International Journal of
Agriculture, Environment and Food Sciences
e-ISSN: 2618-5946 https://dergipark.org.tr/jaefs

DOI: https://doi.org/10.31015/2025.3.30 Int. J. Agric. Environ. Food Sci. 2025; 9 (3): 906-912

Determination of Salt Tolerance Levels of Some Avocado Species

Selvihan KANDEMİR[1] , Meral İNCESU[2]

[1]Department of Horticulture, Faculty of Agriculture, Cukurova University, Adana, Türkiye
[2]Department of Horticulture, Faculty of Agriculture, Cukurova University, Adana, Türkiye

Article History
Received: July 3, 2025
Accepted: September 13, 2025
Published Online: September 22, 2025

Article Info
Type: Research Article
Subject: Horticultural Production

Corresponding Author
Meral İncesu
mincesu@cu.edu.tr

Author ORCID
[1]https://orcid.org/0009-0000-3394-0689
[2]https://orcid.org/0000-0001-7892-3794

Available at
https://dergipark.org.tr/jaefs/issue/93545/1733656

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution-NonCommercial (CC BY-NC) 4.0 International License.

Copyright © 2025 by the authors.

Abstract

Due to global climate change, the salinity problem is increasing day by day. Avocado (*Persea americana* Mill.) is one of the species most sensitive to salinity and even at low salt levels, the vegetative growth, yield and fruit quality of avocado are affected. Therefore, it is important to determine the salt tolerance levels of avocado seedlings. In the study, seedlings of Duke, Mexicola and Topa Topa varieties belonging to the Mexican race were used. In the study, morphological parameters such as shoot growth, stem diameter development, leaf number, leaf burning and chlorosis status and leaf chlorophyll amount (SPAD), Photosystem II (PSII), and leaf nutrient element (Na+, K+, Ca+2, Cl-) values were examined. In order to mimic salt stress on seedlings, NaCl was applied at concentrations of 0 mM, 50 mM and 75 mM during the experiment. At the end of the experiment, it was observed that increasing salt concentration caused a decrease in plant shoot growth and stem diameter, leaf necrosis and severe leaf losses. It was determined that there was a decrease in the amount of chlorophyll in the leaves of the plant and the activation of PSII with increasing salinity. Na+ and Cl- concentrations increased in the leaves of all rootstocks with increasing salinity. K/Na and Ca/Na ratios decreased with increasing salinity and the highest K/Na and Ca/Na ratios were found in the control group in the Topa Topa rootstock. No difference was found in terms of K/Na and Ca/Na ratios between Duke and Mexicola rootstocks.

Keywords: Avocado, Salinity, Rootstock, Chlorophyll, PSII.

Cite this article as: Kandemir, S., Incesu, M. (2025). Determination of Salt Tolerance Levels of Some Avocado Species. International Journal of Agriculture, Environment and Food Sciences, 9 (3): 906-912. https://doi.org/10.31015/2025.3.30

INTRODUCTION

Avocado (*Persea americana* Mill.) is an evergreen, polymorphic tree species that originates from Central America and is grown in many regions around the world (tropical, subtropical or semitropical) depending on its climate adaptation. Avocado (Persea americana Mill.) is currently grown on 5 continents and 65 countries around the world due to its cold tolerance and climate adaptation (Anonymous, 2021).

Avocado is among the 20 most commercially important fruit trees worldwide due to its high nutritional value, antioxidant properties and health-beneficial biochemical content (Scahffer et al., 2013). Recently, its production and trade have been rapidly increasing worldwide. Avocado (Persea americana Mill.) is one of the species most sensitive to salinity. Even low salt levels inhibit the vegetative growth of avocado (Mickelbart and Arpaia, 2002). Na+ and Cl- concentrations, which are considered tolerable for many crops, cause serious leaf damage in avocado. Since this salt-induced leaf damage reduces the photosynthetic leaf area, the photosynthesis rate decreases, thus negatively affecting plant growth and yield. Soussi et al. (1998) observed that salinity greatly affects photosynthesis (Berkessa, 2020).

