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Effect of Tomato Grafting onto Novel and Commercial Rootstocks on Improved Salinity Tolerance and Enhanced Growth, Physiology, and Yield in Soilless Culture

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Abstract: Grafting high-yielding tomato varieties onto stress-tolerant rootstocks can mitigate the adverse effects of saline water irrigation on plant tomato productivity in arid regions like Saudi Arabia. This study investigates the efficacy of grafting tomatoes onto both novel and commercial rootstocks to enhance salinity tolerance and its impact on growth, physiological parameters, and yield in a soilless culture system. The experiment involved two water quality levels, 2 (S1) and 4 (S2) dS m^{-1}, two growth media types, volcanic rock (M1) and sand (M2), and six grafting treatments: Tone Guitar F1 non-grafted (G1) (commercial scion), grafted onto itself (G2), Tone Guitar F1* Maxifort F1 (G3) (commercial rootstock), and grafting the scion onto three novel rootstocks, X-218 (G4), X-238 (G5), and Alawamiya365 (G6). Growth, physiology, photosynthetic pigments, and yield improved with lower salinity (2 dS m^{-1}) in volcanic rock and with the grafting treatments (G2–G6) compared to the non-grafted treatment (G1). The best results were achieved with the S1M1G5 treatment, where yield increased by 53% compared to the lowest yield in non-grafted plants grown in sand under higher salinity (S2M2G1). All studied traits were adversely affected under high salinity (S2) in sandy media, with the G1 treatment resulting in the lowest values for these traits.

Keywords: grafting; abiotic stress; salt; novel rootstock; soilless culture; tomato; growth; physiological; yield

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1. Introduction

The tomato plant (*Solanum lycopersicum* Mill.) belongs to the family Solanaceae. Tomatoes rank as the most cultivated vegetable crop globally, with significant demand in Saudi Arabia, necessitating high yields to address growing food security concerns. Tomatoes are grown annually for fresh consumption and processing [1]. Tomatoes are abundant in lycopene, phenolics, and flavonoids, which act as chemoprotective agents and provide primary protection against chronic diseases. They also have high concentrations of minerals and antioxidants [2]. Tomatoes are grown on about 5 million hectares of land worldwide, yielding an average of 36.98 tons of fruit per hectare. In 2021, global tomato production reached 189 million tons [3]. In 2022, Saudi Arabia dedicated approximately 15.208 hectares of land to cultivating tomatoes, producing 658.540 thousand tons. Protective cultivation contributed around 284.981 thousand tons to this production, accounting for 43.3% of the national tomato production [4].

There has been an increase in the use of saline water for agricultural irrigation in arid regions with limited freshwater resources. Saudi Arabia has limited freshwater supplies. We hypothesize that grafting high-yielding cultivars onto stress-tolerant rootstocks offers a potential solution to reduce losses caused by abiotic stress factors brought on by brackish water irrigation [5]. Furthermore, the detrimental effects of salinity lead to significant risks to tomato production [6], resulting in substantial declines in crop growth and yield [7]. Most commercially grown tomato varieties are classified as moderately susceptible to salt stress, impacting crucial developmental stages like seed germination, vegetative growth, and reproductive processes [1,5,6]. While concerted efforts have been directed toward enhancing tomato salt tolerance through plant breeding, biotechnological interventions, and agronomic practices, progress remains limited due to the inherent complexity of salt tolerance traits at both the genetic and physiological levels [8]. While grafting is an effective way to minimize salinity issues, particularly in dry regions, the complicated process of salt tolerance genetic development has not advanced as much as anticipated in recent decades, where increasing salt tolerance through plant breeding is difficult due to the intricate relations between the various traits, their quantitative nature, epistatic gene action, low to moderate heritability, and increased sensitivity to environmental factors [9,10]. Although genetic engineering has demonstrated potential in enhancing salt tolerance in plants [7,11], its practical feasibility for commercial applications is still to be fully realized.

Crops exposed to salinity stress experience detrimental effects through two main mechanisms: (1) osmotic stress due to elevated solute concentrations in the rhizosphere, primarily Na^+ and Cl^-, which impede water uptake and stomatal conductance, leading to decreased transpiration rates and (2) increasing ion toxicity from excess ionic strength, predominantly Na^+ and Cl^-, which disrupts physiological functions and cellular homeostasis, consequentially affecting crop productivity [12,13]. There is increasing pressure on agricultural productivity due to urbanization, water shortages, and climate change, along with projections by the United Nations indicating that the world's population will rise from 7.79 billion to 9.77 billion by 2050 [14]. Various approaches have been proposed to address this multifaceted challenge, including sustainable intensification, which aims to enhance agricultural productivity within environmental constraints. As demonstrated, protected soilless culture systems (SCS) are one of the strategies to maximize production efficiency while minimizing environmental impact.

Using indigenous genetic resources to choose suitable rootstocks is expected to address specific localized issues and be more beneficial than imported cultivars. Local cultivars are naturally suited to local environmental conditions due to adaptation through selection pressures. Moreover, the significant price difference for hybrid types emphasizes the financial benefits of using local counterparts [15,16]. Furthermore, choosing of rootstocks that can withstand salt can be an essential strategy for improving salt tolerance [17]. Through grafting, natural genetic diversity with particular root features can be efficiently harnessed [18]. Several wild tomato/Solanum species, such as *S. cheesmaniae*, *S. chmielewskii*, *S. habrochaites*, *S. pennellii*, *S. pimpinellifolium*, and *S. peruvianum*, are salt tolerant [9,19]. It is challenging to transfer salt-tolerant genes from wild tomato cultivars to cultivated tomato cultivars because of crossing incompatibilities and linkage drag [9]. These wild species may be used as salt-resistant rootstocks to transplant commercial tomato cultivars that are susceptible but yield high quantities. In contrast to tomatoes cultivated commercially (*S. lycopersicum*), these often do not contain harmful ions [20].

The grafting technique offers a promising solution for saline stress in arid environments. Numerous studies have demonstrated the advantages of grafting tomatoes, as it facilitates the harmonious combination of desirable traits. Grafting involves the union of preferred characteristics, allowing for increased overall salt tolerance. This is achieved by grafting high-yielding or high-quality cultivars susceptible to salinity stress onto salt-tolerant rootstocks possessing robust root systems. Notably, it has been proposed that utilizing genotypes with salt-tolerant traits as rootstocks is a viable approach to enhancing the salt resistance of tomato plants [21].

Turhan et al. [22] found that grafted tomato plants produced much more than non-grafted controls, particularly in greenhouse environments. Similarly, Öztekin et al. [23] mentioned that grafting can increase tomatoes' water-use efficiency and salinity tolerance; it is also a valuable technique for improving the productivity of vegetable crops, including tomatoes [24].

