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Grafting onto Different Rootstocks Modulates Fruit Quality in Eggplant Under Salt Stress[1]

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ABSTRACT: Grafting has emerged as an effective agronomic strategy in eggplant cultivation to mitigate the adverse effects of salt stress—a major abiotic factor limiting yield and quality. In this study, the effects of grafting onto different rootstocks on fruit quality traits under salt stress were investigated. The experiment was conducted in 2024 in a soilless greenhouse equipped with automated irrigation and fertilization systems. Eight rootstocks (AG38R F_1, AGR 703 F_1, Boğaç F_1, Kingkong F_1, Hercules, Hikyaku F_1, Yula F_1, and Hawk) were used, with the commercial cultivar Anamur RZ F_1 as the scion. Non-grafted and self-grafted Anamur RZ F_1 plants served as controls. Plants were grown in a peat-perlite substrate and subjected to 0, 25, and 50 mM NaCl treatments. A modified Hoagland nutrient solution was used, and fruit quality traits were analyzed.The parameters evaluated included soluble solids content (SSC), pH, electrical conductivity (EC), titratable acidity (TA), fruit firmness, and fruit skin color (L*, Chroma, Hue°). Salt stress generally increased SSC, EC, TA, and fruit firmness, while pH and color parameters varied depending on rootstock. AG38R F_1 and Hawk showed high SSC and pH values; Hercules and Hawk were effective in reducing EC and limiting ionic accumulation. Hikyaku F_1 had the highest fruit firmness. Hawk and Hercules enhanced skin brightness under salt stress. TA levels increased in response to salinity. Overall, the negative effects of salt stress were significantly mitigated through proper rootstock selection, and fruit quality was preserved. Certain rootstocks proved effective in improving physiological and quality performance under high salinity conditions.

Keywords- *Solanum melongena, salt stress, fruit color, fruit quality, rootstock*

1. Introduction

Eggplant (Solanum melongena L.) is one of the most important vegetable crops. It is widely cultivated across diverse regions, particularly in Asia, the Middle East and the Mediterranean region. Its cultivation spans over 94 countries, extending from Asia to Europe, Africa, and the Americas. According to data from the Food and Agriculture Organization (FAOSTAT, 2023), world eggplant production has reached 60.79 million tons, cultivated over an area of 1.92 million hectares. Türkiye ranks fourth globally, producing 817,590 tons on 16,660 hectares . Despite its wide distribution, eggplant cultivation faces significant constraints both globally and in Türkiye, primarily due to various environmental stress factors, particularly biotic and abiotic stresses. Abiotic stress factors such as drought, extreme temperatures, salinity, and alkalinity are considered major limitations to crop productivity (Bhatti et al., 2013; Rao et al., 2016). Notably, the impacts of drought and salinity are anticipated to intensify in the coming decades due to climate change.

Eggplant demonstrates moderate sensitivity to abiotic stress conditions, which adversely affect plant growth, yield, and fruit quality, posing substantial risks to growers (Bhatti et

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al., 2013; Rao et al., 2016). Salinity is a major constraint for sustainable agriculture (Singh, 2022). Under saline conditions, the accumulation of dissolved salts in the rhizosphere impairs water uptake, leading to hyperionic stress (Munns and Tester, 2008). The primary mechanism of salinity stress is osmotic stress, which limits water availability to the plant. Over time, the accumulation of toxic ions further disrupts cellular homeostasis and impairs morphological, physiological, and biochemical processes, ultimately reducing growth, yield, and quality (Hannachi, 2022). The severity of salt stress varies depending on species, developmental stage, and salinity levels in the growing medium (Yadav et al., 2019; Petretto et al., 2019).

Although grafting was originally developed to confer resistance to biotic stress factors, it is now recognized for its efficacy in improving tolerance to abiotic stress conditions as well (Rouphael et al., 2010). However, few studies have evaluated the effects of multiple rootstocks on eggplant fruit quality under graded salt stress conditions, particularly focusing on the modulation of physiological and biochemical fruit quality traits such as firmness, soluble solids, and antioxidant content. This study aims to fill this gap by assessing the influence of different rootstock-scion combinations under varying salinity levels.” The use of genetically resistant wild relatives as rootstocks has become an effective approach to overcoming adverse conditions such as salinity, nutrient deficiency, water scarcity and alkalinity (Savvas et al., 2010; Schwarz et al., 2010). Furthermore, rootstocks with robust root systems contribute to enhanced plant vigor and potentially lower production costs (Colla et al., 2011). Under salt stress, grafting can mitigate ionic toxicity and support physiological resilience. Salt-induced stress often leads to the accumulation of reactive oxygen species, resulting in oxidative damage (Liu et al., 2007). Research has demonstrated that grafting onto Solanum torvum-derived rootstocks, such as ‘Torvum Vigor’, significantly alleviates the effects of salt stress in eggplant (Liu et al., 2007). In the literature, eggplant is categorized as moderately salt-sensitive (Maas, 1984) or even salt-sensitive (Bresler et al., 1982). The complexity of salt stress responses in eggplant highlights the need for effective mitigation strategies, among which grafting has proven particularly promising (Panagiotakis, 2013; Giuffrida et al., 2014; Semiz and Suarez, 2019).

In vegetable crops, quality is a multifaceted trait influenced by both the physical and chemical attributes of the fruit, as well as by consumer preferences. The impact of grafting on fruit quality is determined not only by genetic factors but also by the compatibility between the scion and rootstock and as well as by environmental growing conditions. For example, grafting onto vigorous rootstocks can enhance nutrient and water uptake, thereby leading to improved fruit size and quality. Studies evaluating the effects of grafting on eggplant fruit quality have yielded variable findings with some reporting significant improvements, while others have indicating minimal or no effects (Cassaniti et al., 2011; Sabatino et al., 2018). These discrepancies are often attributed to differences in stress intensity and rootstock type (Moncada et al., 2013; Arvanitoyannis et al., 2005). Graft-induced salt tolerance in eggplant has been linked to various physiological and biochemical mechanisms, including ionic homeostasis, restricted Na^+ translocation to aerial parts, activation of antioxidant defense pathways, and preservation of chlorophyll content and photosynthetic activity. Additionally, the appropriate selection of scion–rootstock combinations play a crucial role in improving salt tolerance, with the superior performance of S. torvum widely documented in the literature.

