J. BIOL. ENVIRON. SCI.,
2022, 16(46), 35-47

Original Research Article

Influence of grafting on fruit quality traits in eggplant grafted onto *Solanum torvum* and interspecific rootstocks

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Received: 09.05.2022; Accepted: 14.11.2022; Published Online: 18.11.2022

ABSTRACT

The present use of grafted seedlings is dramatically increasing because of the intensive use of agricultural land, global warming, and environmental pollution. However, grafting of seedlings can cause changes in fruit appearance, earliness, and yield. This study aimed to determine the changes in fruit morphology depending on different rootstocks with new parameters and on different observation dates. *Solanum melongena* L. varieties Amadeo and BT Bıldırcın were used as scions. In addition, *Solanum torvum* Sw. (ST) variety Hawk and interspecific eggplant hybrid (IEH) variety Anafor were used as rootstocks. Our results showed that grafting had a positive effect on peduncle length, and time of physiological ripeness depending on the scion/rootstock combination. Grafting of both scions onto *S. torvum* had the highest increase in peduncle length. Additionally, the Amadeo/*S. torvum* combination reached physiological ripeness at the latest. However, grafting also had negative effects on fruit earliness and browning of pulp tissue depending on the scion/rootstock type combination. The *S. torvum* combination had delayed fruit earliness compared with the other rootstock combination and ungrafted plants. Meanwhile, the BT Bıldırcın/IEH combination had the most browning of the fruit pulp. Consequently, rootstocks can make the eggplant suitable for mechanical harvest by extending the fruit peduncle length.

Keywords: Anthocyanin, Browning of pulp, Calyx, Color, Earliness, Fruit shape

INTRODUCTION

Eggplant is one of the most cultivated crops and greatly consumed worldwide. It is mostly grown in China and India, followed by Egypt, Türkiye, and Indonesia (FAOSTAT 2020). Its fruits have considerably high antioxidant content and nutritional value for human health. Because of the limited cultivated lands in the world and the increased daily vegetable consumption, vegetables are cultivated even in unfavorable soil and environmental conditions through alternative techniques. Grafting has become a very important horticultural practice, and the demand for grafted plants has increased dramatically in the world horticulture industry (Rouphael *et al.* 2017).

Grafting is used for a range of vegetables such as cucurbits (watermelon, melon, cucumber), tomato, pepper, and eggplant to increase tolerance against salinity, flooding, drought, temperature extremes, soil-borne diseases/pests, and the effects of abiotic and biotic stress; increase nutrient and water intake; extend harvest time; and improve morphological traits of scions (Kyriacou *et al.* 2017, Devi *et al.* 2021, Tsaballa *et al.* 2021). In addition, it causes less harm to the environment due to the reduced use of pesticides and fertilizers compared with traditional farming. The prohibition of methyl bromide use has also brought about the rising interest in eggplant grafting (Sabatino *et al.* 2018). Moreover, grafting is an environmentally friendly method that can be used in organic agriculture (Sen *et al*. 2018, Mozafarian and Kappel 2020).

Wild eggplant species, interspecific hybrids, tomato hybrids, and some varieties of *S. melongena* are used as rootstock for grafting. Rootstocks have varying degrees of resistance to disease/pest and different compatibilities with scions. Additionally, the type of rootstocks and grafting can influence the yield, plant growth, and morphology of the scion (Kyriacou *et al.* 2020, Ulas *et al.* 2020). In addition, rootstocks can also influence some fruit quality traits such as calyx size, peduncle length, fruit length, and fruit width of the scion (Gisbert *et al.* 2011a, Sabatino *et al.* 2018, Sabatino *et al.* 2019, Ulas 2021). In this regard, species of rootstocks and scions should be selected carefully (Kombo and Sari, 2019). Basic parameters in breeding such as fruit firmness (Miceli *et al.* 2014) and fruit yield (Akter and Rahman 2018) are related to maturity time, fruit skin and flesh structure, harvest period, and number of fruits. Moreover, Portis *et al.* (2015) stated that large calyxes, long fruit peduncles, fruit shape, fruit firmness, fruit shelf life, spininess of fruit calyx, and green flesh color are important morphological

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traits. Therefore, fruit morphology is important for both consumers and breeders because it is related to fruit quality and yield.

