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Effect of Boric Acid on Enhancing Salt Tolerance in Grapevine Rootstocks

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Research Article

Keywords: Boron, 41 B, 1103 P, Salinity

Posted Date: March 25th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9148310/v1

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Additional Declarations: No competing interests reported.

Abstract

‘41B’ and ‘1103 P rootstock wood cuttings were used as materials. The cuttings were planted in a perlite filled planting tray and reached the 9th developmental stage, foliar applications of H_3BO_3 at different concentrations (0, 0.5, 1, and 2 mM) were carried out by spraying. After applying boric acid, some cuttings were cultivated in saline conditions (5120 ppm NaCl). After 8 weeks of application, shoot, root and some physiological parameters were measured in plants. 1103 P rootstock showed better shoot development compared to the 41 B rootstock. 1103 P rootstock benefited more from the supportive effect of boron in terms of its efficacy in salt resistance. Even in saline conditions, the application of 0.5 mM boron, in the instance of rootstock 41B, improved shoot development with increased fresh and dry shoot weights, indicating that this may be the optimal boron dose for this rootstock. In particular at concentrations of 0.5 and 1 mM, boron has been shown to have a positive impact on supporting root development against salt stress. Salinity with the application of 0.5 mM and 1 mM boron was significantly reduced in ion flux and harmful levels. 1103 P rootstock maintained its water and physiological balance better than the 41 B rootstock.

Introduction

It is known that 2 million hectares of the world's 954 million hectares of salty soil are located in Turkey (Anonim, 2021). Salinity adversely influences plant growth and development by causing low osmotic potential, nutritional imbalance, and ion toxicity (Marschner, 2012). The high salinity in the soil's root zone restricts the plant's water absorption, resulting in physiological drought (Dolarslan and Gül, 2012). Plant reactions to salinity vary based on the plant species and variety, as well as the duration and severity of the stress (Dajic, 2006). There are known to be differences among grapevine cultivars and that grapevines have a moderate tolerance to salinity. American grapevine species have become crucial in vineyards due to the phylloxera pest. It is known that these species are more resistant to the root form of phylloxera, while *Vitis vinifera* L. is more resistant to the leaf form of the pest. Although the salt tolerance of American grapevine rootstocks varies among varieties, it is known to be significantly lower compared to the varieties belonging to the *Vitis vinifera* species (Bakır, 2012). 41B rootstock is favored for table grape cultivars because it promotes early ripening, particularly in highly calcareous soil (Çetin et al., 2011; Karimi and Yusef-Zadeh, 2013). According to Warington (1923), boron is essential for plants. It is additionally related to significant physiological and biochemical impacts, as well as how plants react to abiotic stresses (Aydın et al., 2019). Due to its antioxidant qualities, boron helps plants recover from oxidative damage brought on by abiotic stress (Yousefi et al., 2019; Mahmoud et al., 2020). An essential part of the cell wall's pectin, boron gives the wall structural stability and affects its ability to withstand stress (Lu et al., 2023). Although being necessary, too much boron can be toxic to plants (Riaz ve ark.,2019). Plants may experience a boron deficit as a result of the reduction in boron availability caused by salts in the soil, especially those that contain chloride (Yermiyahu ve ark., 2008; Smith ve ark., 2010). As a result, keeping a sufficient amount of boron in the soil is crucial for plant health and resistance to abiotic stress. The effects of foliar boric acid applications at varying concentrations (0, 0.5, 1, and 2 mM)

on plant growth and salt tolerance enhancement were examined in this study in both salty and salt free conditions using two grapevine rootstocks: 1103P, which is known for its salt tolerance, and 41B, which has very low salt tolerance.

Materials Methods

The wood cuttings of 41 B and 1103 P rootstocks used in the study were acquired from the Manisa Viticulture Research Institute during the vineyard pruning season. Prior to planting, they were kept in plastic bags in a cold storage chamber at + 4°C and 90% relative humidity. The cuttings were taken out of cold storage and soaked in water the day before planting and were planted in a perlite (Metaper, 0.5-2.0 mm)-filled planting tray on April 16, 2024. When the cuttings reached the 9th developmental stage defined by Eichhorn and Lorenz (1977), foliar applications of H_3BO_3 (1.00165 Merck) at different concentrations (0, 0.5, 1, and 2 mM) were carried out by spraying on May 26, 2024. Pure water was used to treat the cuttings in the control group with 0 mM boric acid. In this study, the upper limit value of 8 ds/m (5120 ppm), which is the upper limit value of salinity that reduces the crop yield of plants in soils where many plant species grow, was taken into consideration (Kök 2012; Bilir Ekbic et al. 2020). After applying boric acid, some cuttings were cultivated in saline ($NaCl^+$) conditions (5120 ppm NaCl), whereas the remaining cuttings were cultivated in non-saline ($NaCl^-$) conditions. Salt (NaCl, MERCK 7647-14-5) treatment began one week after the boron application. The cuttings subjected to salt treatment were irrigated with saline water for one week, followed by irrigation with non-saline water in the subsequent week. The experiment was planned to last for 8 weeks and following the removal of the cuttings, several parameters were measured: plant viability (%), shoot and root length (cm), shoot and root fresh weight (g) using a precision balance with ± 0.001 g sensitivity (Radwag WTB200), shoot and root dry weight (g) after drying at 65°C in an oven (Memmert UN55) for 72 hours, as well as the number of nodes and leaves (n). To estimate the leaf area, the leaves from the middle sections of the shoots were employed. It was scanned in the scanner and then computed in cm^2 using the "Digimizer 4.0" program. A chlorophyll meter (SPAD-502) was used to determine the chlorophyll content in the leaves. The degree of damage was based on the scale created by Martinez Barroso and Alvarez (1997) for strawberry plants and modified by Bilir Ekbic (2017) for grapevine. This scale assigned a degree of '0' to plants that had no necrotic tissue from salt stress, a degree of '1' for mild drying and necrosis at the leaf tips, a degree of '2' for necrosis affecting more than 50% of the leaf area and the stem, and a degree of '3' for necrosis that resulted in plant death. Shoot and root tolerance ratios have been determined for each rootstock and boric acid dose based on shoot and root dry weight (g). TR = Tx / To, where Tx is the shoot or root dry weight (g) of the cutting treated with boric acid, and To is the shoot or root dry weight (g) of the cutting without boric acid treatment. Leaf samples weighing 0.3 g were taken from the plants, divided into equal parts, and put into glass tubes measuring 25 mm x 150 mm. 15 ml of distilled water were then added to the tubes. For one day, the samples were shaken at 100 rpm in a shaker. Following the shaking procedure, an EC meter (HANNA HI 99300) was used to calculate the EC value, which was assigned as EC1. The EC2 value was then calculated when the same samples were allowed to stand at room temperature for 24 hours. Ion flux (%) was determined using the method described by Ozden et al.