In summary, grafting is widely regarded as a viable and effective method for sustaining eggplant productivity and fruit quality under salinity stress. However, the selection of suitable rootstocks is essential to achieving optimal results. Accordingly, the present study aimed to investigate the effects of grafting onto different rootstocks under varying levels of salt stress, with a specific focus on fruit quality attributes in eggplant.

2. Material and Methods

Experimental Site and Greenhouse Conditions: This study was conducted between April 15 and December 1, 2024, in a climate-controlled soilless greenhouse with a total enclosed area of 2,000 m^2. The greenhouse was equipped with automated systems for heating, shading, and fertigation. Plants were grown in plastic pots (75 × 25 × 21 cm) with a volume of 24 liters, filled with a peat-to-perlite (3:1, v/v) substrate. Sodium chloride (NaCl, >99% purity) was used as the source of salinity stress.

Plant Materials and Grafting Procedure: Eight eggplant rootstocks were evaluated: AG38R F_1 (AG Seed), AGR 703 F_1 (Agromar Seeds; S. melongena × S. aethiopicum), Boğaç F_1 (Yüksel Seed), Kingkong F_1 (Rijk Zwaan; S. lycopersicum × S. habrochaites), Hercules (United Genetics; S. torvum), Hikyaku F_1 (United Genetics; S. melongena), Yula F_1 (NGS Seed), and Hawk (Vilmorin-Mikado; S. torvum). The commercial cultivar Anamur RZ F_1 (10-704, Rijk Zwaan) was used as the scion in all grafting combinations. In this study, an effort was made to include as many rootstocks as possible. To this end, both national and international companies operating in Türkiye were contacted, and commercially available eggplant rootstocks currently used in the market were requested. Additionally, information regarding the origin of the rootstocks was also requested from the companies, and the available data have been presented here. The rationale for selecting the scion cultivar Anamur RZ F1 lies in the absence of any official information indicating that this variety possesses resistance or tolerance to any biotic or abiotic stress factors. Furthermore, it is a widely cultivated variety suitable for both greenhouse and open-field conditions. Given the variation in growth vigor among rootstocks, seed germination tests were conducted prior to sowing, and sowing dates were adjusted accordingly to ensure uniform grafting compatibility. Grafting was performed using the slant-cut method, and post-graft healing conditions were maintained according to the procedures described by Lee(1994). Grafting was carried out at the United Genetics Turkey seedling facility, located in Bafra and following grafting, seedlings were cultivated under standard commercial conditions.

Nutrient Solution and Irrigation Management: After transplanting, nutrient solutions were prepared at appropriate concentrations and applied to plants via a drip irrigation system. Irrigation water had an average pH of 6.7 ± 0.2 and an electrical conductivity (EC) of 0.352 ± 0.110 dS m^{-1}. After initial watering, daily irrigation was carried out with 20% drainage to prevent salt accumulation. A modified Hoagland nutrient solution was used, and the EC of the control treatment was adjusted to 2.0 dS m^{-1}. Macronutrients were provided as follows: N (210 ppm), P (100 ppm), K (200 ppm until flowering, 300 ppm afterward), Ca (100 ppm), Mg (50 ppm), and S (50 ppm). Micronutrients included Fe (3.0 ppm), Cu (0.03 ppm), Mn (0.5 ppm), B (0.5 ppm), Zn (0.05 ppm), and Mo (0.01 ppm). In the study, the EC and pH values of the drainage water were measured twice a week. When an increase in EC or pH was detected, irrigation was carried out using water with an

EC level of 1.0 dS m^{-1} in order to prevent the EC and pH of the drainage water from exceeding the desired levels.

Salt Stress Treatments: To assess the impact of salinity, three NaCl concentrations were applied: 0 mM (control), 25 mM, and 50 mM. These concentrations were maintained from transplanting until the final harvest. Preliminary experiments indicated that when the irrigation solution had an EC of 2.0 dS m^{-1}, supplementation with 25 mM and 50 mM NaCl increased the EC to approximately 4.0 and 6.0 dS m^{-1}, respectively. Drainage water was routinely monitored for EC and pH to prevent excessive salt accumulation and maintain nutrient solution stability.

Cultivation Practices and Harvesting: Transplanting was performed on April 15, 2024. Plants were spaced 50 cm apart within rows and 120 cm apart between rows, with two plants per pot. The pots were kept fixed in the same positions throughout the experiment, and no repositioning of the plants was performed. An additional border row was added on both the front and back sides to minimize edge effects. Once lateral branching occurred, plants were pruned to maintain four main stems, each supported by an individual trellising string. Fruits were harvested at commercial maturity. Eight rootstocks were evaluated, along with non-grafted and self-grafted control plants. For biochemical and quality analyses, fruits harvested from the third and sixth harvests were used.

Fruit Quality Assessments: In the fruit quality analyses, two fruits were taken from each plant. Thus, observations and analyses were conducted on six fruits per plot. Soluble solids content (SSC, °Brix) was measured using a digital refractometer, electrical conductivity (EC, dS m^{-1}) with an EC meter, and fruit juice pH with a digital pH meter. Titratable acidity (TA, %) was determined by titrating fruit juice with 0.1 N NaOH until a final pH of 8.1 was reached. The volume of NaOH consumed was recorded, and TA was calculated as citric acid equivalent using the following formula:
Titratable acidity (%)=(V x N x E)/Mx100
Where: V: volume of NaOH used (mL)
N: normality of NaOH (0.1)
E: equivalent weight of dominant organic acid (citric acid, 0.0064 for eggplant)
M: volume of juice sample (mL)

Fruit Flesh Firmness (N): Fruit firmness was measured using a modified method based on Dilmaçünal et al., (2011) and Gerçekçioğlu et al.,(2019). A dynamometer (PCE-FM 200 Force Gauge) mounted on a test stand (Model SL J-B; capacity: 500 N; stroke: 150 mm; PCE Instruments) was employed. A 1.54 mm diameter, 2 cm long puncture probe, expanding up to 3 mm in width, was inserted 10 mm into the fruit tissue. Force was recorded as Newtons.

