Research Article

SCREENING OF SALT-TOLERANT DATE PALM CULTIVARS AT THE SEEDLING STAGE

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ABSTRACT

Date palm (*Phoenix dactylifera L.*), belongs to the Aceraceae family, is a cost-effective and nutritionally important crop. Although considered moderately salt tolerant, excessive salt accumulation caused by irrigation with brackish water severely reduces yield and survival rates. The physiological and anatomical mechanisms underlying salt tolerance in date palm remain only partially understood. This study aims to evaluate the salt tolerance in four commercially important date palm cultivars at the seedling stage under NaCl stress levels of 0, 6, 8, and 10 dS m^{-1}. The objective was to identify cultivars with higher tolerance and those more susceptible to salinity stress. Morphological and physiological parameters were recorded under both control and saline conditions, and the data was analyzed through the ANOVA (analysis of variance) test. Significant genotypic variation was observed for traits such as days to emergence, root and shoot biomass (fresh and dry), shoot and root length, chlorophyll content, stomatal conductance, photosynthetic rate, transpiration rate and cell membrane thermostability. The results revealed that while date palms can withstand high salinity, the degree of tolerance varies across cultivars. Shoot Na^+ exclusion emerged as a key determinant of salinity resistance and may serve as a reliable criterion for screening tolerant genotypes. Importantly, two cultivars (Zahidi and Aseel) exhibited superior tolerance and can be utilized as genetic resources for future breeding programs aimed at enhancing salt resistance. The identification of these tolerant cultivars offers practical opportunities for cultivation in salt-affected areas, thereby sustaining productivity and improving the resilience of date palm cultivation.

Keywords: cell membrane thermostability, chlorophyll content, Date palm, salinity, screen out, susceptible, tolerance, sodium, potassium.

INTRODUCTION

The date palm (*Phoenix dactylifera* L.), belongs to the Arecaceae family. The (Middle East and North Africa) region is the date palm's primary place of origin.
Over the past century, its cultivation has extended to South Africa, Australia, and America. Because date palm can withstand harsh weather conditions, they are widely grown throughout Pakistan. The arid climates of Upper Sindh, Southern Punjab, and Baluchistan are ideal for date palm production. Pakistan is ranked sixth among nations that produce dates 535,000 tons annually from its 102.68 thousand hectares of cultivation (Ministry of National Food Security Government of Pakistan 2018-19). The current environmental circumstances have resulted in a reduction in date palm productivity. Several factors, including severe pests and illnesses, salinity, drought, inadequate harvesting, and post-harvest procedures, might hinder the productivity of date palms (Alhammadi & Kurup, 2012).
A serious challenge to agriculture is posed by saline environments, partly caused by the irrigation of salt-containing water fields agriculture. More than $12 billion is lost annually due to salinization in crops worldwide (Alrasbi et al., 2010). The earliest consequences of salinity, which is a multifactorial feature, are osmotic, wherein sensitive plants have slowed development, growth halt, and ultimately death when exposed to excessive concentrations of

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NaCl (Aljuburi, 1992). This osmotic component becomes especially severe because it uses abscisic acid (ABA) signaling pathways to cause stomatal closure which lowers gas exchange and consequently the rate of photosynthesis. Excess Na^+ reduces chlorophyll content and overall biomass by disrupting photosynthetic machinery (Youssef & Awad, 2008).

Salt-induced Na^+ accumulation also triggers oxidative stress, generating ROS that damage membrane lipids and cause electrolyte leakage. Potassium ion is a very important component of these leaky electrolytes. It is involved in physiological activity such as protein trafficking, stomatal aperture regulation, nyctinastic leaf movements, pH regulation, membrane potential maintenance, and nearly every stage of plant growth. Because K^+ serves so many different purposes, research on stress tolerance has turned their attention to the homeostasis of K^+ under salt stress. The low degree ratio of K^+ /Na^+ is not good indicator for salt stress tolerant (Anschütz et al., 2014). High concentration of Na^+ leads to nutrient deficiency as it blocks the uptake of other elements. As many enzymes in the photosynthetic pathway are activated by K^+, this causes metabolic processes like photosynthesis to be interrupted. Therefore, keeping Na^+ ions out of the environment, especially from leaves, is very helpful in protecting vital metabolic functions like photosynthesis, which are critical for biomass growth. Recirculation of Na^+ ions from shoots to roots, the removal of Na^+ ions from root cells into the surrounding soil, and retrieving Na^+ ions from xylem vessels into xylem parenchyma cells, ultimately returning them to the soil via the phloem are just a few examples of the effective exclusion mechanisms that many plant species have developed to control Na^+ levels (Fujimaki et al., 2015).

Moreover, tissue tolerance is essential because it offers a less expensive osmotic solution for preserving cell turgor compared to plants' energy-intensive process of synthesizing organic solutes (Shabala, 2013). Even with the help of genetic engineering, salinity stress remains a very complex problem with very little chance of resolution. This is caused by the reason that many plant species, cultivars within the same species, and even individual cultivar members have distinctly varied salinity adaptations (Yaish & Kumar, 2015). Therefore, identifying the various cultivars' varying susceptibilities to salt stress would yield important genetic resources for the advancement of agriculture through screening. This had great success in a lot of cereals, such as rice (Mekawy et al., 2015) and wheat (Munns et al., 2012). In many hot and semi-arid areas of the Middle East and North America, the date palm is a monocot and a staple fruit crop. Despite the existence of more than 100 cultivars, nothing is known about the methods via which these plants tolerate salinity. Furthermore, the studies that have already been done have a narrow focus and usually only look at one to four cultivars (Munns, 2002).

There is a serious information vacuum that requires immediate attention since salt is encroaching on large areas of agricultural land, particularly those where date palms are abundant. Since fresh water is scarce in these dry areas, farmers are frequently forced to use water that contains salt for irrigation, which frequently causes salt to build up in the soil. Some varieties of date palm, especially those found in coastal areas, have proven to be extremely resilient and have flourished in salinities higher than 300 mM NaCl (Shabala, 2013).

