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Mitigating Salt Stress in Maize Seedlings: Comparative Effects of Lemon Juice and Citric Acid Application

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ABSTRACT

This study examined the effects of exogenous lemon juice (LJ) and citric acid (CA) applications on the morphological and physiological responses of two commercial maize *(Zea mays* L.) cultivars, DKC6050 and P2088, under salt stress conditions. Plants were treated with distilled water (control), CA (100 ppm), and LJ (5%) as foliar applications under both non-saline (Distilled water) and saline conditions (15 dS m^{-1} NaCl). Evaluated parameters included plant height, fresh weight, leaf area, SPAD value, leaf relative water content (LRWC), electrolyte leakage, stomatal density, and ionic indicators (Na^+, K^+, Na^+/K^+ ratio). Under salt stress, neither CA nor LJ significantly improved plant height or fresh weight in either cultivar. However, CA treatment in DKC6050 significantly enhanced leaf area, SPAD values, and LRWC, reflecting improved photosynthetic capacity and water retention. In P2088, LJ application led to increases in leaf area, stomatal density, and SPAD values, reduced electrolyte leakage and Na^+ accumulation, and improved the Na^+/K^+ ratio, indicating better ionic regulation. Overall, the results demonstrated that the effectiveness of CA and LJ in alleviating salt stress was genotype-dependent. DKC6050 showed greater improvements in water status and chlorophyll stability, while P2088 exhibited more robust responses in maintaining membrane integrity and ionic balance. These findings highlighted the significance of genotype-specific approaches when using organic acid-based treatments for managing salinity stress in maize.

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Keywords
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Mısır Fidelerinde Tuz Stresinin Azaltılması: Limon Suyu ve Sitrik Asit Uygulamalarının Karşılaştırmalı Etkileri

ÖZET

Bu çalışma, iki ticari mısır (*Zea mays* L.) çeşidi olan DKC6050 ve P2088'in tuz stresine karşı morfolojik ve fizyolojik yanıtları üzerine dışsal limon suyu (LJ) ve sitrik asit (CA) uygulamalarının etkilerini araştırmıştır. Bitkiler, hem tuzsuz (Saf su) hem de tuzlu koşullarda (15 dS m^{-1} NaCl) saf su (kontrol), CA (100 ppm) ve LJ (%5) ile yapraktan uygulamaya tabi tutulmuştur. Değerlendirilen parametreler; bitki boyu, yaş ağırlık, yaprak alanı, SPAD değeri, yaprak bağıl su içeriği (LRWC), elektrolit sızıntısı, stoma yoğunluğu ve iyonik göstergeler (Na^+, K^+ ve Na^+/K^+ oranı) olarak belirlenmiştir. Tuz stresi altında, CA ve LJ uygulamaları her iki çeşitte de bitki boyu ve yaş ağırlık üzerinde anlamlı bir artış sağlamamıştır. Bununla birlikte, DKC6050 çeşidinde CA uygulaması; yaprak alanı, SPAD değeri ve LRWC açısından anlamlı artışlar sağlamış, bu da fotosentetik kapasite ve su tutma potansiyelinde iyileşmeye işaret etmiştir. P2088 çeşidinde ise LJ uygulaması, yaprak alanı, stoma yoğunluğu ve SPAD değerlerini artırmış; elektrolit sızıntısını ve Na^+ birikimini azaltmış ve Na^+/K^+ oranını iyileştirerek iyonik dengenin korunmasına katkı sağlamıştır. Elde edilen bulgular, CA ve LJ uygulamalarının tuz stresini hafifletme etkinliğinin genotipe bağlı

Tarla Bitkileri

Araştırma Makalesi

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Mısır
Tuz stresi
Limon suyu
Sodyum (Na)
Elektrolit sızıntısı

olduğunu ortaya koymuştur. DKC6050 çeşidi, su durumu ve klorofil stabilitesinde daha olumlu tepkiler verirken; P2088 çeşidi, membran bütünlüğü ve iyonik dengeyi sürdürme açısından daha güçlü yanıtlar göstermiştir. Bu sonuçlar, mısırda tuzluluk stresinin yönetiminde organik asit temelli uygulamalarda genotipe özgü stratejilerin önemini vurgulamaktadır.

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INTRODUCTION

Maize (*Zea mays* L.) stands among the most important cereal crops worldwide, serving as a fundamental resource for food security, livestock feed, and a wide range of industrial applications (FAOSTAT, 2022; Kılınç et al., 2018; Kılınç et al., 2023). However, its cultivation is increasingly challenged by various abiotic stresses, with soil salinity recognized as one of the most critical threats. It is estimated that approximately 20% of cultivated land globally and around 5% of Turkey's agricultural areas are affected by salinity-related problems (Nachshon, 2018; Anonymous, 2021). Escalating salinity levels, primarily driven by climate change, poor irrigation practices, and land mismanagement, severely restrict maize growth and yield potential (Singh, 2022).

Salinity stress impairs vital physiological and biochemical processes in maize, including nutrient absorption, osmotic regulation, and antioxidant defense mechanisms (Hasanuzzaman et al., 2013; Yadav et al., 2022). Although maize exhibits certain adaptive responses to saline conditions, these are often insufficient to sustain optimal growth under severe stress. Therefore, the development of effective and sustainable strategies to enhance salt tolerance is critical for maintaining maize productivity and securing agricultural sustainability.

In recent years, the exogenous application of organic compounds such as citric acid has gained considerable attention as a potential strategy for mitigating salt-induced damage in plants (El-Hawary & Nashed, 2019). Citric acid has been shown to play a crucial role in improving osmotic balance, enhancing antioxidant capacity, and maintaining ion homeostasis under stress conditions. Notably, lemon juice, a natural and abundant source of citric acid and other bioactive compounds (Klimek-Szczykutowicz et al., 2020), represents a promising, eco-friendly, and cost-effective alternative to synthetic treatments.