Color Measurement of Fruit Skin: Fruit skin color parameters (L*, a*, b*) were recorded on ten fruits per plot, four times at 15-day intervals following the start of harvest, using a colorimeter (CR-300, Minolta, Japan). Hue angle (H°) and chroma (C*) values were subsequently calculated from the a* and b* coordinates using standard equations.
Hue angle (H°)= ((a*)/(b*))
Chroma (C*)=$\sqrt{(a^2+b^2)}$

Statistical Analysis: The experiment was arranged in a split-plot design with three replications. Main plots were assigned to salinity treatments, and subplots to grafting combinations, with randomization within subplots. Each plot included three pots containing a total of six plants. In total, 10 grafting treatments × 3 salinity levels × 3 replications = 90 plots and 540 plants were included. Data analysis was performed using IBM SPSS Statistics 20. Differences among treatments were assessed using Duncan's multiple range test at a significance level of $p \leq 0.05$.

3. Results and Discussion

Soluble Solids Content (SSC): In the study, it was determined that the rootstock factor ($\eta^2 = 0.513$; $P < 0.001$) and salt × rootstock interaction ($\eta^2 = 0.495$; $P < 0.001$) had a strong effect on SSC, while salt stress ($\eta^2 = 0.103$; $P = 0.007$) had a moderate effect (Table 1and 2). When average SSC contents were examined by rootstock, the AG38R F_1 rootstock gave the highest value (6.52%). This was followed by Hawk (6.40%), Hikyaku F_1 (6.35%), and selfgrafted plants (6.33%). The lowest average SSC was observed in Yula F_1 rootstock (5.90%). As salt stress increased, SSC content increased; the average SSC was 6.12% in the control group and rose to 6.28% with 50 mM NaCl treatment. When rootstocks and salt levels were evaluated together, higher SSC values were obtained under high salt stress particularly in cases using AG38R F_1 and Hawk rootstocks compared to control plants. Conversely, grafting had less effect on SSC under control and 25 mM NaCl treatments. In the literature, different results have been reported regarding the effects of grafting on SSC in eggplant. Sabatino et al. (2019) reported an increase in SSC following grafting with hybrid rootstocks; Gisbert et al. (2011) found no significant change despite different rootstocks. Mozafarian et al. (2020) reported that some rootstocks reduced SSC, with the highest value in self-grafted plants; Tezcan et al. (2025) and Mozafarian et al. (2023) stated that grafting increased SSC, but that this effect depended on the rootstock used. In light of these findings, it is concluded that SSC content in eggplant increases under salt stress, and the effect of grafting varies depending on the rootstock and salt stress level.

pH of Fruit Juice: The study showed that the rootstock factor ($\eta^2 = 0.557$; $P < 0.001$) and the salt × rootstock interaction ($\eta^2 = 0.418$; $P < 0.001$) had strong effects on fruit pH, while salt stress alone ($\eta^2 = 0.33$; $P = 0.219$) had a moderate but statistically insignificant effect (Table 1and 2). When average pH values were examined by rootstock, the highest pH was found in Hawk rootstock (5.61), followed by AG38R F_1 (5.52) and Hercules and Yula F_1 (5.51). The lowest average value was detected in self-grafted plants (5.36). The pH increase due to salt stress was limited; average pH was 5.47 in the control group, 5.44 and 5,46 under 25 and 50 mM NaCl treatments, respectively. However, some rootstocks stood out under 50 mM NaCl conditions. For example, Hawk (5.73) and AG38R F_1 (5.63) rootstocks had 6.41% and 5.78% higher pH values than self-grafted plants, respectively. Under the same conditions, the lowest pH values were measured in Hikyaku F_1 and KingKong F_1 rootstocks (5.33). Different findings exist in the literature on the effect of grafting on pH. Tezcan et al. (2025) reported that grafting under stress preserved pH balance, while fluctuations increased in non-grafted plants; Mozafarian et al. (2020) found no significant effect of grafting on pH with different rootstocks; Mozafarian et al. (2023) reported that the S. grandifolium × S. melongena hybrid rootstock reduced pH under salt stress. Considering the results and literature, it is concluded that pH may increase under salt stress, but the effect of grafting varies depending on the rootstock used.