(2009) and calculated with the formula EC1/EC2 × 100. Based on ion flux, the cell membrane damage rate (CMDR) (%) was calculated using the formula: CMDR (%) = [(Ion flux of treatment (%) – Ion flux of control (%)) / (100 – Ion flux of control (%))] × 100 (Arora et al.,1998). After measuring the fresh weights of the leaves, the relative water content (RWC) of the leaves was determined based on the method of Yamasaki and Dillenburg (1999) and calculated using the formula: RWC (%) = [(FW – DW) / (TW – DW)] × 100, where FW is fresh weight, DW is dry weight, and TW is turgor weight.

Experimental Design and Statistical Analysis

The experiment was arranged in a Randomized Complete Block Design with 3 replications, using 10 cuttings per replication. Differences between groups were determined at a 5% significance level using the LSD test and statistical analyses were performed with the JMP 13.0.2 software package (SAS Institute, NC, USA). Percentage (%) values were analyzed by applying the data angular transformation.

Results

Shoot Growth Parameters

Effects of different H_3BO_3 doses applied to rootstock cuttings grown in salty and salt-free conditions on shoot growth characteristics are presented in Table 1. It was determined that 41B (9.17 cm) produced a greater shoot length compared to 1103P (5.09 cm) and that the salt-free condition (8.19 cm) resulted in longer shoot growth than the salty condition (6.09 cm). Among the applied H_3BO_3 doses, the highest shoot length was obtained with the 1 mM H_3BO_3 treatment, reaching a value of 8.30 cm. In terms of rootstock (R) × boron (B) interaction, longer shoots were obtained from the 1 mM H_3BO_3 treatment in both rootstocks. According to the three-way interaction of the experimental factors, the longest shoots (11.27 cm) were obtained from the 1103 P × $NaCl^-$ × 0.5 mM treatment. According to the R × B interaction findings, the 0.5 mM H_3BO_3 application in 41 B and the 0.5 and 1 mM H_3BO_3 applications in 1103 P resulted in higher shoot fresh and dry weights. The RxSxB interaction results showed that, in saline conditions, 1 mM and 2 mM H_3BO_3 applications produced highest shoot fresh weight in 41 B and1103 P rootstock (1.849 g and 2.027 g, respectively), the 1 mM H_3BO_3 produced the highest shoot fresh weight (1.754 g). The RxSxB interaction results for shoot dry weight also showed similarities to the shoot fresh weight results. The overall mean results of H_3BO_3 application did not lead to a significant difference in leaf number; however, higher node numbers were obtained from the 0.5 mM (5.7) and 1 mM (5.6) H_3BO_3 treatments. RxS interaction results showed that the 1103 P x $NaCl^+$ combination produced the greatest number of nodes (7.0) and leaves (6.9). According to the R x B interaction, 1103 P rootstock produced higher node and leaf numbers in all H_3BO_3 doses compared to all H_3BO_3 applications of 41 B. The Sx B interaction indicated that the $NaCl^+$ × 1 mM (5.7) and $NaCl^-$ × 0.5 mM (5.8) combinations produced higher node numbers. 41 B, which is known to be susceptible to salinity, had the largest node number (4.7) from the 1 mM and 2 mM H_3BO_3 applications in saline conditions, per the triple interaction results. Based on the leaf area results, the study showed that, according to the overall means of the

single factors, superior outcomes were obtained from 41 B, salt free conditions, and 0.5 mM H_3BO_3 application. 41 B rootstock produced bigger leaves, measuring 26.55 cm², in saline conditions. According to the triple interaction results, the highest leaf area value of 30.18 cm² was obtained with the 41 B × $NaCl^+$ × 2 mM treatment in saline conditions.

Root Growth Parameters

All the examined root development parameters were statistically affected by the individual application factors and their combinations (Table 2). It was determined that 41 B rootstock exhibited higher values in terms of root number, fresh weight, and dry weight. All root characteristics showed more positive effects in salt free condition compared to saline growing conditions. Among the applied H_3BO_3 doses, 1 mM dose was found to produce the highest values for root number as well as root fresh and dry weight, while for root length, all H_3BO_3 doses except the control were grouped statistically together, indicating longer roots compared to the control. In terms of the Rx B interaction, the highest values for root number, root fresh weight, and root dry weight were observed in the 41 B × 1 mM H_3BO_3 application. Additionally, 1 mM H_3BO_3 application on 1103 P produced the maximum root length value, followed by 0.5 and 1 mM H_3BO_3 applications on 41 B rootstock, all of which were included in the same statistical group. The highest root length in saline conditions was determined in the $NaCl^+$ x 1 mM H_3BO_3 combination, with a value of 15.82 cm. According to the same interaction, it was determined that root fresh weight and root dry weight were also obtained from the $NaCl^+$x1 mM H_3BO_3 combination, with values of 2.802 g and 0.700 g, respectively. When the triple interaction on root number was evaluated, roots with high numbers were obtained from the application combinations of 41 B x $NaCl^-$ x 0.5 mM H_3BO_3, 41 B x $NaCl^-$ x 1 mM H_3BO_3 and 41 B x $NaCl^+$ x 1 mM H_3BO_3, all of which had 7 roots and were included in the same statistical group. It was determined that 41 B x $NaCl^+$ x 1 mM H_3BO_3 and 41 B x $NaCl^-$ x 1 mM H_3BO_3 combinations, which were in the same statistical group, showed the highest root fresh weight values, with 3.513 g and 3.530 g, respectively. The combination of 41 B × $NaCl^+$ + 2 mM H_3BO_3 combination yielded the highest root dry weight (0.816 g), while the combination of 1103 P × $NaCl^+$ + 2 mM H_3BO_3 combination yielded the lowest value (0.301 g).