On the other hand, certain cultivars are sensitive to comparable salinities. In spite of this finding, little is known about the physiological processes behind this variation in sensitivity or tolerance. Therefore, evaluating these cultivars' resistance to salt stress is vital since it can provide important insights into the coping strategies these plants use and provide helpful resources to increase the productivity of date palms in these remote areas. Thus, the primary objective of this research was to assess many date palm cultivars at the seedling stage that were grown in pots with varied salinity levels.

MATERIALS AND METHODS

Germplasm Collection and Plant Growth

Seeds of four date palm cultivars Aseel, Zahidi, Shamran, and Khudravi were collected from Horticultural Research Station, Bahawalpur. The MNS University of Agriculture in Multan's glasshouse served as the venue for this experiment. The plants were kept at a constant temperature of thirty degrees Celsius in a glasshouse that received direct sunlight. Genotypes of date palms were grown in 1 inch into a small pot filled with 50% peat moss and 50% sand using factorial under a complete randomized design. For six weeks before to establishment, the pots were simply watered with tap water. Every genotype was replicated three times, with one plant per pot in each of the four replications. The replications were subjected to four distinct doses of salt (0 dS m^{-1}, 6 dS m^{-1}, 8 dS m^{-1}, and 10 dS m^{-1}). Salt was applied to the plantlets after six weeks of emergence. After twelve weeks, the data of four plants of each genotype in each replication were collected from each treatment for various morphological and physiological analyses.

Day to the Emergence

The viable date seeds germinate between 14-20 days in ideal conditions. Data was recorded after the emergence of seeds.

Root and Shoot Length (cm)

The length of the shoot and root was determined using a measuring scale. Three plants were selected for recording data and the average was computed.

Fresh Root and Shoot Weight (g)

The plants were selected, and their fresh weights were recorded. Fresh root and shoot weight were determined using a weighing balance. Three plants were selected for recording data and the average was computed.

Dry Root and Shoot Weight (g)

After the plants were chosen, samples were dried in an oven for 48 hours at 80 degrees Celsius, and their dry weights were noted. Dry root and shoot weight were determined using a weighing balance. Three plants were selected for recording data and the average was computed.

Physiological Parameters

The flame photometer, CIRAS-III Portable Photosynthetic System, and the EC-meter equipment were used to record the parameters (Chlorophyll content (µg/g), Photosynthesis rate (µmol m^{-2} s^{-1}), Rate transpiration and stomatal conductance (µmol m^{-2} s^{-1}) at the seedling stage of plant leaves from 11:00 am to 2:00 pm.

Electrolyte Leakage

Measurements of electrolyte leakage were carried out using the protocol (Aljuburi & Maroff, 2006). Vials containing 10 ml of deionized water were filled with fresh leaf samples, which were there after shaken for 24 hours at room temperature at 100 rpm. After that, the first electrolyte leak (EC_1) was noted. The vials were then autoclaved (Aster, Inc., Placentia, CA, USA) for 20 minutes at 120°C to determine the maximum conductivity (EC_2), which was then noted. The formula for calculating electrolyte leakage was (EC_1/EC_2) × 100. The results were then represented as a percentage of maximal conductivity.

Measurement of Na^+ and K^+ concentrations

Samples of leaves and roots were dried for 48 hours at 80 °C, then weighed. The dried materials were next digested using H_2O_2 (5:1 v:v) and concentrated HNO_3 acid, as previously mentioned by (Aljuburi & Maroff, 2006). Na^+ and K^+ concentrations in the digested samples were quantified using a flame photometer (Model: Sherwood Flame Photometer 410, Sherwood Scientific Ltd., UK).

Statistical Analysis

The data were analyzed using ANOVA in Statistic 8.1 (Steel & Torrie, 1981)." The DMR test was performed to select salt-tolerant genotypes.

RESULTS AND DISCUSSION

Analysis of Variance

Analysis of variance for physiological and morphological-related traits to verify the existence of variation in features, analysis of variance was done by using R Studio. Table 1 showed that the mean square values for day to the emergence, length shoot (cm), root length (cm), fresh root weight (g), fresh shoot weight (g), dry root weight (g), dry shoot weight (g), photosynthesis rate (µmol $m^{-2}s^{-1}$), chlorophyll content (mg/l), rate transpiration (mmol m^{-2}s/1), conductance stomatal rate (µmol $m^{-2}s^{-1}$), cell membrane thermostability (CMT), measurement of Na^+ and K^+ concentrations for different genotypes were found to be highly significant ($P < 0.05$) means square values in the experiment among genotypes.

The effects of salinity stress on plant metabolism are profound, mainly due to the obstruction of water intake, which causes problems with seed germination, plant development, and total biomass of the plant. This stress induces the generation of free radicals within plant cells, contributing to a slowdown in growth and developmental processes. This study focuses on assessing salt tolerance in four cultivars of date palm, namely Zahidi, Aseel Shamran, and Khudravi, which are nutritionally and medicinally important.

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Table 1. Analysis of Variance for Morphological and Physiological Traits.