Electrical Conductivity (EC): The electrical conductivity of eggplant fruits is evaluated as an indirect indicator of salt accumulation and ionic stress in both plant and fruit. In the study, salt stress ($\eta^2 = 0.717$; $P < 0.001$), rootstock effect ($\eta^2 = 0.484$; $P < 0.001$), and salt × rootstock interaction ($\eta^2 = 0.460$; $P < 0.001$) played statistically significant roles with large effect sizes on EC (Table 1and 2). These findings show that NaCl applications are the main determinant of EC levels, but ionic balance can be modulated depending on the rootstock. The average EC value was 5.67 dS/m in the control, rising to 6.39 dS/m at 25 mM NaCl and 7.24 dS/m at 50 mM NaCl. This increase with higher salt level shows dose-dependent ion accumulation and indicates increased ionic load in fruit tissue due to salt stress. EC in non-grafted plants increased to 8.38 dS/m and in selfgrafted plants to 8.53 dS/m at 50 mM NaCl, highlighting these two groups as unable to adequately regulate ions under salt stress. By rootstock, Hercules (5.82 dS/m), Boğaç F_1 (5.87 dS/m), and Hawk (6.00 dS/m) showed the lowest average EC values. Hawk rootstock reduced EC by 27.4% and Hercules by up to 30% compared to self-grafted plants under 50 mM NaCl. These two rootstocks, originating from S. torvum, are notable for their high ion retention capacity, limiting Na^+ and Cl^- accumulation in fruit tissue and lowering EC values. Conversely, rootstocks like KingKong F_1 and Yula F_1 showed higher EC values of 7.65 dS/m respectively under high salt stress, indicating insufficient ion regulation. Although these values are lower compared to non-grafted plants, they are weaker compared to effective rootstocks like Hawk and Hercules. The increase in EC may reflects dissolved ion accumulation in fruit tissue, particularly Na^+ and Cl^-. In this study, EC values clearly increased with NaCl treatments, indicating salt accumulation in fruits. Semiz and Suarez (2019) noted that Na^+ accumulation is the main cause of yield loss due to salinity in eggplant, causing toxic effects in leaves and fruits; Mozafarian et al. (2023) found that S. torvum and S. habrochaites rootstocks limit Na^+ translocation by retaining ions in roots and reduce fruit accumulation; Talhouni et al. (2019) stated grafting reduces Na^+ accumulation in upper parts of the plant; Sanwal et al. (2022) indicated that Na^+ ions are stored in older leaves in grafted plants, limiting transfer to fruits. Giuffrida et al. (2014) suggested that although some interspecific hybrid rootstocks have limited ion retention capacity, they effectively restrict Na^+ transport. Collectively, these studies support the view that grafting, particularly with wild or interspecific rootstocks, can mitigate salt-induced ion toxicity by restricting Na^+ translocation to the fruit. In light of all these literature findings, our results demonstrate that especially S. torvum-derived Hawk and Hercules rootstocks are effective in reducing EC levels and protecting fruit quality under salt stress.

Titratable Acidity (TA): In the experiment, rootstock factor ($\eta^2 = 0.647$; $P < 0.001$), salt stress ($\eta^2 = 0.541$; $P < 0.001$), and salt × rootstock interaction ($\eta^2 = 0.557$; $P < 0.001$) had highly significant effects on TA content in eggplant fruits (Table 1and 2). These findings indicate that TA content is sensitive to both rootstocks and salt stress conditions. Under control conditions, the highest TA was measured in self-grafted plants (0.160%), and the lowest in KingKong F_1 rootstock (0.125%). TA values increased under 25 mM NaCl, with the highest again in self-grafted plants (0.167%). At 50 mM NaCl, KingKong F_1 rootstock gave the highest TA value (0.168%), followed by self-grafted (0.167%) and Hikyaku F_1 (0.158%). Based on average values, the highest TA content was 0.165% in self-grafted plants and the lowest 0.136% in Yula F_1. Considering averages of salt applications, 25 mM and 50 mM NaCl treatments caused TA increases of 10.8% and 8.6%, respectively. This shows that low to moderate salt stress increases fruit acidity. Additionally, self-grafted plants stood out with high TA values across all NaCl doses. Similar effects of salt stress and grafting on TA are frequently emphasized in the literature. Mizrahi (1982) stated that salt stress increased TA in tomato; Turhan et al. (2011) noted direct positive effects of grafting on TA; Huang et al. (2015) reported that highly salt-tolerant rootstocks increased TA and quality; Flores et al. (2010) showed rootstock-scion combinations determine quality; El-Shraiy et al. (2011) indicated some rootstocks might reduce this effect.