Many different traits relating to the fruit quality of eggplant have been reported, but so far, peduncle length, calyx size, spininess of fruit calyx, fruit apex, size of pistil scar, and time of physiological ripeness has received little emphasis. Moreover, previous studies have different results about the effect of grafting on fruit morphology. Some noted the positive effects of grafting while others reported negative or insignificant effects (Doltu *et al.* 2017, Mozafarian and Kappel 2020, Kyriacou *et al.* 2017). These differences may be partially related to environmental factors, cultivation methods (soilless, soil, irrigation, fertilization, etc.), rootstock type/scion combination, harvest time (Fallik and Ilic 2014, Carvalho *et al.* 2018), strength of rootstock and scion varieties (Çürük *et al*. 2009), and the inability to standardize the fruit harvest maturity (Kyriacou *et al*. 2017, Sabatino *et al.* 2019). Therefore, identifying new traits and standardizing the observation dates and locations that expose the effects of grafting can minimize differences.

This study aims to determine the effects of grafting eggplant onto *S. torvum* and interspecific hybrid eggplant rootstock with new traits on fruit morphological traits and to evaluate the compatibility and tolerance of rootstock/scion combinations in non-infested soil. Additionally, the effect of observation dates on grafting studies was investigated.

MATERIALS AND METHODS

The experiment was performed in an open field area in Antalya Province, south of Türkiye, which is geographically located between 36.53'30 north latitude and 31.08.13 east longitude.

Plant Material

The eggplant hybrid cultivars "BT Bıldırcın" (striped cylindrical) and F1 hybrid "Amadeo" (pear shape) were used as scion, and their ungrafted ones as control. On the other hand, Hawk (*S. torvum*) and Anafor (*S. melongena* interspecific hybrid) were used as rootstocks. Seeds of rootstocks were sown in 150-cell seedling trays on 28 February 2019. Seeds of scions and controls were sown 20 days after sowing the seeds of rootstocks. A mixture of peat and perlite (1:3) was used as the growing medium in trays. Seed sown trays were then covered with vermiculite and placed them in a germination room at 25 – 30°C and 60 – 70% relative humidity. The experiment was performed using the same procedure for all combinations. No plant growth regulator was applied to the seedlings before grafting.

Grafting and Transplanting

The "BT Bıldırcın" and "Amadeo" hybrids were grafted onto rootstock varieties of Hawk and Anafor via tube grafting method. Since the growth rates of rootstocks are different, it was expected that the most appropriate grafting time would come. Eggplant seedlings at 3–4 leaf stage was grafted 55 days after sowing the rootstocks. The grafted seedlings were maintained for 7 days under controlled conditions at 25°C and 95% relative humidity. Afterward, the grafted plants were acclimatized outside for 7 days.

The field trials were conducted in a clay loam (CL) soil (10.40 $CaCO_3$ (%) at pH 7.5). In addition, the experiment soil was non-infested (e.g., root-knot nematodes, *Fusarium oxysporum*, and *Verticillium dahliae*). A total of 30 seedlings of each combination were transplanted at 70 days after the rootstocks sowing. Seedlings were planting with 100 x 80 cm between the rows and between the plants. The experiment was performed using the same procedure for all combinations as well as the standard horticultural practices for eggplant cultivation. The weather during the experimental period in terms of temperature was like the average monthly temperature values (i.e., between 20.5°C and 28.4°C) (TSMS, 2020).