SOV	DTE	SL	RL	FRW	FSW	DRW	DSW	PR
G	3.58***	332.6***	80.00***	0.14545***	0.76167***	0.031558.	0.30854***	133.47***
T	884.08 ***	1371.69***	0.43223***	0.73487 NS	2.51667***	0.241147***	1.20299***	831.58***
G*T	3.58 ***	3.69	0	0.00175	0.00389***	0.000253NS	0.00187	1.19
SOV	**CC**	**TR**	**SCR**	**CMT**	**Na^+CL**	**Na^+CR**	**K^+CL**	**K^+CR**
G	0.011383.	0.31278***	0.04839.	602.06***	0.50687***	0.22410***	0.17187***	0.08299**
T	0.065083***	2.61056***	0.35742***	1489.44***	0.72910***	0.41687***	0.54743***	0.48410***
G*T	0.000156	0.00222	0.00107	2.54	0.00262	0.00391	0.00225	0.00113

NS =non-significant, *=Significant <0.05, **=Highly Significant<0.01 probability level, ***= Highly Significant at< 0.001 probability level G=Genotypes, T=Treatments DAE= days to emergence, SL= Shoot length, RL= Root length, FSW= Fresh shoot weight, DSW= Dry shoot weight, FRW= Fresh root weight, DRW= Dry root weight, PR= Photosynthesis, SCR= Stomatal conductance, TR= Transpiration rate, CC= Chlorophyll contents, CMT= Cell membrane thermostability, Na^+CL= Sodium concentration sin leaves, Na^+CR= Sodium concentration in roots, K^+CL= Potassium concentration in leaves, K^+CR= Potassium concentration in leaves.

Days to Emergence (DTE)

To evaluate salt tolerance, seeds from both cultivars were subjected to varying concentrations of NaCl (0 dS m^{-1}, 6 dS m^{-1}, 8 dS m^{-1}, and 10 dS m^{-1}) during germination. The date palm cultivar seedlings were investigated in a controlled glasshouse environment. Examining the growth statistics for each cultivar, which are expressed as a percentage of the control, statistical analysis revealed germination patterns. Zahidi and Aseel exhibited earlier germination, occurring on the 14th and 16th days, respectively, while Shamran and Khudravi displayed delayed germination on the 18th and 20th days. These findings align with existing literature reporting decreased seed germination in different crops under salt stress (Munns & Tester, 2008). Notably, Zahidi, as illustrated in (Fig.1), emerged earlier than other varieties in pot trials. The data presented signify significant values based on Duncan's test ($p < 0.05$), emphasizing the reliability and significance of the observed germination variations among the investigated date palm cultivars. Germination is adversely impacted by soil salinity stress, attributable to either the deleterious effects of ionic toxicity or the imposition of osmotic stress (Munns & Tester, 2008).

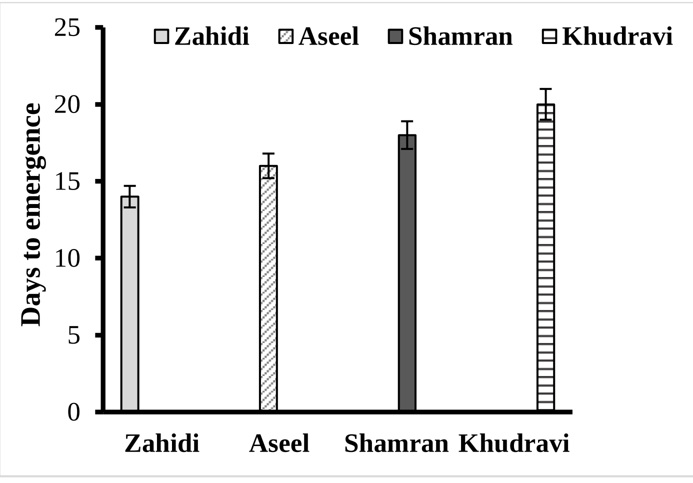

Figure 1. Comparison of genotypes based on their respective days to emergence.

The Effect of Salt on Shoot Length

Salinity stress significantly affected morphological traits within different cultivars. Notably, Zahidi exhibited a greater shoot length than other cultivars under salinity stress. Furthermore, Zahidi's shoot length was less adversely affected compared to the other cultivars, and a statistically significant was found to be within the Zahidi variety (Fig. 2). The data presented are based on significant values derived from Duncan's test ($p < 0.05$), underscoring the reliability of the observed differences. Remarkably, in this study, the impact on shoot length was found to be less pronounced than that on root length under salinity stress. This result is consistent with our earlier studies (Sperling et al., 2014) on the Khalas cultivar of date palms exposed to NaCl concentrations. On the other hand, Zahidi's shoot length showed less variation than Aseel's, and this difference was also considered statistically significant. Our knowledge of the many ways that date palm cultivars react to salt stress is enhanced by these findings, which have ramifications for future cultivation techniques and stress mitigation.

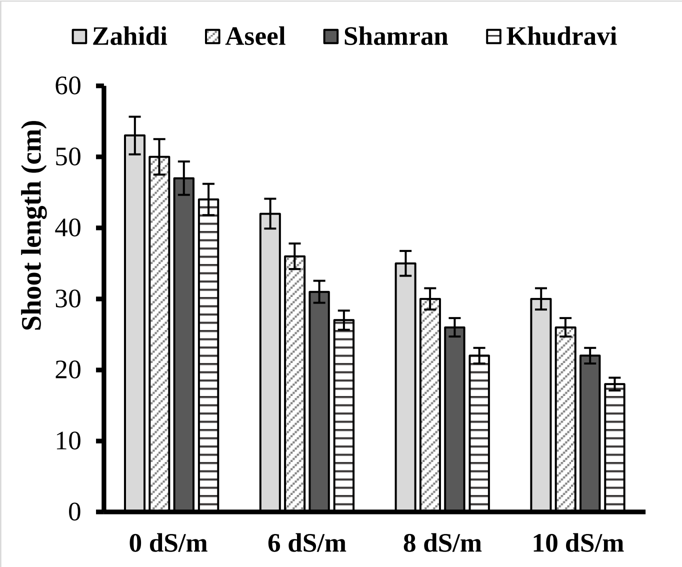

Figure 2. Effect of salinity stress on shoot length.

The Effect of Salt on Root Length

The detrimental impact of salinity stress on cultivar development and growth was evident in our study. Nevertheless, the Aseel cultivar demonstrated a more resilient performance in terms of root systems compared to the other cultivars (Fig. 3). Several measurements of root architecture in other cultivars were adversely affected by salt stress, as reflected in the data presenting significant to Duncan's test ($p < 0.05$). Interestingly, in contrast to the observed patterns in shoot length, the reduction in root length was more pronounced both between different cultivars and significantly within the same cultivar. These findings underscore the differential responses of date palm cultivars to salt stress, with the Aseel variety exhibiting a more robust root system under challenging conditions.