Soilless cultivation techniques have increased significantly in global vegetable production over the past five decades [25,26]. Furthermore, this method allows for the efficient and intensive maintenance of plant production [27]. It is more manageable and offers a superior growing media to traditional soil cultivation [28,29]. Standard solid media used in hydroponics to support plants include sand, gravel, rock wool, peat moss, sawdust, coconut fiber, vermiculite, and perlite [30,31]. This study utilized volcanic rock and sand as the growth media due to their abundant presence and economic feasibility in Saudi Arabia. The study's main objective is to assess various rootstocks of local tomatoes and the novel hybrids' potential as rootstocks alongside commercial varieties and their capacity to withstand salinity stress under soilless conditions.

2. Materials and Methods

2.1. The Location of the Experiments

A greenhouse experiment was conducted from November 2022 to June 2023 at the National Centre for Agricultural and Livestock Research farm (latitude 24°201 N and longitude 47°382 E, with an average elevation of 438 m above sea level), situated approximately 117 km south of Riyadh city in Saudi Arabia's Al-Kharj Region (Figure 1).

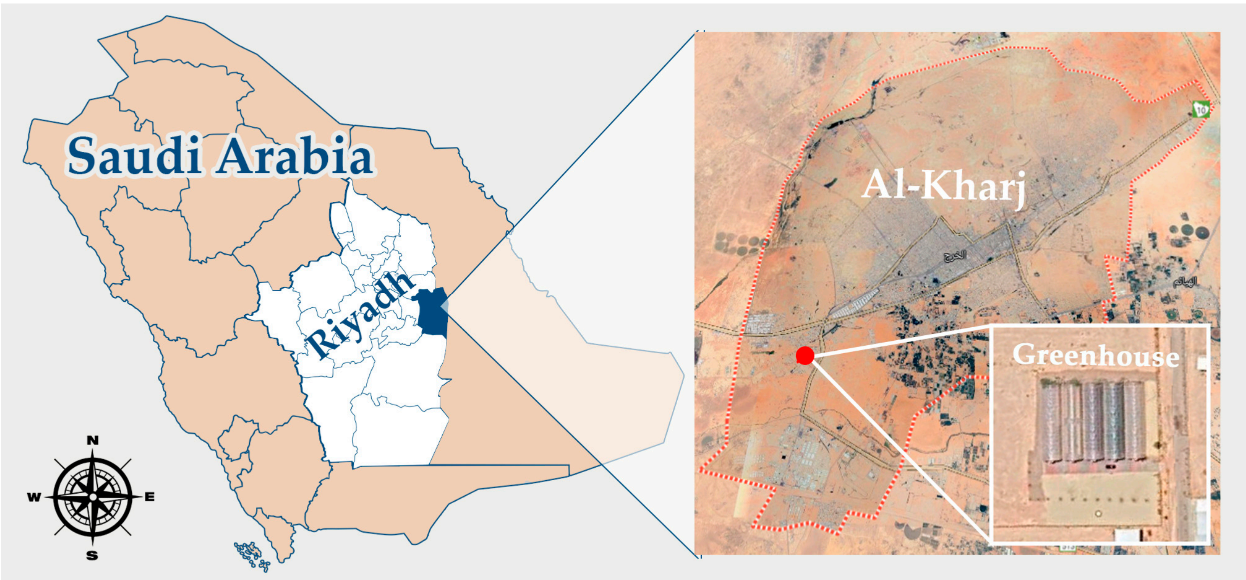


Figure 1. Al-Kharj Governorate, Riyadh, Saudi Arabia (location of the experiment).

2.2. Experimental Design and Treatment Distribution

The experiment was a factorial experiment with three factors arranged in a randomized complete block design (RCBD) with three replications. The experiment had 72 experimental units (two types of irrigation water salinity × two growth media × six grafting treatments [five grafting treatments and the control] × three replications) comprising 24 treatments.

- Factor 1: Irrigation Water Salinity
  Two salinity levels are used
  1. EC2 (2 dS m^{-1}, non-saline): achieved with a standard nutrient solution and desalinated water, considered ideal for tomato growth [32].

2. EC4 (4 dS m^{-1}, saline): obtained by adding NaCl to the standard solution, inducing salt stress in tomatoes [33].
   Treatments are applied weekly after transplanting to the greenhouse.

- Factor 2: Growth Media
  Volcanic rock and sand are used as the growing substrate. These materials are chosen for their cost-effectiveness and availability in Saudi Arabia.
- Factor 3: Grafting Treatments
  Involves six grafting treatments, including the commercial tomato variety Tone Guitar F1 (Seminis company—St. Louis, MI, USA) as the scion. This variety is commonly cultivated in greenhouses in Saudi Arabia (KSA). Tone Guitar F1 was subjected to grafting into four different rootstocks, including the local variety Alawamiya365, sourced from the Seed Centre and the Plant Genetic Assets Bank of the Ministry of Environment, Water, and Agriculture in Saudi Arabia. Additionally, X-218 and X-238 were obtained from the King Abdullah University of Science and Technology in Saudi Arabia and are interspecific hybrids between *Solanum lycopersicum* and *S. pimpinellifolium*, along with the commercial variety Maxifort F1 (De Ruiter—Bleiswijk, The Netherlands). Furthermore, Tone Guitar F1 was self-grafted, while a control group consisted of non-grafted plants.

The experiment consists of six doubled rows, with twelve individual rows. Every three consecutive rows were filled with growth media from the selected media. The experimental unit comprises five Dutch Buckets with dimensions of 23 × 31 × 25 cm (five plants) distributed randomly across the experimental sectors involving different factors. The spacing between each plant and its neighboring plant was 40 cm, and there was a 1 m gap between each row, as illustrated in (Figure 2).