The level of tolerance to salt stress varies among rootstocks of the same species. Studies conducted in the USA have shown that avocado rootstocks have different tolerance levels. Accordingly, Mexican rootstocks are the most sensitive to salt stress. Guatemalan rootstocks are moderately resistant and West Indian rootstocks are the most resistant. It has been determined that avocado rootstocks with salinity tolerance are related to their ability to prevent Na+ and Cl- accumulation and to maintain the K/Na ratio in older leaves (Mickelbart and Arpaia, 2002; Mickelbart et al., 2007).

In arid climates, high salt soil concentration due to limited rainfall and low quality salty irrigation water are among the factors limiting avocado cultivation. Since the root system of avocado trees is particularly affected by salt stress, it is important to find a rootstock resistant to this stress (Castro et al., 2009).

In recent years, avocado production areas have been rapidly expanding in our country. Especially in the Mediterranean region, the presence of suitable ecological areas provides significant advantages in terms of the contribution of avocado to

the economy. Avocado production is mostly grown in Antalya province. In recent years, significant avocado orchards have been established in Mersin and Adana.

In the early 1970s, four important varieties were brought to our country from California through FAO: 'Fuerte', 'Hass', 'Bacon' and 'Zutano', and these varieties were tested in the ecological conditions of Antalya, Dalaman-Muğla, Alata-Mersin, Adana and İskenderun-Hatay. The high performance of these varieties and the increasing consumer demands have led to an increase in planting areas.

The vast majority of seed rootstocks are produced with Topa Topa, Mexicola and Duke varieties in terms of their tolerance to cold. Seed rootstocks are also used in avocado cultivation in our country. However, seedling producers do not have sufficient knowledge about which variety the seed source of these rootstocks belongs to.

In avocado collection plots established with varieties brought from BATEM (Batı Akdeniz Agricultural Research Institute) at Çukurova University between 1980-1992, the performances of 60 varieties in Adana ecological conditions are observed. There is no study conducted to date on rootstock quality in seedlings obtained from fruits of Topa Topa, Mexicola and Duke varieties in the avocado germplasm collection. Avocado orchards in Adana are widespread in the Karataş and Yumurtalık regions, where cold damage is least experienced. However, salinity problems are experienced in these regions due to their proximity to the sea.

In this study, our aim was to examine the plant development status of seedlings obtained from Topa Topa, Mexicola and Duke varieties and to determine their tolerance to salt and to recommend the most suitable seed rootstock to producers. For this purpose, the plant development status of Duke, Mexicola and Topa topa seedlings were examined and the responses of seedlings obtained from these varieties to salt stress were evaluated at control (0 mM NaCl), 50 mM NaCl and 75 mM NaCl salt doses.

MATERIALS AND METHODS

Seeds of Duke, Mexicola, Topa Topa were obtained from Cukurova University, Faculty of Agriculture, Department of Horticulture, Avocado Germplasm orchard. Topa Topa, Duke and Mexicocola rootstocks were used because of their cold tolerance. The experiment was carried out in greenhouse conditions at the Cukurova University Research Farm in Adana, Turkey. Seeds were planted in 1:1 peat: soil medium and transplanted to 1:1 peat: soil medium approximately 7 months after planting. Transplanted seedlings were grown with Hoagland nutrient solution modified for citrus plants for approximately 10 months until the experimental period (Yeşiloğlu et al., 2009). During the experiment, plants were exposed to 0 mM NaCl, 50 mM NaCl and 75 mM NaCl salinity. Seedlings were progressively adapted to salt stress to avoid osmotic shock. Stress conditions were maintained between February 2024 and May 2024 for 120 days. 2.5 liter pots were used. During this period, plants were irrigated with 500 ml water three times a week.

Plant growth measurements

At the beginning of the experiment, shoot growth (cm), stem diameter (mm) and leaf number were recorded for each replicants. After 120 days of salinity stress treatment, those variables were recorded again. The differences between the latter and initial values were calculated to assess plant growth during the experimental period. Stem diameter (mm) was measured in mm with a caliper, 5 cm above the soil level of the plants. Shoot lengths were measured in cm with a ruler from the soil level. The leaves of each plant were counted. Measurements were made at the beginning and at the end of the experiment, and the difference between the two measurements was plant shoot growth rate, stem diameter rate and leaf number were found.