Physiological Parameters

The findings of some physiological parameters of the study are presented in Table 3. It was shown that every factor, with the exception of the rootstock factor, had a statistically significant impact on the traits of both shoot and root tolerance, which are important indicators of stress resistance. The highest tolerance values for shoot tolerance among the rootstocks were obtained from 41 B with a value of 1.234. In terms of the salt factor, the highest shoot and root tolerance values were recorded in the salt free medium, with values of 1.253 and 1.090, respectively. Regarding H_3BO_3 applications, the highest shoot tolerance values were obtained from 0.5 mM and 1 mM H_3BO_3 applications, with values of 1.331 and 1.250, respectively, while the highest root tolerance value was 1.218, observed in 1 mM H_3BO_3

application. 0.5 mM and 1 mM H_3BO_3 applications also often produced the highest shoot and root tolerance ratio values in 1103 P for RXB interaction. According to the results of the SxB interaction, 1 mM H_3BO_3 application was found to be the most effective dose in achieving the highest shoot and root tolerance values in saline conditions. According to the RxSxB triple interaction, the highest shoot and root tolerance values for both 41 B and 1103 P were generally obtained from the 1 mM H_3BO_3 application in saline conditions. Chlorophyll content measured in SPAD units showed statistically significant results for the interactions of single, double, and triple factors. According to the overall average results of the single factors, 41 B showed the highest leaf chlorophyll content with a value of 24.54, while the saline medium had a value of 20.91 and all H_3BO_3 doses except the control exhibited higher leaf chlorophyll contents. According to the RxS interaction, the highest chlorophyll content was obtained from the saline medium of 41 B rootstock, with a SPAD value of 25.26. The highest leaf chlorophyll content was determined at 16.86 with the 0.5 mM H_3BO_3 application in 1103 P. When examining the SxB interaction, all H_3BO_3 doses except the control showed higher chlorophyll content compared to the control. 41 B rootstock in saline conditions had the highest leaf chlorophyll content (27.06) when the RxSxB triple interaction was evaluated, with a 2 mM H_3BO_3 application; 1103 P rootstock in saline conditions had the highest values from boron applications at 0.5 mM and 2 mM doses. When evaluating the findings on leaf relative water content, it was determined that all factors except for the individual effect of the salt factor and their interactions with each other had significant effects (Table 3). According to the overall rootstock averages, the leaf relative water content of 1103 P, with a value of 88.83%, was found to be higher than that of 41 B. When evaluated based on overall averages of H_3BO_3 applications, the highest leaf relative water content, at 88.67%, was obtained from 1 mM H_3BO_3 application. Regarding the interaction between the salt applications and rootstock, 1103 P, which is in the same statistical group, had the highest relative water content in the leaves in both salt applications (%82.67). With a leaf relative water content of 90.60%, 1103 P with a 1 mM H_3BO_3 application had the highest value for RXB interaction. In terms of the interaction, the best result in 41 B, as in 1103 P, was obtained from the 1 mM H_3BO_3 application, with a value of 86.73%. 1 mM H_3BO_3 application produced higher values for SxB interaction in both salinity conditions ($NaCl^-$ × 1 mM B: 88.62%; $NaCl^+$ × 1 mM B: 88.72%). According to the findings on the degree of damage in the study, all factors and interactions except for the rootstock resulted in statistically significant outcomes. According to the overall mean results for salinity, a higher level of damage was observed in saline conditions, with a value of 0.99. While all boron treatments were within the same statistical group and significantly reduced damage levels, the control treatment, which did not receive any boron application, showed higher damage in the overall average of boron application. When evaluating the interaction between rootstock and salinity, the highest damage level (1.16) was observed in 41 B in salt conditions, while the lowest damage (0.53) was recorded in 1103 P grown in salt free conditions. Control treatments without H_3BO_3 application for both rootstocks showed the highest amounts of damage when R×B interaction was analyzed, and these were determined to be in the same statistical group. A reduction in damage compared to the control was observed with H_3BO_3 applications for both rootstocks. When the degree of

