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Early seedling features and mineral content of maize seeds grown under salinity stress

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Abstract

High seedling performance is crucial for the growth and development of plants, as it directly affects the potential for crop yield. Therefore, robust early seedling characteristics can lead to higher yields and better crop productivity. This work evaluated the early seedling characteristics of maize seeds grown under four irrigation water salinities (0.30, 1.5, 3.5, and 7 dS m^{-1}). For this purpose, maize plants were grown to maturity in pots under rain shelter conditions, and then maize seeds were harvested. Subsequently, the maize seeds germinated to determine the early seedling characteristics, the leaf's Na^{+}, Ca^{+2}, K^{+} content, and the K^{+}/ Na^{+}, Ca^{+2}/ Na^{+}. The results showed that irrigation of maize crops at 7.0 dS m^{-1} reduced seedling fresh weight, root fresh weight, and SPAD parameters by 46.9%, 78.1%, and 38.7%, respectively, compared to 0.30 dS m^{-1}. Irrigation of maize plants with 8.0 dS m^{-1} significantly hampered the reusability of maize seeds and decreased seedling height (7.81 cm), root dry weight (0.13 g), and root length (5.5 cm). Moreover, the highest ratios of K^{+}/Na^{+} (12.58) and Ca^{+2}/Na^{+} (3.46) ratios and the lowest leaf Na^{+} content (0.24%) of maize seedlings were found in 0.30 dS m^{-1} treatment. Based on the results, it could be suggested that the reusability of maize seeds, which irrigation maize crops with ≥ 3.5 dS m^{-1} saline water, is not recommended for sustainable maize production due to low seedling growth performance. Finally, the current study has the potential to provide important insights into identifying robust and healthy maize seeds grown in high-salinity environments.

Keywords: Salinity stress, maize germination, seed quality, seedling growth.

Introduction

Maize is an essential crop in many cultures worldwide due to its versatility and importance as a staple food (Erenstein et al., 2022). Maize is the third most cultivated cereal globally, after wheat and rice, with a worldwide production of 1.13 billion tonnes in 2021, as stated by FAO (2021). In addition to its role as the primary food source for millions of people, maize is also used to produce animal feed, biofuels, and industrial products (Chaudhary et al., 2013; Rouf Shah et al., 2016). Up to now, maize production has faced numerous environmental problems (Ahmad et al., 2020). Climate change, erratic rainfall patterns, salinity, and water stress have become critical areas of concern for researchers because they seriously affect grain-filling processes and quality, ultimately leading to lower crop productivity (Vaughan et al., 2018; Salika and Riffat, 2021).

Climate change significantly impacts resources worldwide, including increasing water scarcity in many regions (Lu et al., 2019) due to higher temperatures, changing precipitation patterns, and more frequent extreme weather events (Hopmans et al., 2021). As a result, many farmers are turning to alternative water sources, such as saline water, for irrigated agriculture (Singh, 2022). Although using salt water can be a viable solution to freshwater scarcity, it also presents new challenges. Sustainable management practices and

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technologies must be developed to ensure that using high water salinity in irrigated agriculture is practical and environmentally responsible.

Using saline water for irrigation can affect crop yield, physiology, morphology, and grain quality (Kiremit and Arslan, 2016; Arif et al., 2020). High soil salinity can reduce the availability of essential nutrients and water to plants, resulting in lower yields (Arif et al., 2020). In addition, saline water can adversely influence plant physiology by interfering with water uptake, photosynthesis, and other physiological processes (Alkharabsheh et al., 2021; Mukhopadhyay et al., 2021). Moreover, the high salt concentration in saline water can affect plant morphology, including changes in root and shoot development (Bistgani et al., 2019). The seed quality of plants irrigated with saline water may also be affected, with lower protein content, starch content, and altered mineral composition (Koyro and Eisa, 2008).

Seed quality is a vital component in the growth of plants and yield. It can increase seed resistance to environmental factors by providing a high germination rate and seedling growth characteristics (Sehgal et al., 2018). The germination process depends on efficiently mobilizing stored reserves to promote successful emergence (Bewley et al., 2013). The seed's high growth capacity significantly improved the productivity of the crops. Therefore, examining early seedling growth attributes of seeds grown under unfavorable conditions is necessary to facilitate the selection of strong and healthy seeds.