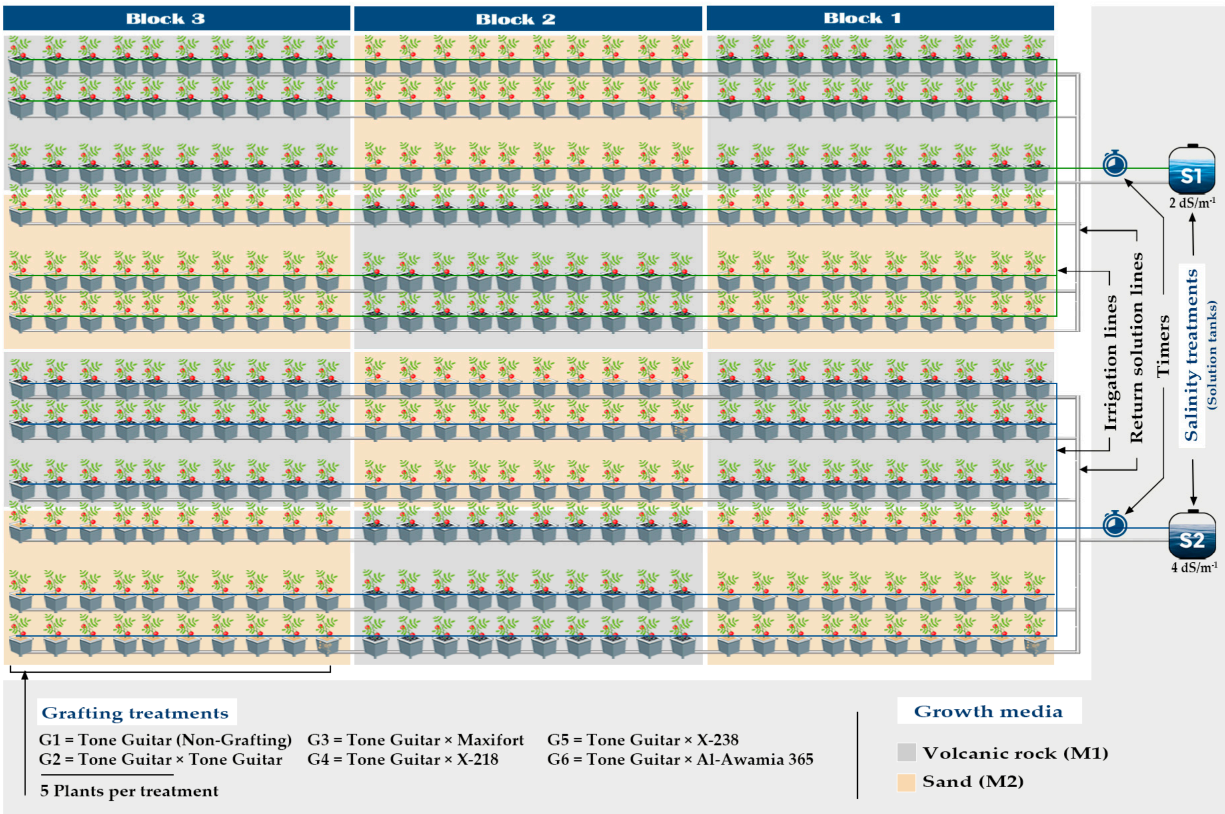


Figure 2. Diagram showing the design and layout of the experiment and treatment randomization.

2.3. Plant Grafting

To ensure the successful grafting process, it is crucial to have equal stem diameters between the rootstock and scion plants, as stated in [34]. A preliminary experiment was conducted to assess the germination rates, revealing that local rootstock varieties (Alawamia365, X-218, and X-238) have a slower germination rate compared to Maxifort F1 and Tone Guitar F1, which are used as scions [35]. It was observed that rootstock cultivars generally exhibit slower germination compared to scion cultivars. As a result, the seeds of the local rootstock varieties were sown in a polycarbonate-covered greenhouse on 29 November 2022. Five days later, the seeds of the commercial rootstock (Maxifort F1) were sown, followed by the planting of scion seeds (Tone Guitar F1) three days after that.

Jiffy-7 (Jiffy Company—Zwijndrecht—The Netherlands) discs were utilized for planting the seedlings and once they reached approximately 10 cm in height, they were transplanted into 9 cm pots filled with peat moss. On December 15, when the tomato seedlings had developed their third and fourth true leaves, seedlings with matching stem diameters were selected for grafting. The tube grafting technique, known for its ease of application to crops of the Solanaceae family, was employed [36].

The stems of the scion and rootstock were prepared according to the grafting technique commonly employed in tomato grafting, as described by Bie Zhi Long et al. [37]. This involved cutting the scion's upper part and the rootstock's lower part. The grafting clip was then secured onto the rootstock to join the two pieces (Figure 3). Once the seedlings were grafted, they were placed in a controlled healing environment with specific conditions: a temperature of 23 °C, relative humidity of 80%, and 45% shade, as mentioned in references [38,39]. The seedlings were left in the healing chamber for 10 days to recover fully, taking into account the steps and methods to ensure their recovery, as mentioned in Bie Zhi Long et al. [37].

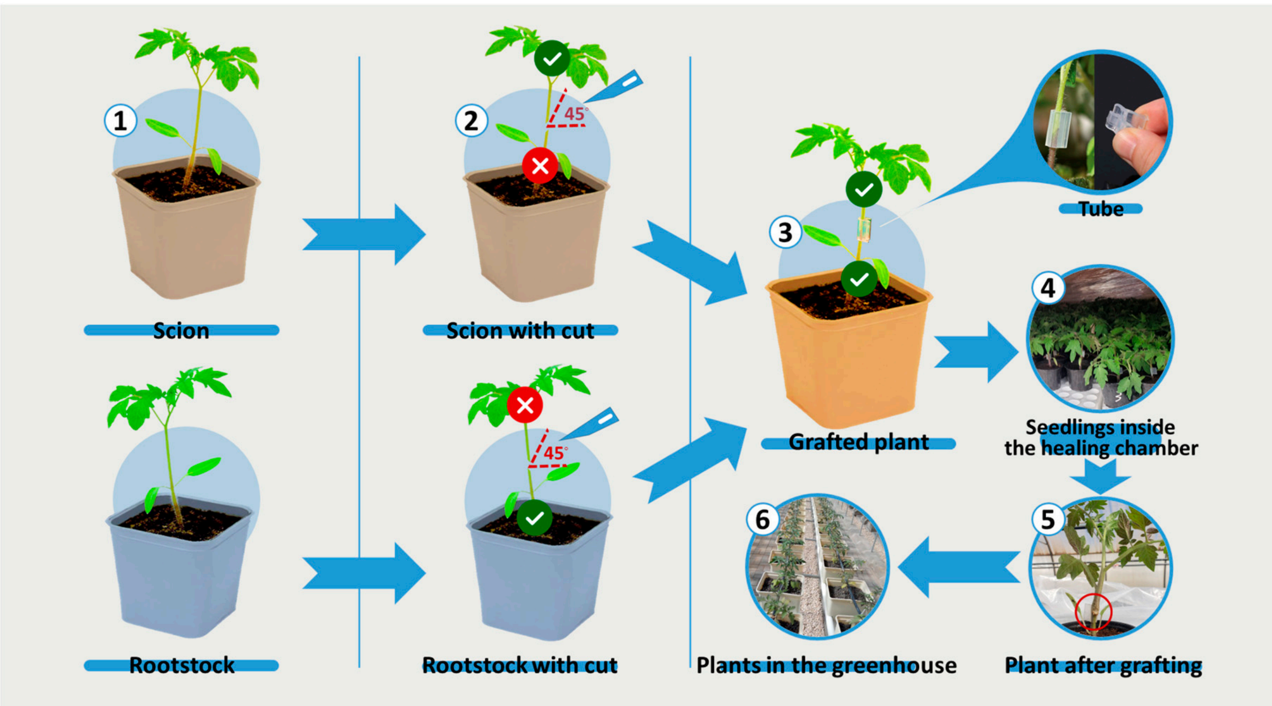


Figure 3. An illustration of the tomato grafting method, often referred to as "tube grafting" or "splice grafting".

