

Article

Yield Response of Grafted and Self-Rooted Tomato Plants Grown Hydroponically under Varying Levels of Water Salinity

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Abstract: To overcome the scarcity of fresh water, researchers have turned to investigating different techniques that enable using saline water to irrigate crops, aiming to increase the efficiency of using available water resources. A glasshouse experiment was conducted to investigate the yield responses of grafted and non-grafted (self-rooted) tomato plants grown hydroponically under three levels of water salinity (2.5, 6.0, and 9.5 dS m⁻¹). Three tomato varieties (Ghandowra-F1, Forester-F1, and Feisty-Red) were grafted onto five rootstocks (Maxifort, Unifort, Dynafort, Vivifort, and Beaufort). The implemented treatments were studied in terms of tomato fruit yield and quality parameters. Although increasing the concentration of salts in the nutrient solution led to a decrease in fruit yield, the moderate salinity level (S-2: 6.0 dS m⁻¹) showed its superiority over both low salinity (S-1: 2.5 dS m⁻¹) and high salinity (S-3: 9.5 dS m⁻¹) in terms of tomato yield parameters. The studied rootstocks did not significantly improve the tomato fruit yield, but the interaction between the grafting combinations and salinity was significant for both production and quality. More specifically, tomato plants grafted onto the rootstocks “Vivifort and Beaufort” rendered the highest yield at a low salinity level (S-1: 2.5 dS m⁻¹) and a moderate salinity level (S-2: 6.0 dS m⁻¹), respectively, while at high salinity (S-3: 9.5 dS m⁻¹), grafting did not improve tomato productivity, irrespective of the rootstock. These results confirm that tomatoes can be successfully grown under hydroponic systems using salinity levels of up to 6.0 dS m⁻¹ without sacrificing fruit yield and quality. Among the studied tomato varieties, Feisty-Red was found to be appropriate for hydroponic production. The results also demonstrated that Vivifort and Beaufort rootstocks are suitable for grafting hydroponic tomatoes under low and moderate salinity levels, respectively.

Keywords: hydroponics; tomatoes; salinity; grafting; rootstocks



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1. Introduction

Since salinity and water scarcity are among the main environmental factors that hinder agricultural production in the Kingdom of Saudi Arabia, it has become necessary to investigate the possibility of using saline water in irrigating crops to increase the efficiency of using the available water resources. In this regard, numerous studies have proven the effectiveness of using saline water to irrigate selected crops under specific conditions [1]. The proper use of saline water and the recycling of wastewater, in addition to developing crops with a high ability to tolerate salt, as well as adopting effective water management strategies, are effective practices to increase the amounts of water available for irrigation purposes. Furthermore, another way to reduce production losses in high-yielding crops due to salinity is to graft them onto rootstocks capable of resisting the effect of salinity on plant growth and production [2].

Although grafting aims to reduce the negative effects of various abiotic stresses, salinity stress is given the top priority because it negatively affects the physiological and

biochemical processes of the plant and leads to changes in the morphological characteristics, which ultimately lead to significant production losses. In general, grafted plants outperform non-grafted plants, especially when either abiotic or biotic stress is prevalent [3]. It has been proven that the tolerance of grafted tomatoes to abiotic and biotic stresses is greatly affected by the type and characteristics of rootstocks, as the scion–rootstock combinations play important roles in influencing tomato fruit yield and quality [4].

There is a wide range of hybrid tomato rootstocks that have the potential to increase yield; however, inconsistent results have been reported on the effect of grafting on fruit quality, raising the question of whether grafting is beneficial or detrimental to post-harvest fruit quality [5]. Grafting tomatoes onto suitable rootstocks has positive effects on crop health and vigor and increases tolerance to biotic and abiotic stresses [6,7]; therefore, grafted plants that provide increased yield, and thus a higher profit, can be of great value to farmers [8]. Therefore, a thorough investigation is crucial before selecting the appropriate combination of scions and grafting rootstocks to achieve the desired goal [9]. Improving the growth and productivity of tomato varieties that are more sensitive to salt stress depends mainly on the positive response to grafting and, of course, on the optimal selection of the appropriate scion–rootstock combination [10].

Hydroponics, or soilless farming, is an effective technology for more sustainable food production, with less use of water and agricultural chemicals, and is expected to contribute significantly to increasing food production and improving its quality, conserving water resources, and preserving the environment. According to the World Bank [11], hydroponics is a climate-smart technology that is highly efficient at producing more food using at least 80% less water than open farming. Suresh et al. [12] stated the same, including that hydroponic systems are environmentally friendly and innovative technologies that aim to provide reasonable prospects for future agricultural production, especially in areas suffering from severe drought and low water and soil quality.

Since the major amounts of available irrigation water in Saudi Arabia come from aquifers with moderate to high salinity levels, this study focuses on improving hydroponic farming practices by selecting appropriate combinations of tomato scions and rootstocks for proper plant growth, increased yields, and improved salt stress tolerance. Although some tomato rootstocks can provide high levels of resistance or tolerance to a wide range of plant pathogens, little is known about the yield response of scions with vigorous rootstocks in the presence of low soil-borne pathogens [13], such as in soilless culture. This is why it is necessary to conduct more research on tomato grafting in hydroponics, especially those irrigated with salt water. Therefore, this study aimed to explore the role of grafting in improving the salinity tolerance of tomato plants and to select the optimal combinations of scions and rootstocks that are most suitable for hydroponically grown tomatoes under saline water conditions in terms of fruit yield and quality parameters.

2. Materials and Methods

2.1. The Hydroponic Glasshouse

The study was conducted in a hydroponic glasshouse (32 m × 28 m × 4.5 m), Figure 1, belonging to the Precision Agriculture Research Chair (PARC) and located within the premises of the Educational Farm of the College of Food and Agriculture Sciences, King Saud University, Riyadh (24°44′12″ N, 46°37′10″ E). The glasshouse was equipped with MACQU systems (Geosmart, Athens, Greece) to control the indoor climate and the fertigation system. The glasshouse was also equipped with a hydroponic system consisting of 12 plant lines established with stainless steel troughs of 1.0 m height, automatic electric motors, and self-compensating drippers with a discharge capacity of 3.0 L per hour for irrigation purposes.



Figure 1. The hydroponic glasshouse: (A) the glasshouse structure, (B) the hydroponic system, and (C) the climate and hydroponic control unit.

2.2. Experimental Setup

Three commercial greenhouse tomato (*Solanum lycopersicum* L.) varieties, Gandhowra-F1 (Western Seed, USA), Forester-F1 (Western Seed, USA), and Feisty-Red (Seminis, St. Louis, MO, USA), were used as scions. The selected tomato scions were grafted, using the tube-grafting technique, onto five interspecific tomato hybrid rootstocks, namely Maxifort, Unifort, Dynafort, Vivifort, and Beaufort.

Seedlings of the three tomato varieties (grafted and non-grafted) were transplanted on 15 November 2022, i.e., 54 days from the sowing date (22 September 2022). Seedlings were transplanted in the hydroponic glasshouse into perlite sacks (100 cm × 25 cm × 20 cm) soaked with a nutrient solution. Plant seedlings were transplanted 25 cm apart in the row, with 1.78 cm between rows (i.e., 2.25 plants m⁻²). A climate and hydroponic control system (MACQU, Geosmart, Athens, Greece) was used to implement the planned treatments. An automatic climate controller was used to adjust the indoor air temperatures at 23 ± 2 °C and 20 ± 2 °C during the day and night, respectively, whereas, the relative humidity was maintained at 50–60%.