Previous studies have demonstrated that citric acid application can enhance plant growth and salt tolerance across various species, including *Gossypium barbadense* (El-Beltagi et al., 2017), *Leymus chinensis* (Sun & Hong, 2011), *Hibiscus sabdariffa* (Abdellatif & Ibrahim, 2018), *Melissa officinalis* (Ahmed et al., 2017a), and *Beta vulgaris* (Ahmed et al., 2017b). In maize, foliar application of citric acid, either alone or combined with ascorbic or salicylic acid, has been reported to improve growth and yield under saline conditions (El-Hawary & Nashed, 2019). Moreover, lemon juice has exhibited superior protective effects compared to pure citric acid in mitigating cadmium stress in *Phaseolus vulgaris* (Rady et al., 2023). Despite these promising findings, the specific effects of lemon juice application on salt stress tolerance in maize have not yet been thoroughly investigated.

Given the urgent need for sustainable agricultural practices, exploring natural, low-cost, and readily available treatments such as lemon juice is of considerable significance. Understanding its potential to enhance salt tolerance during the critical early seedling stages could offer practical, accessible solutions for maize cultivation in salt-affected areas. Ultimately, this study investigated the potential of lemon juice in mitigating salinity stress, with the aim of promoting sustainable crop production and strengthening food security under increasingly challenging environmental conditions.

MATERIAL and METHOD

Experimental Material and Its Characteristics

Two maize cultivars, Dekalb (DKC6050) and Pioneer (P2088), were selected as seed materials for early seedling studies under saline conditions. As biostimulants, citric acid (Merck 100244.1000 Citric acid monohydrate) and lemon juice (Lemas variety) were applied. Lemon juice was squeezed and then freeze-dried (lyophilization) to produce a powder, from which appropriate concentrations were prepared. Sodium chloride (NaCl, CAS No: 7647-14-5, Purity: 99.0%) was used to create salt stress.

Citric Acid Applications

The citric acid dose used was 100 ppm, as determined by El-Hawary & Nashed (2019) for maize. The lemon juice concentration used was 5%, as specified by Rady et al. (2023). The salt dose applied was 15 dSm^{-1}, which had previously proven effective in germination and emergence studies. The experiment was designed as a randomized complete block with four replications. The first factor was maize varieties (DKC6050 and P2088), the second factor was foliar citric acid applications (distilled water, 100 ppm citric acid, and 5% lemon juice), and the third factor was salt doses (0, distilled water, and 15 dSm^{-1}). After the germination process, maize seeds were transplanted into small pots containing peat and irrigated with appropriate salt solutions. The moisture content in the pots was checked every two days, and any deficiency was compensated for with the appropriate solution. Maize seedlings received 20 mL of Hoagland solution twice at the V2 and V3 stages. Citric acid applications were applied foliarly at 7-day intervals during the V3 and V4 stages.

In the study, the following parameters were measured: seedling height, stem diameter, fresh weight, dry weight, SPAD value, leaf area (leaf area = leaf length × leaf width × 0.75), leaf relative water content (Jones et al., 1978), electrolyte leakage (Lutts et al., 1996), and stomatal density.

After citric acid applications, the salinity level of the peat was determined by measuring the EC (electrical conductivity) in 24 samples from each treatment (0 and 15 dSm^{-1}). Samples were first washed free of roots and sieved. They were then dried at 70°C for 48 hours. From these peat samples, 5 grams were weighed and mixed with 40 mL of water. After one hour of shaking, the EC of the water-saturated samples was measured.

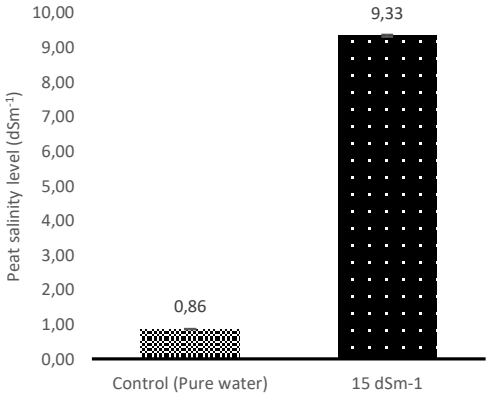

Figure 1. Electrical conductivity (EC) of the peat used for salt application in pots following citric acid treatments. (Vertical bars represent mean values ± standard error.)

Şekil 1. Sitrik asit uygulamaları sonrasında tuz uygulaması yapılan saksılarda kullanılan torfun elektriksel iletkenliği. (Dikey çubuklar ortalama değerleri ± standart hata ile temsil etmektedir).

According to the measurements, the EC of the peat at 15 dSm^{-1} salinity was 9.33 dSm^{-1}, and the EC of the control (Distilled water) was 0.86 dSm^{-1}. According to Maas (1986), this EC range (8–15 dSm^{-1}) corresponds to moderately saline soil.

Element Analyses

Elemental analyses were performed for Na and K. First, 0.2 grams of ground plant samples were treated with 65% nitric acid in a microwave oven for digestion. The resulting filtrate was then analyzed using an ICP device at the Geçit Kuşağı Agricultural Research Institute.

Data Analysis

The data obtained from the experiments were analyzed using the JMP 14 software package. Morphological and physiological data obtained from citric acid applications were analyzed using a factorial design with four replications. Elemental data were analyzed using a factorial design with three replications. Analysis of variance (ANOVA) was performed to assess the significance of differences between treatments, and the LSD test was used to determine the level of significance.

RESULTS and DISCUSSION

Under control conditions, citric acid application (CA) led to a reduction in plant height; however, under saline conditions, plant height decreased in the P2088 variety but increased in DKC6050 (Figure 2). Salt stress can markedly impair plant growth and stature by affecting various physiological and biochemical processes (Pandit et

al., 2024). Javed et al. (2022) highlighted that NaCl is more harmful than Na_2SO_4 or mixed salts due to the dominance of Na^+ and Cl^- ions, with its detrimental effects on maize becoming particularly evident at a salinity level of 15 dS m^{-1}. Citric acid (CA) has been shown to alleviate salinity stress by enhancing growth and physiology in various species. Shareef et al. (2022) reported improved plant height in *Phoenix dactylifera*, while Hossain et al. (2024) observed increased height and leaf number in *Vigna mungo*. Similarly, Hajaji et al. (2024) found enhanced shoot growth, pigments, and proteins in *Moringa oleifera*, confirming CA's broad stress-mitigating role.