2.4. Plant Transplanting and Experimental Site Preparation

The experimental site was prepared by arranging Dutch Bucket pots above drainage pipes (3 inches). A drip irrigation system was installed using 16 mm GR pipes, which delivered a flow rate of 4 L per hour (L/H). Additionally, two 1000 L irrigation tanks were set up and connected to the irrigation network, controlled by digital timers (Model EMT769A—Brand GAO—Chinese-made). The growth media from local suppliers consisted of volcanic rock and sand. The sand was carefully sifted to obtain the largest grain size and underwent multiple washes. It was then sterilized using a broad-spectrum viral–bacterial–fungal disinfectant called Virkon S to clean the growth medium. Subsequently, the Dutch Buckets were filled with the prepared growth media.

On 8 January 2023, vigorous seedlings with a uniform size of six leaves were carefully chosen from the grafted seedlings. These selected seedlings were transplanted into the dedicated greenhouse for the experiment, where the relative humidity was maintained at 75%. The temperature was adjusted to 25 ± 2 °C during the day and 20 ± 2 °C at night.

2.5. Irrigation Water and Nutrient Solutions

Water with suitable electrical conductivity (EC = 0.4 dS m^{-1}) for tomato irrigation was produced at the research site's desalination plant. The nutrient solution was prepared according to Cooper [40], with periodic measurements of EC and pH.

2.6. The Vegetative Characteristics

Measurements of various parameters were initiated 60 days after transplanting.

2.6.1. Determination of Growth and Physiological Parameters

Growth Parameters

Plant growth characteristics were assessed by measuring plant height in meters, stem diameter using a digital vernier caliper, and leaf area with a portable area meter (Model LI-3000A-LI-COR Company-Lincoln, NE-USA). Additionally, the fresh weight of the leaves was recorded using a digital scale. Subsequently, the leaves were dried in a forced-air oven at 70 °C until their weight stabilized, and their final dry weight was measured.

Physiological Parameters

- Leaf gas exchange: In each treatment, three plants were randomly selected from each replication. From each plant, a single upper leaf was chosen for gas exchange measurements (photosynthesis, stomatal conductance, and transpiration rate) between 9:00 a.m. and 11:00 a.m. using a portable photosynthesis system (LI-COR 6400, Lincoln, NE, USA) equipped with a reading arm.
- Proline: For the exact number of plants and leaves in each treatment and from each replication, we determined the proline content using the ninhydrin acid method according to Clausen [41].
- Leaf relative water content: Portions of plant leaves were collected to assess leaf relative water content (LRWC). The procedure involved taking fresh weight measurements of leaf samples and immersing them in distilled water for 4 h to obtain the turgid weight. Subsequently, the samples were dried in an oven at approximately 85 degrees Celsius until a stable weight was achieved. Leaf relative water content was computed using the formula specified in [42].

$$LRWC = \frac{fresh\ weight - dry\ weight}{turgid\ weight - dry\ weight} \times 100 \quad (1)$$

2.6.2. Determination of Yield and Photosynthetic Pigments

The fresh tomato yield (t ha^{-1}) was recorded. The number of fruits on each plant was also recorded.

To estimate chlorophyll a, b, and total chlorophyll, three randomly chosen plants from each treatment and each replication with three leaves were taken. 0.05 g of fresh leaf sample was weighed, collected, and put into test tubes of size 15 mL with 10 mL of acetone at a concentration of 80%. It was wrapped in aluminum foil and stored in a dark place for seven to ten days. The absorption was measured at wavelengths of 663 for chlorophyll a and 645 for chlorophyll b with the use of a device (UV-6705, Spectrophotometer, Jenway Co., Staffordshire, UK); then, chlorophyll a, chlorophyll b, and total chlorophyll concentrations were calculated according to Equations (2)–(4).

$$Chlorophyll\ a = \frac{[(12.7 \times O.D\ 663) - (2.69 \times O.D\ 645)] \times V}{1000 \times W} \quad (2)$$

$$Chlorophyll\ b = \frac{[(22.9 \times O.D\ 645) - (4.68 \times O.D\ 663)] \times V}{100} \quad (3)$$

$$Total\ Chlorophyll = \frac{[(20.2 \times O.D\ 645 + (8.02 \times O.D\ 663)] \times V}{1000 \times W} \quad (4)$$

O.D. is the extract's optical density at the shown wavelength. *V* is the extract's volume (mL). *W* is the fresh weight of leaves (g) [43].

2.7. Statistical Analysis

The data were analyzed via the Statistix 8 software to perform an analysis of variance (ANOVA) and compare the means using the least significant difference (LSD) for determining the statistical significance of differences among the main components at a confidence level of 0.05, according to Steel and Torrie [44]. A randomized complete block design (RCBD) with three replications was used to carry out a three-factor experiment. The experimental treatments were distributed using a formula: two types of irrigation water salinity, two growth media, six grafting, and three replications.

3. Results

3.1. Growth Media and Rootstock Type Influence Vegetative Growth of Tomato Plants

Salinity level (S2) negatively affected the morphological traits of tomato plants (plant height, stem diameter, leaf area index, leaf fresh weight, leaf dry weight, and leaf relative water content (LRWC)) (Figure 4). Cultivation in sand (M2) significantly decreased most morphological characteristics due to the decreased porosity of the media compared with volcanic rock (M1).

Growth traits were significantly enhanced in salinity and growth media in grafted plants compared to non-grafted plants (G1). Across all growth media, the grafting treatment G5 produced the most outstanding results. The rootstock employed in said treatment arose from a cross between *S. lycopersicum* and its wild relative *S. pimpinellifolium*, which is known for its salinity tolerance.

Furthermore, self-grafted plants (G2) showed improved growth traits in both growth media and under salt stress compared to non-grafted plants (Figure 4). Most commercial rootstocks are interspecific hybrids of tomato and wild relative species; in the case of Maxifort F1 (G3), the parental species are *S. lycopersicum* and *S. habrochaites*, while X-218 (G4) and X-238 (G5) are hybrids of *S. lycopersicum* and different accessions of *S. pimpinellifolium.* From the three scion/rootstock combinations, grafting to rootstock G5 enhanced the vegetative development characteristics in both growth media (M1 and M2) at low salinity (S1). Under salt stress (S2), the grafting combination G5 was also the best performer in both growth media.