Leaf chlorophyll concentration and florescence measurements

The concentrations of chlorophyll per area were estimated in the same attached leaves as those for which gas exchange measurements were taken using a SPAD portable apparatus (Minolta Co., Osaka, Japan). Chlorophyll fluorescence parameter (Fv'/Fm') was measured with a portable fluorimeter in light adapted stage of the fully developed leaf of each plant.

Symptom scale

At the end of the experiment, the severity of leaf symptom score was ranked as follows : 1 -normal healthy green plants without any injury; 2 -slightly wilted, damages on leaf tip; 3 -moderate to severe damage on leaves (70% of defoliated leaves); 4 -most leaves with drying damages (90% of defoliated leaves).

Leaf mineral analysis

At the end of the experiment, plants were removed from the pots and separated to root and shoots then washed with deionized water. Shoots were oven dried for two days at 72 oC. The dry material was grounded. Chloride concentration was determined using a scientific chloride analyzer. K, Ca and Na were determined by atomic absorption spectrophotometry.

Experimental Design and Data analysis

The experiment was arranged as 3 × 3 × 10, three treatments, three rootstocks, and 10 replicates, respectively, in a complete randomized factorial design. Data were subjected to a two-way analysis of variance (ANOVA). Significant differences between means were calculated by using LSD test at a significance level of $P \leq 0.05$. The correlation coefficients between all measured parameters were also calculated. All statistical analyses were performed with R (v4.4.0).

RESULTS AND DISCUSSION

Growth Parameters and Symptom scale

At the end of the study, when two-way variance analysis was examined, the effect of different salt levels on shoot growth of rootstocks was found to be statistically significant ($p<0.05$), but the effect of rootstock and rootstock x dose interaction was found to be insignificant (Table 1). Since seedlings produced from seeds were used, it was thought that no difference could be detected in the interaction due to heterozygosity. Although there was no significant difference in shoot growth among rootstocks, the highest shoot growth was in 0 mM NaCl salt application (5.71 cm) and the lowest shoot growth was in 75 mM NaCl application (1.64 cm). (Table 1). It was observed that shoot development decreased significantly with increasing salt levels. It is known that NaCl treatment affects cell division and elongation in plants and causes a decrease in the number of cells in the root and stem (Burssens et al., 2000). Mickelbart and Arpaia (2002) reported that shoot growth decreased in all avocado rootstocks exposed to salinity. In this study, it was determined that shoot growth decreased with increasing salt doses.

At the end of the experiment, when the variance analysis of stem diameter growth was examined, it was determined that rootstock and dose treatment had statistically significant effects ($p<0.05$). The effect of rootstock x dose interaction was found to be statistically insignificant (Table 1). The highest stem diameter in rootstocks was determined as 1.17 mm and 1.08 mm in Topa Topa and Mexicola rootstocks. The lowest was determined as 0.64 mm in Duke rootstock (Table 1). In different dose treatments, the highest stem diameter development was determined in control (0 mM NaCl) treatment (1.29 mm) and the lowest stem diameter development was determined in 75 mM NaCl treatment (0.65 mm) (Table 1). Since high salinity prevents the plant from taking nutrients and water, plant stem diameter growth decreases as salt content increases (Küçükyumuk et al., 2014). Celis et al. (2018) reported that increasing salt treatment reduced stem diameter development compared to the control group. In this study, it was determined that the stem diameter development of salt-applied plants was lower than the control group.