damage was examined in terms of SxB interaction, $NaCl^+$ × 0 (Control) interaction showed the highest level of damage, with a value of 1.64. All H_3BO_3 doses applied in salt free conditions were included in the statistical group with the lowest level of damage. According to the three-way interaction of the factors examined, the highest damage was obtained from 41 B × $NaCl^+$ × 0 mM application, with a damage level of 2, followed by the 1103 P × $NaCl^+$ × 0 mM application, which showed a damage level of 1.28. For 41 B in salt condition, the lowest damage level of 0.63 was obtained with the 2 mM H_3BO_3 application, while for 1103 P in salt condition, the lowest damage level of 0.5 was also achieved with the 2 mM H_3BO_3 applications. The treatments were followed by 1 mM H_3BO_3 application, which showed a similar damage level. It was determined that the rootstocks alone did not have a significant effect when evaluating the ion flux values, which were supposed to increase due to the effect of salt. However, factors other than the rootstock, whether individually, in pairs, or in triple interactions, caused significant differences. A higher ion flux effect was observed in salty conditions, with an ion flux value of 60.6%, as opposed to the 37.5% recorded in salt free conditions. According to the overall means of H_3BO_3 applications, the highest ion flux value was obtained from the 2 mM boron application with 65.8%, while the lowest ion flux values were recorded in the same statistical group as 35.6% for the 1 mM H_3BO_3 application and 45.8% for the control treatment. According to RxS interaction results, lower ion flux values were obtained when both rootstocks were grown in salt conditions. The most favorable results in RxB interaction were obtained from 1 mM H_3BO_3 application for both rootstocks with lower ion flux values. In terms of SXB interaction, lower ion flux values were obtained from all H_3BO_3 doses in salt free conditions, except for 2 mM H_3BO_3 application. 1 mM H_3BO_3 application produced the highest effective boric acid dose in salty condition, with the lowest ion flux value (37.72%). Lower ion flow values from 1 mM H_3BO_3 application in both rootstocks produced better outcomes in salty condition when the triple interaction findings were assessed in terms of ion flux (41 B x $NaCl^+$ x 1 mM: 48.7%; 1103 P x $NaCl^+$ x 1 mM: 45.67%).

Discussion

In this study, the plant features and appearance responses of the effective 41 B and 1103 P rootstocks were compared under various boron doses and salt conditions. The findings show that both rootstock and environmental stresses have significant effects on plant development and physiological responses. Salt stress is known to cause problems with the ion balance in plant cells, lower the uptake of potassium, nitrate, phosphate, and calcium, lower metabolic activity, and finally restrict and restrict growth of plants through osmotic stress (Batool ve Sahzad, 2014; Jogaiah, 2015; Gajjar et al., 2023). In this study, all shoot growth indices decreased under saline conditions which generally had a negative impact on plant development. However, it was determined that this effect varied depending on the interaction between the rootstock and boron application. In this study, 1103 P, which has been reported in various studies (Martin et al., 2020; Zhou-Tsang et al., 2021; Abdullateef et al., 2025) as having a high salt tolerance in terms of shoot length, was found to maintain this trait, and the longest shoot length was obtained with the application of 1 mM H_3BO_3 under salt-free conditions. The study observed that under

both saline and non-saline conditions, 1103 P showed better shoot development compared to 41 B, forming longer shoots, a greater number of nodes, and more leaves. 1103 P rootstock's low leaf number and limited leaf area seem to show salt tolerance adaptation. 41B produced larger leaves though having smaller leaves overall. Evaluating the growth of both rootstocks under saline conditions reveals that photosynthetic capacity can be supported by different adaptation mechanisms. It was considered that 1103 P benefited more from the supportive effect of boron in terms of its efficacy in salt resistance. Even in saline conditions, the application of 0.5 mM boron, in the instance of 41B, improved shoot development with increased fresh and dry shoot weights, indicating that this may be the optimal boron dose for this rootstock. It also results in the experiment that boron is effective in the antioxidant defense mechanism and can increase cellular salt stress tolerance, even at low doses (Alharby et al., 2021; Rahman et al., 2021). In Ersöz's (2009) study, which used stress-related physiological parameters and antioxidant enzymes to determine the tolerance mechanisms to boron and salt stress *in vivo* in six grapevine rootstocks, including 41 B and 1103 P, they observed an increase in shoot dry weight in 110 R when boron and salt were utilized. Salim (2014) observed an increase in shoot dry weight when 100 ppm B and 500 ppm Si were applied to maize plants. According to Akden et al. (2024), using 0.5 mM boron was appropriate for encouraging shoot development and reducing the detrimental effects of salt in their *in vitro* study on fox genotype. Studies by Sotiropoulos et al. (2005) and Neocleous and Vasilakakis (2008) also emphasized that B has a positive effect on shoot development under high salt conditions.

Root development was adversely affected by salt stress as well. Significant reductions in root development characteristics were generally noted in salty conditions. 1103 P with 0 mM boron application had the lowest values for all root parameters examined, especially in saline conditions. The concentration of chloride ions (Cl) and the nitrogen absorption potential of an environment are known to be inversely related. Plant roots tend to respond by absorbing less nitrate when salt concentrations increases. As a result, there is an increase in the amount of chloride that plant roots absorb (Hasana and Mayake, 2017; Kanagaraj and Desingh, 2017). The findings, combined with those of some other studies, suggest that salt limits growth by causing osmotic stress and ionic toxicity in the root system (Karimi and Yusef-Zadeh, 2013; Bilir Ekbic et al., 2021; Bilir Ekbic et al., 2022). These effective boron applications have generally had a positive effect on root development. Boron plays a role in cell structure stability and lignin synthesis, thereby positively impacting root development (Barut et. al., 2018). According to this study, a boron dose of 1 mM produced the most root development. At the applied dose, both fresh and dry root dry weights reached their highest values. The situation was observed particularly in the application of 1 mM boron to 41 B under both salty and salt-free conditions. When the rootstocks' root development was evaluated, it was found that 41 B usually showed greater root development than 1103 P. Specifically, 41 B responded more positively to boron treatments in terms of root development, and a significant increase in root weights was noted. This study reveals that 41B can develop a more resistant root structure under salt stress conditions with boron applications. In particular at concentrations of 0.5 and 1 mM, boron has been shown to have a positive impact on supporting root development against salt stress. Boron's role in enhancing membrane stability and antioxidant defense systems helps to explain this result (Brdar-Jokanovic´, 2020; Alharby et al., 2021; Rahman et al., 2021). However, this protective