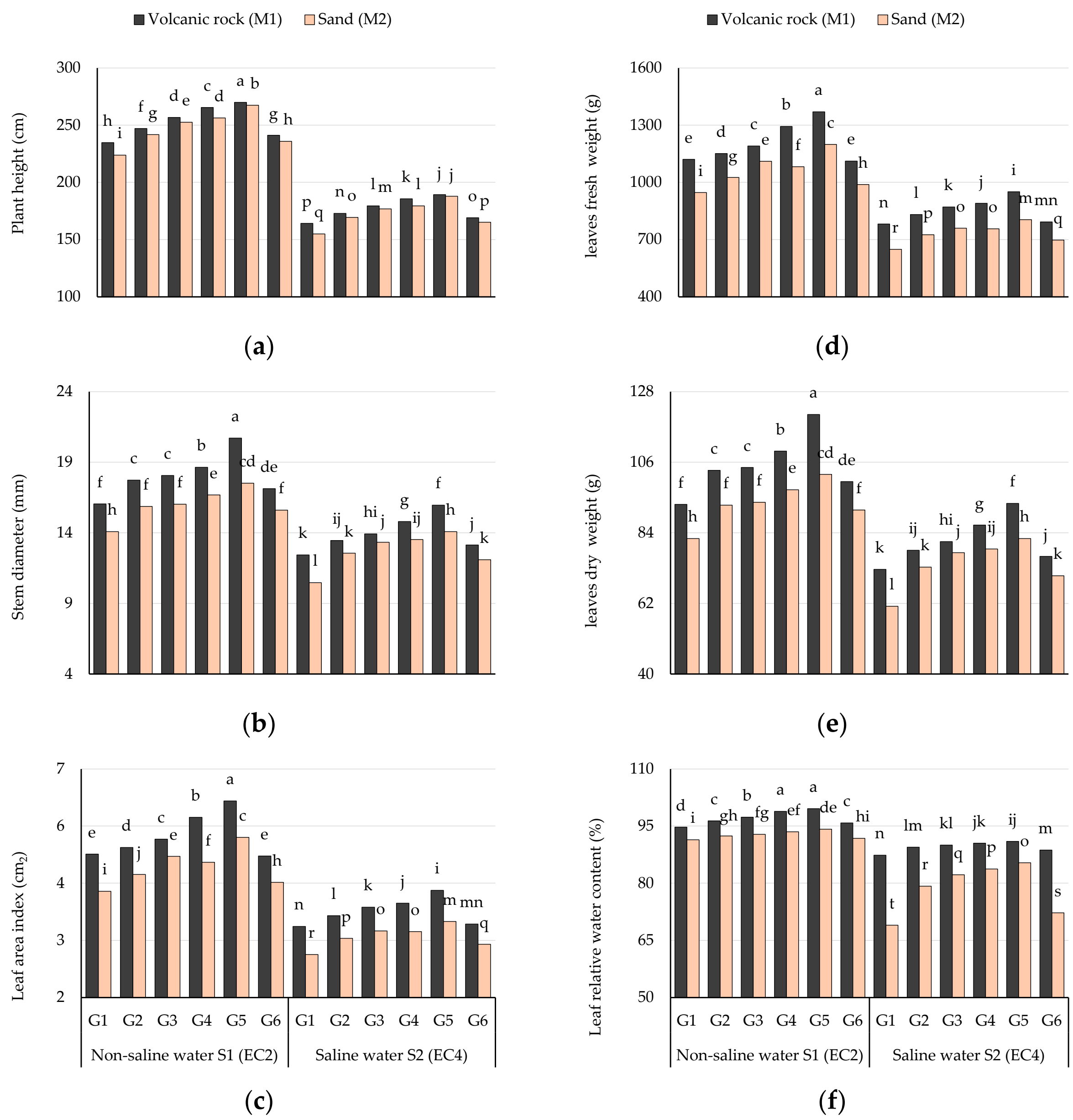


Figure 4. Interaction effects between salinity (S), growth media (M), and grafting (G) on tomato plant morphological traits such as plant height (**a**), stem diameter (**b**), leaf area index (**c**), leaves fresh weight (**d**), leaves dry weight (**e**), and leaf relative water content (**f**). Means followed by the same letter are not significantly different at a 0.05 probability level.

3.2. Growth Media and Rootstock Type Influence Physiological Processes of Tomato Plants

Plants grown in volcanic rock (M1) exhibited overall improved photosynthesis, conductivity, and transpiration compared to the plants grown in sand (M2) (Figure 5).

Photosynthesis, conductivity, and transpiration were better in grafted plants than non-grafted plants (G1) across all growth media. Plants grafted to rootstock G5 showed significantly superior characteristics to the other grafted combinations.

Grafting improved the leaf gas exchange traits (photosynthesis, conductivity, and transpiration rate) under both salinity levels (S1 and S2) (Figure 5). However, the growth medium M2 adversely influenced the plants compared to the growth medium M1.

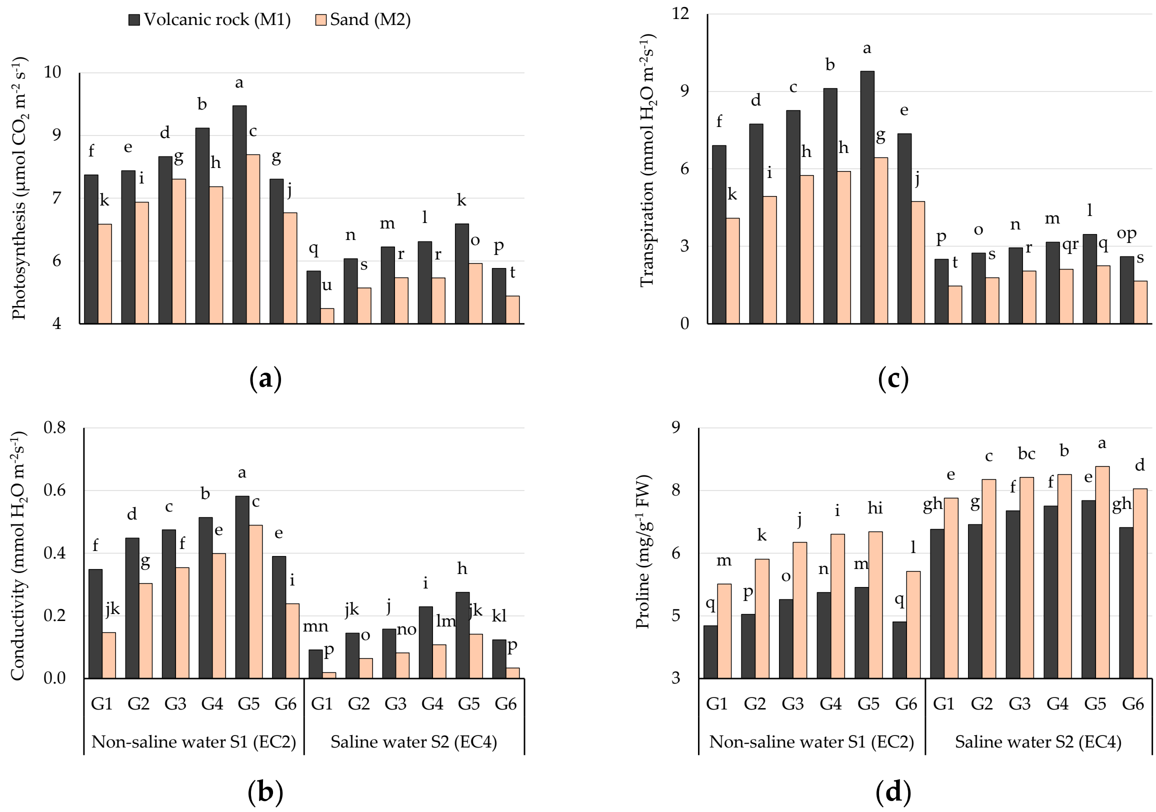


Figure 5. Interaction effects between salinity (S), growth media (M), and grafting (G) on tomato plant physiological traits such as photosynthesis (**a**), conductivity (**b**), transpiration (**c**), and proline content (**d**). Means followed by the same letter are not significantly different at a 0.05 probability level.