Fruit Morphological Measurements and Observation

In total, 34 fruit characteristics determined by considering The International Union for the Protection of New Varieties of Plants (UPOV) eggplant test guideline were examined (UPOV 2002). Table 1 lists the traits examined in the experiment. In the experiment, all observations were made using the fruits of a minimum of 12 plants: commercially mature, second cluster fruits that did not lose their glossiness. Measured observations were made on 3 fruits each replicate. The physiological ripeness of the second cluster fruits was assessed when they reached full physiological ripeness. Next, the grafting combinations were compared with the ungrafted control group for visual properties using the calibration book (Naktuinbouw and NCSS 2019). The soluble solid content (SSC, %) of the fruit was measured using a digital refractometer on the fruit juice. Fruit firmness was measured using small, hand-operated penetrometer, and a weigher was used for fruit measurements.

Table 1. Eggplant fruit characteristics examined in the study.

Characteristics			Note- Characteristics
1	Apparent Fruit Quality	Length (cm)	
2		Width (cm)	
3		Ratio length/width	
4		Peduncle length (cm)	
5		Average fruit weight (g)	
6		General shape	1- globular 2- ovoid 3- obovate 4- pear shaped 5- club shaped 6- ellipsoid 7- cylindirical
7		Size of pistil scar (cm)	
8		Depth of indentation of pistil scar	1- absent or very shallow 3- shallow 5- medium 7- deep 9- very deep
9		Only cylindrical fruits: Curvature	1- absent or very weak 3- weak 5- medium 7- strong 9- very strong
10		Apex	1- indented 2- flattened 3- rounded 4- pointed
11		Patches	1- absent 9- present
12		Stripes	1- absent 9- present
13		Prominence of stripes	3- weak 5- medium 7-strong
14		Density of stripes	3- sparse 5- medium 7-dense
15		Ribs	1- absent or very weak 3- weak 5- medium 7- strong 9- very strong
16		Anthocyanin coloration underneath calyx	1- absent 9- present
17		Intensity of anthocyanin coloration underneath calyx	3- weak 5- medium 7- strong
18		Anthocyanin coloration of calyx	1- Absent 9- Present
19		Intensity of anthocyanin coloration of calyx	1- very weak 3- weak 5- medium 7- strong 9- very strong
20		Calyx size (cm)	
21		Spininess of calyx	1- absent or very weak 3- weak 5- medium 7- strong 9- very strong
22		Creasing of calyx	1- very weak 3- weak 5- medium 7- strong 9- very strong
23	Fruit Color	Main color of skin at harvest maturity	1- white 2- green 3- violet
24		Intensity of main color of skin at harvest maturity	1- very light 3- light 5- medium 7- dark 9- very dark
25		Glossiness	3- weak 5- medium 7-strong
26		Color of skin at physiological ripeness	1- yellow 2- orange 3- ochre 4- brown
27		Flesh color	1- whitish 2- greenish
28		Flesh color (30 min later)	
29	Earliness and Fruit Composition	Seedness of flesh	3- weak 5- medium 7- intense
30		Firmness at harvest maturity (kg)	
31		Firmness at physiological ripeness (kg)	
32		Water soluble dry matter amount (SSC) (%)	
33		Plants with early fruit (%)	
34		Time of physiological ripeness	3- early 5- medium 7- late

Skin color was assessed on the middle portion of three fruits per rootstock/scion combination with a reflectance calorimeter (Konica Minolta CR 410, Osaka, Japan). A calorimeter was also used to assess the flesh color, fruit browning, and fruit brightness. Fruits were cut into longitudinal sections, and the flesh color was measured in the middle portion after cutting and then after 30 min. Fruit brightness was determined using the same device with the L* value (0: Black and 100: White) since the color space is divided into three dimensions (L*, a*, and b*, where L* is the brightness, +a* is the red direction, -a* is the green direction, +b* is the yellow direction, and -b* is the blue direction) (Minolta 2007). Hue angle and Chroma were calculated by the following formula (1) (Mclellan *et al*. 1994).

Chroma (C*) = $(a^{*2} + b^{*2})^{1/2.}$ (1)
Hue angle (H°) (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) : $H^o = 360 + \tan^{-1}(b^*/a^*)$

Statistical Analysis
The experiment was performed in a randomized complete block design with 3 replications, each consisting of 10 plants. All data were statistically analyzed using the "JMP 7.0" package program. The significant differences between the means were compared using the criterion of the T-test at $p \leq 0.05$.