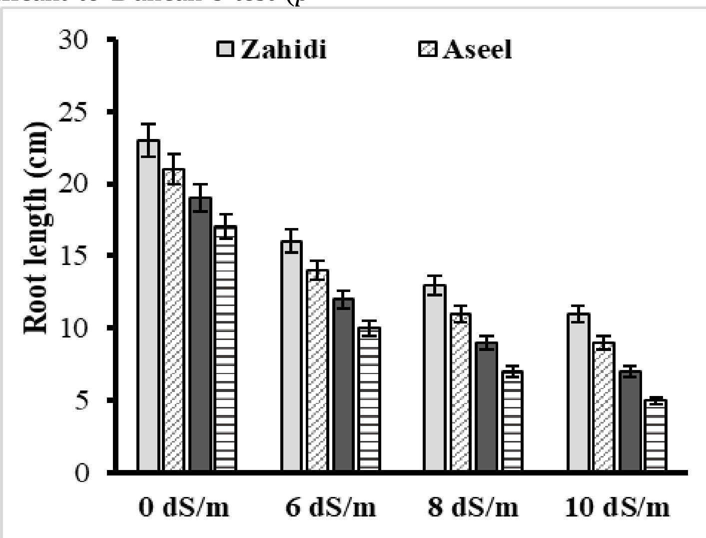

Figure 3. Effect of salinity stress on root length.

The effect of Salt on the Fresh Shoot and Root Weight

The variance of analysis for the fresh shoot weight data in date palm cultivars reveals a statistically significant influence of salinity on fresh shoot weight, with a noticeable decline as salinity levels increase. Among the cultivars, Khudravi exhibited the lowest shoot biomass under salt stress, whereas Zahidi displayed the highest biomass (Fig. 4). The presented data reflect significance to Duncan's test ($p<0.05$), emphasizing the reliability of these observed differences. Aseel, despite the challenging conditions of salinity stress, demonstrated a greater shoot mass compared to the other cultivars, and this difference was deemed statistically significant (Al-Qurainy et al., 2020). The analysis of variance for the fresh root weight data in date palm cultivars underscores the statistically significant impact of salinity on fresh root weight, revealing a notable decline with escalating salinity levels. Within the context of salt stress, Khudravi exhibited the lowest root biomass compared to other cultivars, whereas Aseel displayed the highest biomass (Fig. 5). The data presented highlight significant values according to Duncan's test ($p < 0.05$), underscoring the reliability of these observed distinctions. These findings contribute valuable insights into the varying responses of date palm cultivars to salinity stress, emphasizing the substantial reduction in fresh root weight and further elucidating the distinct sensitivities of Khudravi and Aseel varieties to salinity-induced changes in root biomass. The impact of salinity stress was particularly pronounced on shoot mass, with significant differences observed both between cultivars and within the Khudravi cultivar. These results on the different ways that different date palm cultivars react to salinity stress, highlight the differential effects on shoot and root masses and provide valuable insights for understanding and managing salt stress in date palm cultivation (Al-Qurainy et al., 2020).

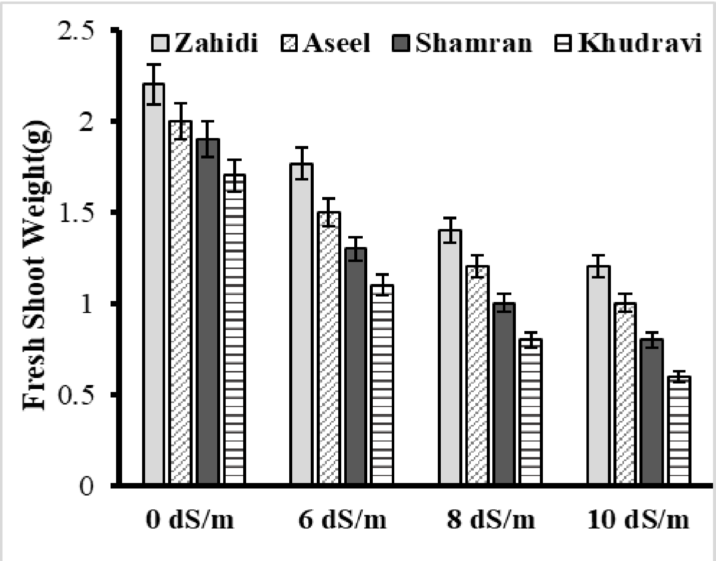

Figure 4. Effect of salinity stress on fresh shoot weight.

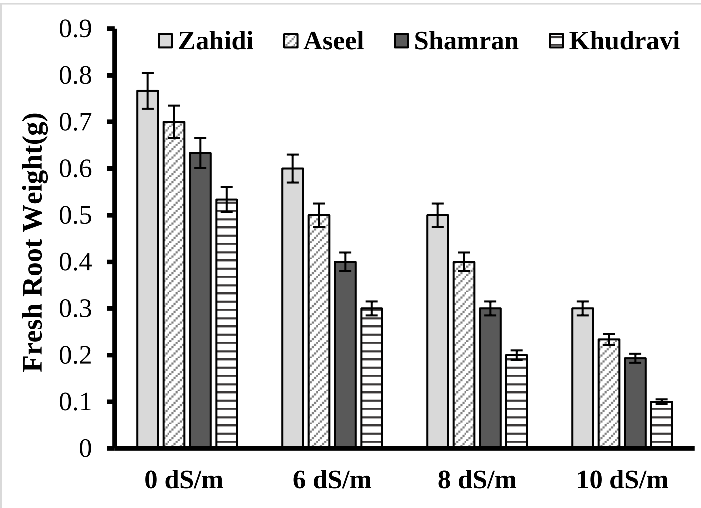

Figure 5. Effect of salinity stress on fresh root weight.