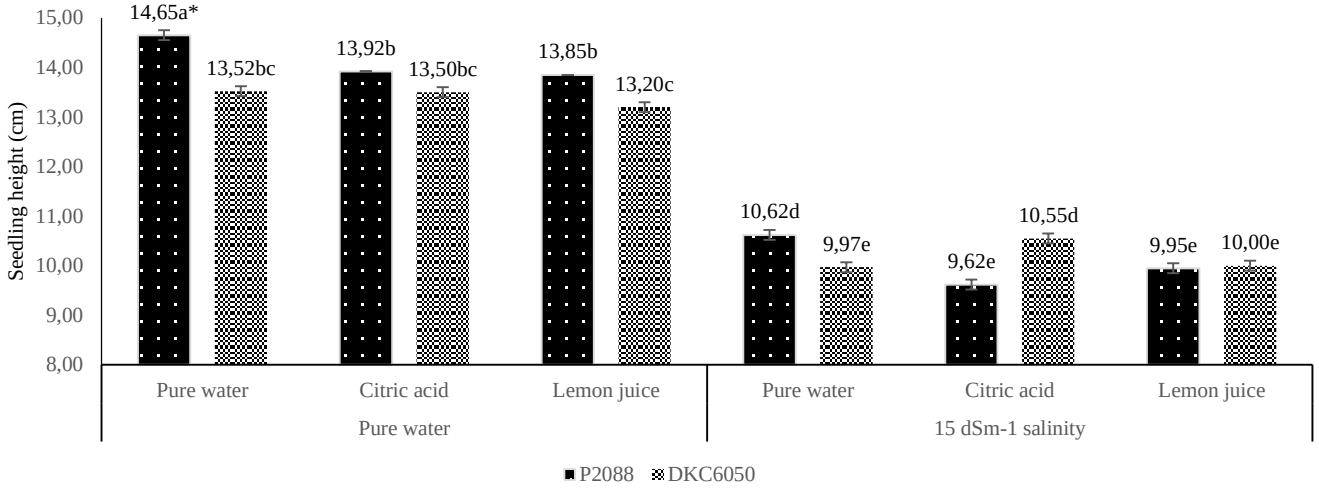

Figure 2. The data on seedling height are presented as means ± standard error (*Means sharing the same letter are not significantly different at p≤0.020, as determined by the LSD test. F (2, 36): 4,56.

*Şekil 2. Fide boyu verileri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.020 düzeyinde istatistiksel olarak farklı değildir. F (2, 36): 4,56.*

Under non-saline conditions, lemon juice treatment (LJ) in the P2088 variety produced fresh weight values similar to those observed in the water-treated control group (PW) (Figure 3). Under saline conditions, although the DKC6050 variety showed a relatively higher fresh weight, both varieties exhibited consistent internal responses. Salt stress typically leads to a decline in fresh weight due to disruptions in water uptake and nutrient homeostasis. Nonetheless, citric acid has been shown to counteract the detrimental effects of salinity by boosting antioxidant defense mechanisms and supporting cellular stability, ultimately contributing to improved fresh weight (Tahjib-Ul-Arif et al., 2021). El-Hawary and Nashed (2019) found that applying CA along with ascorbic and salicylic acids under salt stress enhanced growth performance in maize. Consistently, Aslam et al. (2023) also reported that CA treatment under saline conditions significantly improved fresh weight in maize plants.

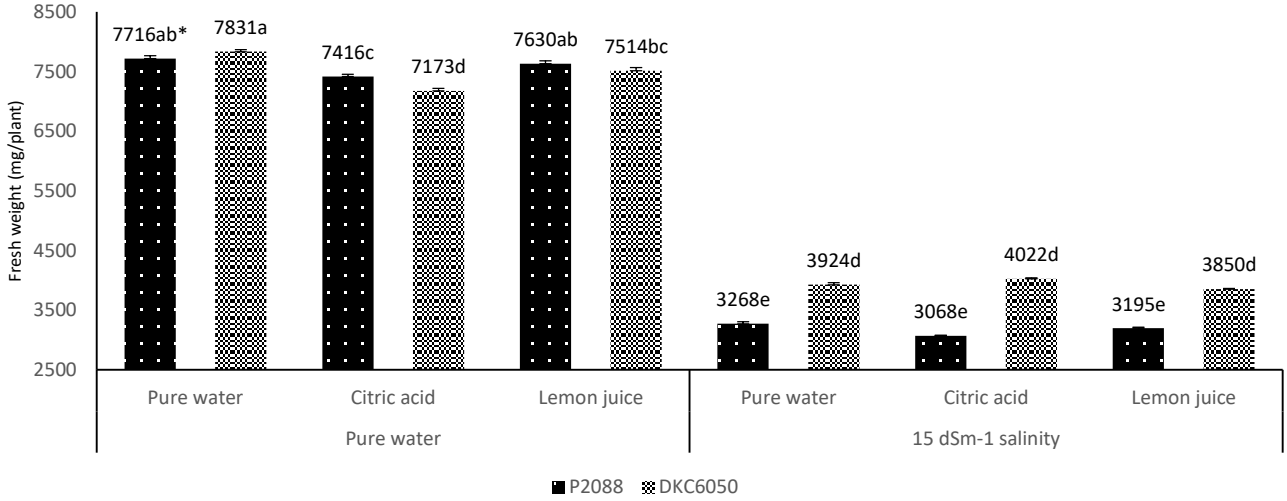

Figure 3. Fresh weight data are presented as means ± standard error (*Means sharing the same letter are not significantly different at the p≤0.008 level according to the LSD test. F (2, 36): 5.52.