effect decreases and may even result in adverse effects if the boron dose is too high. The study found that a 2 mM boron treatment significantly reduced shoot and root growth features in both rootstocks, suggesting that boron's damaging impact is only effective at high concentrations. In particular, root development was observed to decrease significantly with the application of 2 mM boron to 1103 P rootstock. This indicates that the effective and applicable dose range of boron is narrow and that it can have toxic effects at high doses (Fujiyama et al., 2019; Brdar-Jokanovic´, 2020). 1103 P under saline conditions with 2 mM boron application showed the lowest root dry weight, indicating that boron toxicity may have a synergistic adverse effect with salt. It is well known that salt stress increases ion flux and decreases stomatal resistance in plants. It also reduces intracellular water potential, disrupting cell turgor and negatively impacting membrane stability (Sevgi and Leblebici, 2023). This was observed by measuring the highest degree of damage and ion flux in control plants that were not treated with boron under saline conditions. The study noted that salinity levels were significantly reduced in ion flux and harmful levels with the application of 0.5 mM and 1 mM boron. These results demonstrate that boron is effective in maintaining cell membrane integrity by reducing the level of damage and limiting the entry of harmful ions. These findings indicate that by decreasing the degree of damage and limiting the flow of dangerous ions, boron effectively maintains the integrity of cell membranes (Akden et al., (2024). The study also revealed significant differences among the rootstocks. It was found that 1103 P maintained its water and physiological balance better than 41 B, with a higher relative water content and less damage. In contrast, it was determined that 41B showed a higher chlorophyll content (SPAD) under saline conditions. In contrast, it was determined that 41B showed a higher chlorophyll content (SPAD) under salty conditions. In particular, the highest chlorophyll content (27.06) was detected in this rootstock under saline conditions with the application of 2 mM boron. The fact that 41 B, which is known to be sensitive to salinity, exhibits this phenomenon indicates that boron increases the stability of photosynthetic pigments. The significant rate of ion flux (72.24%) in the same application, however, increases the possibility that large boron doses could also be toxic (Günes et al., 2003; Fujiyama et al., 2019; Brdar-Jokanovic´, 2020). Among the boron doses applied in the study, 1 mM boron application provided the most positive effect in terms of stress parameters in both rootstocks, increasing shoot tolerance rate, relative water content, and chlorophyll content, while decreasing damage degree and ion flux values. These physiological findings demonstrated that the use of 1 mM boron was effective in preserving plants' stomatal openness and photosynthetic capacity while reducing the negative effects of stress. This effect was determined in 1103 P rootstock plants treated with 1 mM boron under saline conditions, with the highest relative water content (91.5%) and a low damage level (0.69). However, the highest boron dose used in the study, 2 mM, caused a decrease in shoot and root tolerance rates of 1103 P plants, especially under saline conditions. This suggests that high doses of boron have a reducing effect on photosynthetic area, chlorophyll content, and ultimately photosynthetic activity (Naeem ve ark., 2018; Huo ve ark., 2022).

Conclusion

Salt stress causes several physiological problems in grapevine rootstocks, including morphological and cell membrane integrity issues, as well as disruptions in water balance. This study found that under saline conditions, 0.5 and 1 mM boron application to both rootstocks had a positive effect on stomatal opening, chlorophyll content, and water-holding capacity, thus increasing salt stress tolerance. However, the highest dose of 2 mM boron in this study was observed to have a toxic effect on some of the parameters examined. The study determined that rootstock 1103 P showed better resistance to salt stress, while rootstock 41 B showed a significant increase in chlorophyll content with boron applications. All these results indicate that in studies investigating the effects of boron application on salt stress in viticulture, the boron dose should be evaluated separately for each rootstock.

Declarations

Conflict of interest:

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author Contribution

H.B.E wrote the main manuscript text and N.S.S. prepared figures 1-3. All authors reviewed the manuscript."

Acknowledgement

This study was conducted within the scope of TÜBITAK Project No. 1919B012314300, Project No. 2209-A.

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Tables

Table 1. Effects of different H_3BO_3 doses applied to 41 B and 1103 P rootstocks in varying salinity conditions on shoot development parameters

Rootstock (R)	*SL* *(cm)*	*SFW* *(g)*	SDW (g)	*NN* *(n)*	*LN* *(n)*	*LA* (cm^2)
41 B	9.17 a	1.722	0.555 a	4.0 b	4.5 b	29.41 a
1103 P	5.09 b	1.707	0.495 b	6.8 a	6.9 a	20.06 b
$LSD_{\%5}$	0.20	N.S.	0.046	0.3	4.1	0.95
NaCl (S)						
$NaCl^+$	6.09 b	1.797 a	0.484 b	5.4	5.7	22.54 b
$NaCl^-$ (Control)	8.19 a	1.633 b	0.567 a	5.4	5.7	26.93 a
$LSD_{\%5}$	0.20	0.081	0.046	N.S.	N.S.	1.00
H_3BO_3 (B)						
0 (Control)	6.67 c	1.571 b	0.440 b	5.3 ab	5.5	24.29 bc
0.5 mM	7.99 b	1.910 a	0.616 a	5.7 a	5.9	26.12 a
1 mM	8.30 a	1.814 a	0.585 a	5.6 a	5.8	26.37 ab
2 mM	5.55 d	1.564 b	0.459 b	5.0 b	5.5	23.17 c
$LSD_{\%5}$	0.28	0.115	0.066	0.4	N.S.	1.27
R x S						
41 B x $NaCl^-$	6.30 c	1.723 b	0.599 a	4.3 c	4.5 b	32.26 a
41 B x $NaCl^+$	3.87 d	1.721 b	0.512 bc	3.8 d	4.4 b	26.55 b
1103 P x $NaCl^-$	10.03 a	1.870 a	0.534 ab	6.5 b	6.8 a	21.60 c
1103 P x $NaCl^+$	8.30 b	1.545 c	0.456 c	7.0 a	6.9 a	18.53 d
$LSD_{\%5}$	0.28	0.115	0.066	0.4	0.6	1.27
A x B						
41 B x 0 (Control)	4.52 de	1.444 d	0.407 d	3.5 d	4.0 b	28.9 b
41 B X 0.5 mM	5.80 cd	1.959 a	0.679 a	4.3 c	4.7 b	31.0 a
41 B X 1 mM	6.09 c	1.751 bc	0.613 ab	4.3 c	4.7 b	29.4 ab
41 B X 2 mM	3.92 e	1.734 bc	0.523 bc	4.0 cd	4.5 b	28.5 b
1103 P x 0 (Control)	8.82 b	1.698 c	0.473 cd	7.2 a	7.0 a	19.7 c