The Effect of Salt on Dry Root and Shoot Weight

The analysis of variance for the data on dry root weight in date palm cultivars reveals a statistically significant influence of salinity on dry root weight, characterized by a notable reduction with increasing salinity levels. When subjected to salt stress, Khudravi displayed the lowest root biomass among the cultivars, while Zahidi exhibited the highest biomass (Fig. 7). The data presented signify significance to Duncan's test ($p < 0.05$), affirming the robustness of these observed distinctions. The analysis of variance for the data on dry shoot weight in date palm cultivars highlights a statistically significant impact of salt on dry shoot weight, characterized by a significant reduction with increasing salinity levels. In the presence of salt stress, Khudravi exhibited the lowest biomass in the dry shoot compared to other cultivars, whereas Zahidi displayed the highest biomass (Fig. 6). The presented data signify significant values according to Duncan's test ($p < 0.05$), underscoring the reliability of these observed distinctions. These results indicate how salt stress clearly affects the dry shoot weight of various date palm cultivars, providing valuable insights into their varying sensitivities to salinity-induced changes in biomass. It is noteworthy that within the context of salt stress, the root mass in the Zahidi cultivar was found to be significantly different compared to other cultivars. These findings are consistent with research conducted on a variety of plant species growing in salt stress, where it was found that morphological features and biomass yield were both impacted (Alam et al., 2020). This concurrence reinforces the broader applicability of the observed trends in the response of cultivars to salinity-induced changes in dry root weight.

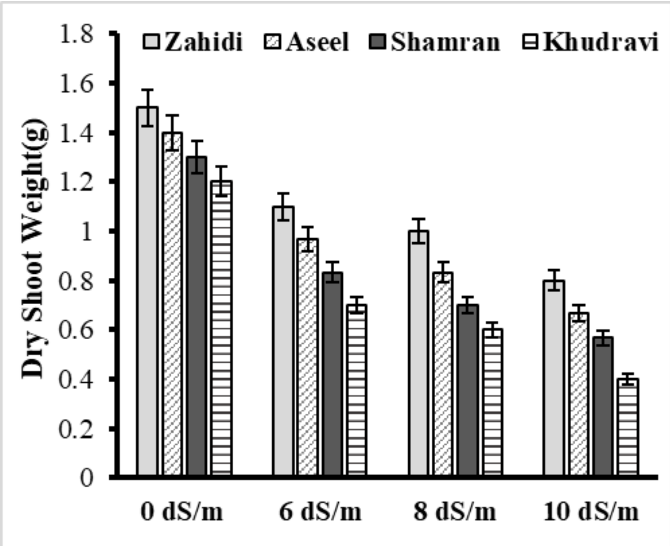

Figure 6. Effect of salinity stress on dry shoot weight**.**

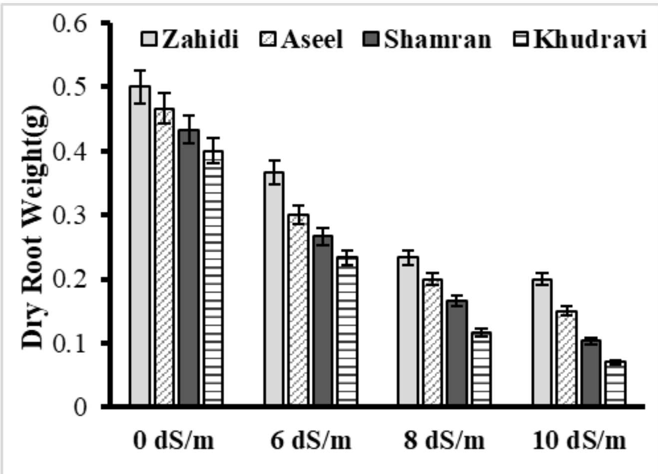

Figure 7. Effect of salinity stress on dry root weight.

The Effect of Salinity on the Photosynthesis Rate

The analysis of variance for the data on photosynthesis rate reveals a consistent decrease with an increase in salinity, and considerable variations were noted within and among cultivars (Fig. 8). Notably, under salt stress, the Shamran cultivar exhibited a more substantial reduction in photosynthesis rate compared to the other cultivars. The data presented highlight Duncan's test ($p < 0.05$), confirming the reliability of these observed variations. It is crucial to note that a higher photosynthetic rate under salinity stress is typically associated with biomass production increased and, consequently, enhanced plant growth. This implies that salt stress tolerance and photosynthetic rate are directly correlated. Salt stress, however, negatively impacts several photosynthetic processes. They include stomatal closure, reduced CO_2 availability for carboxylation, inhibition of mesophyll conductance to CO_2 diffusion, and impairment of the photosynthetic machinery. This results in decreased or halted electron transport for the Calvin cycle's essential synthesis of ATP and reductants (NADPH). This investigation revealed an intriguing interaction effect between treatments and cultivars for the majority of photosynthetic metrics, consistent with previous findings (Al-Kateeb et al., 2002). These findings underscore the intricate relationship between salt stress and photosynthetic performance in different date palm cultivars, contributing valuable insights to the understanding of their responses to environmental challenges.

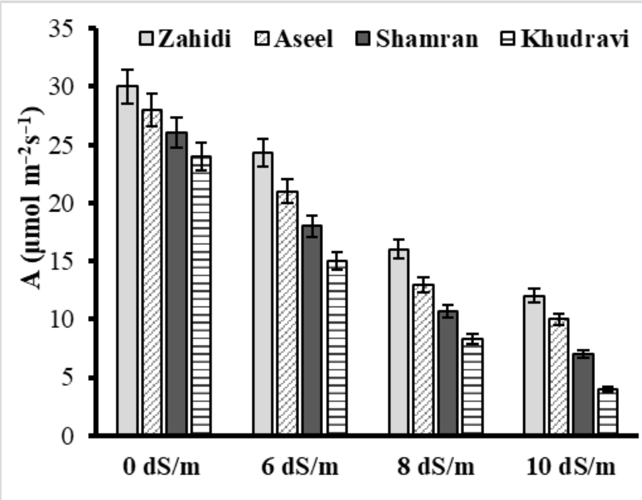

Figure 8. Effect of salinity stress on total photosynthetic rate (A) in fresh leaves.