Table 1. Effect of grafting on the biochemical composition of eggplant fruit

NaCl	Rootstocks	SSC (%)	pH	EC (dS/m)	TA (%)
0 (Control)	AGR 703 F$_1$	6,20±0,75^{c-h}	5,37±0,29^{efg}	5,74±0,52^{h-l}	0,138±0,012^{j-n}
	Hawk	6,13±0,55^{d-i}	5,53±0,29^{bcd}	5,71±0,88^{h-l}	0,133±0,012^{l-o}
	Hercules	5,87±0,57^{h-k}	5,57±0,29^{bc}	5,18±0,54^{l}	0,135±0,018^{k-o}
	Hikyaku F$_1$	6,27±0,60^{b-g}	5,43±0,25^{c-g}	5,72±0,89^{h-l}	0,152±0,021^{c-i}
	AG38R F$_1$	6,31±0,58^{b-f}	5,47±0,29^{c-f}	5,85±0,57^{g-l}	0,143±0,013^{h-l}
	KingKong F$_1$	5,90±0,43^{g-k}	5,43±0,19^{c-g}	5,97±0,60^{g-k}	0,125±0,013^{o}
	Boğaç F$_1$	5,58±0,41^{k}	5,43±0,19^{c-g}	5,23±1,05^{kl}	0,127±0,016^{no}
	Yula F$_1$	6,17±0,58^{c-h}	5,57±0,19^{bc}	6,25±0,62^{e-i}	0,131±0,011^{mno}
	Nongrafted	6,43±0,51^{bcd}	5,57±0,29^{bc}	5,40±1,07^{jkl}	0,146±0,011^{e-k}
	Selfgrafted	6,37±0,58^{b-e}	5,33±0,29^{fg}	5,68±0,70^{i-l}	0,160±0,013^{abc}
25 mM	AGR 703 F$_1$	6,28±0,54^{b-g}	5,43±0,25^{c-g}	6,50±1,23^{e-h}	0,156±0,012^{b-g}
	Hawk	6,43±0,55^{bcd}	5,57±0,29^{bc}	6,09±0,68^{f-j}	0,148±0,014^{d-l}
	Hercules	5,77±0,50^{jk}	5,47±0,19^{c-f}	6,30±0,93^{e-i}	0,163±0,014^{abc}
	Hikyaku F$_1$	6,53±0,65^{abc}	5,40±0,16^{d-g}	6,54±0,62^{d-g}	0,160±0,019^{abc}
	AG38R F$_1$	6,43±0,65^{bcd}	5,47±0,29^{c-f}	6,43±0,52^{e-i}	0,157±0,015^{a-f}
	KingKong F$_1$	6,00±0,53^{e-j}	5,40±0,16^{d-g}	6,91±0,55^{cde}	0,142±0,014^{i-m}
	Boğaç F$_1$	6,30±0,49^{b-f}	5,50±0,16^{cde}	5,95±0,87^{g-k}	0,157±0,014^{a-f}
	Yula F$_1$	5,93±0,57^{f-k}	5,50±0,16^{cde}	6,01±0,61^{f-j}	0,132±0,018^{l-o}
	Nongrafted	5,80±0,59i^{jk}	5,30±0,28^{g}	6,37±1,27^{e-i}	0,161±0,015^{abc}
	Selfgrafted	6,27±0,58^{b-g}	5,37±0,19^{efg}	6,77±1,24^{c-f}	0,167±0,015^{ab}
50 mM	AGR 703 F$_1$	6,27±0,57^{b-g}	5,40±0,20^{d-g}	7,39±0,98^{bc}	0,154±0,014^{c-i}
	Hawk	6,63±0,69^{ab}	5,73±0,19^{a}	6,19±0,35^{e-i}	0,132±0,015^{l-o}
	Hercules	6,17±0,55^{c-h}	5,50±0,20^{cde}	5,97±0,34^{g-k}	0,144±0,012^{g-k}
	Hikyaku F$_1$	6,25±0,53^{c-g}	5,33±0,19^{fg}	7,25±0,66^{bcd}	0,158±0,016^{a-d}
	AG38R F$_1$	6,82±0,55^{a}	5,63±0,19^{ab}	6,93±0,66^{b-e}	0,139±0,017^{j-m}
	KingKong F$_1$	6,30±0,53^{b-f}	5,33±0,19^{fg}	7,65±1,38^{b}	0,168±0,017^{a}
	Boğaç F$_1$	6,30±0,58^{b-f}	5,50±0,16^{cde}	6,42±0,61^{e-i}	0,148±0,014^{d-l}
	Yula F$_1$	5,59±0,55^{k}	5,47±0,19^{c-f}	7,65±1,55^{b}	0,145±0,011^{f-k}
	Nongrafted	6,10±0,53^{d-j}	5,37±0,19^{efg}	8,38±1,06^{a}	0,155±0,015^{b-h}
	Selfgrafted	6,37±0,58^{b-e}	5,37±0,19^{efg}	8,53±1,30^{a}	0,167±0,019^{ab}
P value		0,000	0,000	0,000	0,000
Level of significance		***	***	***	***
η^2		0,495	0,418	0,460	0,557

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test

***: Represents a statistically significant difference at $P<0.001$, respectively (Duncan's multiple range test). η^2 (eta squared) indicates the effect size and represents the proportion of total variance explained by the treatment. According to Cohen (1988), η^2 values of 0.01, 0.06, and 0.14 correspond to small, medium, and large effect sizes, respectively. The η^2 values in this table (0.495, 0.418, 0.460, and 0.557) indicate large effect sizes for all measured parameters.

Table 2. Effects of rootstock and NaCl treatments on average SSC, pH, EC, and TA levels in fruit juice of eggplant

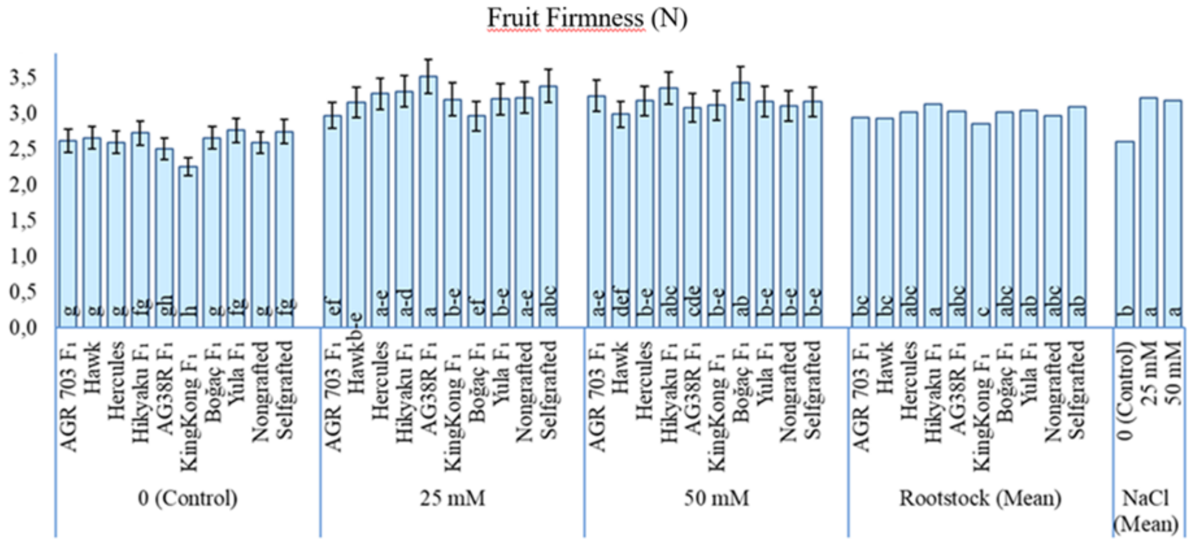
Rootstocks	SSC (%)	pH	EC dS/m	TA (%)
AGR 703 F$_1$	6,25^{bc}	5,40^{c}	6,54^{bc}	0,149^{cd}
Hawk	6,40^{ab}	5,61^{a}	6,00^{d}	0,138^{e}
Hercules	5,93^{de}	5,51^{b}	5,82^{d}	0,147^{d}
Hikyaku F$_1$	6,35^{ab}	5,39^{c}	6,51^{bc}	0,157^{b}
AG38R F$_1$	6,52^{a}	5,52^{b}	6,41^{c}	0,146^{d}
KingKong F$_1$	6,07^{cde}	5,39^{c}	6,84^{ab}	0,145^{d}
Boğaç F$_1$	6,06^{cde}	5,48^{bc}	5,87^{d}	0,144^{d}
Yula F$_1$	5,90^{e}	5,51^{b}	6,64^{abc}	0,136^{e}
Nongrafted	6,11^{cd}	5,41^{c}	6,72^{abc}	0,154^{bc}
Selfgrafted	6,33^{ab}	5,36^{c}	6,99^{a}	0,165^{a}
P value	0,000	0,000	0,000	0,000
Level of significance	***	***	***	***
η^2	0,513	0,557	0,484	0,647
NaCl				
0 (Control)	6,12 b	5,47	5,67^{c}	0,139^{b}
25 mM	6,17 b	5,44	6,39^{b}	0,154^{a}
50 mM	6,28 a	5,46	7,24^{a}	0,151^{a}
P value	0,007	0,219	0,000	0,000
Level of significance	**	n.s.	***	***
η^2	0,103	0,033	0,717	0,541