In literature, generally, the researchers have been focused on how saline water affects the germination and seedling growth ability of maize seeds (Khodarahmpour et al., 2014; Li et al., 2019; Öztürk et al., 2021). However, no study has been investigated to determine the seedling growth performance of maize seeds grown under saline water conditions. Therefore, to fill this gap in the literature, this study aimed to find out how saline irrigation water affected seedling development and leaf macronutrient content in maize seeds.

Material and Methods

Growing environment and seed sources

The study was established under a rain shelter in the Experimental Area of the University of Ondokuz Mayıs (Samsun, Türkiye) during the summer of 2021. The mean daily temperature and relative humidity under the rain shelter fluctuated between 19-36 °C and 44-72% during growth. The study soil was classified as clay loam, consisting of 36.5% clay, 22.8% silt, and 40.7% sand, collected at a depth of 30 cm at the Ondokuz Mayıs University Experimental Farm. The collected soil was air-dried under a rain shelter, grounded, and passed through a 4 mm sieve. After that, each plastic pot (0.30 m high × 0.28 m top × 0.26 m bottom) was filled with 2 kg of gravel at the bottom and then with 12 kg of sieved soil. Chemical analysis showed that the contents of Ca^{+2}, Mg^{+2}, $Na^{+,}$ and K^{+} were 1.20, 2.30, 2.80, and 0.8 mg/100 g of soil, respectively. The field capacity, permanent wilting point, electrical conductivity (EC), and soil pH were 25.7%, 15.7%, 0.15 dS m^{-1}, and 6.85, respectively. Cin mısır (Zea mays everta Sturt) seed, one of the most widely grown cereal varieties in Turkey, was used in the study. Maize seeds were sown on June 17, 2021, and harvested on October 10, 2021 respectively.

Experimental setup and agronomic practices

The study was set up as a factorial experiment in a completely randomized design consisting of four saline waters (S_1 = 0.30 dS m^{-1}, S_2 = 1.5 dS m^{-1}, S_3 = 3.5 dS m^{-1}, S_4 = 7.0 dS m^{-1}) with three replicates per treatment (4 salinity levels × 3 replicates = 12 pots). Five seeds were sown in each pot and thinned to one uniform healthy seedling per pot 20 days after sowing. All pots were irrigated with the same amount of tap water during the germination period. After thinning, irrigation with saline water was started according to the treatments. To achieve this, S_1 was tap water, while salinity levels of S_2, S_3, and S_4 were prepared by adding NaCI and $CaCI_2$ to the water of S_1 in a 1:1 ratio. Before sowing, all pots were saturated with tap water to determine the field capacity weight of each pot. The surface of the pots was wrapped with a plastic cover to prevent water loss by evaporation. After stopping the drainage and establishing the balance between air and water in the soil, each pot was weighed, and this was taken as the field capacity of each pot. Irrigation practices were realized when 0.40% of the available water in the soil was consumed by evapotranspiration throughout the growing cycle. Each pot was weighed daily to determine soil moisture loss due to evapotranspiration. Also, to minimize high salt buildup in the root zone, 15% leachate was given at each irrigation.

The maize plant was fertilized with 250 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, and 180 kg K_2O ha^{-1}. Phosphorus and potassium were employed as base fertilizers in the form of triple superphosphate (1.41 g pot^{-1}) and potassium sulfate (0.88 g pot^{-1}), respectively, before sowing. Nitrogen was applied in two doses: 50% nitrogen at the time of the grand growth stage and a second dose of 50% nitrogen at the tessling stage.

Germination experiment

The surface of the harvested maize seeds was sterilized in a 5% NaOCl solution for 10 min prior to germination. The germination study was set up as a factorial experiment in a completely randomized design with three replicates per treatment (ten seedlings per replicate). A total of 12 petri dishes (4 irrigation water salinity × 3 replicates = 12 petri dishes) were used to achieve this purpose. Twenty seeds were sown with tweezers in glass petri dishes (9×9×4cm) with double-layer blotting paper for each treatment. The seeds were irrigated daily with 10 ml of 0.22 dSm^{-1} irrigation water. Petri dishes were kept in an incubator at a temperature of 25 ± 1^0C and a relative humidity of 50%. During each day of the experiment, the dishes were exposed to a light intensity of 1200 l x for 12 hours.