At the end of the trial, when the two-way variance analysis results were examined, there were no significant differences in terms of leaf number among the rootstocks, but the effect of salt treatment ($p<0.05$) and rootstock x dose interaction ($p<0.05$) was found to be statistically significant (Table 1). In salt treatment, the highest value was determined in the Control (0 mM NaCl) treatment (6.24), and the lowest value was determined in the 75 mM NaCl treatment (-37.58) (Table 1). In the rootstock x dose interaction, the highest leaf number was determined in the control group of Topa Topa (14.09) and Mexicola (12.00) rootstocks, and the lowest was determined in the Topa Topa rootstock in the 75 mM NaCl treatment (-46.64) (Table 1). Acosta-Rangel et al. (2019) reported that avocado leaves irrigated with salt water were visibly damaged. In our study, leaf losses occurred in all rootstocks with increasing salinity. At the end of the study, when two-way analysis of variance was examined, the effect of different salt levels on chlorosis and symptom scale of rootstocks was found to be statistically significant ($p<0.05$), but the effect of rootstock and rootstock x dose interaction was found to be insignificant (Table 1). In salt treatment, the highest leaf chlorosis and symptom scale was detected in 75 mM NaCl treatment, and the lowest in control (0 mM NaCl) treatment (Table 1). Mickelbart et al., (2007) reported that high Cl- levels in avocado caused necrosis in leaves and that the damage level of this element was related to its concentration in the tissues. Celis et al. (2018) reported that intense leaf burn occurred in all rootstocks with increasing salinity.

Leaf chlorophyll concentration and florescence measurements

According to the variance analysis performed at the end of the experiment, it was determined that different salt doses had a statistically significant effect ($p<0.05$) on leaf chlorophyll content (Table 1). Rootstock and rootstock x dose interaction effects on leaf chlorophyll value of plants were not found to be significant (Table 1). The highest leaf chlorophyll content was determined in control (0 mM NaCl) treatment (40.35), and the lowest leaf chlorophyll content was determined in 75 mM NaCl treatment (27.25) (Table 1). Musyimi et al. (2007) reported that total chlorophyll content was higher in control group plants than in NaCl applied plants and that chlorophyll content decreased with high salinity. In our study, the highest leaf chlorophyll value was determined in the control group. As NaCl concentration increased, leaf chlorophyll amount decreased.

At the end of the study, when the results of two-way analysis of variance were examined, the effects of rootstock ($p<0.05$), salt treatment ($p<0.05$) and rootstock x dose interaction ($p<0.05$) on Photosystem II (PSII) were found to be statistically significant (Table 1). Among the rootstocks, the highest PSII values were found in Mexicola (0.3568) and Topa Topa (0.3506) rootstocks, while the lowest value was 0.2511 in Duke rootstock. At different salt levels, the highest PSII value was found in 0 mM NaCl (0.6383) treatment, and the lowest was found in 75 mM NaCl treatment (0.1233) (Table 1). In the rootstock*dose interaction, the highest PSII value was found in 0 mM NaCl (Control) treatment of Mexicola (0.6432) and Topa Topa (0.6971) rootstocks. The lowest value was determined in 75 mM NaCl treatment of Duke and Topa Topa rootstocks (Table 1). Acosta-Ranger et al. (2019) reported that increasing NaCl concentration caused a decrease in photosynthesis rate, which resulted in a decrease in leaf carbon gain and a decrease in PS II activity. In the study, it was determined that increasing salt doses reduced PSII activity.

Leaf mineral analysis

At the end of the experiment, when the variance analysis of leaf Ca+2 concentration was examined, it was determined that rootstock ($p<0.05$), salt treatment ($p<0.05$) and rootstock x The highest leaf Ca+2 value was determined in Duke rootstock (3.59), and the lowest in Mexicola rootstock (3.12). At different salt levels, the highest was found in 75 mM NaCl treatment (3.65) and 50 mM NaCl treatment (3.54), and the lowest was found in 0 mM NaCl treatment (2.85). In the rootstock * dose interaction, the highest was found in Topa Topa rootstock in 75 mM NaCl treatment (3.92), and the lowest was found

in Mexicola Control (2.38) treatment (Table 2). It is known that high salinity reduces Ca+2 concentration in plants by preventing the mobility and transportation of Ca+2 to the growing parts of the plants (Gratten and Grieve, 1999). Castro et al. (2009) reported that an increase in NaCl in avocado rootstocks caused an increase in Ca+2 concentration. Clarkson and Hanson (1980) stated in their study on the increases in Ca+2 content due to salt treatment that the plant probably increased its Ca+2 uptake in the presence of excessive Na+ to resist salinity. In the study, it was found that leaf Ca+2 concentration was higher in rootstocks applied with salt compared to the control group.