The Effect of Salinity on Transpiration Rate

The results of the analysis of variance for the data on transpiration rate (E) in the leaves of date palm cultivars cultivated in salt and control environments showed notable reductions in most of these parameters ($p < 0.05$) when exposed to salinity. Zahidi exhibited the highest transpiration rate, while Khudravi displayed the lowest under salt stress (Fig. 9). The data were found to be significant based on Duncan's test ($p < 0.05$), affirming the reliability of these observed changes. This information contributes valuable into the impact of salinity on transpiration rates in different date palm cultivars, underscoring their varying sensitivities to environmental stressors (Sperling et al., 2014).

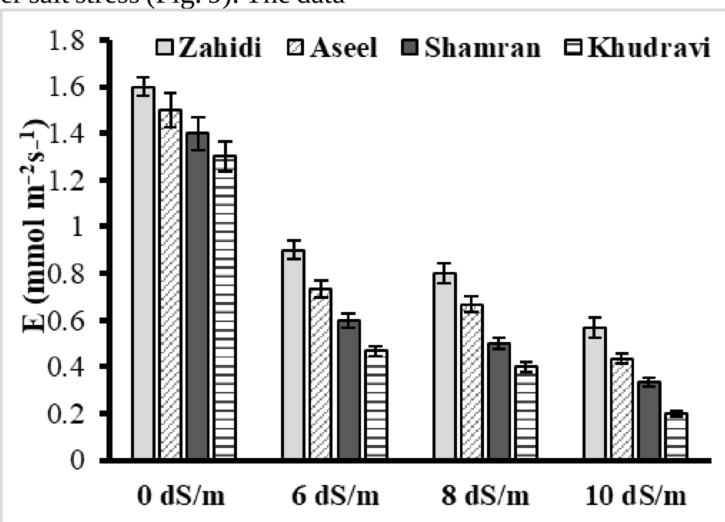

Figure 9. Effect of salinity on transpiration rate (E) of date palm cultivars exposed to control and salinity.

The Effect of Salinity on Stomatal Conductance Rate

Significant variations were seen both within and between cultivars, and an overall decline in stomatal conductance (gs) rate was shown by the analysis of variance (Fig. 10). Stomatal conductance significantly declined in all cultivars ($p < 0.05$), with the least decrease observed in Zahidi and the highest decrease in Khudravi under salt stress. Notably, under normal conditions, Zahidi exhibited a higher gs compared to the other cultivars. The data presented signify according to Duncan's test ($p < 0.05$), confirming the robustness of these observed variations. These findings provide valuable impact of salinity on stomatal conductance in different date palm cultivars, highlighting their diverse responses to environmental stressors (Sperling et al., 2014).

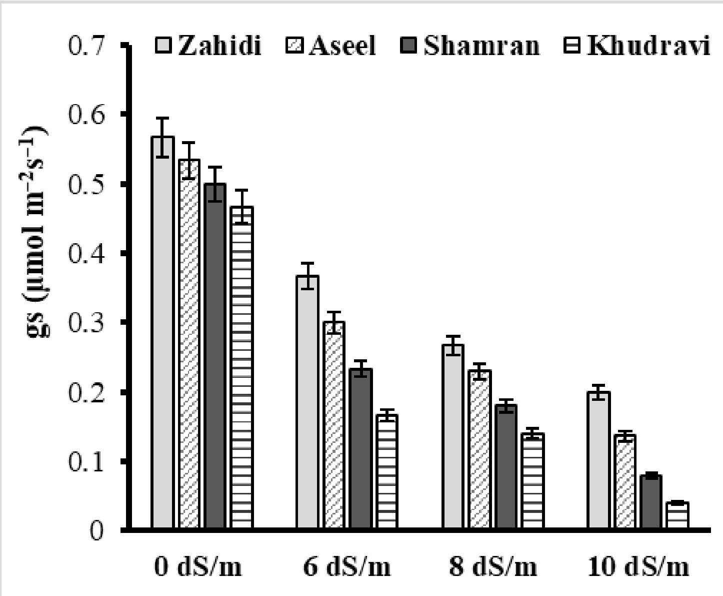

Figure 10. Effect of salinity stress on stomatal conductance rate (gs) in fresh leaves.

The Effect of Salinity on Chlorophyll Content

Significant reductions in most parameters were shown by the analysis of variance for the data on the chlorophyll content in the leaves of cultivars grown in both salinity and control conditions ($p < 0.05$) when exposed to salinity. The chlorophyll content exhibited a decrease with increasing salinity, and significant differences were observed both within and between cultivars (Fig.11). Particularly noteworthy was the greater reduction in chlorophyll content observed in the Khudravi cultivar compared to Zahidi under salt stress. Conversely, under normal conditions, Zahidi consistently demonstrated the highest chlorophyll content among all cultivars. The data presented are deemed significant on Duncan's test ($p < 0.05$), confirming the robustness of these observed variations. These findings contribute valuable insights into the impact of salinity on chlorophyll content in different date palm cultivars, elucidating their diverse responses to environmental stressors. The analysis of chlorophyll content revealed a significant decrease with increasing salinity, with notable variations observed among cultivars. Particularly noteworthy was the Khudravi cultivar, which exhibited a greater reduction in chlorophyll content compared to the other cultivars (García-Sánchez et al., 2002). These findings underscore the sensitivity of chlorophyll levels to salinity stress and highlight the distinct responses of date palm cultivars, providing detailed insights into their varying capacities to cope with environmental challenges (Porra et al., 1989).