RESULTS

Apparent Fruit Quality
In the present study, no significant differences were found in fruit length, fruit width, length/width ratio, average fruit weight, general shape, pistil scar size, pistil scar depth, fruit curvature, fruit apex, fruit patches, fruit stripes (stripes, prominence, density), and fruit ribs in both scion varieties compared with those in the ungrafted plants (Table 2–3). As shown in Table 2, grafting both scion varieties, cv. "Amadeo" and "BT Bıldırcın," onto "Hawk" (*S. torvum*) rootstock significantly increased the peduncle length compared with that in the "Anafor" (IEH) rootstock and ungrafted plants.

No statistical difference was found in calyx size in both ungrafted plants and scion varieties grafted onto rootstocks (Table 4). No visible differences were noted in the intensity of anthocyanin coloration underneath calyx, intensity of anthocyanin coloration of calyx, spininess of calyx, and creasing of calyx due to grafting (Table 4).

Fruit Color Measurements
According to visual and calorimeter L*, a*, b* values, grafting did not significantly affect the main color density of the skin at harvest maturity and fruit glossiness in both scion varieties compared with the ungrafted plants (Table 5). However, in terms of main color of skin at harvest maturity grafting significantly reduced to Hue angle only in Amadeo/Hawk combination and no difference was found between rootstocks. As shown in Table 5, a* value and Hue angle were found to be a significant color of skin at physiological ripeness for only "BT Bıldırcın". The results showed the highest a* value in the ungrafted "BT Bıldırcın" (12.88) variety compared with that in the "BT Bıldırcın/Hawk" and "BT Bıldırcın/Anafor" (6.37 and 6.84, respectively) combinations. In addition to this, grafting significantly increased the hue angle and delayed to intensity of brown in BT Bıldırcın/Hawk and BT Bıldırcın/Anafor combinations but there was no significant difference between rootstocks.

Table 6 presents the results of the measurements of flesh color and pulp tissue browning. Our study found that L*, b*, hue and chroma of flesh color are significant only in "BT Bıldırcın". Moreover, grafting did not significantly affect to a* value of flesh color in both "Amadeo" and "BT Bıldırcın" varieties. According to Table 6, grafting has increased the b* value of flesh color in the only "BT Bıldırcın/Anafor". On the other hand, grafting decreased to hue angle and increased to Chroma only in BT Bıldırcın/Anafor. The study results showed that L* value of flesh color was significantly decreased in the "BT Bıldırcın/Anafor" combination (75.91) compared with that in ungrafted "BT Bıldırcın" (82.87). These results showed that the flesh color was darker in the "BT Bıldırcın/Anafor" combination compared with that in the ungrafted "BT Bıldırcın".

Table 2. Effect of grafting on fruit size and shape

Scion/rootstock	Fruit length (cm)	Fruit width (cm)	Fruit length/width ratio	Peduncle length (cm)	Average fruit weight (g)	General shape
Amadeo	11,88	8,87	1,30	5,88 c	336,79	Pear shaped
Amadeo/Hawk	13,02	9,52	1,37	6,87 a	365,71	Pear shaped
Amadeo/Anafor	13,08	9,27	1,41	6,37 b	368,11	Pear shaped
Significance	NS	NS	NS	*	NS	
BT Bıldırcın	19,42	5,76	3,39	6,17 b	220,37	Club shaped
BT Bıldırcın/Hawk	18,87	6,02	3,16	6,63 a	247,76	Club shaped
BT Bıldırcın/Anafor	18,75	5,54	3,39	6,21 b	242,34	Club shaped
Significance	NS	NS	NS	*	NS	

*, significant at p ≤ 0.05; **, NS, not significant at p > 0.05.

