*Pak. J. Bot.*, 55(1): 393-402, 2023. DOI: http://dx.doi.org/10.30848/PJB2023-1(32)

# EFFECTS OF GRAFTING ON AGRO-MORPHOLOGICAL CHARACTERISTICS IN EGGPLANTS GRAFTED ONTO *SOLANUM TORVUM* AND INTERSPECIFIC HYBRID ROOTSTOCKS

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**Abstract**

Grafting may cause changes in plant growth and morphology. These changes may affect the fruit appearance, earliness, and yield. In these respect, it is important to investigate whether there are changes in the scion due to grafting before the fruit formation phase. The objective of this study was to determine the effects of rootstocks on plant structure, stem, leaf and flower morphology, rootstock/scion compatibility and to investigate the effect of observation dates in different fruit-shaped scions. Two eggplant hybrids, Amadeo and BT Bıldırcın were used as scions and *Solanum torvum* (Hawk) and interspecific eggplant hybrid- "IEH" (Anafor) were used as rootstocks. In the study, grafting positively affected to plant height, stem diameters, number of leaves, growth habit, leaf color and anthocyanin coloration of stem depending on the rootstock/scion combination. However, grafting negatively affected the percentage of plant survival, flowering time and plantlet height. The maximum plant height was found in the "BT Bıldırcın / *S. torvum"* and *"*BT Bıldırcın/ IEH" combination with 81.14 and 77.30 cm, respectively. The highest stem diameter was found in "IEH" rootstock in both scions. Apart from these, rootstocks produced the upright plants compared to ungrafted ones. On the other hand, the most seedling losses and the latest flowering time were in the grafted *S. torvum* combinations in both scions. Consequently, positive effect of grafting depends primarily on chosen scion variety and then rootstock/scion combination. Also our study demostrates that interspecific eggplant hybrid rootstocks may be good alternative to *S. torvum*. In addition, observation dates and plant, stem, leaf and flower traits are important in revealing the effect of the grafting.

**Key words:** Anthocyanin, Color, Flower, Growth habit, Observation dates, Scion compatibility, Vigour

## Introduction

Eggplant is one of the most important vegetables grown in many countries and the 5th most produced vegetables in the world after tomato, onion, cucumber and cabbage (Anon., 2020). Due to limited agricultural lands and increasing food demand, agricultural lands are intensively used for whole year. This situation causes some problems such as increasing soil-borne diseases and pests soil nutrient imbalances, spread of weeds (Farhadi *et al*., 2016).

Grafting is used to prevent soil-borne diseases and pests, increase plant power, extend the harvest period and against environmental stress factors (Lee, 1994). In addition, since the breeding of resistant varieties requires many years, the use of grafted plants are alternative to breeding (Tsaballa *et al*., 2021), especially in older varieties that are not resistant to diseases and pests but are grown intensively in the market, grafting is used to ensure that the variety gains resistance. Moreover grafting is environmental friendly practice and use of grafted seedlings is increasing day by day (Rouphael *et al*., 2017; Musa *et al*., 2020). In addition it can also be used in organic agriculture (Sen *et al*., 2018; Mozafarian & Kappel, 2020).

Different types of rootstocks are used for grafting. Wild eggplant species (*S. torvum, S. aethiopicum, S. integrifolium, S. macrocarpon, S. incanum, S. indicum etc.*), their inter-species hybrid (*S. melongena x S. aethiopicum, S. melongena x S. integrifolium, S. incanum x S. melongena)* and tomato hybrids are used as eggplant rootstocks. *S. torvum* is most commonly used as rootstock among the wild species (Lee *et al*., 2010). However, seed germination is low and not uniform in *S. torvum* (King *et al.,* 2010). For this reason, inter-species hybrids rootstocks are used as an alternative to *S. torvum* (Sabatino *et al*., 2019). Besides the many advantages of grafting, it also has disadvantages such as having more maintenance labor compared to traditional cultivation and long time to obtain grafted seedlings and costly also.

Furthermore rootstock / scion combination has a remarkable effect on plant growth and yield (Voutsela *et al*., 2012). However the selection of rootstock/scion combinations has become difficult with the increase to number of eggplant varieties and more compatibility problems are encountered. Therefore, the selections of rootstock and of scion varieties are very important in grafted cultivation (Salaria *et al*., 2020). Moreover information about the general effects of rootstocks is important by growers in order to choose the most suitable combination for the environment (Devi *et al*., 2020; Okatan, 2020).