After 14 days, ten seedlings were randomly selected from each replicate to measure the shoots' fresh and dry weights as well as shoots and root lengths. The SPAD readings were taken from the leaves of 5 different seedlings from each petri dish using the SPAD 502 Meters [Spectrum Technologies, Inc., USA]. The fresh weights of the shoots and roots were obtained by weighing 10 seedlings chosen at random from each petri plate. The dry weights of the shoot and roots were determined by keeping the seedling at 70 ^oC in the oven-dried up to reaching consistent weight, and then weights were determined with an electronic balance. The lengths of the shoots and roots were measured with a ruler.

Statistical Analysis

One-way analysis of variance was performed on the data, and statistical analysis was made using SPSS 25.0 (SPSS, Chicago, IL, USA). Significant differences between means were separated using the Duncan test at the 0.05 probability level. Bar graphs for leaf macronutrient content were created using Microsoft Office 365 software. The vertical lines on the bar graphs show the standard error of the three replicates for each treatment.

Results and Discussion

The stem fresh and dry weights, root fresh and dry weights, and chlorophyll content were considerably affected by irrigation water salinity (p<0.001); moreover, irrigation water salinity showed a significant effect on seedling height and root length (p< 0.01).

Table 1. Effects of irrigation water salinity on early seedling traits of maize seeds

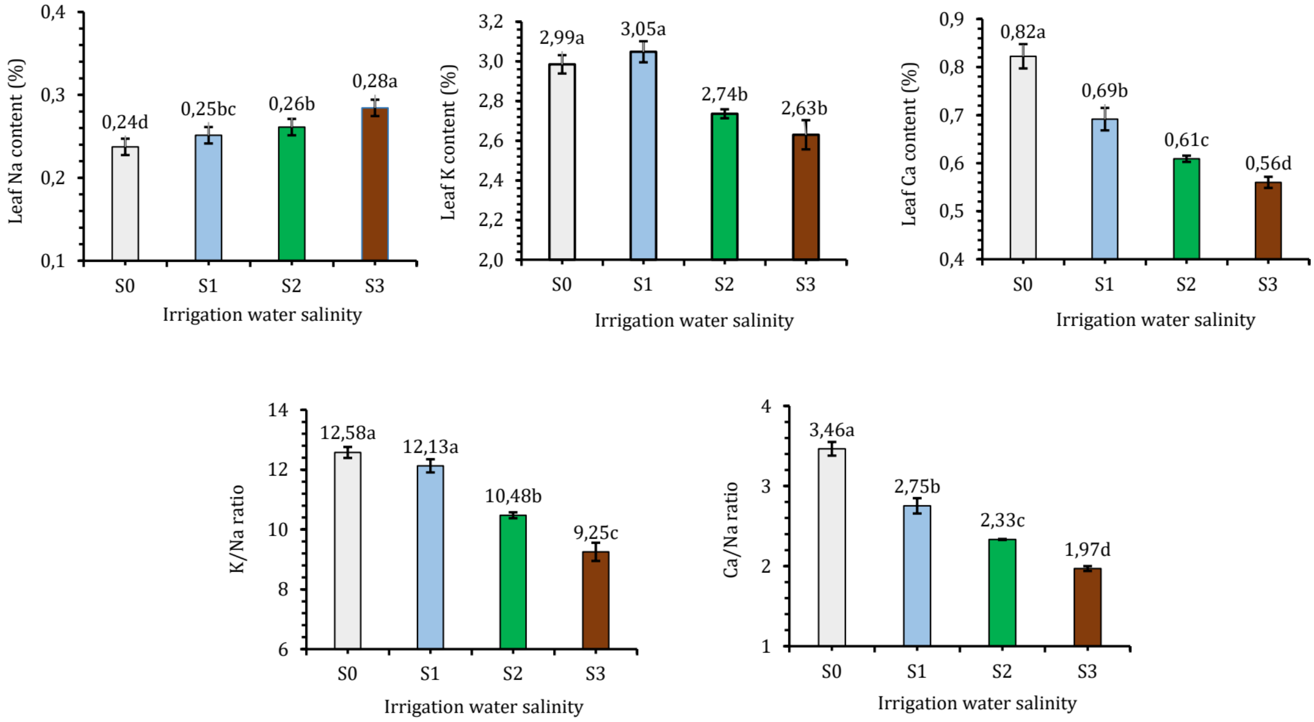
Irrigation water salinity (dS m^{-1})	Seedling Parameters		
	Seedling height (cm)	Stem fresh weight (g)	Stem dry weight (g)
S1	10.34 ± 0.38a	4.9 ± 0.2a	0.45 ± 0.04a
S2	10.02 ± 0.57a	4.8 ± 0.2a	0.44 ± 0.02a
S3	10.19 ± 0.19a	4.0 ± 0.2b	0.34 ± 0.01b
S4	7.81 ± 0.19b	2.6 ± 0.2c	0.27 ± 0.01c
ANOVA			
P>F	**	***	**
	Root fresh weight (g)	Root dry weight (g)	Root length (cm)
S1	3.20 ± 0.06a	0.28 ± 0.01a	8.8 ± 0.6a
S2	2.94 ± 0.24a	0.22 ± 0.001b	7.7 ± 0.2b
S3	1.72 ± 0.35b	0.17 ± 0.02c	6.1 ± 0.3c
S4	0.70 ± 0.02c	0.13 ± 0.003d	5.5 ± 0.2c
ANOVA			
P>F	***	***	**
	SPAD	SDW/SFW ratio	RDW/RFW ratio
S1	26.6 ± 0.3a	9.18 ± 0.35b	8.83 ± 0.48b
S2	25.3 ± 0.6b	9.33 ± 0.81b	8.35 ± 0.23b
S3	21.7 ± 0.8c	9.15 ± 0.06b	9.52 ± 1.02b
S4	16.3 ± 0.4d	11.34 ± 0.35a	17.99 ± 0.17a
ANOVA			
P>F	***	***	**