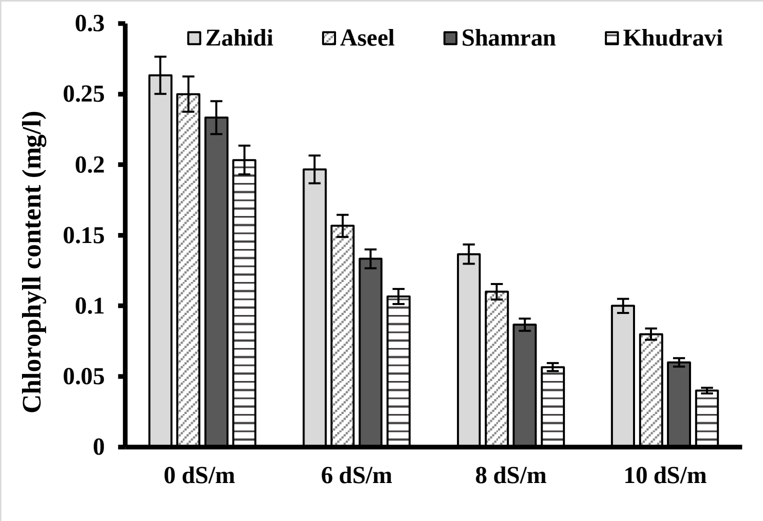

Figure 11. Impact of salinity on chlorophyll content.

The Effect of Salt Stress on Na^+ and K^+ Concentration in Root and Leaf

To determine whether the growth of cultivars under salt stress correlates with differential Na^+ accumulation in the tissues, an analysis of variance was performed to look at the patterns of Na^+ accumulation in date palm tissues. The amounts of Na^+ in the cultivars' root and leaf tissues were measured. In typical circumstances, Shamran's roots gathered more Na^+ than Zahidi's, with the former showing the lowest Na^+ accumulation. Under salt stress conditions, however, Khudravi had the highest concentration of Na^+ in the roots, while Zahidi had the lowest of all the cultivars. Zahidi showed a propensity to regulate the accumulation of Na^+ in leaf tissues, but Khudravi accumulated more Na^+ in the leaves. Of all the cultivars, Khudravi had the highest concentration of Na^+ in its leaves under salt stress, while Zahidi had the lowest. In general, the leaf concentrations of Na^+ were lowest in Zahidi and Aseel. Duncan's test revealed that the data were significant ($p < 0.05$), confirming the strength of these noted trends. These comprehensive results provide insight into the distinct Na^+ accumulation tactics used by different date palm cultivars when exposed to salinity stress. A variance analysis was also performed to evaluate the effect of salinity on the build-up of K^+ ions in plant tissues. Zahidi, in contrast to other cultivars, showed a substantially lower concentration of K^+ ($p < 0.05$) in the leaves than in the roots under control circumstances. Compared to other cultivars, Khudravi had the lowest K^+ content in its leaves under salt stress, whereas Zahidi showed the greatest concentration. Under regulated conditions, Khudravi had the lowest K^+ content among all cultivars, while Zahidi had the highest concentration. Khudravi exhibited the lowest K^+ concentration in its roots when compared to other cultivars. Zahidi exhibited the highest K^+ concentration under salt stress and had the highest concentration among all cultivars, following the trend seen in leaves. Under normal circumstances, on the other hand, Khudravi had the lowest concentration. Duncan's test revealed that the data were significant ($p < 0.05$), supporting the observed variances. These findings highlight the importance of K^+ buildup in various plant tissues and provide insights into the dynamic responses of date palm cultivars to salinity stress. Moreover, Na^+ ions which are known to be the most harmful substances when plants are exposed to salinity cause osmotic stress and mainly disrupt K^+ activities, which deactivates enzymes. In plants, K^+ is involved in several processes, including controlling intracellular pH, stomata regulation, and turgor maintenance (Maathuis, 2014). In addition to causing a K^+ deficit, the suppression of K^+ uptake by Na^+ also prevents K^+-dependent activities from functioning.