Grafting may also cause differences in plant growth and morphology (Eltayb *et al*., 2013; Kyriacou *et al*., 2020). Since the plant morphology is related to fruit morphology, grafted plants can lead to significant changes in fruit appearance and yield (Mozafarian & Kappel, 2020). Parameters such as plant height, plant growth type, leaf size, number of flowers, flower size, flower color are the basic parameters in breeding and are also related to fruit size, fruit color and yield. Some researchers reported that flower size (Genç, 2014), flower color, flower location (Kowalska, 2008), the number of flowers per flowering (Portis *et al*., 2015) was related to fruit size, fruit color and number of fruits. On the other hand, some researchers noted that plant height (Miceli *et al*., 2014), leaf size, leaf formation, growth habit (Portis *et al*., 2015) are associated with strong growth, high yield and ease of harvest. Eggplant morphological descriptors, which are highly effective in eggplant, are used to reveal the differences caused by grafting (Boyaci *et al*., 2020).

Different results have been obtained by researchers in grafting studies. Some researchers stated that the effect of grafting was positive; the others reported that grafting had negative or insignificant effects (Kyriacou *et al.*, 2017; Mozafarian & Kappel, 2020). Grafting studies were carried out under different environmental conditions with different rootstock / scion combinations. Also the same observations were taken at different dates by different researchers. For this reason, there could be contradictions in the results. The differences can be minimized by identifying new characteristics that can reveal the grafting effect and also by standardizing the observation dates. Kyriacou *et al*., (2016) also stated that the non-synchronization of harvest maturity in watermelon caused differences in the grafting results. Similarly, Khah (2011) reported that effect of the grafting varied with the time of measurement.

Moreover many different traits relating to the fruit quality of eggplant have been reported. However little attention has been paid and investigated grafted eggplant plant growth indicators such as anthocyanin coloration of stem, growth habit, intensity of flower color, stem pubescence in few studies until this time. In present study, many plant parameters that could be affected by grafting and related to fruit quality were examined. In the study; it was aimed to determine the effect of different types of rootstocks on plant structure, stem, leaf, and flower characteristics of scions and to evaluate rootstock/scion compatibility in non-infested soil. In addition, the effect of dates in grafting studies was also observed.

## Materials and Methods

The experiment was conducted in the spring-summer seasons in the open field, located in Antalya, south of Turkey (36.53'30 N, 31.08.13 E.).

**Materials:** *S. torvum* Sw. (Hawk) and *S. melongena* L. inter-species hybrid (Anafor), the most widely used commercial rootstocks in Turkey, were used as rootstocks. Commercial eggplant hybrids, BT Bıldırcın (Striped cylindrical type) and Amadeo (pear shape type) were used as scions as well as ungrafted control.

60 seeds of each rootstocks were sown on 28 February 2019. Since the scions had to be planted later for the grafting trial, the rootstock seedlings were checked at regular intervals, and the seeds of the scion varieties and ungrafted control were sown on the 20th day, when all of the leaves of the rootstock seedlings became fully parallel. 50 seeds of the scions were sown for each rootstock for grafting and 36 seeds of the scions were sown for control groups. Peat-perlite (1: 3) was used as the growing medium in trays. Seed sown trays were covered with vermiculite and placed in a germination room at 25-30°C temperature and 60-70% relative humidity.

**Grafting:** Since the growth rates of rootstocks were different, the most appropriate grafting time was expected to come. When the scions had 2-3 real leaves and the rootstocks had 3- 4 true leaves on 55th days of the rootstocks sowing, plants were grafted manually by using tube grafting method (Fig. 1). In this grafting method, rootstocks and scions were given a slanting cut first. Then plastic tubes were put on the rootstocks and cut surfaces were joined together. 40 seedlings of each scion were grafted and grafted plantlets were kept for 7 days under controlled conditions (25°C and 95% relative humidity). Then grafted plants were acclimated to the natural conditions of the greenhouse for 7 days. The same procedure was applied to all combinations and no plant growth regulator was applied.

**Transplanting and observation taken:** The field trials were conducted in a clay loam (CL) soil, $CaCO_3$ 10,40 (%) at pH 7,5. In addition the trial soil was found to be non-infested of disease and pest in terms of root-knot nematodes, *Fusarium oxysporum* and *Verticillium dahliae.* 30 plants of each rootstock/scion combination were transplanted on the $70^{th}$ day after rootstocks sowing. The planting distance between the rows and between the plants was 100 cm and 80 cm, respectively. Fertilization and irrigation were applied with drip irrigation throughout the growing seasons. Standard horticultural practices for eggplant productions in the region were adopted. Same applications were performed for all combinations and control groups. Average monthly temperature values of the trial area during the experimental period had changed between 20.5°C and 28.4°C (Anon., 2020a).

Twenty five plants characteristics which were determined according to The International Union for the Protection of New Varieties of Plants (UPOV) were examined (Anon., 2020b). The characteristics, observation dates and places of observation examined in the study are indicated in (Table 1).