Table 3. Effect of grafting on fruit shape appearance

Scion/rootstock	Pistil scar		Fruit curvature	Apex	Patches	Stripes			Ribs
	Size (cm)	Depth				Stripes	Prominence	Density	
Amadeo	1,58	Shallow	–	Flattened	Absent	Absent	–	–	Very weak
Amadeo/Hawk	1,94	Shallow	–	Flattened	Absent	Absent	–	–	Very weak
Amadeo/Anafor	1,62	Shallow	–	Flattened	Absent	Absent	–	–	Very weak
Significance	NS								
BT Bıldırcın	0,52	Absent or very shallow	Weak	Pointed	Absent	Present	Strong	Medium	Very weak
BT Bıldırcın/Hawk	0,65	Absent or very shallow	Weak	Pointed	Absent	Present	Strong	Medium	Very weak
BT Bıldırcın/Anafor	0,49	Absent or very shallow	Weak	Pointed	Absent	Present	Strong	Medium	Very weak
Significance	NS								

*, significant at p ≤ 0.05; **, NS, not significant at p > 0.05.

Table 4. Effect of grafting on fruit calyx and other quality characteristics.

Scion/rootstock	Anthocyanin coloration underneath calyx		Anthocyanin coloration of calyx		Calyx size (cm)	Spininess of calyx	Creasing of calyx
	Coloration	Intensity	Coloration	Intensity			
Amadeo	Present	Weak	Present	Weak	4,63	Very weak	Weak
Amadeo/Hawk	Present	Weak	Present	Weak	5,30	Very weak	Weak
Amadeo/Anafor	Present	Weak	Present	Weak	4,90	Very weak	Weak
Significance					NS		
BT Bıldırcın	Present	Strong	Present	Weak	5,77	Weak	Strong
BT Bıldırcın/Hawk	Present	Strong	Present	Weak	6,21	Weak	Strong
BT Bıldırcın/Anafor	Present	Strong	Present	Weak	5,93	Weak	Strong
Significance					NS		

*, significant at p ≤ 0.05; NS, not significant at p > 0.05.

Table 5. Effect of grafting on fruit color.

Scion/rootstock	Main color of skin at harvest maturity							Glossiness	Color of skin at physiological ripeness					
	Color	Intensity	(L)	(a)	(b)	Hue	Chroma		Color	(L)	(a)	(b)	Hue	Chroma
Amadeo	Violet	Dark	23,03	6,01	−0,20	360,04 a	6,10	Strong	Brown	36,50	15,90	16,59	45,82	23,05
Amadeo/Hawk	Violet	Dark	25,53	4,13	−2,00	333,44 b	4,61	Strong	Brown	34,30	15,11	13,24	40,95	20,16
Amadeo/Anafor	Violet	Dark	23,58	5,74	−0,99	346,84 ab	5,86	Strong	Brown	38,56	14,04	19,87	54,16	24,45
Significance			NS	NS	NS	*	NS			NS	NS	NS	NS	NS
BT Bıldırcın	Violet	Light	29,11	21,16	−3,93	349,49	21,53	Strong	Ochre	53,19	12,88 a	37,20	70,90 b	39,38
BT Bıldırcın/Hawk	Violet	Light	36,71	21,84	−3,26	351,66	22,10	Strong	Ochre	58,59	6,37 b	43,10	81,28 a	43,69
BT Bıldırcın/Anafor	Violet	Light	34,99	19,87	−3,68	349,52	20,21	Strong	Ochre	59,13	6,84 b	36,04	78,93 a	36,77
Significance			NS	NS	NS	NS	NS			NS	*	NS	*	NS

*, significant at p ≤ 0.05; NS, not significant at p > 0.05.

Table 6. Effect of the grafting on fruit flesh color at harvest maturity.