Table 1. Effect of three different salt doses on shoot lenght, stem diameter, leaf number, SPAD, PSII, and scale of different avocado rootstocks

Variety	Dose	Shoot lenght (cm)	Stem diameter (mm)	Leaf number	SPAD	PSII (Fv/Fm)	Scale
Duke		2.98	0.64 b	-22.36	35.28	0.2511 b	3.39
Mexicola		3.48	1.08 a	-12.39	34.25	0.3568 a	3.09
Topa topa		3.73	1.17 a	-18.45	31.52	0.3506 a	3.21
	0 mM	5.71 a	1.29 a	6.24 a	40.35 a	0.6383 a	1.06 c
	50 mM	2.84 b	0.95 b	-21.88 b	33.45 b	0.1936 b	3.64 b
	75 mM	1.64 c	0.65 c	-37.58 c	27.25 c	0.1233 c	5.00 a
Duke	0 mM	5.40	0.84	-7.36 b	43.17	0.5745 b	1.09
	50 mM	2.28	0.58	-26.18 cd	36.07	0.1175 e	4.09
	75 mM	1.25	0.51	-33.55 de	26.60	0.0611 e	5.00
Mexicola	0 mM	5.36	1.63	12.00 a	38.49	0.6432 a	1.09
	50 mM	3.14	0.98	-16.64 bc	32.77	0.1996 d	3.18
	75 mM	1.94	0.62	-32.55 de	31.50	0.2276 cd	5.00
Topa topa	0 mM	6.36	1.39	14.09 a	39.40	0.6971 a	1.00
	50 mM	3.09	1.30	-22.82 cd	31.50	0.2736 c	3.64
	75 mM	1.73	0.81	-46.64 e	23.65	0.0810 e	5.00
$Prob>F_{(vairety)}$		0.1295	<.0001*	0.0676	0.0938	<.0001*	0.0974
$Prob>F_{(dose)}$		<.0001*	<.0001*	<.0001*	<.0001*	<.0001*	<.0001*
$Prob>F_{(variety\ x\ dose)}$		0.6828	0.1030	0.0333*	0.1522	<.0001*	0.0566
$LSD_{0.05(variety)}$		NS	0.235	NS	NS	0.037	NS
$LSD_{0.05(dose)}$		0.739	0.235	8.470	3.506	0.037	0.277
$LSD_{0.05(variety\ x\ dose)}$		NS	NS	14.671	NS	0.065	NS

At the end of the study, when the results of two-way analysis of variance were examined, it was determined that the rootstocks and salt treatment on leaf K+ concentration were statistically insignificant (Table 2). It was found that the rootstock x dose interaction ($p<0.05$) had a statistically significant effect (Table 2). The highest leaf K+ concentration was determined in the 75 mM NaCl treatment of the Mexicola rootstock (2.26), and the lowest in the 75 mM NaCl treatment of the Duke rootstock (1.49) and the Mexicola rootstock control group (1.48) (Table 2). Studies have reported that an increase in salinity causes an increase in leaf K+ concentration (Mickelbart et al., 2007; Castro et al., 2015; Alvarez-Acosta et al., 2019). Lahav et al. (1993) reported that the increase in leaf K+ is due to a salinity response that transfers K+ from roots to leaves, thus increasing K+ due to its importance as an osmotic regulator on stomatal opening and closing.

At the end of the study, when two-way variance analysis was examined, the effect of different salt levels on leaf Na+ concentration was found to be statistically significant, but the effect of rootstock and rootstock x dose interaction was found to be insignificant (Table 2). At different salt levels, the highest leaf Na+ value was found in the 75 mM NaCl treatment (42.70) and the lowest in the control group (3.56) (Table 2). Castro et al. (2015) reported that increasing NaCl concentration in irrigation water increased leaf Na+ concentration in avocado rootstocks. In our study, it was determined that leaf Na+ concentration increased with increasing salinity.