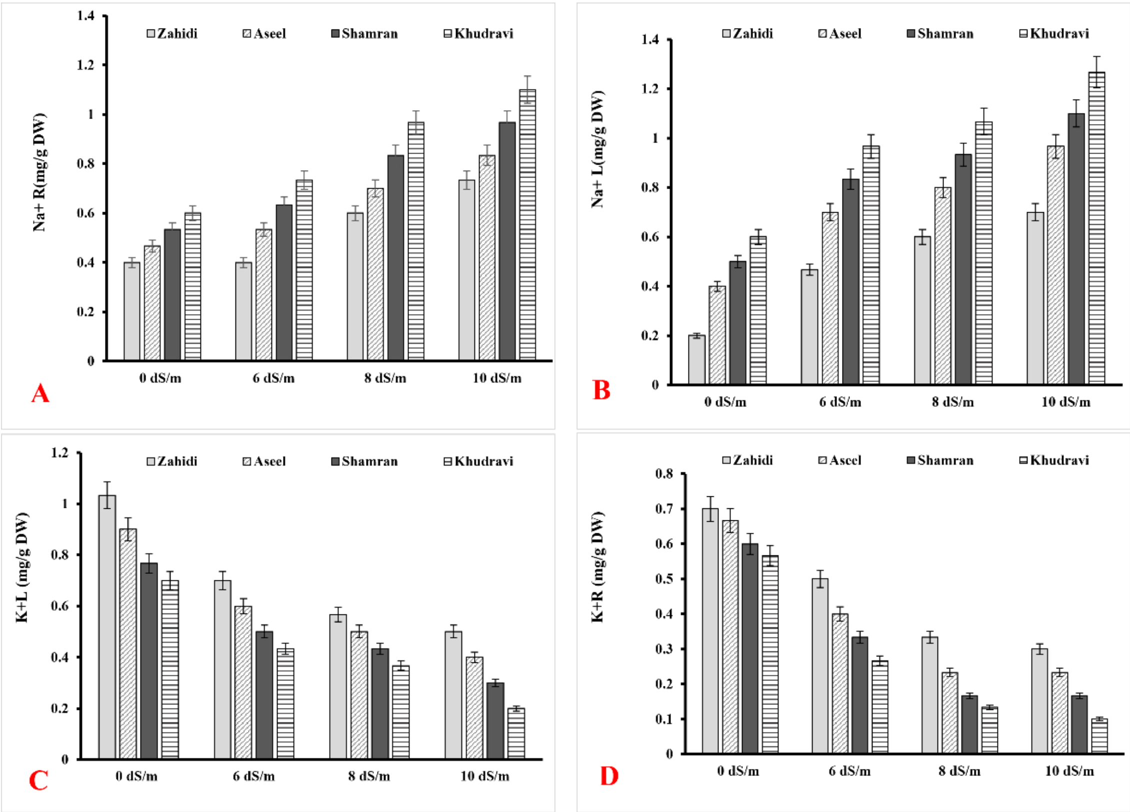

Figure 12. The effect of salinity on the accumulation of sodium (Na^+) and potassium (K^+) in roots (A) and leaves (B) of date palm seedlings when exposed to control and salinity conditions.

In this investigation, during salt stress, sensitive cultivars retained greater Na^+ concentrations in the roots, whereas tolerant cultivars kept lower quantities. It's interesting to note that under salt stress, all cultivars aside from one showed higher K^+ concentrations in the shoots. Maintaining elevated K^+ concentrations is vital to safeguard membrane integrity and avert electrolyte leakage, so functions as a significant tactic for salt tolerance. To determine whether NaCl caused membrane damage in the cultivars, each cultivar's cell membrane thermostability (%) was calculated. The findings showed that while certain cultivars had far lower percentages of electrolyte leakage than others, some had larger percentages. This characteristic has already been linked to another date palm cultivar's ability to withstand salt. These results highlight the complex processes that various date palm cultivars use to manage stress caused by salt, providing insight into the critical roles that membrane stability and ion homeostasis play in these adaptation strategies.

The Effect of Salt Stress on Cell Membrane Thermostability

The analysis of variance for the cell membrane thermo-stability (CMT) data in date palm leaves, under both control and salt stress conditions, revealed a consistent decreasing trend with age across all genotypes (Fig.13). Zahidi exhibited higher CMT values, closely followed by Aseel, while Shamran and Khudravi consistently recorded the lowest values across all stages. Under control conditions, Zahidi maintained higher CMT values, whereas Khudravi consistently recorded the lowest values in all stages. The data presented are deemed significant based on Duncan's test ($p < 0.05$), confirming the robustness of these observed trends. These findings provide valuable insights into the age-dependent dynamics of cell membrane thermo-stability in different date palm genotypes, emphasizing the variations in their responses to salt stress. Calcium has been recognized for its crucial role in preserving plasma membrane integrity. To protect leaf membranes against leakiness brought on by heat stress, calcium is essential. Calcium effectively restricts membrane permeability and lowers electrolyte leakage by binding the polar head groups of membrane phospholipids together. Electrolyte leakage is a sign that the plasma membrane has been damaged after being subjected to a variety of stressors. Cell viability following exposure to heat, salinity, or cold stressors has been demonstrated by this assay to be dependable, repeatable, and quantifiable (Al Busaidi & Farag, 2015). This emphasizes how useful electrolyte leakage is as a tool for assessing how various stresses affect cellular integrity.

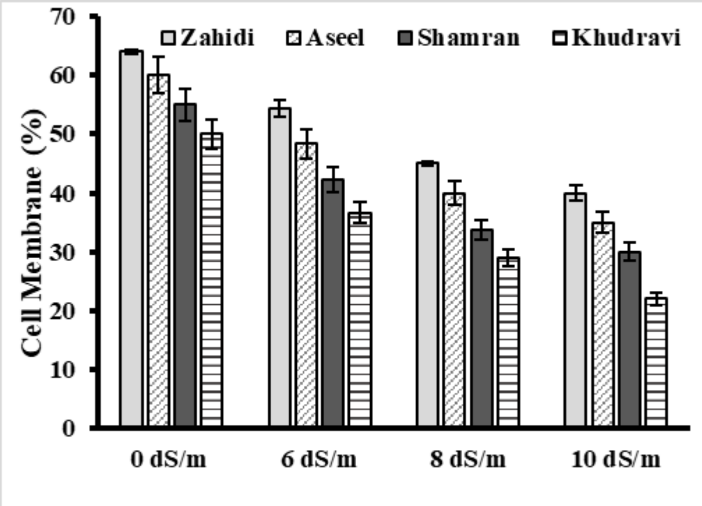

Figure 13. The effect of salinity on cell membrane thermostability.

CONCLUSION

Date palms have adapted to salinity through a variety of processes, including the regulation of oxidative damage and photosynthesis as well as the exclusion of Na^+ from the leaf. Two separate groups of cultivars tolerant and sensitive rose to the surface through screening. Zahidi and Aseel showed more tolerance potential within the tolerant group; they were distinguished by high dry shoot and root weight, minimal electrolyte leakage, and high Na^+ exclusion from the leaves. Their higher resistance to situations with high salinity was explained by these characteristics. On the other hand, Shmaran and Khudravi, two of the sensitive cultivars, showed signs of increased sensitivity, including low Na^+ exclusion from the leaves, significant electrolyte leakage, and low dry shoot and root weight. They may have been more vulnerable to excessive salinity because of these characteristics. The tolerant cultivars identified in this study, particularly Zahidi and Aseel, are suitable for cultivation on saline soil due to their strong Na^+ exclusion ability, lower electrolyte leakage, and higher biomass production. These genotypes can also be used as potential parents in breeding programs aimed at developing salt-tolerant date palm varieties. Thus, the findings provide practical guidance for both farmers in saline regions and breeders working on salinity improvement.

DECLARATION OF COMPETING INTEREST

The author declares that they have no conflict of interest.

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