Observations on stem, leaf blade and flower of chosen 12 plants or parts taken from each of 12 plants parts were taken randomly. Observations were made on 3 plant/plant parts each replicate. Grafting success (%) was calculated in 40 grafted plants and percentage of plant survival (%) was calculated in 30 plants. Stem diameters and flower diameters were measured with a digital caliper. Plant and leaf heights were measured with a ruler. Color (L*, a* and b*) was measured using a colorimeter (Konica Minolta CR 410 Osaka, Japan) <Hue angle and Chroma were calculated by the following formula (1) (Mclellan *et al*., 1994). Color space was divided into a three-dimensional (L*, a* and b*) such that L* (brightness); +a* was red direction, -a* was the green direction, +b* was the yellow direction, and -b* was the blue direction (Anonymous, 2020c). For the purple color; darkness was associated with (+ a) and (-b), and the increase in values as (+) and (-) was evaluated as an increase in darkness. For the green color, it was evaluated that the darkness was related to (-a) and (+ b), especially when (-a) increases, the darkness increases, and as the value (b) approaches 0, the darkness increases (Anon., 2020c).

Chroma $(C^*) = (a^{*2} + b^{*2})^{1/2.}$ (1)

Hue angle $(H^o)$ (1)

First quadrant (+a,+b): $H^o = \tan^{-1}(b^*/a^*)$

Second and third quadrant (-a,+b): $H^o = 180 + \tan^{-1}(b^*/a^*)$

Fourth quadrant (+a,-b): $H^o = 360 + \tan^{-1}(b^*/a^*)$

Fig. 1. a. Cutting the rootstocks just below the cotyledons at an angle of 45 degrees and inserting plastic tubes, b. Cutting the scions just below the cotyledons at an angle of 45 degrees. c. Grafting.

**Statistical analysis**

The experiment was laid out in a randomized complete block design with three replications, each consisting of 10 plants. Statistical analysis was performed using the "JMP7.0" package program (JMP). Data was evaluated by analysis of variance for the main effects and the differences between the means were compared using by the T-test at $p \leq 0.05$.

**Results**

**Effect of rootstocks on grafting compatibility:** Rootstocks did not significantly affect to grafting success (Table 2). Grafting success was recorded to 97% (Amadeo) and 100% (BT Bıldırcın). The results showed that the effect of rootstocks was insignificant on both scions, however; grafting success rate varied depending on the scions.

Grafting significantly affected the percentage of plant survival in both scions (Table 2). While the highest plant survival was found in BT Bıldırcın/Anafor, the lowest was in BT Bıldırcın/Hawk. Percentages of plant survival were determined to 87% and 93% in Amadeo and 77% and 100% in BT Bıldırcın.

**Effect of grafting on plant structure:** Grafting significantly reduced the plantlet height only in Amadeo/Hawk (Table 2). Moreover grafting significantly increased the number of leaves in BT Bıldırcın/Anafor (Table 2). The results showed that plant growth was slow in *S. torvum* rootstock. Since anthocyanin coloration of hypocotyl was present on the hypocotyl part of the seedling, observation was made only on rootstocks and ungrafted scion varieties. As a result of observation; while anthocyanin coloration was weak in Hawk and Amadeo, anthocyanin coloration was strong in the Anafor and no coloration was observed in BT Bıldırcın (Table 2).

Grafting significantly affected the plant growth habit in Amadeo only (Table 2). However, no visible differences were found between rootstocks. Grafting had a positive effect on Amadeo which tended to develop horizontally and the rootstocks kept the plant upright. Grafting did not significantly affect to plant heights at 25 days after transplanting (DAT) on both scions (Table 2). However, at 40 DAT and 50 DAT, grafting significantly affected the plant heights in BT Bıldırcın only. In BT Bıldırcın, grafting increased the plant height in both rootstocks but no significant differences were found among rootstocks. On the other hand although it was found to be statistically insignificant, rootstocks increased the plant height also in Amadeo. Changes in plant height are given in (Fig. 2).

**Effect of grafting on stem characteristics:** Grafting did not significantly affect the stem diameter of rootstocks and of scions at 25 DAT (Table 3). However, at 50 DAT; grafting significantly increased only in BT Bıldırcın/ Anafor. Furthermore grafting significantly increased the stem diameter in both scions at 110 DAT and the thickest stem diameter was obtained from the BT Bıldırcın/Anafor combination. Changes in stem diameter of scions are given in (Fig. 3).

No visible differences were observed in the pubescence of the stem in both the grafted and ungrafted scion (Table 3). Moreover grafting did not significantly affect to L* value in both scions for anthocyanin coloration of stem (Table 3). However, grafting significantly increased to a* value only the Amadeo/Hawk compared to ungrafted. In addition grafting reduced to b* value only BT Bıldırcın and there was no significant difference between rootstocks in b* value. In terms of Hue angle, grafting significantly reduced to intensity of anthocyanin coloration Amadeo/Hawk and Amadeo/Anafor. Grafting significantly reduced the chroma BT Bıldırcın/Hawk, BT Bıldırcın/ Anafor. When the results were evaluated together, Hawk (*S. torvum)* significantly most increased the intensity of anthocyanin coloration in both scions.