At the end of the experiment, when two-way analysis of variance was examined, the effect of different salt levels on leaf Cl- concentration was found to be statistically significant, but the effect of rootstock and rootstock x dose interaction was found to be insignificant (Table 2). At different salt levels, the highest leaf Cl- value was found in 75 mM NaCl treatment (4.61) and the lowest in the control group (0.58). (Table 2). Alvarez-Acosta (2019) reported in their study that leaf Cl- concentration increased with NaCl treatment and rootstocks did not have a significant effect on leaf Cl- concentration.

At the end of the experiment, when the variance analysis of leaf Ca/Na ratio was examined, it was determined that rootstock ($p<0.05$), salt treatment ($p<0.05$) and rootstock x dose interaction ($p<0.05$) had statistically significant effects (Table 2). The effect of rootstocks on Ca/Na ratio was highest in Topa Topa rootstock (4.63), while the values of Mexicola and Duke rootstocks were lower. At different salt levels, the Ca/Na ratio was found to be highest in the Control (0 mm NaCl) group (8.98). It was found to be lower in 50 and 75 mM NaCl treatments. The effect of rootstock x dose interaction on Ca/Na ratio was highest in the Control (0 mm NaCl) group of Topa Topa rootstock (11.55), and the lowest in 50 and 75 mM NaCl

treatments of Duke, Mexicola and Topa Topa rootstocks (Table 2). Davenport et al. (1997); Kreij (1999) reported that the Ca/Na ratio decreased with increasing salinity, and as a result, the severity of toxicity increased due to excess Na intake.

At the end of the experiment, when the variance analysis of leaf K/Na ratio was examined, it was determined that rootstock ($p<0.05$), salt treatment ($p<0.05$) and rootstock x dose interaction ($p<0.05$) had statistically significant effects (Table 2). The effect of rootstocks on K/Na ratio was highest in Topa Topa rootstock (2.59), and the lowest in Duke rootstock (1.74). At different salt levels, K/Na ratio was highest in the Control (0 mm NaCl) group (5.33), and lower in 50 and 75 mM NaCl treatments. The effect of rootstock x dose interaction on K/Na ratio was highest in the Control (0 mm NaCl) group of Topa Topa rootstock (6.64), and the lowest in 50 and 75 mM NaCl treatments of Duke, Mexicola and Topa Topa rootstocks (Table 2). Bonomelli et al. (2018) found that the K/Na ratio was lower in treatments with saline irrigation water than in the control treatment. They reported that the K/Na ratio decreased with increasing salinity.

Table 2. Ca, K, Na, Cl, K/Na, Ca/Na values of different avocado rootstocks under three different salt doses

Variety	Dose	Ca	K	Na	Cl	K/Na	Ca/Na
Duke		3.59 a	1.70	27.14	2.82	1.74 b	3.13 b
Mexicola		3.12 b	1.90	24.89	2.77	2.04 ab	3.39 b
Topa Topa		3.33 ab	1.66	23.53	2.84	2.59 a	4.63 a
	0 mM NaCl	2.85 b	1.73	3.56 c	0.58 c	5.33 a	8.98 a
	50 mM NaCl	3.54 a	1.77	29.30 b	3.24 b	0.63 b	1.27 b
	75 mM NaCl	3.65 a	1.76	42.70 a	4.61 a	0.41 b	0.90 b
Duke	0 mM NaCl	3.33 bcd	2.04 ab	5.01	0.72	4.39 b	7.32 b
	50 mM NaCl	3.78 ab	1.58 bc	32.31	3.35	0.49 c	1.22 c
	75 mM NaCl	3.78 ab	1.49 c	44.09	4.40	0.33 c	0.86 c
Mexicola	0 mM NaCl	2.38 e	1.48 c	3.10	0.59	4.94 b	8.08 b
	50 mM NaCl	3.61 abc	1.96 abc	31.02	3.23	0.61 c	1.22 c
	75 mM NaCl	3.37 bc	2.26 a	40.57	4.48	0.57 c	0.88 c
Topa Topa	0 mM NaCl	2.85 de	1.66 bc	2.58	0.41	6.64 a	11.55 a
	50 mM NaCl	3.22 cd	1.78 abc	24.57	3.14	0.79 c	1.37 c
	75 mM NaCl	3.92 a	1.54 bc	43.44	4.97	0.35 c	0.95 c
$Prob>F_{(vairety)}$		0.0049*	0.2180	0.1599	0.8457	0.0163*	0.0081*
$Prob>F_{(dose)}$		<.0001*	0.9450	<.0001*	<.0001*	<.0001*	<.0001*
$Prob>F_{(variety\ x\ dose)}$		0.0092*	0.0067*	0.3297	0.0676	0.0165*	0.0039*
$LSD_{0.05(variety)}$		2.788	NS	NS	NS	0.583	0.987
$LSD_{0.05(dose)}$		2.788	NS	3.748	0.269	0.583	0.987
$LSD_{0.05(variety\ x\ dose)}$		4.830	5.057	NS	NS	1.011	1.711