*Şekil 3. Yaş ağırlık değerleri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.008 düzeyinde istatistiksel olarak farklı değildir. F (2, 36): 5.52.*

In the absence of salt stress, CA and LJ applications led to a reduction in leaf area in the P2088 variety, whereas they promoted an increase in the DKC6050 variety (Figure 4). Although salinity generally reduced leaf area across both genotypes, the application of CA—particularly LJ—helped alleviate this negative impact. Leaf area plays a vital role in plant physiology, as it determines the efficiency of photosynthesis, transpiration, and gas exchange, thereby influencing the plant's ability to capture light and sustain growth (Yang et al., 2022). Supporting these findings, Ali and Fatma (2011) observed a decline in leaf area in maize under prolonged exposure to 100 and 150 mM NaCl. In line with these results, Aslam et al. (2023) reported that 150 mg/L citric acid treatment under saline conditions improved leaf area. Additionally, Ali et al. (2024) showed that CA at a concentration of 300 ppm positively affected growth traits in eggplant, not only under salt stress but also under non-stress conditions. Finally, Hemdan et al. (2025) reported that foliar application of citric acid nanoparticles (n-CA) increased leaf area under 10.5 dS m^{-1} salinity, with the greatest effect at 0.4 mM, suggesting CA can mitigate salt-induced growth inhibition by supporting leaf development and photosynthetic capacity.

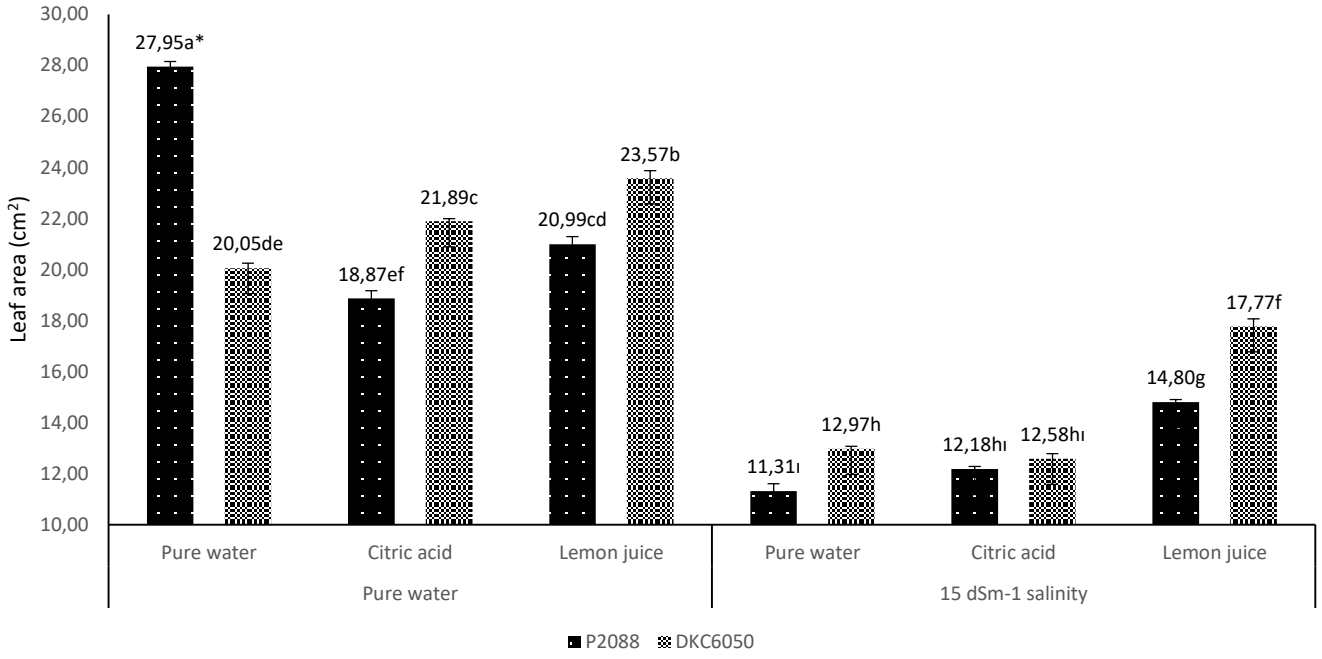

Figure 4. Leaf area values are presented as means ± standard error. (*Means sharing the same letter are not significantly different according to the LSD test at the p≤0.001 level. F (2,36): 50.28).

*Şekil 4. Yaprak alanına ilişkin veriler, ortalama ± standart hata biçiminde ifade edilmiştir. (*Aynı harfle gösterilen ortalamalar, LSD testi sonuçlarına göre p≤0.001 düzeyinde istatistiksel olarak farklılık göstermemektedir. F (2,36): 50.28).*

SPAD values were generally lower under control conditions compared to saline environments (Figure 5). In the absence of salt stress, LJ application led to a reduction in SPAD values in the P2088 variety, while it caused an increase in DKC6050. Under saline conditions, LJ treatment in P2088 and CA application in DKC6050 resulted in the highest SPAD values within their respective varieties. As an indirect measure of chlorophyll content, SPAD values are widely used to evaluate plant health, photosynthetic capacity, and responses to environmental stressors such as salinity. Salt stress can affect chlorophyll concentration through ion toxicity, osmotic imbalance, and nutrient deficiencies, all of which can be reflected in SPAD measurements (Shah et al., 2017). According to Kandel (2020), SPAD values increase with leaf age and tend to decline at maturity, and there is a positive association between SPAD values and grain yield, especially in leaves that contribute more to yield formation. Farida et al. (2017) reported that citric acid (CA) application gradually increased SPAD values in sunflowers. Similarly, Hajaji et al. (2024) demonstrated that CA supply in saline solution enhanced photosynthetic pigment content and soluble protein levels in *Moringa oleifera* seedlings. In contrast to these findings, Iqbal et al. (2025) found a significant decline in chlorophyll index (SPAD values) in maize exposed to salt stress and its combinations. Collectively, these results indicate that the effects of CA or LJ on photosynthetic traits are species- and genotype-dependent and may be influenced by the severity and type of stress conditions.