Scion/rootstock	Flesh color						Flesh color (30 min later)					Browning of pulp tissue
	Color	(L)	(a)	(b)	Hue	Chroma	(L)	(a)	(b)	Hue	Chroma	Browning
Amadeo	Greenish	82,66	−4,83	24,68	101,29	25,15	82,86	−3,82	21,38	100,26	21,73	Weak
Amadeo/Hawk	Greenish	82,45	−5,80	21,32	105,13	22,10	80,73	−2,85	22,83	97,13	23,02	Weak
Amadeo/Anafor	Greenish	83,10	−5,11	21,03	103,88	21,65	80,45	−2,93	23,61	97,50	23,83	Weak
Significance		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	
BT Bıldırcın	Whitish	82,87 a	−3,87	19,46 b	101,25 a	19,85 b	80,08 a	−2,31 c	21,13 ab	96,23 a	21,26 ab	Weak
BT Bıldırcın/Hawk	Whitish	79,51 ab	−3,09	16,89 b	100,33 a	17,18 b	78,72 a	−0,71 b	17,81 b	92,30 b	17,82 b	Weak
BT Bıldırcın/Anafor	Whitish	75,91 b	−0,73	24,50 a	91,44 b	24,59 a	72,08 b	2,73 a	24,29 a	83,60 c	24,45 a	Medium
Significance		*	NS	*	*	*	*	*	*	*	*	

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

Table 7. Effect of grafting on other quality characteristics.

Scion/rootstock	Seedness of flesh	Firmness (kg)		Soluble solid content (SSC) (%)	Plants with early fruit (%)	Time of physiological ripeness
		At harvest maturity	At physiological ripeness			
Amadeo	Medium	5,33	8,83	3,99	80,00 a	Early
Amadeo/Hawk	Medium	5,94	10,33	4,69	13,33 c	Late
Amadeo/Anafor	Medium	5,99	10,13	4,39	43,33 b	Medium
Significance		NS	NS	NS	*	
BT Bıldırcın	Intense	6,17	11,73	4,29	100 a	Early
BT Bıldırcın/Hawk	Intense	5,81	10,53	4,49	0 c	Medium
BT Bıldırcın/Anafor	Intense	6,13	10,53	4,64	30 b	Medium
Significance		NS	NS	NS	*	

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

The L*, a*, b*, Hue and Chroma values of the browning of pulp tissue was found statistically significant for “BT Bıldırcın”, while it was not significant for “Amadeo”. In addition, grafting significantly reduced to Hue angle in both rootstocks. Furthermore, it was only difference for chroma value between rootstocks. Grafting reduced the L* value only in the “BT Bıldırcın”/Anafor (72.08) combination versus ungrafted “BT Bıldırcın” (80.08) and “BT Bıldırcın/Hawk” combination (78.72). This showed that the “BT Bıldırcın/Anafor” combination had more browning than ungrafted and other combination. In addition, grafting increased the a* value in both “BT Bıldırcın/Anafor” and “BT Bıldırcın/Hawk” combinations (2.73 and −0.71, respectively). The b* value difference between “BT Bıldırcın/Anafor” and “BT Bıldırcın/Hawk” combinations (24.29 and 17.81, respectively) was found statistically significant.

Earliness and Fruit Composition

No significant differences were found between treatments for seedness of flesh, firmness at harvest maturity, firmness at physiological ripeness, and SSC (Table 7). When the change of fruit firmness according to maturity level is evaluated; the results showed that fruit firmness increased in both of varieties (Amadeo and BT Bıldırcın) towards physiological ripeness. Moreover, grafting significantly delayed the fruit maturity and physiological ripeness time of both scion varieties (Amadeo and BT Bıldırcın) (Table 7). This shows that grafting had a negative effect on fruit earliness. Our results showed that the “Anafor” rootstock provided the more earliness among the grafted combinations. The “Amadeo/Hawk” combination reached physiological ripeness at the latest.

As shown in Table 7, the percentage of plants with early fruit maturity for “Amadeo” and “BT Bıldırcın” was negatively affected by grafting onto “Hawk” rootstock (13.33% and 0%, respectively), while the ungrafted varieties (both Amadeo and BT Bıldırcın) had the highest percentage early fruit maturity (80 % and 100%, respectively).

DISCUSSION

Fruit appearance, especially shape, color, size, and absence of decay or deformity, is one of the consumer’s main criteria for buying. While some traits that affect fruit appearance are genetic, some are influenced by environmental factors and techniques such as grafting. In this study investigated fruit traits that may be affected by rootstock/scion combinations. Grafting is an efficient technique for improving fruit quality under both optimum growth conditions and biotic and abiotic stress conditions.