**Table 1. Characteristics examined in the study.**

| | Characteristics | Observation dates | Observation section |
|---|---|---|---|
| Seedling | Grafting success (%) | At 15 days after grafting | Calculated to living plant |
| | Plantlet height (cm) | At transplanting | Seedling |
| | Number of leaves (No.) | At transplanting | Seedling |
| | Intensity of anthocyanin coloration of hypocotyl | After the cotyledon leaves are fully developed and before transplanting | Hypocotyl |
| Plant | Percentage of plant survival (%) | At 20 DAT | Calculated to living plant |
| | Height (cm) | At 25-40-50 DAT | The part from the soil surface to the top of the plant |
| | Growth habit | The period when more than 50% of the plants planted of the variety have normally developed fruit | Stem angle |
| Stem | Stem diameter of rootstocks (mm) | At 25 DAT | Under the graft point |
| | Stem diameter of scions (mm) | At 25-40-50 DAT | Over the graft point |
| | Intensity of anthocyanin coloration<br>Pubescence | The period before the beginning of the first harvest | In the third part of the top shoot |
| Leaf blade | Width (cm)<br>Length (cm)<br>Leaf petiole length (cm)<br>Intensity of green color<br>Sinuation of margin<br>Blistering | The period before the beginning of the first harvest | Fully mature leaves where in the middle of the plant |
| Flower | Time of flowering (day)<br>Distance from cotyledons to the node of the first flower (cm) | When 50% of the plants belonging to the variety are flowering | First inflorescences |
| | Inflorescence: number of flowers (No.) | | Number of flowers in a cluster |
| | Flower: Intensity of purple color<br>Size (cm) | When 50% of the plants belonging to the variety are 2nd or 3rd flowering | In the fully opened and unbroken flowers of the plant<br>Measurement of the largest diameter of fully opened and unbroken flowers |

**Table 2. Effect of grafting on plant structure.**

| Scion/Rootstock | Grafting success (%) | Percentage of plant survival (%) | Plantlet height (cm) | Number of leaves (No.) | Plant Growth habit | Anthocyanin coloration of hypocotyl | | Plant height (cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Colaration | Intensity | 25 DAT | 40 DAT | 50 DAT |
| Amadeo | - | 100 a | 25,67 a | 4,00 | Horizontal | Present | Weak | 20,67 | 40,33 | 54,25 |
| Amadeo/Hawk | 97 | 87 b | 21,67 b | 4,33 | Semi-erect | Present*** | Weak | 22,00 | 44,33 | 59,85 |
| Amadeo/Anafor | 97 | 93 ab | 23,33 ab | 3,67 | Semi-erect | Present*** | Strong | 19,67 | 46,67 | 60,85 |
| Significance | NS | * | * | NS | | | | NS | NS | NS |
| BT Bıldırcın | - | 100 a | 23,33 | 5,00 b | Erect | Absent | Absent | 23,00 | 54,00 c | 67,82 b |
| BT Bıldırcın/ Hawk | 100 | 77 b | 19,33 | 5,33 ab | Erect | - | - | 21,33 | 63,00 a | 81,14 a |
| BT Bıldırcın/ Anafor | 100 | 100 a | 23,00 | 6,00 a | Erect | - | - | 23,00 | 58,67 b | 77,50 a |
| Significance | NS | * | NS | * | | | | NS | * | * |

*Significant at $p \leq 0.05$; NS, not significant at $p > 0.05$., *** Observation result of scion variety

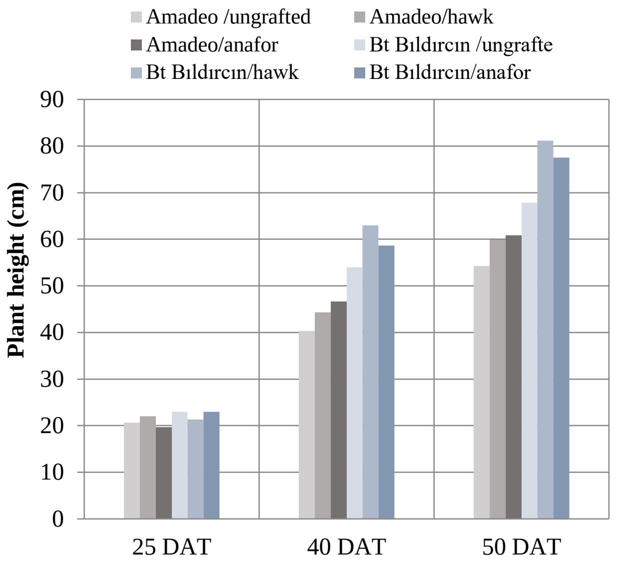


Fig. 2. Changes in plant height.