3.3. Growth Media and Rootstock Type Influence the Photosynthetic Pigment Production in Tomato Plants

The nutrient solution salinity (S2) decreased photosynthetic pigments, encompassing chlorophyll a and b, and total chlorophyll in the tomato plant leaves.

The decrease was more pronounced in plants grown in sand (M2), even in nutrient solution salinity S1. The grafting treatment G5 in the growth medium M1 under the salinity level S1 increased photosynthetic pigments in tomato plant leaves, including chlorophyll a, chlorophyll b, and total chlorophyll.

Meanwhile, non-grafted plants (G1) grown in the growth medium M2 and the salinity level S2 showed a decrease in photosynthetic pigments (Figure 6a–c).

3.4. Growth Media and Rootstock Type Influence Yield Characters in Tomato Plants

Self-grafted plants and plants grafted onto other rootstocks (G2–G6) showed significant enhancements in crop characteristics, particularly in fruit number and overall yield, compared to the non-grafted plants (G1). The G5 rootstock showed the best result for productivity characteristics compared to other rootstocks in this study (Figure 7a,b).

Grafting treatment G5 in volcanic rock (M1) under non-saline water (S1) resulted in the highest fruit number/plant (Figure 7a) and highest average yield (169.4 t ha^{-1}), exceeding the lowest value (80.2 t ha^{-1}) by 52.65% when using grafting treatment G1 with S2M2 (Figure 7b).

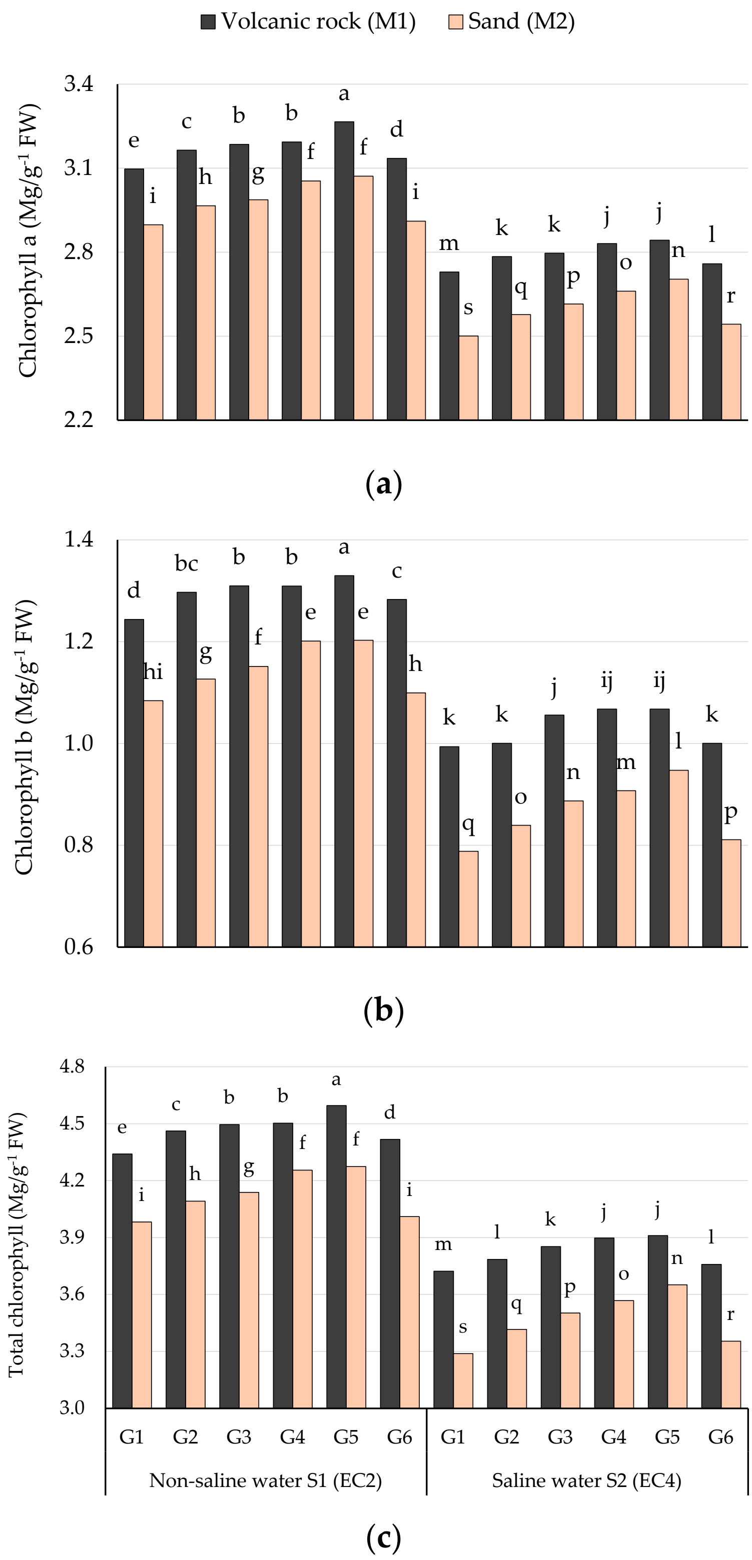
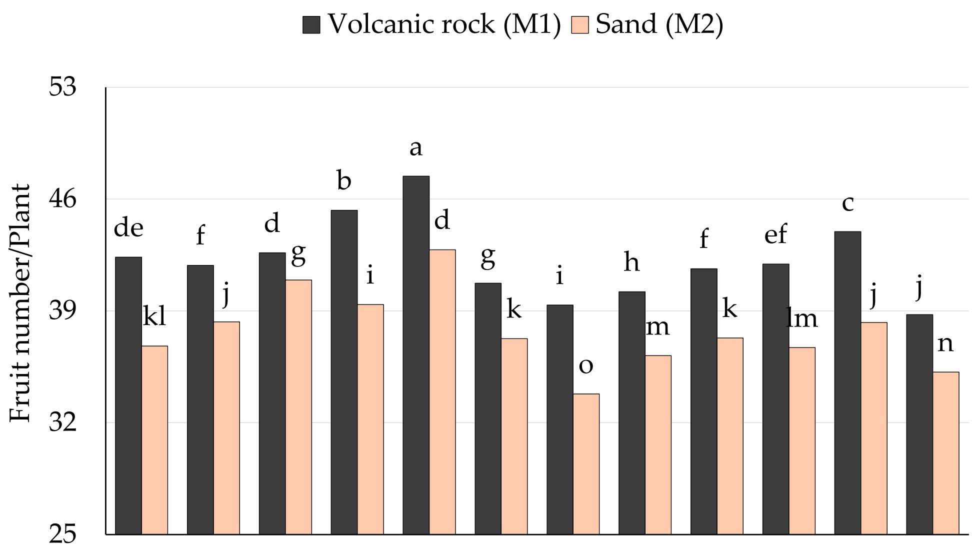
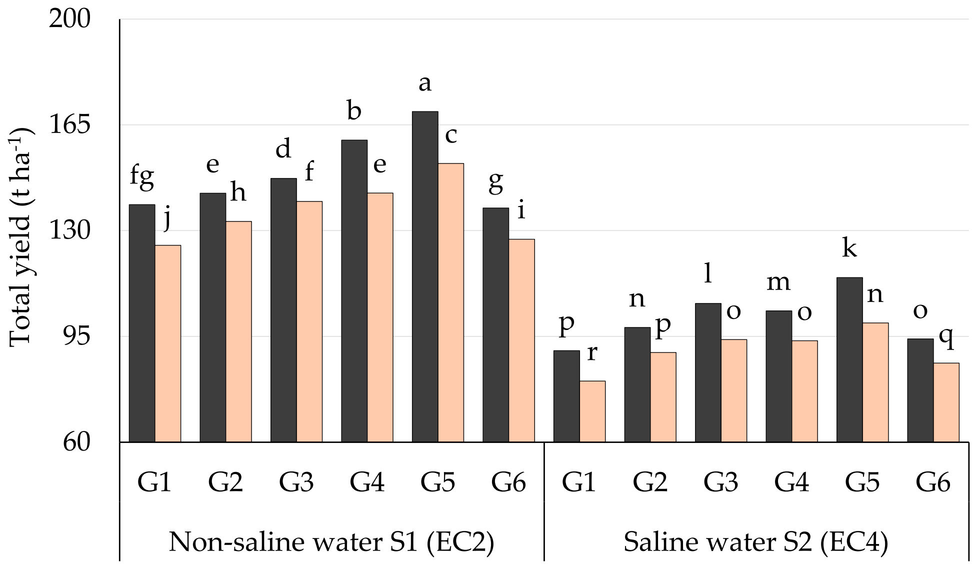