Fruit size and weight are related to higher yield since grafted plants have increased photosynthesis, vigorous root systems, and resistance to soil-borne diseases, (Rouphael *et al.* 2010, Akter and Rahman 2018). Our results showed that no significant statistical differences were found on average fruit weight between ungrafted and grafted plants. These results are consistent with those of Gisbert *et al.* (2011a), Khah (2011), and Sabatino *et al.* (2016), who found that the average fruit weight of both ungrafted and grafted plants is the same. The present study also showed no significant differences in fruit length, fruit width, and length/width ratio, which is important for determining fruit shape. Our results are consistent with those of Sabatino et al. (2019) and Kaplan (2019), who noted no significant differences in fruit width, fruit length/width ratio among eggplant rootstocks. Krommydas *et al*. (2018) revealed that grafting “Tsakoniki” did not influence fruit weight, fruit length, fruit width, and length/width ratio. Recent studies showed that the effect of grafting on fruit shape index has been nonsignificant for most part when used with *S. incanum*, *S. incanum* × *S. melongena*, and *S. torvum* rootstocks (Cassaniti *et al.* 2011, Gisbert *et al.* 2011a, 2011b, Doltu *et al.* 2017, Kyriacou *et al.* 2017), and these findings are in line with the our results.

Consumers mostly prefer eggplant fruits with wide calyxes and long peduncles (Portis *et al.* 2015). This trait, which is of interest to very few researchers, is important for the ease of mechanical harvesting (Song *et al.* 2016). Grafting significantly increased the length of the peduncle and the rate of increase varied depending on scion/rootstock combination, with *S. torvum* having the most increase in both varieties. This result showed that the products obtained from the grafting combinations may be preferred more by consumers. Krommydas *et al*. (2018) also reported that grafting had a significant effect on fruit peduncle length. Since the calyx plays an important role in fruit water loss via fruit transpiration, reducing water loss from the calyx may be beneficial in the extending shelf life of eggplants (Diaz Perez 1998). The findings of the present study showed that rootstocks had no significant influence on calyx size. A similar result has been reported by Sabatino *et al.* (2018) and Ulas (2021) regarding calyx size.

Spininess of fruit calyxes makes harvesting by hand difficult and may damage the packaging of other fruits (Portis *et al.* 2015). In a previous study, the spininess of fruit calyxes had no significant differences for “Langada,” “Emi,” and “Tsakoniki.” These changes may be due to grafting-induced epigenetic changes in the scion (Tsaballa *et al.* 2013), different degrees of rootstock vigor (Gisbert *et al.* 2011a, 2011b), or changes in the concentration of growth regulators (Krommydas *et al*. 2018). Our results are consistent with those of Sabatino *et al.* (2019), who noted no significant differences in spininess of fruit calyxes among eggplant rootstocks tested. On the other hand, Kacjan Marsic *et al.* (2014) reported that grafting significantly reduce the spininess of the calyx. According to the results of the present study, the intensity of anthocyanin coloration underneath the calyx, intensity of anthocyanin coloration of the calyx, and creasing of the calyx in a visually discernible way were not influenced by grafting. The findings showed that grafting had no influence on fruit apex shape, size of pistil scar, depth of indentation of pistil scar, the degree of fruit curvature, fruit patches, fruit stripes, prominence of stripes, and density of stripes and fruit ribs in the eggplant, consistent with those of Sabatino *et al.* (2018) and Sabatino *et al.* (2019), who found that fruit curvature had no significant differences. To date, there has been no detailed research on these parameters, except on fruit curvature.