S_1, S_2, S_3, and S_4 show 0.30, 1.5, 3.5, and 7.0 dSm^{-1}, respectively. According to Duncan's Test, different letters in each feature significantly differ at a 0.05% probability level. ***: *p≤0.001* **: *p≤0.01*.

The S_1 treatment produced the greatest seedling height (10.34 cm), whereas the S_4 treatment obtained the lowest (7.81 cm). Seedling lengths decreased by 3%, 1.5%, and 24.46% in S_2, S_3, and S_4, respectively, when compared to the S_1. In addition, the seedling heights for S_1, S_2, and S_3 treatments were not statistically different (Table 1). Stem fresh and dry weights of the highest saline irrigation treatment (S_4) were reduced by 46.8% and 40%, respectively, relative to the S_1 treatment. However, there was no statistical difference between S_1 and S_2 treatments in both stem fresh and dry weights. The highest root wet weight value (3.20 g) was found in S_1, while the lowest (0.70 g) was observed in the S_4 treatment. Root dry weight values were reduced with an increment in irrigation water salinity. Root dry weight decreased by 21.4%, 39.28%, and 57.53% in S_2, S_3, and S_4, respectively, compared to S_1 treatment. The greatest root length was measured in S_1 (8.8 cm) and the lowest in S_4 (5.5 cm). SPAD values for maize seedlings changed between 16.3-26.6, and the highest value (26.6) was observed in the S_1 treatment, whereas the lowest was in the S_4 treatment. However, the SPAD value between the S_1 and S_2 treatments statistically differed, but no high differences were found between the two treatments. SDW/SFW and RDW/RFW ratios were increased with increments in saline water. For the two parameters, the highest values (11.34 and 17.99) were observed in the S_4 treatment, while no significant differences were observed between the S_1, S_2, and S_3 treatments. Considering all the early growth attributes of the maize seeds, irrigation of the maize plants with 3.5 and 7 dSm^{-1} caused a greater reduction in the growth capacity of the seeds compared to water salinity of 1.5 and 0.30 dSm^{-1}. This reduction in the early seedling growth ability of the seed could be related to seed reserve content. For this, carbohydrate accumulation decreased at 3.5 and 7.0 dSm^{-1} water salinity, caused by the toxic salinity concentration in the root zone. Similar results to our study, Meena and Yadav (2018) reported that assimilated reserves in the embryo of the seeds might reduce with increasing salinity stress. Soriano et al. (2014) explained that seed reserve content is closely related to the germination percentage. In a study conducted by Begcy and Walia (2015), it was found that seed reserve proteins play a crucial role as a reservoir of amino acids and nitrogen, which are essential for the growth and development of new seedlings. The study also suggested that any disturbance in the quantity or quality of these proteins could inhibit seedling establishment and vigor. The findings of the current investigation suggested that the water salinity should not exceed 3.5 dSm^{-1} to avoid any adverse effects on the quality and serve of the seeds due to the buildup of salt minerals in the root zone during the seed filling period.