CONCLUSION

In this study, the morphological and physiological performances of some avocado seedlings used as rootstocks in avocado cultivation were evaluated at different salt levels. It was determined that increasing salt concentration in Duke Mexicola and Topa Topa seedlings used in the study caused a decrease in plant shoot growth, stem diameter and leaf number. The effect of Mexicola and Topa Topa rootstocks on stem diameter was found to be significant. In addition, severe chlorosis and burning were observed with increasing salinity except in the Control (0 mM NaCl) group. Except for the control treatment, advanced leaf scorching and necrosis occurred in plants applied with different salt levels. Therefore, photosynthesis rate, stomal conductance, transpiration rate and water use efficiency measurements could not be made. As salinity increased, leaf chlorophyll amount and Photosystem II (PS II) activation decreased in all rootstocks. It was determined that the effect of Mexicola and Topa Topa rootstocks on PSII activation was significant. In the study, Na^+ and Cl^- values increased in all rootstocks with increasing salt concentration in leaves. High Na^+ and Cl^- caused leaf burn, scorching and severe necrosis and leaf loss. In the study, it was determined that there was an interaction between rootstocks and salt treatment in terms of leaf Ca^{+2} and leaf K^+ concentrations and that leaf Ca^{+2} and K^+ ratios increased with salinity compared to the control group. The highest Ca^{+2} value was found in Topa Topa rootstock, and the highest K^+ value was found in Mexicola rootstock in 75 mM NaCl treatment. K/Na and Ca/Na ratios decreased with increasing salinity. The highest K/Na and Ca/Na ratios were found in the control group of Topa Topa rootstock. No difference was found between

Duke and Mexicola rootstocks in terms of K/Na and Ca/Na ratios. In this study, it is suggested that Topa Topa rootstock may be tolerant to 50nM NaCl application among the 3 rootstocks tested.Studies on these three seedlings or rootstocks should be continued for the salt problem that will occur in the future.

Compliance with Ethical Standards

Peer Review

This article has been reviewed by independent experts in the field using a rigorous double-blind peer review process.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

All authors contributed equally to the study design, data collection, analysis, and manuscript preparation.

Ethics Committee Approval

Ethical approval was not required for this study.

Consent to Participate / Publish

Not applicable.

Funding

The authors declare that this study received no financial support.

Data Availability

Not applicable.

REFERENCES

Acosta-Rangel, A. M., Li, R., Celis, N., Suarez, D. L., Santiago, L. S., Arpaia, M. L., & Mauk, P. A. (2019). The physiological response of 'Hass' avocado to salinity as influenced by rootstock. *Scientia horticulturae*,*256*, 108629.

Alvarez-Acosta, C., Marrero-Dominguez, A., Gallo-Llobet, L., & Gonzalez-Rodriguez, A. M. (2019). Effects of NaCl and NaHCO3 stress on morphological growth and nutrient metabolism on selected avocados (Persea americana Mill.).*Journal of Plant Nutrition*,*42*(2), 164-177.