The experimental work was conducted in the period from 15 November 2022 (transplanting) to 5 April 2023 (last harvest). The experiment was arranged in a 3 × 5 × 3 factorial treatment structure in a randomized complete block design with three replicates, and each replicate contained six plants.

The treatment factors were the three scions, the five rootstocks, and the three salinity levels (Salinity-1: 2.5 dS m⁻¹, Salinity-2: 6.0 dS m⁻¹, and Salinity-3: 9.5 dS m⁻¹). Salinity levels were prepared by adding different amounts of sodium chloride (NaCl) to the irrigation water. Nutrient solutions were supplied to plants at different crop growth stages, as recommended by Hochmuth and Hochmuth [14], through a drip fertigation system, which was designed to deliver 100 mL d⁻¹ (initial growth stage) to 1600 mL d⁻¹ (late growth stage) of a nutrient solution per plant using one dripper for each plant at a flow rate of 3 L h⁻¹.

2.3. Data Collection and Statistical Analysis

Harvest data were collected for four clusters (first harvest: 26 February 2023 to last harvest: 5 April 2023). Tomato fruit yield parameters (number of fruits/plants, single fruit weight, fruit diameter and height, total fruit weight/plant, and total fruit weight/unit area) and quality parameters (total soluble solids, pH, EC, Na^+ , K^+ , and NO_3^- concentrations) were determined immediately at harvest time. The mean diameter and height of tomato fruits at harvest were measured using a Vernier caliper in millimeters. The mean weight of tomato fruits, and hence the total weight per plant and per unit area, was determined using a digital weighing scale.

Fresh tomatoes were cut into small pieces and then squeezed using an electric blender for two to three minutes. Three to four fruits were randomly selected from each replicate for fruit quality analysis. The tomato juice was then placed on a filter paper (e.g., Whatman No. 1), and the extracted solution was used to measure the selected chemical quality parameters of tomato fruits. A LAQUA Twin set of devices (Spectrum Technology Inc.) was used to measure the EC (EC Meter; dS m^{-1}), pH (pH Meter), Na^+ (Sodium Meter; ppm), K^+ (Potassium Meter; ppm), and NO_3^- (Nitrate Meter; ppm), while the total soluble solids were measured using the KRUS Optronic DR6000 digital refractometer ($^\circ\text{Brix}$).

The collected data were analyzed statistically using the Statistix (version 10.0) software program, through which significant differences between individual treatments and interactions between treatments were examined using the analysis of variance (ANOVA) tri-factorial ANOVA (cultivar $\times$ grafting $\times$ salinity) and least significant difference ($\text{LSD}_{0.05}$) test.

3. Results and Discussion

3.1. Tomato Fruit Yield Parameters

3.1.1. Tomato Variety

The studied tomato varieties showed different trends in fruit physical characteristics, whereas the statistical results showed significant differences between them in fruit diameter ($\text{Pr}>\text{F} = 0.0000$), fruit height ($\text{Pr}>\text{F} = 0.0000$), single fruit weight ($\text{Pr}>\text{F} = 0.0002$), fruit yield per plant ($\text{Pr}>\text{F} = 0.0671$), and fruit yield per unit area ($\text{Pr}>\text{F} = 0.0886$). No significant differences ($\text{Pr}>\text{F} = 0.1904$) were recorded for the number of tomato fruits per plant between the three varieties. The results presented in Figure 2 indicated that Feisty-Red recorded the highest fruit yield parameters, with significant differences in the mean fruit diameter and height (74.9 mm and 55.8 mm), compared to both Forester-F1 (71.9 mm and 51.8 mm) and Ghandowra-F1 (63.0 mm and 48.1 mm). The highest values of the single fruit weight, fruit weight per plant, and total fruit yield per unit area were recorded for Feisty-Red (131.5 g, 1911.5 g/plant, and 4.295 kg m^{-2}), with no-significant differences compared to Forester-F1 (118.1 g, 1597.1 g/plant, and 3.650 kg m^{-2}). The lowest fruit characteristics and yield parameters were recorded for Ghandowra-F1, with significant differences when compared to both Forester-F1 and Feisty-Red varieties. Although the highest number of fruits per plant was recorded for Ghandowra-F1 (18.16 fruits/plant), no significant differences were observed when compared to Forester-F1 (17.43 fruits/plant) and Feisty-Red (16.31 fruits/plant). In general, yield characteristics proved that Feisty-Red is an appropriate tomato variety for hydroponic production, followed by Forester-F1.

3.1.2. Salinity Level

The highest salinity concentration (S-3; 9.5 dS m^{-1}) resulted in the lowest tomato fruit yield parameters, with significant differences compared to the low (S-1; 2.5 dS m^{-1}) and moderate (S-2; 6.0 dS m^{-1}) salinity concentrations (Figure 2). There were no significant differences between the mean values of fruit diameter, single fruit weight, fruit yield per plant, and fruit yield per unit area under S-1 (71.1 mm, 124.9 g, 1809.9 g/plant , and 4.110 kg m^{-2}) and S-2 (72.0 mm, 117.2 g, 1837.9 g/plant , and 4.173 kg m^{-2}). The highest mean values of the number of fruits per plant and fruit height (19.2 fruits/plant and 54.9 mm) were recorded under S-2, with significant differences under both S-1 (17.2 fruits/plant and 51.9 mm) and S-3 (15.5 fruits/plant and 48.8 mm). In general, the highest fruit yield parameters were recorded for the moderate salinity level (S-2; 6.0 dS m^{-1}). Similar results were reported by

Voutsela et al. [15], where grafted plants produced more tomato fruits and a higher total fruit yield than non-grafted plants at a level of 6.0 dS m^{-1} when grown indoors. Also, these results are consistent with Zhang et al. [16], who reported that salinity equal to or greater than 5.0 dS m^{-1} led to a significant decrease in the total tomato yield. Similar results were reported by Zaki et al. [17], who reported that regardless of the used rootstock, the highest average tomato fruit yield (1444.82 g/plant) was obtained at the salinity level of 448 ppm, and the lowest average yield (1024.4 g/plant) was obtained at the highest salinity level of 6000 ppm. The same was reported by Krauss et al. [18], who reported that the total fruit yield and weight per fruit decreased significantly with higher EC levels. Also, Zaki et al. [17] reported that increasing salinity levels gradually decreased average tomato fruit weight. Helaly et al. [19] stated that irrigating tomatoes with saline water resulted in a decreased fruit yield, compared to the control. In general, increasing salt concentration in the nutrient solution led to a decrease in fruit yield. However, the moderate salinity level (S-2: 6.0 dS m^{-1}) showed its superiority over both low salinity (S-1: 2.5 dS m^{-1}) and high salinity (S-3: 9.5 dS m^{-1}) in the results of tomato yield parameters for the three tested tomato varieties. These results confirm that tomatoes can be successfully grown under hydroponic systems using a salinity level of up to 6.0 dS m^{-1} without sacrificing fruit yield and quality.