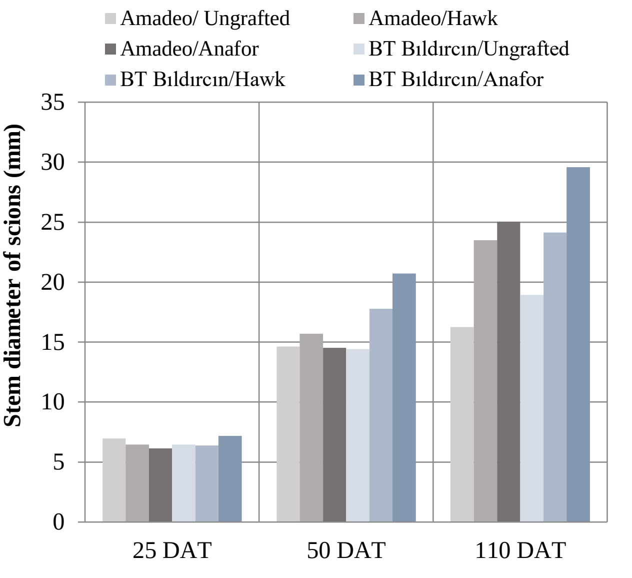


Fig. 3. Changes in stem diameter of scions.

**Effect of grafting on leaf characteristics:** Grafting did not significantly affect to leaf length, leaf width, petiole length, sinuation of margin and leaf blistering in both scions compared with the ungrafted (Table 4). Although it was statistically insignificant, the rootstocks increased to leaf size in both scions.

Grafting did not significantly affect to L* and a* values for leaf color in both scions. However grafting significantly reduced to b* value only Amadeo/Anafor compared to ungrafted. In terms of Hue angle, grafting significantly increased only in Amadeo/Anafor. Grafting significantly reduced the chroma only Amadeo/Anafor (Table 4). As a result, interspecific hybrid rootstock (Anafor) increased the leaf darkness in Amadeo.

**Effect of grafting on flower characteristics:** Grafting did not significantly affect the distance from cotyledons to the node of the first flower, flower size and number of flowers in both scions compared with the ungrafted plants (Table 5). Although it was statistically insignificant, the rootstocks decreased the flower size and distance of first flowering were higher in both scions.

Grafting significantly delayed to flowering time in both scions depending on the combination (Table 5). The highest delay was in *S. torvum* (Hawk) in both scions. Grafting did not significantly affect to L* value with regard to intensity of purple color of flower in both scions, but it significantly affected to a*,b*, Chroma and Hue angle in both scions (Table 5). However, the effect was different according to the scion variety. Grafting significantly increased a* value and decreased b* value in all Amadeo combinations. Although in BT Bıldırcın/ Hawk combination, grafting significantly decreased a* value and increased b* value. In terms of Hue angle, grafting significantly increased in Amadeo/Hawk and Amadeo/Anafor, while it decreased only BT Bıldırcın/ Hawk. On the other hand grafting significantly reduced chroma in BT Bıldırcın/Anafor combination, while it increased in BT Bıldırcın/Hawk. In result, Hawk (*S. torvum*) significantly increased the intensity of flower color in Amadeo while in BT Bıldırcın significantly reduced to intensity of flower color.

## Discussion

Many researchers have been working on the effect of rootstocks and the compatibility of grafting combinations and different results have emerged. Until now, researchers generally evaluated rootstock/scion in terms of fruit parameters and yield. However, since plant growth parameters such as plant height, leaf color, flower size, stem diameter are related to fruit quality and yield, it is important to investigate these characteristics. In this study, it was aimed to reveal the importance of observation dates in grafting studies and to determine the morphological features that could be used in grafting studies. Moreover grafting had a significant effect on some of the plant's properties and effect of the rootstocks varied according to the characteristics examined.

Grafting success and percentage of plant survival are among the most important features in evaluating rootstock/scion compatibility. In present study, rootstocks did not significantly affect the grafting success but grafting success rate varied according to the scion varieties. Similar to our results; Hoza *et al.*, (2017) also demonstrated that the effect of rootstocks was statistically insignificant in all other combinations except for one. In addition our results were in accord with those obtained by Sarıbaş (2019) who reported rootstocks did not significantly affect the grafting success. Our research showed that the scion varieties were more effective according to rootstock varieties in the grafting success. Furthermore only the seedling stage was not sufficient in determining the rootstock/scion compatibility because of incompatibility could be seen after planting.