Figure 1 illustrates the differences in leaf Na^+, Ca^{+2}, K^+ contents, K^+/Na^+, and Ca^{2+}/Na^+ ratios in maize seed grown under different irrigation water salinity conditions. The salinity of irrigation water had significant effects on the contents of leaf nutrients of the maize seedlings, and the leaf Na^+ content increased with the increment in water salinity level. Compared with the highest saline water (S_4), S_1, S_2, and S_3 decreased leaf Na^+ by 16.5%, 11.6%, and 8.1%, respectively. Moreover, the greatest leaf K^+ content (3.05%) was observed in the S_1 (Figure 1). Furthermore, the leaf K^+ content of S_1 was slightly lower than that of S_2, and no significant differences were observed between the S_1 and S_2 treatments ($p>0.05$) (Figure 1). The leaf Ca^{+2} contents of maize seedling were significantly differed between saline irrigation waters. Consequently, S_1 had the highest leaf Ca^{+2} content (0.82%), which decreased by 15.9%, 25.9%, and 31.9% for the S_1, S_2, and S_3 treatments, respectively (Figure 1).

The K^+/Na^+ ratio depicted a decrease with increment in water salinity level. Compared with the S_1 treatment, the K^+/Na^+ ratio of the maize seeds grown at S_2, S_3, and S_4 treatments decreased by 3.6%, 16.7%, and 26.4%, respectively. Irrigation with saline water induced decreases in the Ca^{+2}/Na^+ ratio of maize seeds (Figure 1). The S_1 treatment exhibited the greatest Ca^{+2}/Na^+ ratio (3.46%), followed by the S_2 treatment (Figure 1). The reductions in the Ca^{+2}/Na^+ ratio were around 20.6%, 32.7, and 43.2% for S_1, S_2, and S_3, respectively, compared with the S_1 treatment (Figure 1). Considering all mineral contents of maize, it could be noted that the increment in salinity of irrigation water resulted in a significant reduction in K^+ and Ca^{2+} content of maize seeds. The greatest decrease in these parameters was observed in the S_4 treatment; this could be linked with the salinity of the irrigation water causing high osmotic stress and ion toxicity in the root zone, resulting in low nutrient availability to the maize crops. Farooq et al. (2015) explained that excessive accumulation of sodium and chloride ions in the root zone of maize in saline soils causes severe nutritional imbalances. These ions interact with other vital mineral elements such as potassium, nitrogen, and calcium (Läuchli and Grattan, 2007). Hu and Schmidhalter (2005) also reported that increasing the level of salt concentration within a root zone induces an increment in the soil osmotic potential, thereby decreasing the movement of K^+ ions in the soil and ultimately affecting the K^+ uptake potential of the plants. Like ours, Sezer et al. (2021) found that the K^+ and Ca^{+2} content in maize seedlings reduced with increasing water salinity. Regarding our research, the presence of K^+, Ca^{2+}, and Na^+ ions in seed reserves can be attributed to the ability of plants to withstand osmotic stress under salinity conditions. Therefore, irrigating maize plants with ≥ 3.5 dS m^{-1} saline waters is not recommended due to decreasing assimilate movement from root to grain, thus causing poor seed quality.



	ANOVA				
	Na^{+2}	K^{+}	Ca^{+2}	K^{+}/Na^{+2}	Ca^{+2}/Na^{+2}
P>F	**	***	**	***	***

Figure 1. Changes in leaf Na^{+2}, Ca^{+2}, K^{+} levels, $K+/Na^{2+}$, and Ca^{2+}/Na^{2+} ratios in maize seeds grown at different salinities of irrigation water. ***: $p \le 0.001$ **: $p \le 0.01$.

Conclusion

This study aimed to test a practical method for indicating the reuse potential and the early seedling capacity of maize seeds grown under irrigation water salinities. The findings showed that the saline irrigation water significantly affected the growth parameters, with the highest growth observed at the lowest salinity (0.30 dSm^{-1}). Additionally, the research indicated that using saline water for irrigation led to a noteworthy variation in the nutrient levels of maize seedlings' leaves, whereby the amount of Na^{+} in the leaves rose proportionally to the salinity level of the irrigation water. In contrast, leaf K^{+} and Ca^{2+} ions reduced markedly with increasing water salinity. According to our study, it is recommended that the water salinity level should be kept below 3.5 dS m^{-1} to prevent salt buildup in the root zone during the seed-filling period, which can adversely impact seed quality and yield. Overall, the results of this study provide new insights for farmers and researchers in reusing and selecting maize seeds harvested from saline soils.

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