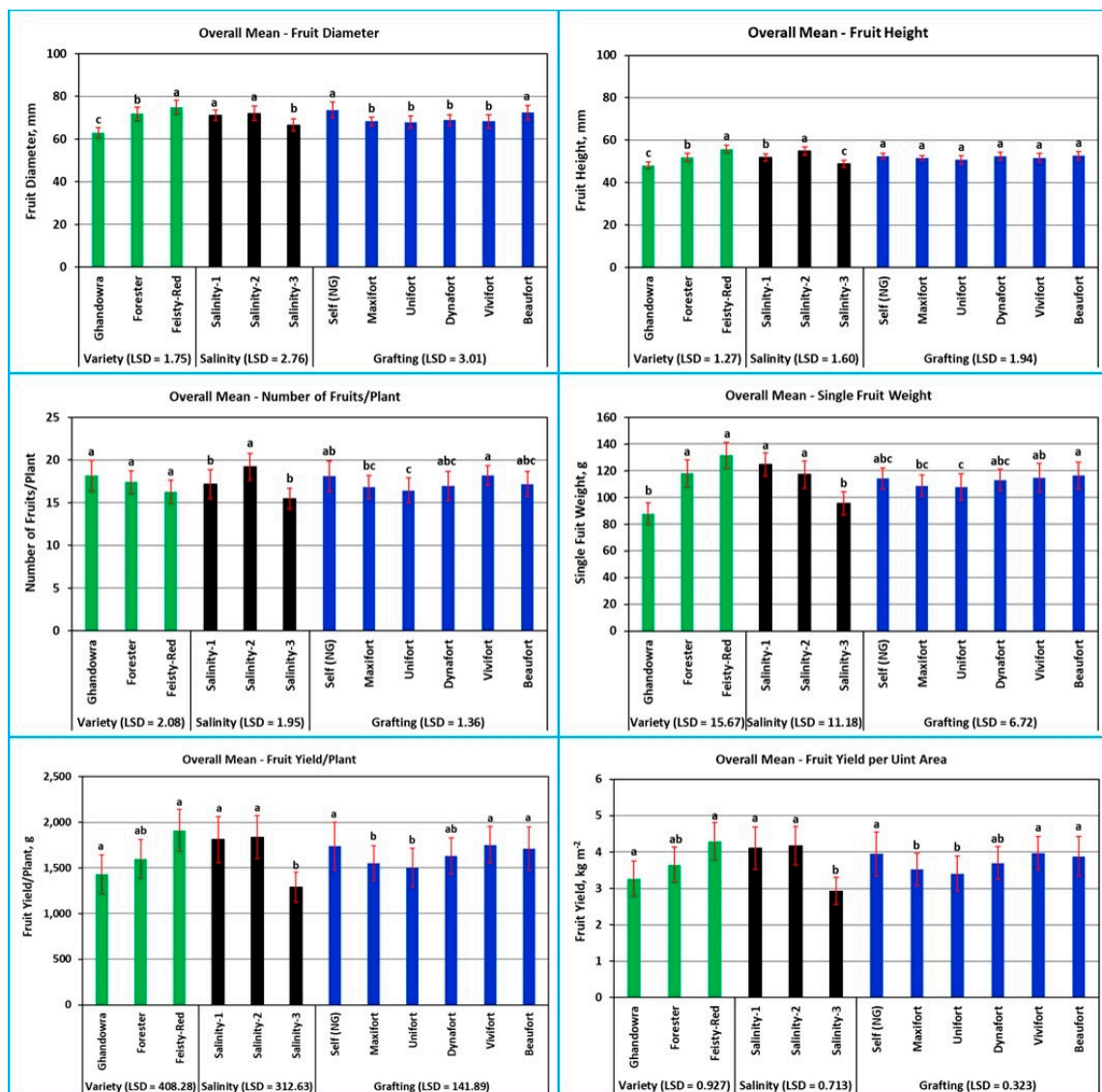


Figure 2. Response of tomato yield parameters to variety, salinity, and rootstocks. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

3.1.3. Grafting Rootstocks

Different grafting rootstocks used in this study showed dissimilar results of tomato fruit yield characteristics (Figure 2). The best tomato fruit yield parameters were obtained with the Vivifort and Beaufort rootstocks, and the lowest yield results were recorded for the Unifort. On average, both Vivifort and Beaufort rootstocks showed a positive impact on tomato fruit yield but showed no significant differences, compared to the non-grafted plants. Similar results reported by Soare et al. [20] showed that grafting tomato plants onto Beaufort rootstock had significant effects on morphological characteristics and production, with tomato production per plant increased in most variants, compared to the control plant. Turhan et al. [8] also reported that a positive effect of grafting on tomato production was recorded when Beaufort was used as a rootstock. Also, Savvas et al. [21] reported that NaCl salinity had no effect on the yield of plants grafted onto He-Man but restricted the yields in all other grafting treatments due to the reduction in the mean fruit weight. The same was reported by Rahmatian et al. [22], who reported that grafting tomatoes significantly increased the mean fruit weight, number of fruits, and yield by 11, 17.8, and 27%, respectively.

3.1.4. Salinity–Variety Interaction

The interactive results of salinity level and tomato variety, illustrated in Figure 3, indicated that the combination of S-2 (6.0 dS m^{-1}) and the Feisty-Red variety produced the highest values of number of fruits per plant (19.6 fruits/plant), fruit yield per plant (2152.6 g/plant), and fruit yield per unit area (4.837 kg m^{-2}), with significant differences compared to the combination of S-3 (9.5 dS m^{-1}) and the Feisty-Red variety (15.2 fruits/plant, 1485.8 g/plant, and 3.339 kg m^{-2}). On the other hand, Ghandowra-F1 produced the lowest values of yield components under all salinity levels, indicating that it is not a suitable variety for hydroponic production.

3.1.5. Salinity–Grafting Interaction

Although salinity-3 (S-3; 9.5 dS m^{-1}) was associated with the lowest values of all the measured yield parameters, with significant differences compared to that under the other two salinity levels (S-1: 2.5 dS m^{-1} and S-2: 6.0 dS m^{-1}), as shown in Figure 4, the studied grafting rootstocks did not show any significant improvement over the non-grafted plants in tomato yield parameters. However, the combined effects of the grafting rootstocks and the level of salinity caused significant changes in the production of tomato fruits. The best results of tomato yield characteristics were obtained with the Vivifort rootstock under a low salinity level (S-1: 2.5 dS m^{-1}) and Beaufort under a moderate salinity level (S-2: 6.0 dS m^{-1}). Grafting showed no significant improvement in tomato yield parameters under high salinity (S-3: 9.5 dS m^{-1}).

3.1.6. Variety–Grafting Interaction

The interactive effects of tomato varieties and rootstocks on fruit yield parameters are shown in Figure 5. Statistical results showed that the overall impact of the interaction between tomato varieties and grafting rootstocks was highly significant for tomato fruit diameter ($\text{Pr}>\text{F} = 0.0053$), fruit yield per plant ($\text{Pr}>\text{F} = 0.0060$), and fruit yield per unit area ($\text{Pr}>\text{F} = 0.0061$). Similar results were reported by Jafari and Jalali [23], who reported that the interaction of salinity and the tomato cultivar significantly ($p < 0.01$) increased the yield per plant at different salinity levels, specifically at the 2.3 dS m^{-1} salinity level. However, these results indicated that grafting tomato plants onto rootstocks significantly improved fruit yield parameters the most for the Feisty-Red variety. The combination of the Feisty-Red scion grafted onto the Vivifort rootstock (4.798 kg m^{-2}) and onto Dynafort (4.511 kg m^{-2}) produced the highest yields, with significant differences compared to that of non-grafted plants (3.941 kg m^{-2}). On the other hand, the combination of the Feisty-Red scion grafted onto the Vivifort rootstock produced the highest tomato fruit weight per plant (2135.3 g/plant), with a significant difference compared to that of non-grafted plants (1753.6 g/plant). The varying results of the combinations of grafting rootstocks and

tomato plant scions were also reported by Grieneisen et al. [24], who reported that rootstock performance on tomatoes can vary greatly, depending on the scion variety.