Means in the same column followed by the same letter are not significantly different ($P \leq 0.05$) according to Duncan's multiple range test.

; * and n.s.represents a statistically significant difference at P<0.01, P<0.001 and nonsignificant, respectively (Duncan's multiple range test).

η^2 (eta squared) indicates the effect size and represents the proportion of total variance explained by the treatment. According to Cohen (1988), η^2 values of 0.01, 0.06, and 0.14 correspond to small, medium, and large effect sizes, respectively. In this table, rootstock treatments had large effects on all measured parameters: SSC ($\eta^2 = 0.513$), pH ($\eta^2 = 0.557$), EC (η^2 =0 .484), and TA ($\eta^2 = 0.647$). For NaCl treatments, large effects were observed on EC ($\eta^2 = 0.717$) and TA ($\eta^2 = 0.541$), a medium effect on SSC ($\eta^2 = 0.103$), and a small effect on pH ($\eta^2 = 0.033$).

Fruit Flesh Firmness (kg/m3): The study found that salt stress had a large effect size on fruit flesh firmness ($\eta^2 = 0.741$; $P < 0.001$), while rootstock effect was moderately to highly significant ($\eta^2 = 0.181$; P =0,029). The salt × rootstock interaction was also significant ($\eta^2 = 0.349$; P= 0.001) (Figure 1). A general increase in fruit flesh firmness was observed with salt applications. Firmness was 2.61 kg/cm^3 in the control, increasing by 20.6% to 3.22 kg/cm^3 at 25 mM NaCl and by 19.2% to 3.19 kg/cm^3 at 50 mM NaCl. Among rootstocks, the highest average firmness was measured in Hikyaku F$_1$ (3.13 kg/cm^3), followed by self-grafted plants (3.10 kg/cm^3) and Yula F$_1$ (3.05 kg/cm^3). The lowest average was 2.86 kg/cm^3 in KingKong F$_1$. Hikyaku F$_1$ provided 5,38% higher firmness than non-grafted and 0.96% higher than self-grafted plants. The positive effect of salt treatments on fruit firmness is associated with water loss and changes in cell wall structure. Sifola et al. (1995) reported that salt stress increased firmness by enhancing water loss and cell wall density in fruit tissue; Mozafarian et al. (2023) observed that grafted eggplants under salt stress maintained firmness, with some rootstocks enhancing this effect more notably. In our study rootstocks such as Hikyaku F$_1$, Boğaç F$_1$, and AG38R F$_1$ were effective in increasing fruit firmness under salt stress, whreas some rootstocks like KingKong F$_1$ negatively affected this parameter. This finding aligns with Mozafarian et al. (2020), who reported that certain rootstocks can reduce fruit flesh firmness.



Bars represent mean values, with standard deviation indicated by error bars above each bar. Different letters inside the bars denote statistically significant differences between groups according to Duncan's multiple range test at $p < 0.05$.

Figure 1. Effect of grafting on fruit flesh firmness of eggplant under different salt stress conditions

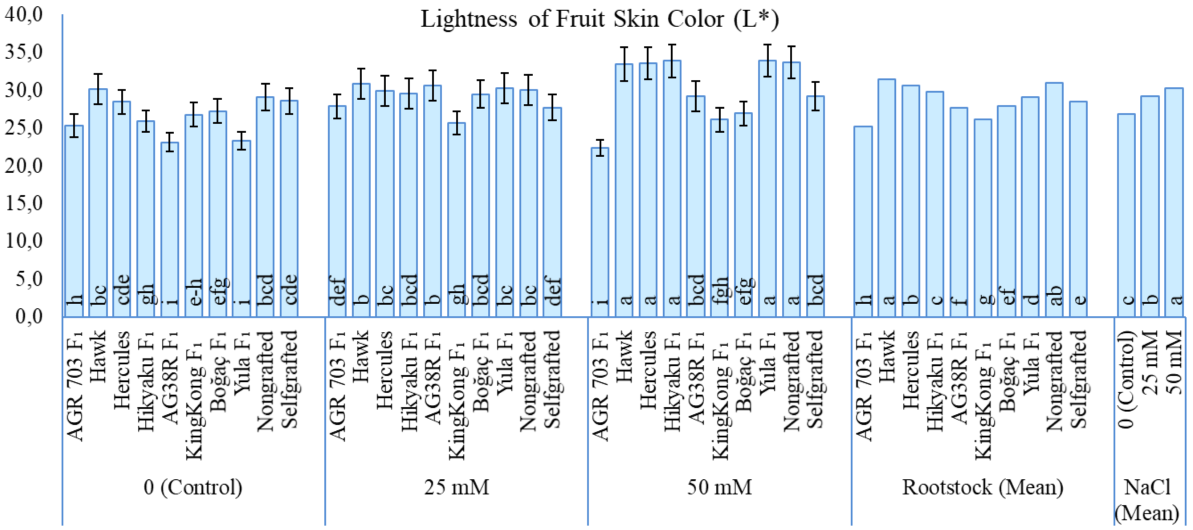
Lightness of Fruit Skin Color (L*):