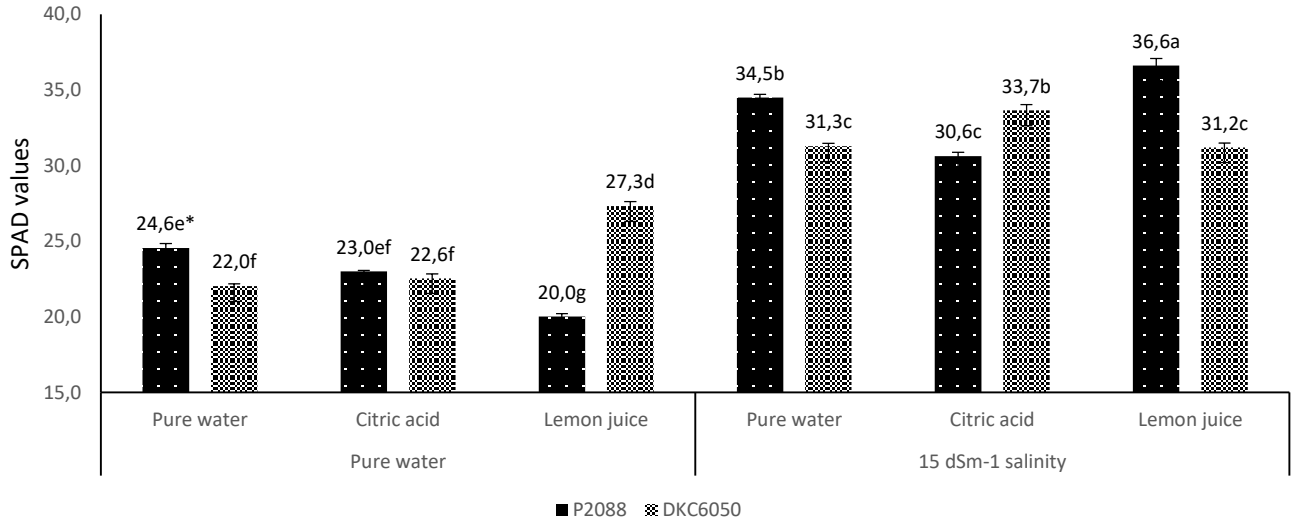

Figure 5. The data of SPAD value are presented as means ± standard error (*Means sharing the same letter are not significantly different at p≤0.0001, as determined by the LSD test. F (2,36): 57,0.

*Şekil 5. SPAD değerleri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.0001 düzeyinde istatistiksel olarak farklı değildir. F (2,36): 57,0.*

Leaf relative water content (LRWC) was generally higher under control conditions compared to saline treatments (Figure 6), reflecting the negative impact of salt stress on plant water status. In non-saline environments, LJ enhanced LRWC in both maize varieties, with a particularly pronounced effect in the P2088 genotype. Under saline conditions, citric acid treatments produced contrasting responses: LRWC increased in the DKC6050 variety, while a slight reduction was noted in P2088. LRWC is a key indicator of plant water balance, especially under salinity stress, where osmotic stress and ionic toxicity hinder water uptake, reducing cellular hydration and turgor pressure (Balasubramaniam et al., 2023). Gul Jan et al. (2019) reported significant reductions in LRWC in maize seedlings subjected to salinity, emphasizing the negative effects of salt stress on plant water status. The effects of citric acid (CA) on relative water content (LRWC) under salt stress are species- and genotype-dependent. Sun et al. (2011) reported no significant change in LRWC in two *Leymus chinensis* genotypes, while Chakrobortty et al. (2022) observed that CA mitigated salinity-induced declines in okra. Similarly, Shareef et al. (2022) showed that foliar CA (1,000 ppm) increased LRWC in date palm offshoots by enhancing osmotic balance and proline accumulation, outperforming salicylic acid.

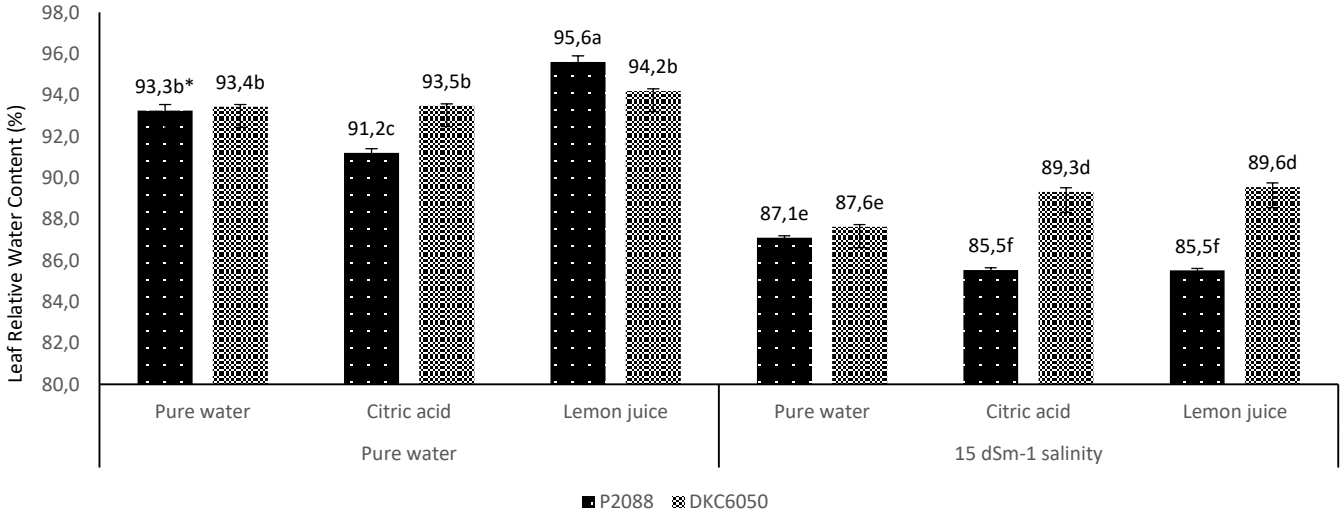

Figure 6. Leaf relative water content data are presented as mean ± standard error (*Means followed by the same letter are not significantly different according to the LSD test at p≤0.0001. F (2, 36): 13,11.