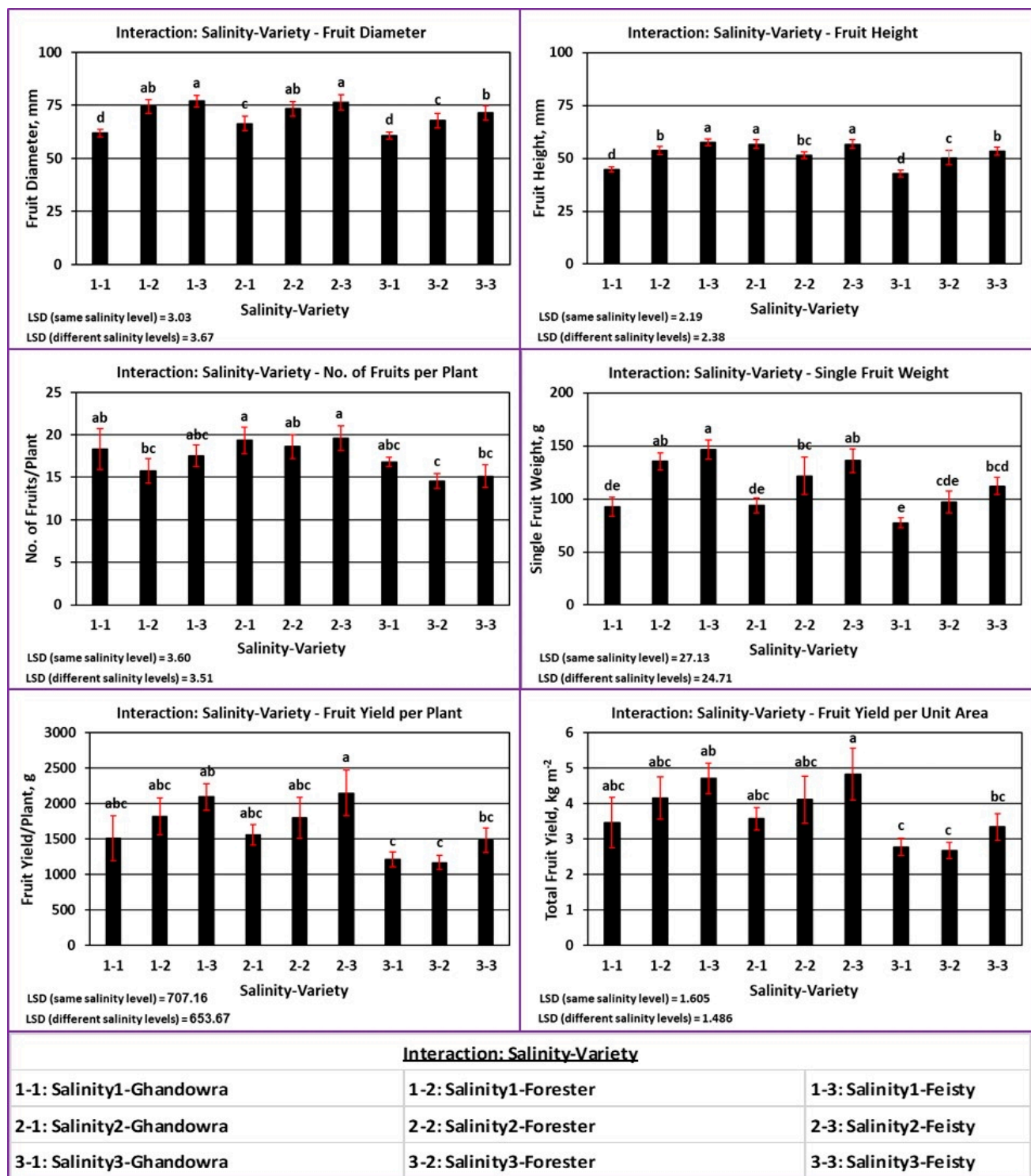


Figure 3. Response of tomato yield parameters to the interaction of salinity and variety. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.



Figure 4. Response of tomato yield parameters to the interaction of salinity and rootstocks. Columns with different letters showed significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

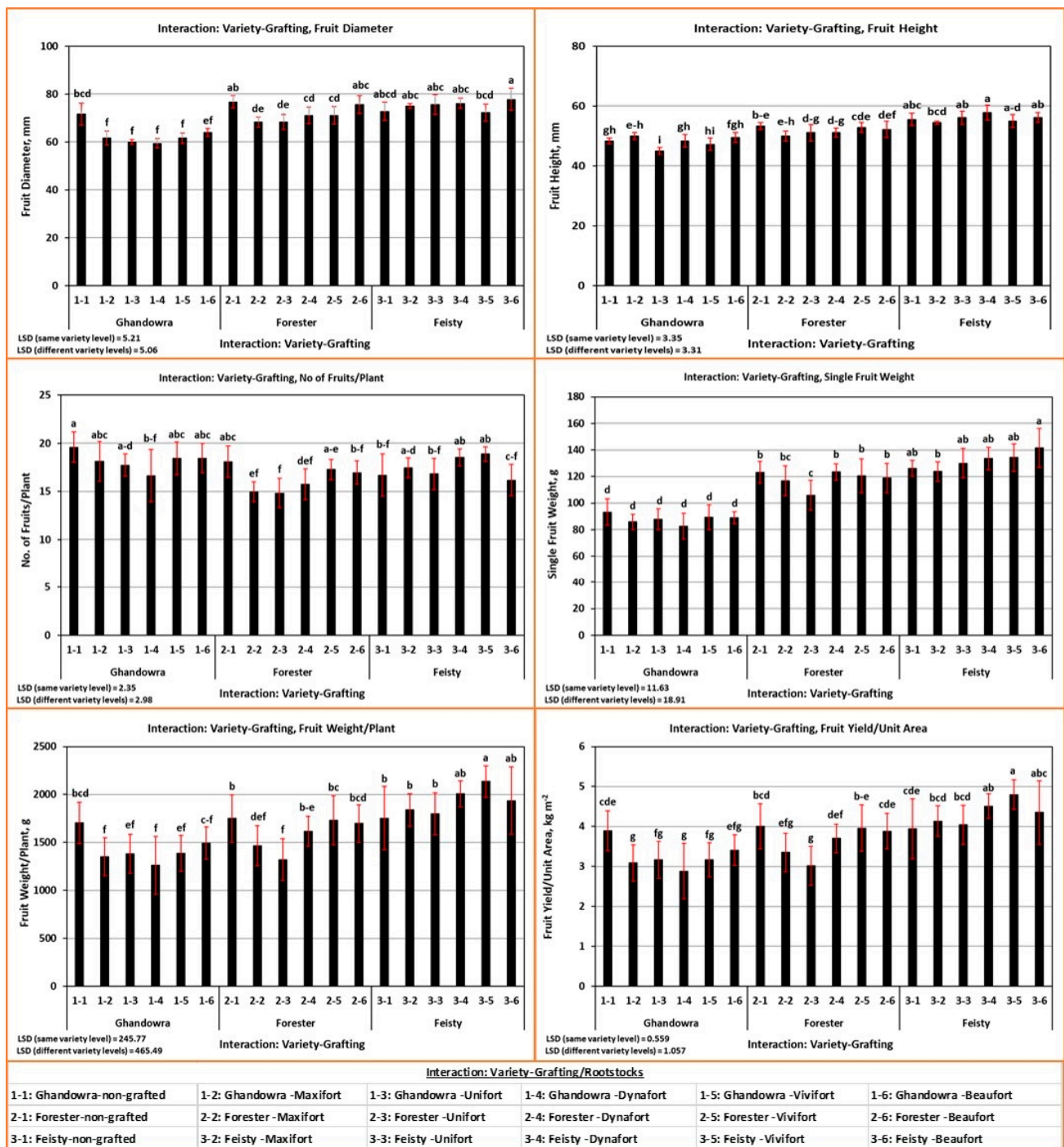


Figure 5. Response of tomato yield parameters to the interaction of variety and grafting. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