Salt stress, rootstock, and their interaction had highly significant effects on the L* color value of eggplant fruits ($P < 0.001$). The majority of variation was due to rootstock ($\eta^2 = 0.897$), with salt stress ($\eta^2 = 0.824$) and their interaction ($\eta^2 = 0.894$) also showing strong effects (Figure 2). Salt stress generally increased L* values, indicating lighter fruit skin, especially at 50 mM NaCl, where the average L* rose from 26.78 (control) to 30.22. However, this increase varied by rootstock. Under 50 mM NaCl, Hawk, Hercules, and Hikyaku F_1 showed the highest L* values, supporting significant color lightening, while AGR 703 F_1 and KingKong F_1 maintained lower L* values, showing limited or no lightening. Across all salt levels, Hawk and Hercules consistently lightened fruit skin color the most, while AGR 703 F_1 and KingKong F_1 had the lowest L* values. Notably, AGR 703 F_1 was the only rootstock with a significant L* decrease under 50 mM NaCl. Non-grafted and self-grafted plants showed moderate lightness.

Chroma (C*): Chroma was highly affected by both rootstock ($\eta^2 = 0.381$; $P < 0.001$) and salt × rootstock interaction ($\eta^2 = 0.761$; $P < 0.001$), while salt application alone, although statistically significant ($\eta^2 = 0.166$; $P = 0.010$), had a moderate effect (Figure 3). The effect of salt applications on color saturation did not follow a linear trend. Under 25 mM NaCl, the average chroma value decreased slightly to 4,08 compared to the control group (4.11). Under 50 mM NaCl, this value increased to 4.23. This indicates that low-level salt stress might slightly suppress color vividness, but higher salt levels increased this characteristic in some rootstocks. When evaluated by rootstocks, Boğaç F_1 (4.47) had the highest average chroma value, followed by Hawk (4.28) and Yula F_1 (4.23). However, the change in these values under salt stress varied by rootstock. For example, AG38R F_1 had the highest chroma (4.59) under control conditions but dropped to 3.99 under 50 mM NaCl, indicating a failure to maintain color saturation under salt stress. In contrast, Boğaç F_1 had lower chroma (4.32) under the control conditions but rose to 5.30 under 50 mM NaCl conditions. Boğaç F_1 and Yula F_1 reached the highest chroma values under 50 mM NaCl, standing out as rootstocks capable of maintaining or increasing color saturation under high salt stress.

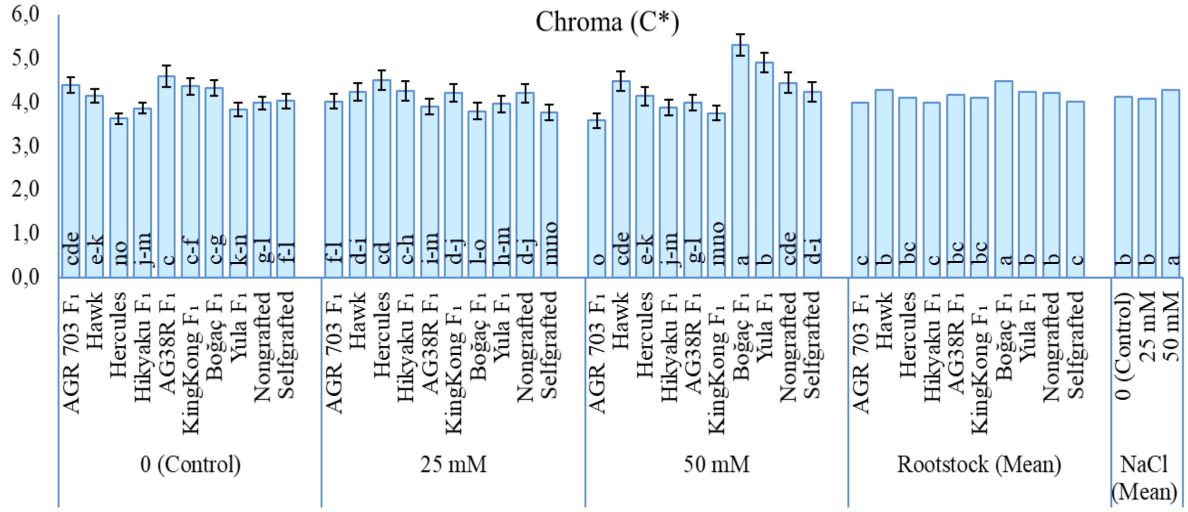
Hue Angle (Hue°): The effects of rootstock ($\eta^2 = 0.564$; $P < 0.001$) and salt × rootstock interaction ($\eta^2 = 0.672$; $P < 0.001$) on fruit hue angle were very strong, while the effect of salt application ($\eta^2 = 0.113$; $P = 0.005$) was moderately high and significant. Salt treatments caused an increase in average Hue° values (Figure 4). The control group's value was 34.33, which increased to 35.88 under 25 mM NaCl, and rised to 36.07 under 50 mM NaCl. This indicates that salt stress directed the fruit skin color toward lighter tones. However, this increase varied depending on the rootstock. For example, under 50 mM NaCl, rootstocks Yula F_1 (44.35) and Boğaç F_1 (42.17) showed very high hue values, while AG38R F_1 (29.56) and KingKong F_1 (29.86) maintained lower hue values, resulting in darker color tones compared to the control group. Examining the rootstock averages, non-grafted plants (38.31) and Yula F_1 (39.63) stood out with high hue values, whereas AG38R F_1 (31.41) and KingKong F_1 (32.62) had the lowest hue values. Particularly, AG38R F_1 was notable for its low hue value even under control conditions. Self-grafted plants showed an average hue value of 34.31, remaining moderate without showing a stress-resistant increase.