**Table 3. Effect of grafting on stem characteristics**

| Scion/Rootstock | Stem diameter of rootstock (mm) | Stem diameter of scions (mm) | | | Stem: Intensity of anthocyanin coloration | | | | | Stem: Pubescence |
|---|---|---|---|---|---|---|---|---|---|---|
| | 25 DAT | 25 DAT | 50 DAT | 110 DAT | L* | a* | b* | Hue | Chroma | |
| Amadeo | 6,97 | 6,97 | 14,64 | 16,26 b | 33,32 | -0,74 b | 13,67 | 92,85 a | 13,70 | Medium |
| Amadeo/Hawk | 6,47 | 6,46 | 15,70 | 23,50 a | 37,33 | 4,20 a | 10,63 | 68,35 c | 11,43 | Medium |
| Amadeo/Anafor | 6,54 | 6,14 | 14,53 | 25,05 a | 39,32 | 0,74 b | 8,64 | 85,25 b | 8,68 | Medium |
| Significance | NS | NS | NS | * | NS | * | NS | * | NS | |
| BT Bıldırcın | 6,45 | 6,45 | 14,41 b | 18,94 c | 33,97 | 1,48 | 14,07 a | 83,71 | 14,19 a | Weak |
| BT Bıldırcın/ Hawk | 6,22 | 6,37 | 17,78ab | 24,14 b | 30,46 | 3,12 | 9,89 b | 72,90 | 8,01 b | Weak |
| BT Bıldırcın/ Anafor | 6,81 | 7,17 | 20,71 a | 29,59 a | 28,78 | 1,80 | 7,79 b | 76,64 | 10,42 b | Weak |
| Significance | NS | NS | * | * | NS | NS | * | NS | * | |

*Significant at $p \leq 0.05$; ** NS, not significant at $p > 0.05$. DAT: Days after transplanting.

**Table 4. Effect of grafting on leaf characteristics.**

| Scion/Rootstock | Leaf: Width (cm) | Leaf: Length (cm) | Leaf: Petiole length (cm) | Leaf: Sinuation of margin | Leaf: Blistering | Leaf: Intensity of green color | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | L* | a* | b* | Hue | Chroma |
| Amadeo | 16,43 | 24,40 | 8,73 | Weak | Weak | 38,96 | -11,23 | 21,18 a | 118,06 b | 24,00 a |
| Amadeo/Hawk | 17,83 | 27,00 | 9,03 | Weak | Weak | 41,65 | -11,33 | 21,43 a | 117,91 b | 24,26 a |
| Amadeo/Anafor | 18,17 | 27,50 | 10,43 | Weak | Weak | 41,08 | -8,79 | 9,37 b | 133,87 a | 12,88 b |
| Significance | NS | NS | NS | | | NS | NS | * | * | * |
| BT Bıldırcın | 12,80 | 22,13 | 6,77 | Weak | Very weak | 38,03 | -10,43 | 19,27 | 118,44 | 21,92 |
| BT Bıldırcın/Hawk | 16,13 | 23,73 | 7,07 | Weak | Very weak | 38,00 | -9,81 | 17,59 | 119,18 | 20,14 |
| BT Bıldırcın/Anafor | 13,07 | 22,50 | 6,83 | Weak | Very weak | 39,72 | -11,18 | 19,43 | 120,23 | 22,47 |
| Significance | NS | NS | NS | | | NS | NS | NS | NS | NS |

* Significant at $p \leq 0.05$; NS, not significant at $p > 0.05$

**Table 5. Effect of grafting on flower characteristics.**

| Scion/Rootstock | Time of flowering (day) | Distance from cotyledons to the node of the first flower (cm) | Inflorescence: Number of flowers (pcs) | Flower: Size (cm) | Flower: Intensity of purple color | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | L* | a* | b* | Hue | Chroma |
| Amadeo | 25 c | 13,67 | One to three | 4,30 | 50,37 | 5,83 b | 15,23 a | 68,32 b | 16,36 |
| Amadeo/Hawk | 37 a | 14,50 | One to three | 3,87 | 53,60 | 8,52 a | -3,09 b | 339,46 a | 9,09 |
| Amadeo/Anafor | 33 b | 14,67 | One to three | 3,90 | 57,32 | 9,16 a | -2,10 b | 347,31 a | 9,40 |
| Significance | * | NS | | NS | NS | * | * | * | NS |
| BT Bıldırcın | 33 b | 20,33 | One to three | 4,40 | 50,92 | 13,80 a | -2,02 b | 357,98 a | 13,98 b |
| BT Bıldırcın/ Hawk | 40 a | 27,50 | One to three | 4,20 | 51,70 | 12,00 b | 9,45 a | 38,22 b | 15,33 a |
| BT Bıldırcın/ Anafor | 33 b | 24,67 | One to three | 4,17 | 53,46 | 11,41 b | -3,13 b | 356,87 a | 11,85 c |
| Significance | * | NS | | NS | NS | * | * | * | * |