3.2. Tomato Fruit Quality Parameters

3.2.1. Tomato Variety

The results of tomato fruit quality presented in Figure 6 indicated that the Feisty-Red variety resulted in the highest values of nitrates (NO_3^- ; 440.2 ppm), potassium (K^+ ; 1668.5 ppm) concentrations, and total soluble solids (TSS; 7.74 °Brix), with significant differences when compared to both the Forester (405.2 ppm, 1594.4 ppm, 6.77 °Brix) and Feisty-Red (376.1 ppm, 1537.0 ppm, 6.56 °Brix). However, no significant differences were obtained between the

three varieties in the EC concentrations of tomato fruits. The Forester-F1 variety resulted in the highest mean EC value of tomato fruit (3.78 dS m^{-1}), with significant differences when compared to that of both Ghandowra-F1 (3.61 dS m^{-1}) and Feisty-Red (3.66 dS m^{-1}).

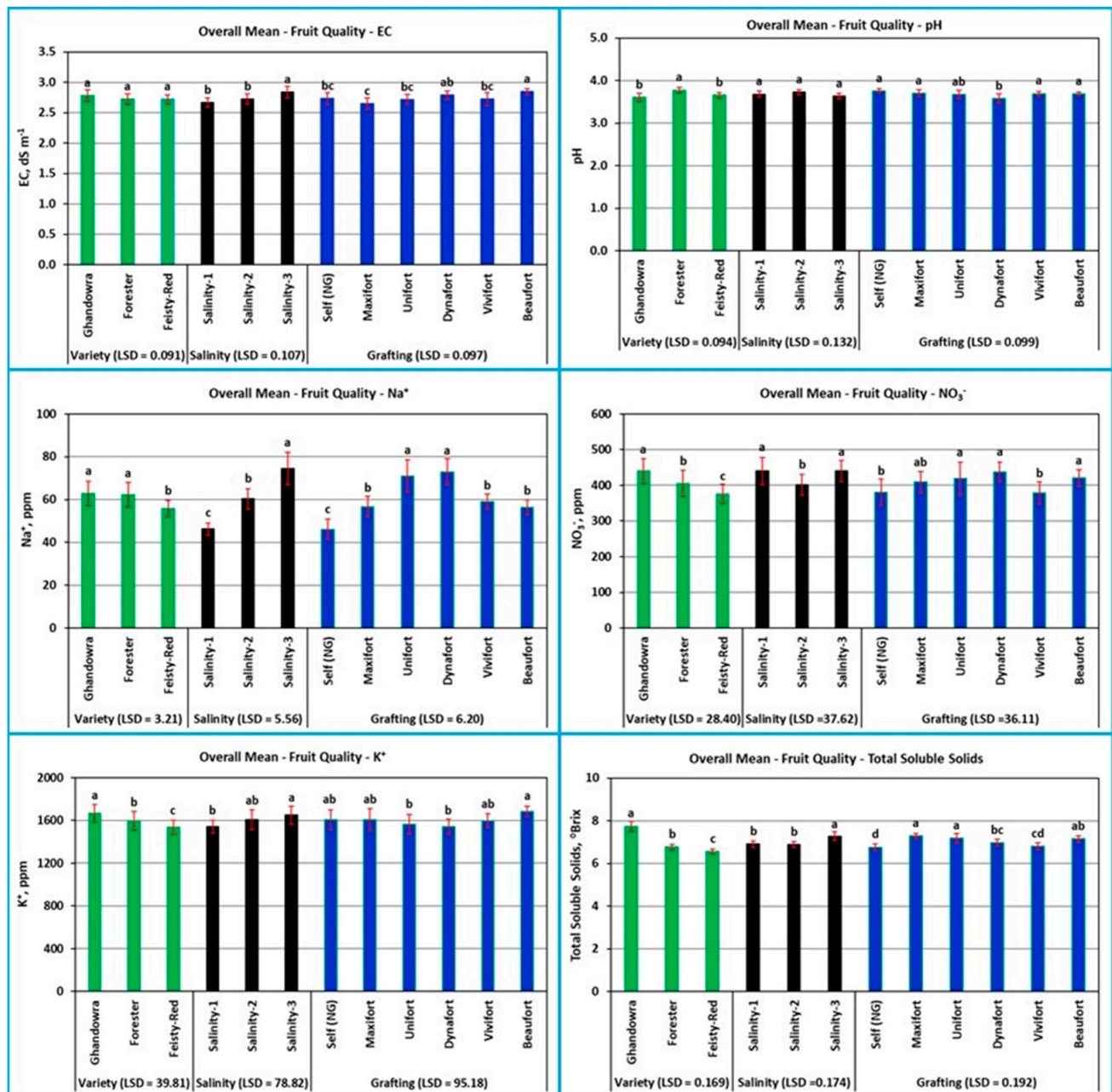


Figure 6. Responses of tomato fruit quality parameters to variety, salinity, and grafting. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

3.2.2. Salinity Level

The results of tomato fruit quality presented in Figure 6 indicated that increasing salinity concentration in the nutrient solution increased most tomato fruit quality characteristics. S-3 (9.5 dS m^{-1}) led to the highest values of nitrates (NO_3^- ; 440.2 ppm), sodium (Na^+ ; 74.5 ppm), potassium (K^+ ; 1650.0 ppm), EC (2.83 dS m^{-1}), and total soluble solids (TSS; 7.28°Brix), with significant differences when compared to both S-1: 2.5 dS m^{-1} (440.2 ppm , 46.2 ppm , 1540.7 ppm , 2.67 dS m^{-1} , 6.90°Brix) and S-2: 6.0 dS m^{-1} (401 ppm , 60.4 ppm , 1609.3 ppm ,

2.72 dS m⁻¹, 6.89 °Brix). However, no significant differences were recorded in the pH values of tomato fruits as a result of increasing salt concentrations in the nutrient solution. These results are consistent with Zhang et al. [16], who reported that adding an amount of salt to the nutrient solution improves the quality of tomato fruits. The same was reported by Helaly et al. [19], who reported that irrigating tomatoes with saline water resulted in a significant increase in total soluble solids and improved fruit quality, compared to the control. Although total tomato fruit production decreased with increasing irrigation water salinity, internal quality, characterized by taste and health-promoting compounds, such as total soluble solids and organic acids in tomato fruits, can be improved [18]. Similar results were reported by Savvas et al. [21], who reported that, with respect to fruit quality, salinity enhanced the titratable acidity, the total soluble solids, and the ascorbic acid concentrations. In contrast, Saleh et al. [25] reported that the essential nutrients in tomato fruits, such as N, K, Ca, and Mg, were decreased, while the total soluble solids (TSS) and Na contents were increased under saline conditions, compared to the non-saline control.