The effects of grafting on different rootstocks caused significant differences in fruit skin color of eggplants, depending both on rootstock choice and salt levels. The obtained results largely align with various findings in the literature, revealing that grafting and salt stress play a decisive role in the formation and stability of fruit skin color. Generally, measurements and observations regarding the effects of grafting and salt stress on fruit color in the literature are limited. The different color structures of eggplant varieties complicate the evaluation of color parameters. The results indicate that grafting and salt stress cause different effects on fruit skin color; under stress, grafted plants show more stable color parameters, but important quality criteria like fruit color must definitely be considered when selecting rootstocks. Tezcan et al. (2025) reported that grafting preserves the L* value, while darkening is a stress symptom in non-grafted plants; Moncada et al. (2013), however, reported that grafting reduces L* value, causing darker colors to appear. These differences suggest that depending on the rootstocks used, both increases and decreases in L* value may occur, supporting the results obtained in this study. Mozafarian et al. (2020 and 2023) reported that certain rootstocks increase chroma values, whereas Moncada et al. (2013) indicated that grafting lowers chroma values, leading to duller colors. These contradictions in the literature emphasize the impact of rootstock selection and stress conditions, similarly to the results in the experiment. Sabatino et al. (2019) reported that S. torvum rootstock increases hue° values, but some rootstocks decrease them; likewise, Mozafarian et al. (2020) noted that grafting affects hue° values, causing changes in color tone. The limited findings in the literature support the results obtained in this trial.



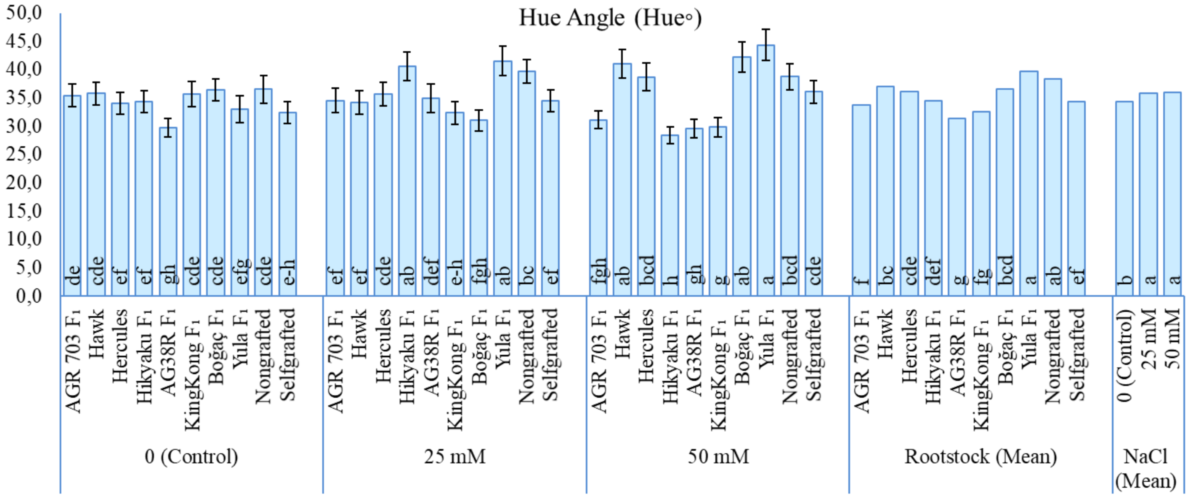
Bars represent mean values, with standard deviation indicated by error bars above each bar. Different letters inside the bars denote statistically significant differences between groups according to Duncan's multiple range test at $p < 0.05$.

Figure 2. Effect of grafting on the lightness (L*) *of eggplant fruit skin under different salt stress conditions*



Bars represent mean values, with standard deviation indicated by error bars above each bar. Different letters inside the bars denote statistically significant differences between groups according to Duncan's multiple range test at $p < 0.05$.

Figure 3. Effect of grafting on fruit skin color saturation (Chroma, C) under different salt stress conditions



Bars represent mean values, with standard deviation indicated by error bars above each bar. Different letters inside the bars denote statistically significant differences between groups according to Duncan’s multiple range test at $p < 0.05$.

Figure 4. Effect of grafting on fruit skin color hue angle (H°) under different salt stress conditions

4. Conclusion

This study demonstrated that grafting can significantly influence the response of eggplant to salinity stress, particularly in terms of fruit quality parameters such as soluble solids content (SSC), pH, electrical conductivity (EC), titratable acidity (TA), firmness, and skin color attributes. Increasing salinity levels (25 and 50 mM NaCl) generally resulted in higher SSC, TA, and firmness, but also led to increased EC and alterations in fruit skin color. Notably, rootstocks derived from Solanum torvum (Hawk and Hercules) were the most effective in mitigating the negative effects of salinity by reducing EC and preserving fruit quality under high salt stress. Rootstock selection proved to be a critical determinant of salt tolerance and fruit biochemical stability. For example, AG38R F₁ and Hawk enhanced SSC under salt stress, while Hikyaku F₁ improved fruit firmness. In contrast, rootstocks such as KingKong F₁ and AGR 703 F₁ were less effective in regulating salt-induced changes, particularly in EC and color saturation. Variations in fruit color parameters (L*, C*, H°) under salinity were strongly dependent on the rootstock, emphasizing the importance of considering aesthetic and market quality traits in rootstock selection.

5. Acknowledgment

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Conflict of ınterest the authors declare that they have no known competing fnancial interests or personal relationships that could have appeared to infuence them.

This article was derived from Emine Polat's doctoral dissertation. Naif Geboloğlu is the doctoral thesis advisor. Both researchers contributed equally to the planning, execution, evaluation of results, and writing of

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