*Şekil 6.Yaprak bağıl sı içeriği değerleri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.0001 düzeyinde istatistiksel olarak farklı değildir. F (2, 36): 13,11.*

Electrolyte leakage decreased in the P2088 variety, whereas it either increased or remained unchanged in the DKC6050 variety following CA and LJ applications under control conditions (Figure 7). Under saline conditions, both CA and LJ treatments significantly decreased electrolyte leakage in P2088, indicating a protective effect; however, in DKC6050, CA application led to an increase in leakage, while LJ treatment resulted in values comparable to the control. Electrolyte leakage is a key indicator of membrane integrity, commonly used to evaluate salt-induced cellular damage, as salinity disrupts homeostasis and induces oxidative stress through Na^+ and Cl^- accumulation (Balasubramaniam et al., 2023; Talakayala et al., 2024). Gul Jan et al. (2019) reported that exposure to 100 mM NaCl significantly elevated electrolyte leakage by approximately 2.5-fold compared to control conditions ($P < 0.05$), while fungal interaction alleviated this effect in maize seedlings. In support of citric acid's protective role, Hu et al. (2016) showed that its exogenous application under heat stress enhanced antioxidant defense, thereby reducing membrane damage, as reflected by decreased electrolyte leakage and malondialdehyde (MDA) content, along with reduced reactive oxygen species (ROS) accumulation and delayed leaf senescence. Contrastingly, Sallah et al. (2017) observed that CA application in *Lemna minor* L. under chromium exposure increased electrolyte leakage, hydrogen peroxide, and MDA levels, suggesting that the response may be stress- and species-specific. Meanwhile, Shareef et al. (2022) reported that 1,000 ppm citric acid reduced electrolyte leakage and MDA content in palm plants under salt stress, further highlighting its potential mitigating effect against salinity-induced oxidative damage.

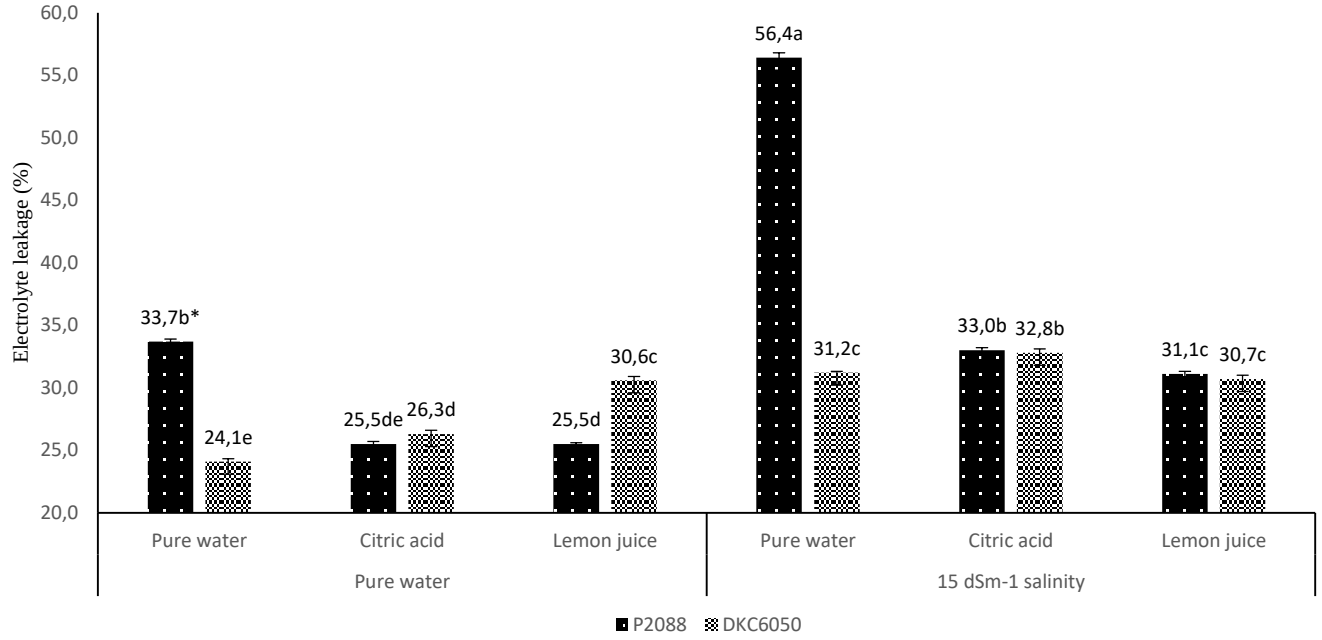

Figure 7. Electrolyte leakage values are presented as mean ± standard error (*Means followed by the same letter are not significantly different according to the LSD test at p≤0.0001. F (2,36): 57,62.

*Şekil 7. Elektrolit sızıntısı değerleri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.0001 düzeyinde istatistiksel olarak farklı değildir. F (2 ,36): 57,62.*

Stomatal density increased in the P2088 genotype following LJ application under both non-saline and saline conditions, whereas in the DKC6050 genotype, it increased after CA treatment under non-saline conditions but decreased under saline conditions in response to both CA and LJ applications (Figure 8). Adjustments in stomatal traits are recognized as adaptive responses under abiotic stress, and recent findings indicate that decreased stomatal density may enhance water use efficiency without significantly compromising yield (Hughes et al., 2017; Wang & Chen, 2020). While these results show genotype-specific variation, previous research has generally reported reduced stomatal number and density under salinity in maize (de Azevedo Neto et al., 2004; Dikobe et al., 2021; Sinthumule et al., 2022). Interestingly, de Azevedo Neto et al. (2004) also highlighted that stomatal behavior in salt-tolerant genotypes may remain stable despite saline conditions.