Figure 6. Interaction effects between salinity (S), growth media (M), and grafting (G) on photosynthetic pigments: chlorophyll a (**a**), chlorophyll b (**b**), and total chlorophyll (**c**). Means followed by the same letter are not significantly different at a 0.05 probability level.



(**a**)



(**b**)

Figure 7. Interaction effects between salinity (S), growth media (M), and grafting (G) on yield characteristics: fruit number (**a**) and total yield (**b**). Means followed by the same letter are not significantly different at a 0.05 probability level.

3.5. Heatmap Analysis for the Different Measurements, and the Interaction between Growth Media and Grafting for Tomatoes

Figure 8 shows that the heatmap dendrogram distributed the treatments of growth media and rootstock type into three groups. The M1G5, M1G3, and M1G4 were in one group and displayed the highest values for all parameters studied, and M2G4, M2G5, and M2G6 were in one group as the poorest performing treatments for all these parameters. On the other hand, the treatments M1G1, G2, and G6 and M2G3, G4, and G5 were grouped into one group. They gave average values for the parameters studied.

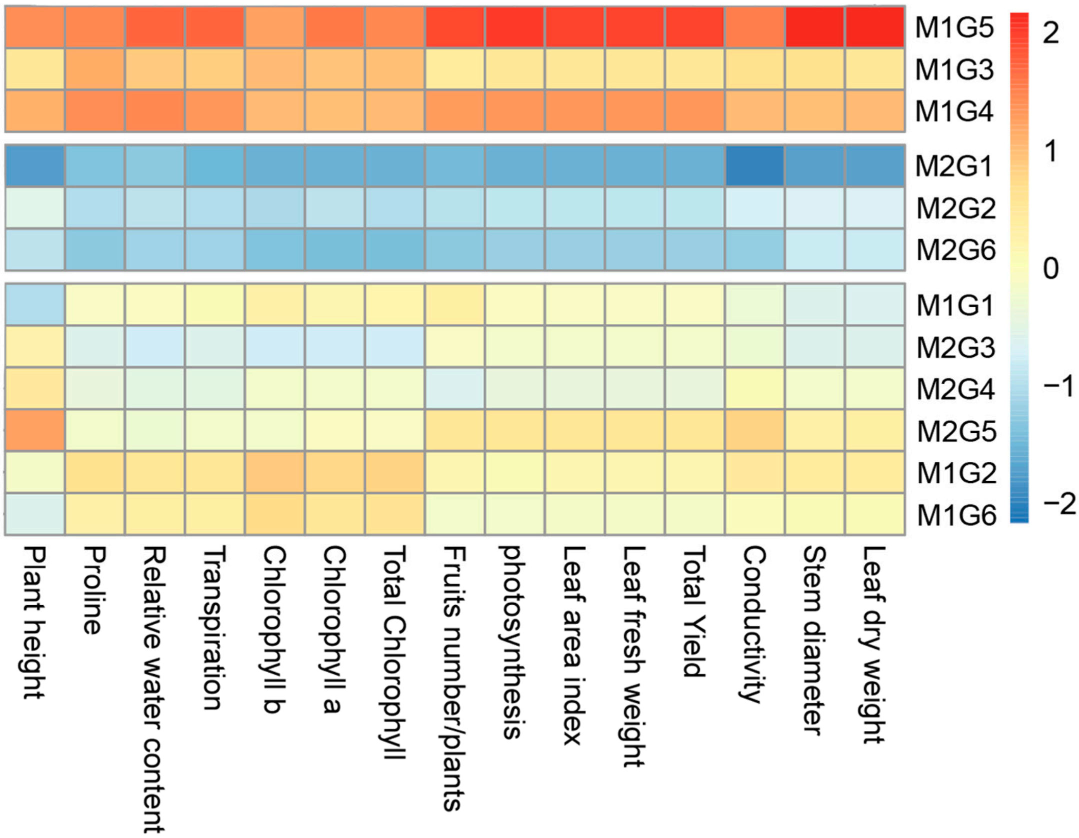


Figure 8. Heatmap of interaction between growth media and rootstock types and studied measurements of tomatoes.

4. Discussion

According to the findings, tomato plant morphological characteristics are strongly influenced by salt level. This effect is due to salt stress. Chinnusamy et al. [45] mentioned that salinity stress causes a metabolic imbalance that negatively affects the morphological traits of tomato plants. High salt concentrations can result in ionic toxicity, leading to the hindrance of plant growth. Plant height, leaf area, and other morphological traits are strongly impacted by the increased accumulation of salt in the growth media of plants, especially sodium chloride [46].