3.2.3. Grafting Rootstocks

The influence of grafting on tomato fruit quality is explained with the mean values of tomato fruit quality characteristics in Figure 6. These results indicated that grafting tomato plants induced significant increases in the EC, Na⁺, NO₃⁻, and TSS values of tomato fruits. However, there were no significant effects of the examined rootstocks on the values of pH and K⁺ of tomato fruits, compared to non-grafted plants. The same was reported by Rahmatian et al. [22], who reported that the contents of total soluble solids (TSS) increased in tomato fruits harvested from the grafted plants. Similar results were reported by Jafari and Jalali [23], who reported that the TSS concentration in tomato fruits at a salinity level of 8.3 dS m⁻¹ were significantly higher in grafted cultivars than non-grafted ones. These results are partially in agreement with Turhan et al. [8], who reported that no significant differences were recorded in pH between the fruits of grafted and non-grafted plants, and in contrast with their findings that fruit quality, measured in terms of the soluble solids concentration, was lower in fruits of grafted plants, compared to non-grafted plants. Also, these results are in contrast with Savvas et al. [21], who reported that grafting and rootstocks had no effects on any quality characteristics of tomato fruit.

3.2.4. Salinity–Variety Interaction

The interactive results of salinity and tomato variety on the quality of tomato fruits, presented in Figure 7, indicated that both EC and Na⁺ increased with the increased salt concentration in the nutrient solution. The combinations 2-1 (S-2 and Ghandowra-F1) and 3-2 (S-3 and Forester-F1) produced the highest EC values, with significant differences compared to other salinity–variety combinations. The highest Na⁺ values were recorded under salinity-3 for the three varieties, with significant differences compared to salinity-1 and salinity-2. However, the high pH values were recorded for the combinations of salinity-2 and tomato varieties, with the highest pH value (3.87) recorded for the combination of salinity-2 (6.0 dS m⁻¹) and Forester-F1. The salinity–variety interaction induced mixed results for the concentration of nitrates (NO₃⁻) in tomato fruits, with the highest values of 488.33 ppm and 478.9 ppm recorded for the combinations 2-1 (salinity-2 and Ghandowra-F1) and 3-2 (salinity-3 and Forester-F1), respectively.

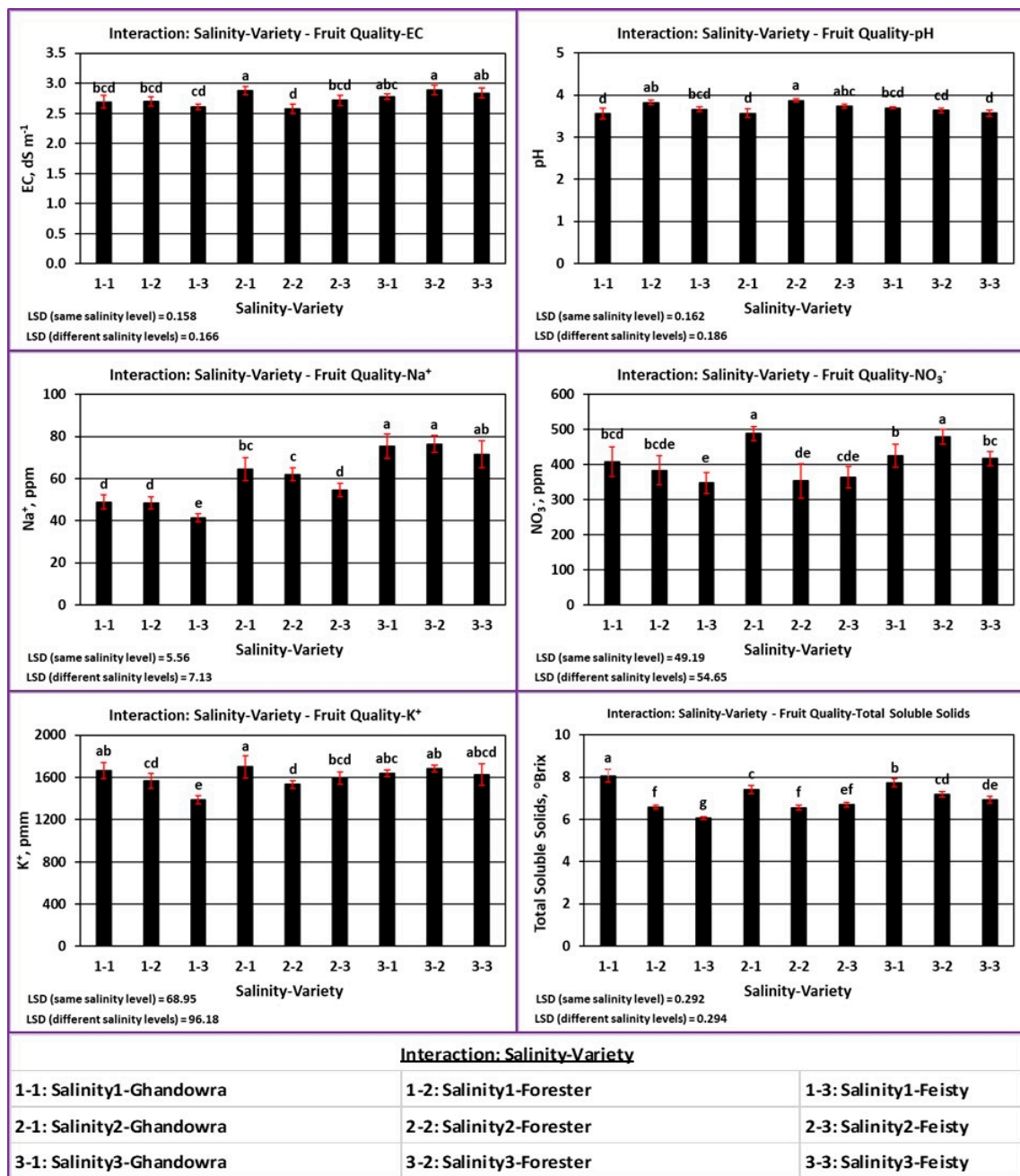


Figure 7. Response of tomato fruits' quality parameters to the interaction of salinity and variety. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

3.2.5. Salinity–Grafting Interaction

The salinity–grafting interactive influence on the quality characteristics of tomato fruits is shown in Figure 8. Different combinations of salinity and grafting rootstocks resulted in different EC values, with significant differences between them ($Pr > F = 0.0000$). The lowest EC values of 2.476, 2.523, and 2.518 dS m⁻¹ were recorded for the combinations 1-2 (S-1 and Maxifort), 2-2 (S-2 and Maxifort), and 2-3 (S-2 and Unifort), respectively. The highest EC values of 2.920 and 2.946 dS m⁻¹ were obtained for the combinations 2-1 (S-2 and non-grafted plants) and 3-2 (S-3 and Maxifort), respectively. What distinguished the pH results was that there were no significant differences between the different salinity–grafting combinations, except for the combination 3-4 (salinity-3 and Dynafort rootstock), which produced the low-

est pH value (3.43), with statistically significant differences from all other salinity-grafting combinations. It was found that all the studied rootstocks increased the Na^+ concentration in tomato fruits under all salinity levels, where Unifort (under salinities 1 and 2)) and Dynafort (under salinity-3) were associated with the highest Na^+ values, with significant differences compared to non-grafted plants. In general, the lowest and highest Na^+ values of 37.1 ppm and 94.4 ppm were recorded for the combinations 1-1 (salinity-1 and non-grafted plants) and 3-3 (salinity-3 and Unifort rootstock), respectively. The highest values of total soluble solids (TSS) were recorded for the combinations 1-2 (S-1 and Maxifort) and 3-2 (S-3 and Maxifort), respectively. Similar results were reported by Zaki et al. [17], who reported that the interaction between rootstocks and salinity levels significantly improved the TSS of tomato fruits under saline conditions, compared to non-grafted plants.