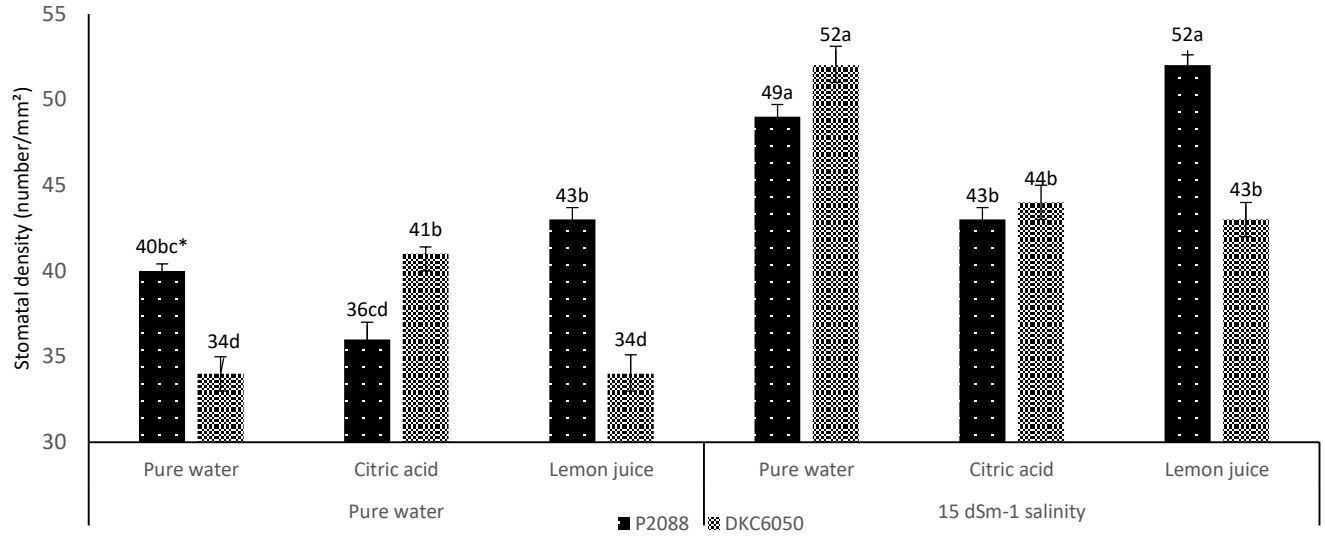

Figure 8. Stomatal density values are presented as mean ± standard error (*Means followed by the same letter are not significantly different according to the LSD test at p≤0.033. F (2, 36): 3,73.

*Şekil 8. Stoma yoğunluğu değerleri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.033 düzeyinde istatistiksel olarak farklı değildir. F (2, 36): 3,73.*

The application of NaCl has the potential to disrupt the homeostatic balance between sodium (Na^+) and potassium (K^+) ions, thereby adversely affecting plant physiological functions and overall development (Figure 9) . In the present study, Na accumulation exhibited statistically significant variation among treatments, while the changes observed in K^+ concentrations were not statistically significant. Sodium (Na^+) levels remained low and consistent across all treatments under non-saline conditions, as expected (Figure 10). However, under saline stress, the P2088 variety exhibited lower Na^+ levels compared to DKC6050, with LJ treatment reducing Na^+ levels in DKC6050. In contrast, in the P2088 variety, both CA and LJ treatments resulted in lower Na^+ concentrations compared to the control. High salinity and elevated sodium levels in soil have been widely recognized for their detrimental effects on plant growth and development (Safdar et al., 2019). Elevated salt concentrations reduce soil water potential, limiting water uptake by plants (Yadav et al., 2011). The accumulation of sodium (Na^+) and chloride (Cl^-) ions in plant tissues disrupts metabolic processes, leading to toxicity and impaired growth (Tester & Davenport, 2003; Tavakkoli et al., 2010). Studies by Gao et al. (2016) suggest that salt-tolerant maize lines can mitigate Na^+ toxicity by sequestering Na^+ in older leaves and excluding excessive Na^+. Additionally, Sun et al. (2018) and Ali et al. (2021) demonstrated that applications of phosphate (H_2PO_4) and silicon improved K^+ retention and enhanced Na^+ exclusion, thereby improving salt tolerance in maize.

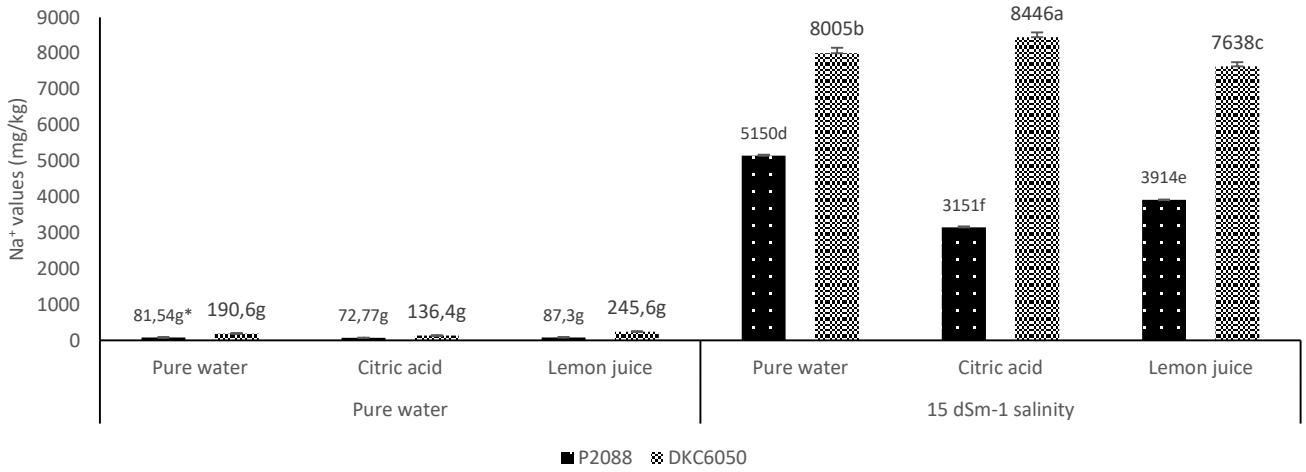

Figure 9. Na^+ values are presented as mean ± standard error (*Means followed by the same letter are not significantly different according to the LSD test at p≤0.006. F (2, 24): 29,46.