Moreover, studies have shown that grafting improves plant growth and production under salinity and water stress conditions [5]. Studies stated that there are significant effects on tomato productivity and growth, such as the number of leaves, stem diameter, and plant productivity using different rootstocks [47]. The improved tolerance of grafted plants to salt stress is attributed to the grafting, which resulted in beneficial effects on plant morphology and root function. Rootstocks employ multiple strategies to mitigate salt stress, including excluding harmful ions from their roots and minimizing transport to new growth [48]. Additionally, grafted plants exhibit reduced accumulation of sodium (Na^+) and chloride (Cl^-) ions in their branches compared to non-grafted plants. Voutsela et al. [20] reported a significant increase in fruit yield for self-grafted tomato plants grown under salt stress compared to non-grafted ones. This is undoubtedly due to improved growth characteristics. Similar effects were observed in plants grafted to rootstock G6, a local variety of tomatoes not commonly used as a rootstock. According to Singh et al. [17], grafting salt-sensitive, high-yielding tomato cultivars onto salt-tolerant or resistant rootstocks is a sustainable method of combating salt stress.

Cultivation in sand (M2) significantly reduced morphological characteristics. This phenomenon could be linked to the incomplete chemical stability of the growth media, leading to a localized increase in salt concentration around plant roots, potentially causing detrimental effects. The growth medium's biological and chemical inertness, suitable porosity, and capillary properties are crucial when choosing a growth medium for soilless agriculture [49]. Moreover, salt stress is detrimental to both grafted and non-grafted plants grown in the sandy growth medium (M2) because salt accumulates due to its lower porosity and partial inertness compared to the volcanic rock growth medium (M1). This could be due to the decline in vegetative growth characteristics in the sand growth medium (M2). On the other hand, the volcanic rock growth medium (M1) has enhanced these characteristics. It provides the roots with the necessary aeration because of its high drainage, inactivity, and relatively neutral pH [50]. Numerous studies have shown that salinity adversely affected numerous plant features, including the leaf relative water content compared to the non-grafted plant, and the grafted plants preserved their leaves in better water conditions [51,52]. Rootstocks employ multiple strategies to mitigate salt stress, including excluding harmful ions from their roots and minimizing transport to new growth [48], which shows the critical role of plant grafting in improving plant characteristics [34].

Grafting has been reported to improve photosynthetic properties [53]. Additionally, grafting plants cultivated under salt stress conditions showed superior photosynthesis compared to non-grafted or self-grafted plants [11]. The lower porosity and incompletely dormant sand growth medium (M2) likely contributed to salt buildup, leading to salt stress and, consequently, the observed low leaf gas exchange rates (photosynthesis, stomatal conductance, and transpiration). Conversely, the growth medium M1, characterized by good drainage, inertness, a slightly neutral pH, and adequate root aeration, exhibited superior results for these traits [50].

Our findings agreed with those of various studies that reported the detrimental effects of increasing salinity on photosynthetic properties and increased proline accumulation in tomato leaves [51,54,55]. The grafted tomato plants have higher leaf proline content than non-grafted plants. This could be attributed to the genetic makeup of the rootstocks, which gives them a high resistance to stresses through multiple mechanisms, such as increasing the proline acid accumulation in plant cells. Proline accumulation is a known response to osmotic stress to compensate for sodium accumulation at the cellular level [12]. Proline accumulation plays a defensive role when plants are exposed to stresses and reduces the damaging effects of sodium chloride on cell membranes [56]. In this way, the cell enhances and expands its growth and development [57]. According to the article, plant cells accumulate compatible solutes like proline to combat salinity stress. This enhances cellular osmolarity, triggering water influx or reducing efflux. This, in turn, maintains cell turgor for expansion despite osmotic stress. This increase in proline content in tomato leaves has been closely associated with increased salinity [58].

Sanwal et al. [52] proposed that elevated salinity reduces chlorophyll content due to the accumulation of Na^{+} and Cl^{-} ions, disrupting the synthesis process. Salinity-induced pressure on plants damages their internal structure, reducing chlorophyll content and impacting light absorption efficiency in the active optical radiation ranges. Osmotic stress resulting from salt stress damages chloroplast layers by increasing cell membrane permeability, contributing to a decrease in photosynthetic pigments in tomato leaves [59–61]. Madugundu et al. [62] conducted a study on the impact of different salinity concentrations on three tomato varieties grafted onto Maxifort rootstock, encompassing vegetative growth, leaf chlorophyll content, leaf area, water use efficiency, and productivity. The study concluded that a combination of grafting onto rootstocks and employing an adequate nutrient recipe could mitigate the adverse effects of salt stress on hydroponic system-grown tomato plants.

Grafting improved yield-related characteristics of tomato plants under salinity stress, such as fruit number and total yield [63]. According to Xiaohui et al. [53], tomato plants can tolerate salinity levels of up to 2.5–2.9 dS m^{-1} in the root zone without causing physiological or crop damage. However, higher salinity levels have a detrimental impact on the productive characteristics of tomatoes, as indicated by Shivani et al. [64], who found that salt stress during the flowering and fruiting stages leads to a reduction in fruit number. Ortega Martínez et al. [65] further investigated the use of various growing media in protected tomato cultivation. These media included volcanic rock, coir, agricultural soil, sawdust compost, and a 1:1 mixture of sawdust and composted sheep manure. Their research revealed that volcanic rock yielded the highest average fruit production at 252 t ha^{-1}. In comparison, plants grown in coir, agricultural soil, sawdust compost, and the sawdust–sheep manure mix produced an average of 168, 194, 221, and 233 t ha^{-1}, respectively. Voutsela et al. [20] reported a significant increase in fruit yield for self-grafted tomato plants grown under salt stress compared to non-grafted ones.

5. Conclusions

The increase in demand for tomato crops in Saudi Arabia and the need to ensure excellent and sufficient production require strategies to mitigate the adverse effects of different stresses, such as water salinity. One of these strategies is grafting the plants onto resistant rootstocks. In this study, generally, plant grafting improved the morphological, physiological, photosynthetic pigment, and yield traits of tomatoes grown in two growth media (M1 and M2) under two salinity levels (S1 and S2) compared to the non-grafted plants. The best were those grown in the volcanic rock (M1) with the salinity level S1. Using a variety such as X-238 (G5) as the new local rootstock with a commercial variety such as Tone Guitar as the scion improved the growth, physiological traits, photosynthetic pigments, and productivity of tomato plants compared to grafting on the rest of the rootstocks (G2–G4 and G6) under salt stress conditions. Grafting of this rootstock increased yield compared to the non-grafting treatment G1 in both sand and volcanic rock. Grafting can be recommended as an effective strategy to improve tomato plants' sustainable growth and productivity under saline conditions and water-limiting environments in soilless agriculture. Furthermore, the X-238 cultivar can be considered a promising and successful local rootstock.

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