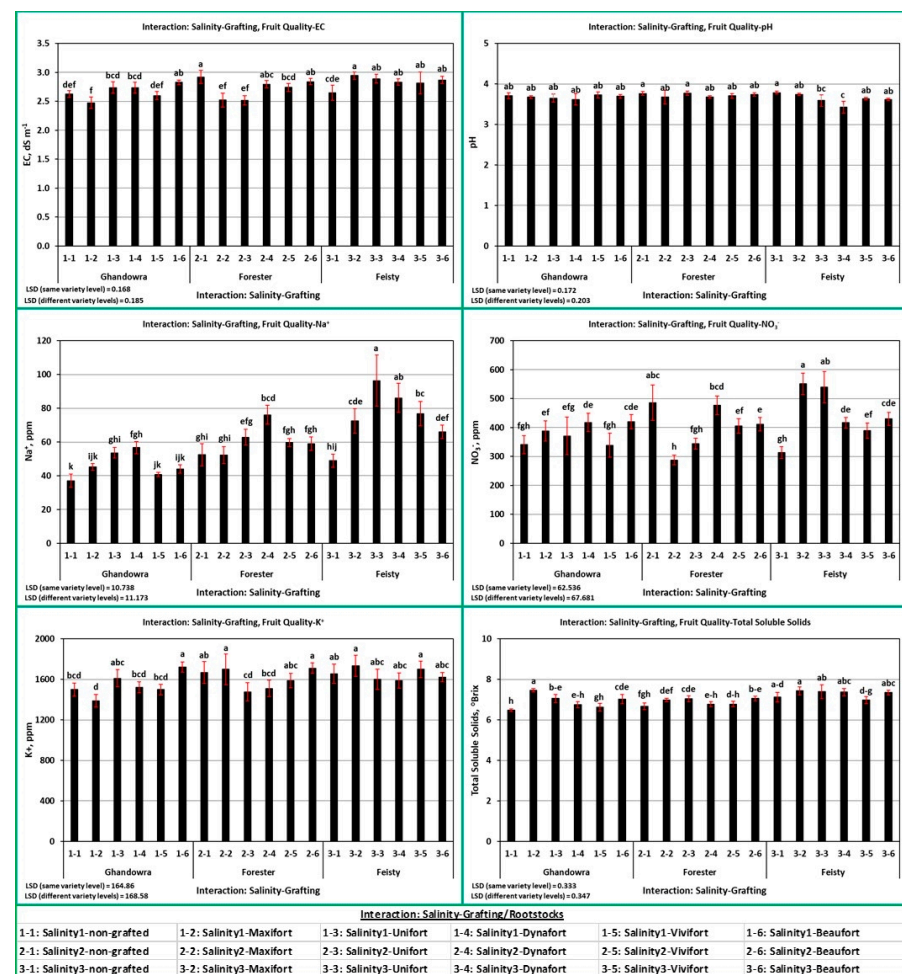


Figure 8. Response of tomato fruit quality to the interaction of salinity and rootstocks. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

3.2.6. Variety–Grafting Interaction

The interactive effects of tomato scions and rootstocks on the quality parameters of tomato fruit are shown in Figure 9. Except Unifort (for Ghandowra-F1) and Vivifort (for Forester-F1), all studied grafting rootstocks resulted in increased EC values, which were statistically significant for the Forester-F1 variety. In contrast, all the studied rootstocks resulted in significantly low EC values, compared to non-grafted plants. The combinations 1-3 (Ghandowra-F1 and Unifort), 2-1 (Forester-F1 and Scion), and 3-2 (Forester-F1 and Maxifort) produced the lowest EC values of 2.512, 2.500, and 2.461 dS m^{-1} , respectively. The studied rootstocks reduced the pH of tomato fruits for both Ghandowra-F1 and Forester-F1 varieties, with the lowest pH values of 3.46 and 3.64 recorded for the combinations 1-4 (Ghandowra-F1 and Dynafort) and 2-3 (Forester-F1 and

Unifort). For the Feisty-Red variety, the studied rootstock showed no significant influence on the pH values of tomato fruit. The results indicated that all the tested rootstocks increased the concentration of Na^+ in tomato fruits of the studied varieties, compared to non-grafted plants. The highest Na^+ values of 80.1, 79.0, and 70.4 ppm were recorded for the combinations 1-4 (Ghandowra-F1 and Dynafort), 2-3 (Forester-F1 and Unifort), and 3-3 (Feisty-Red and Unifort), respectively. On the average, grafting resulted in an increased concentration of nitrates (NO_3^-) in tomato fruits, with the highest values of 504.4, 472.2, and 428.9 ppm recorded for the combinations 1-4 (Ghandowra-F1 and Dynafort), 2-3 (Forester-F1 and Unifort), and 3-3 (Feisty-Red and Unifort), respectively. Grafting induced a significant increase in the total soluble solids (TSS) of tomato fruits for both the Ghandowra-F1 and Forester-F1 varieties, with the highest values of 8.4 and 7.0 °Brix for the combinations 1-2 (Ghandowra-F1 and Maxifort) and 2-3 (Forester-F1 and Unifort), respectively. The plants grafted onto the other two rootstocks produced higher yields only in comparison with the non-grafted plants, and the differences were significant only at low (Beaufort) or moderate (Resistar) salinity. Yield differences between grafting treatments at low and moderate salinities arose from differences between fruit numbers per plant, while mean fruit weight was not influenced by grafting or the rootstock [21].



Figure 9. Response of tomato fruit quality to the interaction of variety and rootstocks. Columns with different letters show significant differences according to LSD at $p \leq 0.05$. Bars represent standard error of means.

4. Conclusions

A glasshouse experiment was carried out to investigate the yield responses of grafted and non-grafted (self-rooted) tomato plants grown under three levels of water salinity (2.5, 6.0, and 9.5 dS m⁻¹). Three tomato varieties (Ghandowra-F1, Forester-F1, and Feisty-Red) were grafted onto five rootstocks (Maxifort, Unifort, Dynafort, Vivifort, and Beaufort). The obtained results are summarized below:

- Vivifort and Beaufort rootstocks performed better at improving tomato yield and are therefore suitable for grafting tomato plants grown under hydroponics at low (S-1: 2.5 dS m⁻¹) and moderate (S-2: 6.0 dS m⁻¹) salinities, respectively. However, no significant impact was recorded across the studied grafting rootstocks under high salinity (S-3: 9.5 dS m⁻¹).
- The results indicated that tomatoes can be grown successfully under hydroponic systems using a nutrient solution with a salinity level of up to 6.0 dS m⁻¹ without sacrificing fruit yield and quality.
- Among the studied tomato varieties, Feisty-Red was found to be the most appropriate for hydroponic production in terms of tomato fruit yield and quality.

