinity cause reductions in fertile tillers, spikelet numbers per spike and grain weight due to the acceleration of the phenological phases in the wheat under stress (Grieve et al., 1994). However, our results clearly align with these findings and those of El-Hendawy et al. (2005) revealing decreases in yield components of durum and bread wheat.

We noticed an initial increase in the percentage of tillers producing spikes under moderate salinity (EC = 8 dS/m) as a possible adaptation to the mild stress conditions as previously observed by Maas et al. (1994) in durum wheat highlighting the complex response of wheat to salinity stress, where an initial stress response can be followed by a decline in production at higher salinity levels.

Emerging research suggests progressive decrease in ear length and weight as salinity levels in the irrigation water increased. as evidenced by Kalhor et al. (2019), Kaya et al. (2009), Tareq et al. (2011), and Ahmed et al. (2013). Our results are further supporting the negative impact of salinity on wheat ear development.

Our findings are also consistent with broader research on cereal crops under salinity stress. For instance, Ashrai & McNelly (1990) and Mahmood et al. (2009) documented reductions in crop

yield due to salt stress in maize and rice, respectively. Similar mechanisms are likely at play in wheat, where salinity reduces soil moisture availability and causes toxicity from high sodium and chloride ion concentrations (Munns and Tester, 2008).

Additionally, Hasan et al. (2015) reported that saline stress significantly reduces grains per spike, 1,000-grain weight, and seed yield in wheat cultivars. This aligns with our observations of reduced grain weight per ear in bread wheat under high salinity. However, wheat overall resilience to salinity, with yield reductions starting at a salinity level of 6 dS/m and around 50% yield reduction at 13 dS/m (Kara et al., 2011). Our study employed a salinity range (8, 16, and 20 dS/m) exceeding the initial threshold for yield decline. This highlights the importance of managing salinity levels.

Coskun and Tas (2017) reported that when the SAR values were kept below 3, salt could have made fertilizer effect with lower levels than 8 dS/m. Under greenhouse conditions, plant growth is hindered when the electrical conductivity of irrigation water went above 16 dS/m. Hexaploid wheat was more tolerant than tetraploid and diploid wheat to irrigation water salinity. Different responses of wheat genotypes to irrigation salinity levels may be resulted from the differences in their genetic structures. Hexaploid wheat is more tolerant to salinity according to tetraploid and diploid wheat (Coskun et al., 2016).

The greenhouse part of this study compared Turkish durum and bread wheat varieties response in two different environments: Tlemcen, Algeria and Çanakkale, Türkiye. Wheat grown under the high-temperature conditions of Tlemcen exhibited heightened sensitivity to salinity stress. This suggests that the inherently higher temperatures in Tlemcen (as shown in Table 1) exacerbated the stress effects of saline irrigation. While the cooler temperatures in Türkiye may have minimized evapotranspiration allowing the plants to manage the saline water more efficiently. These differences in stress responses are likely due to a combination of factors, including the genetic predispositions of the wheat varieties and the specific environmental conditions during their development. Recent advancements in the field have reported the importance of temperature as a key factor controlling salinity tolerance (Frank et al., 1987). This interaction is further observed by Saddiq et al. (2021) and Wu et al. (2021) who demonstrate significant reductions in plant growth and yield under combined salinity and heat stress. In line with our findings Rattey et al. (2009), Sareen et al. (2014), Qaseem et al. (2019), and Khare et al. (2024) demonstrates the significant differences among wheat genotypes regarding grain yield in both heat-stressed and non-stressed environments.

4 CONCLUSION

The findings reveal a clear effect of salinity on wheat performance; different patterns are observed for both types of wheat. High salinity levels significantly affected the germination and the growth of durum wheat and bread wheat, as well as different yield components, in both locations. Germination rates decreased progressively with increasing salinity levels, demonstrating that germination is one of the most sensitive stages to salinity stress. High salinity also reduced ear length, ear weight, fertile tillers, tillers per plant, and plant dry weight in both bread and durum wheat, as well as tiller height in bread wheat. The different responses observed between the two locations highlight the additive effect of Tlemcen's high temperatures on salinity stress, leading to increased sensitivity in wheat at this location. In contrast, the cooler climate of Çanakkale and the fact that the varieties are registered for this location have increased the tolerance of Turkish wheat varieties compared to Tlemcen by mitigating some of the negative effects of salinity. The role of genetic factors in salinity tolerance was also evident in the differences between wheat types and their performance across locations. Genetic predisposition plays a critical role in determining salinity-tolerant wheat genotypes, not only by improving germination rates under stress conditions but also by enhancing yield components. Additionally, better genetic tolerance contributes to overall plant performance and resilience under saline environments, ensuring stable productivity across diverse conditions especially in locations experiencing high temperatures. To better understand genotype x environment interactions, more durum and bread wheat varieties can be tested with different methods in future studies.

As it is known, not only NaCl salt is found dissolved in natural waters. In addition, salts such as Ca, Mg, K are found in significant amounts. When the literature is examined, there are many studies on both irrigation water salinity and soil salinity. For this reason, since the majority of studies on irrigation water salinity only take into account NaCl salt, they are actually studies that include NaCl salt stress rather than total salinity studies (Tas et.al., 2022; Coskun et.al., 2020; Akcaman and Tas, 2020; Kunt and Tas, 2019; Coşkun and Tas, 2017; Akcaman et.al., 2017; Tas and Ozturk 2011). The results obtained from the study examine the threshold value of sodium damage by considering both total salinity and SAR value of irrigation water in terms of irrigation water salinity. From this perspective, it provides important contributions to the literature. Researchers who will conduct research on plant breeding and plant nutrition related to irrigation water quality in the future will obtain more reliable results if they consider the SAR value of irrigation water instead of the electrical conductivity of irrigation water. These results will provide significant contributions to both science and sustainable agricultural production.

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