1103 P X 0.5 mM	10.17 ab	1.861 ab	0.554 bc	7.0 a	7.2 a	21.3 c
1103 P X 1 mM	10.50 a	1.876 ab	0.558 bc	6.8 a	6.8 a	21.4 c
1103 P X 2 mM	7.19 c	1.394 d	0.395 d	6.0 b	6.5 a	17.9 d
$LSD_{\%5}$	1.57	0.163	0.093	0.6	0.8	4.03
Sx B						
$NaCl^-$ X 0 (Control)	7.60 c	1.646 cd	0.483 cd	5.3 ab	5.5	28.37 ab
$NaCl^-$ X 0.5 mM	9.40 a	2.170 a	0.744 a	5.8 a	6.0	29.74 a
$NaCl^-$ X 1 mM	8.80 b	1.826 b	0.596 b	5.5 ab	5.7	26.89 b
NaCl- X 2 mM	6.86 d	1.544 d	0.445 d	5.0 b	5.5	22.73 c
$NaCl^+$ X 0 (Control)	5.73 e	1.497 d	0.397 d	5.3 ab	5.5	20.20 d
$NaCl^+$X 0.5 mM	6.57 d	1.650 cd	0.489 cd	5.5 ab	5.8	22.49 c
$NaCl^+$ X 1 mM	7.79 c	1.801 bc	0.575 bc	5.7 a	5.8	23.84 c
$NaCl^+$ X 2 mM	4.25 f	1.584 d	0.473 d	5.0 b	5.5	23.62 c
$LSD_{\%5}$	0.40	0.163	0.093	0.6	N.S	1.79
R x S x B						
41 B x $NaCl^-$ x 0 mM	5.71 f	1.521 ef	0.450 def	4.0 e	4.0 b	33.34 a
41 B x $NaCl^-$ x 0.5 mM	7.53 e	2.276 a	0.894 a	5.0 d	5.0 b	33.68 a
41 B x NaCl- x 1 mM	7.25 e	1.653 de	0.619 b	4.3 de	4.7 b	33.41 a
41 B x NaCl- x 2 Mm	4.71 h	1.442 ef	0.433 ef	4.0 e	4.3 b	28.63 bc
41 B x $NaCl^+$ x 0 mM	3.33 j	1.367 fg	0.364 f	3.0 f	4.0 b	25.47 d
41 B x $NaCl^+$ x 0.5 mM	4.08 ı	1.643 de	0.464 cdef	3.7 ef	4.3 b	25.13 d
41 B x $NaCl^+$ x 1 mM	4.94 gh	1.849 bcd	0.607 b	4.3 de	4.7 b	25.41 d
41 B x $NaCl^+$ x 2 mM	3.13 j	2.027 b	0.613 b	4.0 e	4.7 b	30.18 b
1103 P x $NaCl^-$ x 0 mM	9.49 c	1.770 cd	0.515 bcde	6.7 bc	7.0 a	20.53 e
1103 P x $NaCl^-$ x 0.5 mM	11.27 a	2.065 ab	0.594 bc	6.7 bc	7.0 a	20.18 e
1103 P x $NaCl^-$ x 1 mM	10.35 b	1.999 bc	0.572 bcd	6.7 bc	6.7 a	20.46 e

1103 P x $NaCl^-$ x 2 mM	9.01 c	1.647 de	0.457 def	6.0 c	6.7 a	25.24 cd
1103 P x $NaCl^+$ x 0 mM	8.14 d	1.627 de	0.431 ef	7.7 a	7.0 a	19.60 e
1103 P x $NaCl^+$ x 0.5 mM	9.07 c	1.658 de	0.514 bcde	7.3 ab	7.3 a	19.95 e
1103 P x $NaCl^+$ x 1 mM	10.65 b	1.754 d	0.544 bcde	7.0 ab	7.0 a	19.67 e
1103 P x $NaCl^+$ x 2 mM	5.36 fg	1.140 g	0.334 f	6.0 c	6.3 a	14.89 f
$LSD_{\%5}$	0.57	0.230	0.132	0.8	1.1	2.73

SL: Shoot length, SFW: Shoot fresh weight, SDW: Shoot dry weight, NN: Number of nodes, LN: Number of leaves, LA: Leaf area, N.S: Not significant, Means not connected by same letter are significantly different (P<0.05) level by LSD

Table 2. Effects of different H_3BO_3 doses on root development parameters of 41 B and 1103 P rootstocks in different salt conditions