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References

1. Rhoades, J.D.; Kandiah, A.; Mashali, A.M. *The Use of Saline Waters for Crop Production*; FAO Irrigation and Drainage Paper 48; Food and Agriculture Organization of the United Nations: Rome, Italy, 1992. Available online: https://www.ars.usda.gov/arsuserfiles/20361500/pdf_pubs/P1313.pdf (accessed on 26 March 2024).
2. Estañ, M.T.; Martinez-Rodriguez, M.M.; Perez-Alfocea, F.; Flowers, T.J.; Bolarin, M.C. Grafting raises the salt tolerance of tomato through limiting the transport of sodium and chloride to the shoot. *J. Exp. Bot.* **2005**, *56*, 703–712. [CrossRef] [PubMed]
3. Hu, B.; Bennett, M.A.; Kleinhenz, M.D. A New Method to Estimate Vegetable Seedling Vigor, Piloted with Tomato, for Use in Grafting and Other Contexts. *Hort Technol.* **2016**, *26*, 767–775. [CrossRef]
4. Zhou, Z.; Yuan, Y.; Wang, K.; Wang, H.; Huang, J.; Yu, H.; Cui, X. Rootstock-scion interactions affect fruit flavor in grafted tomato. *Hortic. Plant J.* **2022**, *8*, 499–510. [CrossRef]
5. Walubengo, D.; Orina, I.; Kubo, Y.; Owino, W. Physico-chemical and postharvest quality characteristics of intra and interspecific grafted tomato fruits. *J. Agric. Food Res.* **2022**, *7*, 100261. [CrossRef]
6. Loewen, D.E.; Pliakoni, E.D.; Rivard, C.L. Yield and Compatibility of Ten Tomato Scion Varieties Grafted with ‘Maxifort’ Rootstock. Urban Food Systems Symposium, October 7, 2020, Kansas State University, USA. Available online: <https://newprairiepress.org/ufss/2020/proceedings/23> (accessed on 20 March 2024).
7. Vanlay, M.; Samnang, S.; Jung, H.J.; Choe, P.; Kang, K.K.; Nou, I.S. Interspecific and Intraspecific Hybrid Rootstocks to Improve Horticultural Traits and Soil-Borne Disease Resistance in Tomato. *Genes* **2022**, *13*, 1468. [CrossRef]
8. Turhan, A.; Ozmen, N.; Serbeci, M.S.; Seniz, V. Effects of grafting on different rootstocks on tomato fruit yield and quality. *Hortic. Sci.* **2011**, *38*, 142–149. [CrossRef]
9. Singh, H.; Kumar, P.; Chaudhar, S.; Edelstein, M. Tomato Grafting: A Global Perspective. *Hortscience* **2017**, *52*, 1328–1336. [CrossRef]
10. Singh, S.; Kumar, P.; Kumar, A.; Kyriacou, M.C.; Colla, G.; Roupahel, Y. Grafting tomato as a tool to improve salt tolerance. *Agron. J.* **2020**, *10*, 263. [CrossRef]

11. World Bank Frontier Agriculture as a Solution to Improve Refugee Livelihoods: Unleashing, Climate-Smart; Water-Saving Agriculture Technologies in, M.E.N.A. Report No: AUS22794, GWA05 Middle East and North Africa, 19 September 2017. Available online: <http://documents.worldbank.org/curated/en/103361524057787356/pdf/RWSAT-AUS.pdf> (accessed on 15 March 2024).
12. Suresh, K.; Satish, K.; Jawahar, L. Assessing Opportunities and Difficulties in Hydroponic Farming. *Bhartiya Krishi Anusandhan Patrika* **2023**, *38*, 56–64. [\[CrossRef\]](#)
13. Ingram, T.W.; Sharpe, S.; Trandel, M.; Perkins-Veazie, P.; Louws, F.J.; Meadows, I. Vigorous rootstocks improve yields and increase fruit sizes in grafted fresh market tomatoes. *Front. Hortic.* **2022**, *1*, 1091342. [\[CrossRef\]](#)
14. Hochmuth, G.J.; Hochmuth, R.C. Nutrient Solution Formulation for Hydroponic (Perlite, Rockwool, NFT) Tomatoes in Florida. University Florida, IFAS Extension, Publication #HS796. 2018. Available online: <https://edis.ifas.ufl.edu/pdf/CV/CV216/CV216-2297144.pdf> (accessed on 10 March 2024).
15. Voutsela, S.; Yarsi, G.; Petropoulos, S.A.; Khan, E.M. The effect of grafting of five different rootstocks on plant growth and yield of tomato plants cultivated outdoors and indoors under salinity stress. *Afr. J. Agric. Res.* **2012**, *7*, 5553–5557.
16. Zhang, P.; Senge, M.; Dai, Y. Effects of salinity stress on growth, yield, fruit quality and water use efficiency of tomato under hydroponics system. *Rev. Agric. Sci.* **2016**, *4*, 46–56. [\[CrossRef\]](#)
17. Zaki, M.E.; Salem, A.A.; Eid, S.M.; Glala, A.A.; Saleh, S.A. Improving Production and Quality of Tomato Yield under Saline Conditions by using Grafting Technology. *Int. J. Chem. Tech. Res.* **2015**, *8*, 111–120. Available online: [https://sphinxsai.com/2015/ch_vol8_no12/1/\(111-120\)%20V8N12CT.pdf](https://sphinxsai.com/2015/ch_vol8_no12/1/(111-120)%20V8N12CT.pdf) (accessed on 20 March 2024).
18. Krauss, S.; Schnitzler, W.H.; Grassmann, J.; Woiatke, M. The Influence of Different Electrical Conductivity Values in a Simplified Recirculating Soilless System on Inner and Outer Fruit Quality Characteristics of Tomato. *J. Agric. Food Chem.* **2005**, *54*, 441–448. [\[CrossRef\]](#)
19. Helaly, A.A.; Goda, Y.; Abd-El-Rehim, A.S.; Mohamed, A.A.; ElZeiny, O.A.H. Effect of irrigation with different levels of saline water type on husk tomato productivity. *Adv. Plants Agric. Res.* **2017**, *6*, 114–120. [\[CrossRef\]](#)
20. Soare, R.; Dinu, M.; Babeanu, C. The effect of using grafted seedlings on the yield and quality of tomatoes grown in greenhouses. *Hortic. Sci.* **2018**, *45*, 76–82. [\[CrossRef\]](#)
21. Savvas, D.; Savva, A.; Ntatsi, G.; Ropokis, A.; Karapanos, I.; Krumbein, A.; Olympios, C. Effects of three commercial rootstocks on mineral nutrition, fruit yield, and quality of salinized tomato. *J. Plant Nutr. Soil. Sci.* **2011**, *174*, 154–162. [\[CrossRef\]](#)
22. Rahmatian, A.; Delshad, M.; Salehi, R. Effect of grafting on growth, yield and fruit quality of single and double stemmed tomato plants grown hydroponically. *Hortic. Environ. Biotechnol.* **2014**, *55*, 115–119. [\[CrossRef\]](#)
23. Jafari, P.A.H.; Jalali, A.H. The use of grafting to improve salt tolerance of tomato in hydroponic conditions. *J. Sci. Technol. Greenh. Cult.* **2012**, *3*, 67–76. Available online: <https://jspi.iut.ac.ir/article-1-392-en.pdf> (accessed on 15 March 2024).
24. Grieneisen, M.L.; Aegerter, B.J.; Scott Stoddard, C.; Zhang, M. Yield and fruit quality of grafted tomatoes, and their potential for soil fumigant use reduction. A meta-analysis. *Agron. Sustain. Dev.* **2018**, *38*, 29. [\[CrossRef\]](#)
25. Saleh, S.; Liu, G.; Liu, M.; Liu, W.; Gruda, N.; He, H. Reducing the salinity impact on soilless culture of tomatoes using supplemental Ca and foliar micronutrients. *Acta Sci. Pol. Hortorum. Cultus* **2019**, *18*, 187–200. [\[CrossRef\]](#)

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