*Şekil 10. Na^+ değerleri ortalama ± standart hata şeklinde verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre p≤0.006 düzeyinde istatistiksel olarak farklı değildir. F (2, 24): 29,46.*

The Na^+/K^+ ratio did not show significant changes under control conditions following citric acid treatments in either of the two maize varieties (Figure 10). However, under saline conditions, the DKC6050 variety showed higher Na^+/K^+ ratios compared to the P2088 variety, with citric acid applications producing similar results in both varieties. In contrast, citric acid treatment in the P2088 variety led to a reduction in the Na^+/K^+ ratio. The balance between Na^+ and K^+ is vital for maintaining cellular functions under salt stress, as Na^+ interferes with K^+-K-regulated processes (Rizk et al., 2024). Maintaining a stable Na^+/K^+ ratio is a critical trait for salt tolerance in plants (Assaha et al., 2017b). For instance, Sun et al. (2018) observed that phosphate application in maize under salt stress reduced the Na^+/K^+ ratio, while Gao et al. (2016) showed that the salt-tolerant maize line TL1317 was more efficient than the sensitive line SL1303 in excluding toxic Na^+ and retaining K^+. Similarly, El-Hawary and Nashed (2019) demonstrated that foliar application of ascorbic acid (AA), citric acid (CA), and salicylic acid (SA) significantly decreased proline, Na^+, and the Na^+/K^+ ratio in maize leaves while enhancing K^+ content. The strongest response occurred with 100 ppm antioxidant mixture, followed by 200 ppm AA, with AA proving most effective in reducing proline levels. These findings collectively highlight the importance of nutrient and antioxidant interventions in maintaining ion homeostasis, osmotic balance, and overall salt tolerance in maize.

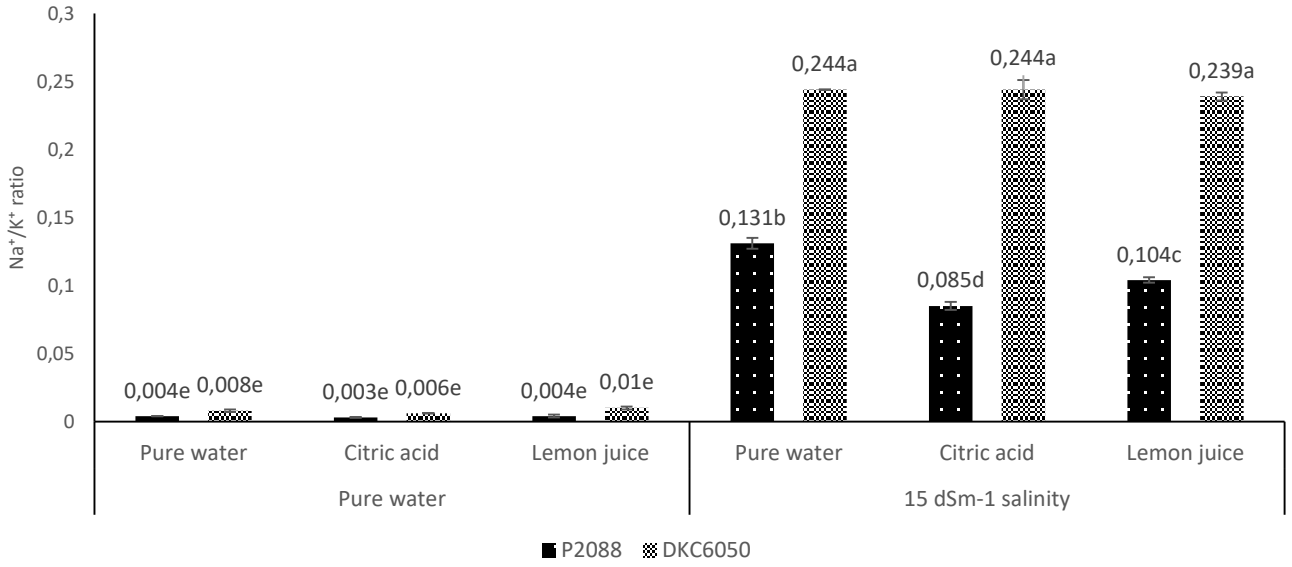

Figure 10. Na^+/K^+ values are presented as mean values (*Means followed by the same letter are not significantly different according to the LSD test at $p \leq 0.006$. F (2, 24): 6,34.

*Şekil 11. Na^+/K^+ değerleri ortalama olarak verilmiştir (*Benzer harfle gösterilen ortalamalar, LSD testine göre $p \leq 0.006$ düzeyinde istatistiksel olarak farklı değildir. F (2, 24): 6,34.*

CONCLUSION

This study clearly demonstrated that the application of CA and LJ induced genotype-specific morphological and physiological responses in maize under both saline and non-saline conditions. The findings indicated that the effects of exogenous CA on salt stress tolerance mechanisms in maize were complex and varied significantly among genotypes, underscoring the importance of genotype-specific assessments. Under saline conditions, CA or LJ treatments did not cause notable changes in plant height or fresh biomass in either genotype. However, in the DKC6050 genotype, increases in leaf area, SPAD values, and relative water content suggested that CA played a role in maintaining photosynthetic capacity and cellular turgor. In the P2088 genotype, improvements in leaf area and SPAD values, along with reduced electrolyte leakage, indicated enhanced membrane stability with LJ. Additionally, LJ treatments significantly affected ionic balance in P2088 by reducing Na^+ accumulation and improving the Na^+/K^+ ratio, implying the involvement of ion exclusion or compartmentalization mechanisms. Overall, CA and LJ appeared to be promising strategies for mitigating salinity stress in maize, though their effectiveness was largely dependent on genotype. P2088 showed stronger defensive responses related to membrane integrity and ionic homeostasis. These results highlighted the need for genotype- and stress-specific considerations when integrating exogenous CA or LJ treatments into agricultural systems.

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Contribution Rate Statement Summary of Researchers

The authors declare that they have contributed equally to the article.

Conflict of Interest

The authors declare that there is no conflict of interest among them.

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