Anonymous, (2021) Avokado, Tarım Ürünleri Piyasaları Raporu,Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü (TEPGE),Tarım ve Orman Bakanlığı, Ankara

Berkessa, A. J. (2020). Salinity and avocado production, a review. Int. J. For. Hort, 6, 32-38.

Bonomelli, C., Celis, V., Lombardi, G., & Mártiz, J. (2018). Salt stress effects on avocado (Persea americana Mill.) plants with and without seaweed extract (Ascophyllum nodosum) application. Agronomy, 8(5), 64.

Burssens, S., Himanen, K., Van de Cotte, B., Beeckman, T., Van Montagu, M., Inzé, D., & Verbruggen, N. (2000). Expression of cell cycle regulatory genes and morphological alterations in response to salt stress in Arabidopsis thaliana. Planta, 211(5), 632-640.

Castro-Valdebenito, M. B., Fassio-Ortiz, C. C., & Iturrieta-Espinoza, R. A. (2009). Rootstock effect on the tolerance of avocado plants cv. Hass to nacl stress.

Castro, M., Fassio, C., Cautin, R., & Ampuero, J. (2015). UCV7, an avocado rootstock tolerant to salinity. Revista fitotecnia mexicana, 38(1), 85-92.

Celis, N., Suarez, D. L., Wu, L., Li, R., Arpaia, M. L., & Mauk, P. (2018). Salt tolerance and growth of 13 avocado rootstocks related best to chloride uptake. HortScience, 53(12), 1737-1745.

Clarkson, D. T., & Hanson, J. B. (1980). Mineral nutrition of higher plants. Annu. Rev. Plant Physiol.;(United States), 31.

Davenport, R. J., Reid, R. J., & Smith, F. A. (1997). Sodium-calcium interactions in two wheat species differing in salinity tolerance. Physiologia Plantarum, 99(2), 323-327.

Grattan, S. R., & Grieve, C. M. (1998). Salinity–mineral nutrient relations in horticultural crops. Scientia horticulturae, 78(1-4), 127-157.

Harding, S. A., Jarvie, M. M., Lindroth, R. L., & Tsai, C. J. (2009). A comparative analysis of phenylpropanoid metabolism, N utilization, and carbon partitioning in fast-and slow-growing Populus hybrid clones. Journal of experimental botany, 60(12), 3443-3452.

Johnson, C. M., & Ulrich, A. (1959). 2. Analytical methods for use in plant analysis.

Kreij, C. D. (1999). Production, blossom-end rot, and cation uptake of sweet pepper as affected by sodium, cation ratio, and EC of the nutrient solution.

Küçükyumuk, Z., Küçükyumuk, C., Erdal, I., & Eraslan, F. (2015). Effects of different sweet cherry rootstocks and drought stress on nutrient concentrations. Journal of Agricultural Sciences, 21(3), 431-438.

Lahav, E., Steinhardt, R., & Kalmar, D. (1993). Effect of salinity on the nutritional level of the avocado. In Optimization of Plant Nutrition: Refereed papers from the Eighth International Colloquium for the Optimization of Plant Nutrition, 31 August–8 September 1992, Lisbon, Portugal (pp. 593-596). Dordrecht: Springer Netherlands.

Mickelbart, M. V., & Arpaia, M. L. (2002). Rootstock Influences Changes in Ion Concentrations, Growth, and Photosynthesis ofHass' Avocado Trees in Response to Salinity. Journal-American Society For Horticultural Science, 127(4), 649-655.

Mickelbart, M. V., Melser, S., & Lu Arpaia, M. (2007). Salinity-induced changes in ion concentrations of 'Hass' avocado trees on three rootstocks. Journal of Plant Nutrition, 30(1), 105-122.

Musyimi, D. M., Netondo, G. W., & Ouma, G. (2007). Effects of salinity on gas exchange and nutrients uptake in avocados.
Yeşiloğlu, T., İncesu, M. (2009). Turunç Anacında Demir Alımı ve Mevcut Problemleri, Bölgemize Uygun Turunçgil Anaçlarının Demir Açısından Değerlendirilmesi.*Ekin Dergisi. Mart (27)*, 7-10. (in Turkish)