Rootstock (R)	*RN* (n)	*RL* (cm)	*RFW* (g)	RDW (g)
41 B	6.0 a	14.41 b	2.855 a	0.695 a
1103 P	5.1 b	14.87 a	1.728 b	0.450 b
$LSD_{5\%}$	0.3	0.39	0.106	0.024
NaCl (S)				
$NaCl^{+}$	5.3 b	13.89 b	2.197 b	0.559 b
$NaCl^{-}$ (Control)	5.8 a	15.39 a	2.386 a	0.590 a
$LSD_{5\%}$	0.3	0.39	0.106	0.024
H_3BO_3 (B)				
0 (Control)	4.6 d	12.77 b	1.859 d	0.475 d
0.5 mM	5.9 b	15.21 a	2.441 b	0.610 b
1 mM	6.6 a	15.51 a	2.805 a	0.664 a
2 mM	5.2 c	15.07 a	2.060 c	0.549 c
$LSD_{5\%}$	0.4	0.55	0.151	0.034
R x S				
41 B x $NaCl^{-}$	6.2 a	14.93 b	2.883 a	0.687 a
41 B x $NaCl^{+}$	5.8 a	13.89 c	2.827 a	0.710 a
1103 P x $NaCl^{-}$	5.4 b	15.86 a	1.889 b	0.493 b
1103 P x $NaCl^{+}$	4.8 c	13.89 c	1.566 c	0.407 c
$LSD_{5\%}$	0.4	0.55	0.151	0.034
R x B				
41 B x 0 (Control)	4.7 ef	12.47 c	2.555 c	0.613 c
41 B X 0.5 mM	6.7 ab	14.96 ab	2.775 b	0.710 b
41 B X 1 mM	7.0 a	15.34 ab	3.522 a	0.791 a
41 B X 2 mM	5.7 cd	14.86 b	2.569 bc	0.679 b
1103 P x 0 (Control)	4.5 f	13.08 c	1.164 f	0.336 f

1103 P X 0.5 mM	5.2 de	15.46 ab	2.108 d	0.509 d
1103 P X 1 mM	6.2 bc	15.68 a	2.088 d	0.536 d
1103 P X 2 mM	4.7 ef	15.27 ab	1.552 e	0.420 e
$LSD_{5\%}$	0.7	0.77	0.213	0.048
S x B				
$NaCl^-$ X 0 (Control)	5.2 c	15.05 bc	2.252 cd	0.548 de
$NaCl^-$ X 0.5 mM	6.0 b	16.31 a	2.482 b	0.669 ab
$NaCl^-$ X 1 mM	6.8 a	15.20 bc	2.807 a	0.628 bc
$NaCl^-$ X 2 mM	5.2 c	15.01 c	2.004 e	0.516 e
$NaCl^+$ X 0 (Kontrol)	4.0 d	10.50 e	1.467 f	0.401 f
$NaCl^+$ X 0.5 mM	5.8 b	14.10 d	2.400 bc	0.551 de
$NaCl^+$ X 1 mM	6.3 ab	15.82 ab	2.802 a	0.700 a
$NaCl^+$ X 2 mM	5.2 c	15.13 bc	2.117 de	0.583 cd
$LSD_{5\%}$	0.5	0.77	0.213	0.048
R x S x B				
41 B x $NaCl^-$ x 0 mM	5.3 de	15.09 cde	2.835 bc	0.694 cd
41 B x $NaCl^-$ x 0.5 mM	7.0 a	15.44 bcd	2.960 b	0.784 ab
41 B x $NaCl^-$ x 1 mM	7.0 a	15.56 bcd	3.513 a	0.687 cd
41 B x $NaCl^-$ x 2 mM	5.3 de	13.61 f	2.225 d	0.581 ef
41 B x $NaCl^+$ x 0 mM	4.0 g	9.84 h	2.274 d	0.703 bc
41 B x $NaCl^+$ x 0.5 mM	6.3 abc	14.47 def	2.589 c	0.613 de
41 B x $NaCl^+$ x 1 mM	7.0 a	15.12 cde	3.530 a	0.710 bc
41 B x $NaCl^+$ x 2 mM	6.0 bcd	16.11 abc	2.913 b	0.816 a
1103 P x $NaCl^-$ x 0 mM	5.0 ef	15.00 de	1.668 f	0.486 fgh
1103 P x $NaCl^-$ x 0.5 mM	5.0 ef	17.18 a	2.004 de	0.396 ghıj
1103 P x $NaCl^-$ x 1 mM	6.7 ab	14.84 de	2.101 d	0.493 fgh

1103 P x $NaCl^-$ x 2 mM	5.0 ef	16.40 ab	1.782 ef	0.599 cde
1103 P x $NaCl^+$ x 0 mM	4.0 g	11.15 g	0.660 h	0.414 hi
1103 P x $NaCl^+$ x 0.5 mM	5.3 de	13.74 f	2.211 d	0.504 efg
1103 P x $NaCl^+$ x 1 mM	5.7 cde	16.52 ab	2.075 de	0.407 hi
1103 P x $NaCl^+$ x 2 mM	4.3 fg	14.14 ef	1.321 g	0.301 j
$LSD_{5\%}$	0.8	1.09	0.301	0.084

RN: Root Number, RL: Root length, RFW, Root Fresh Weight, RDW: Root Dry Weight, N.S: Not significant, Means not connected by same letter are significantly different (P<0.05) level by LSD

Table 3. The effects of different boron doses applied to 41 B and 1103 P rootstocks under varying salt conditions on certain physiological parameters.