* Significant at $p \leq 0.05$; NS, not significant at $p > 0.05$

Determination of percentage of plant survival after transplanting is important in determining whether there are compatibility problems (Quamruzzaman *et al*., 2020).Our results showed that percentage of plant survival was significantly decreased at grafted plants compared to the ungrafted. However its level depended on the rootstock/ scion combination. *S. torvum* (Hawk) rootstock showed the lowest percentage of plant survival for both scions. As a result, the grafting incompatibility of the BT Bıldırcın / Hawk combination was slightly higher than the ungrafted and other rootstock. Similar to our results, Kawaguchi *et al*., (2008) reported that the plant's response to graft incompatibility depended on the rootstock/scion combination. Similarly, Khah (2005) stated that one of the important reasons affecting grafting incompatibility was the properties of the scion. Apart from these, percentage of plant survival changes according to the power of the rootstocks. When the weaker scion varieties are grafted to the strong rootstocks, the scion varieties does not develop and the rootstock develops from the grafting area. Our results on plant power are consistent with findings of Sabatino *et al*., (2017), who reported that plant power caused a decrease in the grafting success. Similar results were obtained by Lee *et al*., (2010), who determined that when a weak scion was made on a strong rootstock, green evening development might be higher.

Rootstocks can also affect the growth and morphology of the seedling. Grafting had a negative effect on the plantlet height, firstly depending on the scion and then rootstocks. Grafting caused to transplanting delayed. Generally, ungrafted plants were taller at transplanting in our study. The shortest plantlet height was found in *S. torvum* (Hawk) combinations. Our results were consistent with those of Miceli *et al*., (2014), whonoted that the grafted plants were ready for planting later, because *S. torvum* seed germination and seedling growth were slow. One of the indicators of plant power is the number of leaves. Grafting increases the number of leaves of seedling depending on the scion and then rootstocks.The highest leaf increment was seen in interspecific hybrid rootstock (Anafor) compared to ungrafted plant. Hoza *et al*., (2017) also reported that number of leaves of grafted plants were 2.5-3 times higher than ungrafted. Our findings were in agreement with those of Ashok *et al.*, (2017) and Ulas (2021) who noted that grafting increased the leaf area. On the other hand, Miceli *et al*., (2014) determined that leaf number was not affected by grafting recorded at 40 and 65 DAT. Hypocotyl properties of the rootstocks and scions are important for ensuring the grafting compatibility (Karaağaç *et al*., 2018) and using to estimate intensity of anthocyanin color of flower (Feher & Füstös, 2016). Intensity of anthocyanin coloration of hypocotyl has been found in different densities on rootstocks and scion. Although anthocyanin coloration of hypocotyl can be affected by environmental conditions; especially the absence of anthocyanin in the seedling which is considered to be one of the methods that can be used to determine whether the producers buy the right rootstock. In other words, while there is anthocyanin coloration of hypocotyl on the ordered rootstock, the absence of anthocyanin coloration of hypocotyl delivered to the producer may indicate that the rootstock may be different from the requested rootstock. For this reason, knowing the anthocyanin coloration of hypocotyl is an important criterion for producer.

Plant height is considered an indicator of plant power (Musa *et al*., 2020). The findings of present study showed that grafting had no significant effect to plant heights at 25 DAT both of scions; however, grafting significantly increased to plant height at 40 DAT and at 50 DAT depending on firstly scion then rootstocks Similar results were obtained by Hoza *et al*., (2017), Kumar *et al*., (2019) and Ulas (2021), who reported that rootstocks increased the plant height. Our results were consistent with those of Sabatino *et al*., (2019) and Musa *et al*., (2020), who reported that rootstocks had increased the plant height depending on rootstock/scion combinations. Furthermore Miceli *et al*., (2014) revealed that the power of *S. torvum* rootstock emerged noticeably on the 65$^{th}$ day after transplanting in the first year trial and on the 40th day after planting in the second year trial. Morever our findings are consistent with those of Sabatino *et al*., (2019) and Quamruzzaman *et al*., (2020), who reported that observation time was important in revealing the effect of the grafting.

Growth type is important for cultural practices and ease of harvest. Breeders are working on the development of new rootstocks that can contribute to the growth habit of eggplant scion (Boyaci & Ellialtioglu, 2020). Portis *et al*., (2015) noted that is important for the upright habit of the plant. Furthermore Quamruzzaman *et al*., (2020) reported that a compatible rootstock / scion combination might cause less damage to the plant and fruit in cultural processes. In the present study, grafting was effective for the plant growth habit depending on the scions, especially in scion varieties with horizontal growth tendency. Grafting caused the plant to stand upright depending on the rootstock/scion combination.

Close stem diameters between rootstocks and scion varieties are important in terms of grafting compatibility (Hoza *et al*., 2017). The findings of present study showed that, grafting had no significant effect to stem diameters of rootstocks and of scions at 25 DAT in both scion varieties. However, grafting significantly increased the stem diameter of scions at 50 and 110 DAT primarily depending on the scions and then the rootstocks the highest stem diameter was found in interspecific eggplant hybrid rootstock (Anafor) in both scions. Talhouni (2016), Kumar *et al.*, (2019), Musa *et al*., (2020) and Ulas (2021) reported that grafting positively affected the stem diameters. Our results showed that observation dates were important in determining the stem diameter. The findings were in accord to those of Sarıbaş (2019), who reported that they could not find a significant difference in 30 days after grafting. This might be due to the early observation time. Intensity of anthocyanin coloration of stem is important because of it is associated with color of hypocotyl, flower and calyx (Feher & Füstös, 2016).

Therefore, it can affect the color of the fruit. Grafting significantly increased the intensity of anthocyanin coloration of stem, depending on rootstock /scion combination In *S. torvum* stem darkness was most significantly increased in both scions.

Prickles of leaf and stem pubescence are important to protect the plant against pests (Kipchirchir, 2016). Grafting had no significant effect on stem pubescence in both scions varieties. On the other hand rootstocks can also affect leaf characteristics due to grafting. Leaf area is an important parameter in determining plant growth and development under normal and stress conditions (Nakanwagi *et al*., 2018; Wang *et al*., 2021). Grafting had no significant effect on leaf length, width and petiole length in both scions. Although it was statistically insignificant, the rootstocks increased the leaf area in both scion varieties. Rahmatian *et al*., (2014) and Talhouni (2016) reported that grafting had a positive effect on the leaf area characteristics. Grafting had no significant effect on sinuation of margin of leaf and leaf blistering. Eltayb *et al*., (2013) determined the changes in the leaves and flowers of eggplant and pepper varieties grafted on tomato rootstock; they found that the leaf shape of the grafted eggplant was completely different from the ungrafted one. Our result was different because it might be caused by the incompatibility with the rootstock / scion combination and the tomato rootstock. Grafting significantly increased the intensity of leaf green color primarily depending on the scion and then rootstock. In the present study, interspecific hybrid rootstock (Anafor) increased the leaf darkness compared to ungrafted ones. Our results were consistent with those of Miceli *et al*., (2014), who found that leaf color was darker with grafting in self-grafted eggplants.

Rootstocks can also affect to morphological features of flower. Grafting had no significant effect on distance from cotyledons to the node of the first flower and flower sizes in both scions. Anthocyanins play a role in the coloring of several flowers and fruits (Toppino *et al.*, 2020). Grafting significantly changed the intensity of flower purple color depending on rootstock/scion combination. In some rootstock/scion combination, grafting increased intensity of flower purple color while it decreased in some combinations. These results showed that the most important criterion for intensity of flower purple color was the scion cultivars. Eltayb *et al*., (2013) found that grafting significantly affected the color of flower in the eggplant variety grafted on tomatoes. Time of flowering is an important feature as it affects fruit harvest time, which can have a direct impact on fruit quality (Lee *et al*., 2010). In present study, grafting delayed the flowering time in both scions. The highest delay was in *S. torvum* (Hawk) in both scions. Our results were in line with the findings of Quamruzzaman *et al*., (2020); Musa *et al.*, (2020). Moreover Moncada *et al*., (2013) reported comparable influence of delayed flowering in grafted tomato and eggplant plants. As a result, it may be based on stress by these plants during grafting (Musa *et al*., 2020).

## Conclusions

There are so many rootstocks and eggplant varieties in the market but each eggplant variety may not be suitable to grafting. The results of present study showed that positive effect of grafting depended primarily on chosen scion variety and then rootstock/scion combination. For this reason, rootstock / scion combinations should be selected for high quality fruit and yield. Thus, by choosing the right rootstock/scion combination, extra grafting and yield losses will be reduced and it will contribute to the protection of the environment. Furthermore, although grafting has some negative effects, rootstocks have significantly improved to plant power even in non-infested soil compared to ungrafted. This will increase the eggplant yield especially in single crop cultivation in long-term. Moreover our findings confirmed that interspecific eggplant hybrid rootstocks might be good alternative for *S. torvum*. In addition it was determined that the observation dates were important in revealing the effect of the grafting. For this reason, it is necessary to pay particular attention to the observation dates and sites of plant in future studies. Apart from these, the inclusion of the effect of the grafting on plant growth parameters and fruit quality will make the results more effective. Moreover, since the rootstock/scion compatibility changes according to the combinations, a compatibility test should be performed before cultivation in order to minimize the fruit quality and yield losses and also to determine the amount of seeds to be planted and the seed sowing times.

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(Received for publication 10 November 2021)