Factors	*STR*	*RTR*	*CC*	*RWC*	DD	*İF*
Rootstock (R)			*(SPAD)*	*(%)*	(0-3)	*(%)*
41 B	1.234 a	1.049	24.54 a	83.90 b	0.71	47.3
1103 P	1.030 b	1.049	16.29 b	88.83 a	0.67	50.9
$LSD_{5\%}$	0.118	Ö.D.	0.51	1.45	Ö.D.	Ö.D.
NaCl (S)						
$NaCl^{+}$	1.011 b	1.007 b	20.91 a	85.69	0.99 a	60.6 a
$NaCl^{-}$ (Control)	1.253 a	1.090 a	19.91 b	87.04	0.40 b	37.5 b
$LSD_{5\%}$	0.118	0.042	0.51	Ö.D.	0.06	13.1
Bor (B)						
0 (Control)	0.911 b	0.851 d	19.37 b	85.3 b	1.01 a	45.8 b
0.5 mM	1.331 a	1.126 b	20.93 a	85.18 b	0.59 b	49.1 ab
1 mM	1.250 a	1.218 a	20.38 a	88.67 a	0.61 b	35.6 b
2 mM	1.035 b	0.999 c	20.95 a	86.32 b	0.55 b	65.8 a
$LSD_{5\%}$	0.167	0.060	0.73	2.05	0.09	18.6
R x S						
41 $BxNaCl^{-}$	1.331 a	1.150 a	23.81 b	85.13 b	0.26 d	34.2 b
41 $BxNaCl^{+}$	1.137 b	1.066 b	25.26 a	82.67 c	1.16 a	60.3 a
1103 $PxNaCl^{-}$	1.174 ab	1.150 a	16.01 c	88.94 a	0.53 c	40.8 b
1103 $PxNaCl^{+}$	0.885 c	0.948 c	16.57 c	88.72 a	0.81 b	60.9 a
$LSD_{5\%}$	0.167	0.060	0.73	2.05	0.09	18.6
R x B						
41 B x 0 (Control)	0.904 d	0.920 d	23.17 c	81.97 d	1.07 a	46.80 ab
41 B X 0.5 mM	1.509 a	1.066 b	25.01 ab	82.62 d	0.57 b	42.47 ab
41 B X 1 mM	1.362 ab	1.188 a	24.41 b	86.73 bc	0.66 b	35.77 b
41 B X 2 mM	1.161 b	1.020 bc	25.55 a	84.28 cd	0.56 b	64.02 a
1103 P x 0 (Control)	0.919 cd	0.782 e	15.58 e	88.63 ab	0.95 a	44.72 ab

1103 P X 0.5 mM	1.152 bc	1.187 a	16.86 d	87.73 ab	0.62 b	55.79 ab
1103 P X 1 mM	1.138 b-d	1.249 a	16.36 de	90.60 a	0.57 b	35.48 b
1103 P X 2 mM	0.909 d	0.979 cd	16.35 de	88.35 ab	0.54 b	67.54 a
$LSD_{5\%}$	0.237	0.085	1.03	2.90	0.12	26.56
S x B						
$NaCl^-$ X 0 (Control)	1.000 cd	1.000 c	19.96 c	86.37 a-c	0.37 d	21.26 c
$NaCl^-$ X 0.5 mM	1.646 a	1.210 ab	20.35 bc	84.73 c	0.37 d	34.52 c
NaCl- X 1 mM	1.298 b	1.160 b	19.56 cd	88.62 a	0.37 d	33.52 c
NaCl- X 2 mM	1.066 bc	0.991 c	19.77 cd	88.43 ab	0.47 d	60.79 ab
$NaCl^+$ X 0 (Control)	0.823 d	0.703 d	18.79 d	84.23 c	1.64 a	70.26 a
$NaCl^+$ X 0.5 mM	1.015 cd	1.042 c	21.51 a	85.62 bc	0.82 b	63.74 ab
$NaCl^+$ X 1 mM	1.202 bc	1.276 a	21.21 ab	88.72 a	0.86 b	37.72 bc
$NaCl^+$ X 2 mM	1.005 cd	1.007 c	22.13 a	84.20 c	0.63 c	70.76 a
$LSD_{5\%}$	0.237	0.085	1.03	2.90	0.12	26.28
R x S x B						
41BxNaCl-x0 mM	1.000 d-g	1.000 d	23.77 d-f	82.33 ef	0.13 h	28.78 ı-n
41BxNaCl-x0.5 mM	1.986 a	1.260 ab	24.54 b-d	83.00 d-f	0.14 h	33.44 e-n
41BxNaCl-x1 mM	1.376 b	1.093 cd	22.91 ef	87.53 a-c	0.29 gh	18.95 n
41BxNaCl-x2 mM	0.961 e-h	0.769 ef	24.04 c-e	87.67 a-c	0.49 ef	55.71 b-k
41BxNaCl+x0 mM	0.808 gh	0.841 ef	22.57 f	81.60 f	2.00 a	59.13 a-j
41BxNaCl+x0.5 mM	1.032 c-g	0.872 e	25.48 bc	82.23 ef	0.99 c	61.20 a-k
41BxNaCl+x1 mM	1.348 bc	1.282 a	25.91 ab	85.93 c-e	1.02 c	48.7 b-n
41BxNaCl+x2 mM	1.361 bc	1.270 ab	27.06 a	80.90 f	0.63 de	72.24 a-f
1103PxNaCl-x0 mM	1.000 d-g	1.000 d	16.14 g-i	90.40 ab	0.61 def	39.65 f-n
1103PxNaCl- x0.5 mM	1.306 b-d	1.161 bc	16.17 g-i	86.47 b-d	0.60 def	41.71 d-n

1103PxNaCl^{-}x1 mM	1.221 b-e	1.227 ab	16.21 g-i	89.70 a-c	0.45 fg	29.19 g-m
1103PxNaCl^{-} x2 mM	1.171 b-f	1.212 a-c	15.51 hi	89.20 a-c	0.45 fg	52.75 c-m
1103PxNaCl^{+}x0 mM	0.837 f-h	0.564 g	15.01 i	86.87 b-d	1.28 b	55.49 b-k
1103PxNaCl^{+}x0.5 mM	0.998 d-g	1.212 a-c	17.55 g	89.00 a-c	0.64 de	60.16 a-ı
1103PxNaCl^{+}x1 mM	1.056 b-g	1.270 ab	16.51 gh	91.50 a	0.69 d	45.67 b-m
1103PxNaCl^{+}x2 mM	0.648 h	0.745 f	17.20 g	87.50 a-c	0.63 de	82.42 ac
$LSD_{5\%}$	0.335	0.120	1.45	4.11	0.17	30.06

STR: Shoot Tolerance Rate, RTR: Root Tolerance Rate, CC: Chlorophyll content, RWC: Relative water content, DD: Damage Degree, IF: Ion flux, N.S: Not significant, Means not connected by same letter are significantly different (P<0.05) level by LSD