The darkest fruit skin color is associated with an intense concentration of anthocyanin (Mozafarian *et al.* 2020). Additionally, anthocyanin pigment, present in eggplant peel, is rich in antioxidants and is anticancerous (Salem *et. al.* 2014). The degree of darkness of the fruit color and fruit glossiness is important in consumer preference and determination of harvest maturity. Although different findings were found on fruit skin color of grafted eggplant and tomato plants compared with ungrafted plants (Moncada *et al.* 2013, Mozafarian *et al.* 2020), these differences can be attributed to the difficulty of standardizing sampling practices for eggplant which depend on optimal harvest maturity (Kyriacou *et al.* 2017). The result of the present study demonstrated that lightness L* of fruit skin color, as regard both harvest maturity and physiological ripeness for all combinations, was not significantly affected in grafted and ungrafted plants. However, when evaluated with the Hue angle, grafting increased to intensity of main color of skin at harvest maturity in only Amadeo/Hawk combination. For this reason, it has been found that grafting can increase to intensity of main color of skin at harvest maturity depending on the rootstock/scion combination. Miceli *et al.* (2014) and Mozafarian *et al.* (2020) reported that the L* value for fruit skin of grafted and ungrafted plants were not affected. Moreover, Cassaniti *et al.* (2011), Doltu *et al.* (2017), Kaplan (2019), and Mancak (2019) found that fruit color at harvest maturity was not affected by grafting. On the other hand, Moncada *et al.* (2013) determined that grafting on *S. torvum* increased to intensity of fruit color. Our results are consistent with the findings that fruit glossiness in grafted and ungrafted plants is similar (Miceli *et al*. 2014).

No visible differences were observed in the skin color at physiological ripeness due to grafting. However, based on calorimeter measurements and depending on scion and rootstock types, grafted plants had darker skin at physiological ripeness compared with the ungrafted plants. These results showed that the grafted plants could reach physiological ripeness later. However, the changes in fruit color occurred after commercial maturity stage in “Langada” and “Emi” cultivars (Krommydas *et al.* 2018). Similarly, our results showed that the changes in fruit color for “BT Bıldırcın” took place at physiological ripeness. This difference can positively affect the yield by affecting the harvest time of the scion variety.

Green flesh color is an undesirable feature by producers as it gives the impression that the fruit is immature (Portis *et al.* 2015). In this study, grafting increased the darkness in the flesh color, depending on the scion and the rootstock. Grafting and using different rootstocks can affect skin or flesh color of the fruit. Late browning in flesh color is significant for eggplant (Mozafarian and Kappel 2020). In the present study, L* value of the flesh color of a recent sliced fruit of grafted and ungrafted plants of the “Amedeo” variety is the same. Our results on flesh color are consistent with the findings of Cassaniti *et al.* (2011), Moncada *et al.* (2013), and Mozafarian *et al.* (2020), who reported that the lightness of flesh color was the same for ungrafted and grafted plants. Our results showed that “Amedeo” fruits of ungrafted and grafted plants did not significantly differ in terms of browning potential. Similar results were obtained by Moncada *et al*. (2013) and Miceli *et al.* (2014), who noted difference in browning level between grafted and ungrafted fruits. However, this study found that the “BT Bıldırcın/Anafor” combination had the darker flesh color compared with ungrafted plants. These results seem to be consistent with those obtained by Lee (1994) who reported that flesh color is affected by the rootstock.

The browning in fruit flesh appears during cutting, when the disorder of cellular structures causes the release of polyphenol oxidase (PPO) that oxidizes phenolics. The presence of oxygen polymerizes quinones, leading to brown-colored pigments as revealed by Mishra *et al.* (2013). Previous studies showed that eggplant cultivars varied in their browning process after cutting, which may be due to differences in the PPO activity or level of soluble phenolics according to King *et al.* (2010), Mishra *et al.* (2013), Sabatino *et al.* (2018), and Sabatino *et al.* (2019). In addition, Radicetti *et al*. (2016) reported a negative relationship between fruit size and fruit browning index. Based on the results of the visual and calorimeter measurement made 30 min after the first observation, grafting negatively affects the browning of the fruit pulp depending on the scion variety and rootstock. Our results showed that the “BT Bıldırcın/Anafor” combination had more intense browning of fruit pulp compared with the ungrafted plants. Similarly, Miceli *et al.* (2014) and Kacjan Marsic *et al.* (2014) found that the browning of the fruit pulp was affected by the grafting combination. Moreover, our findings on pulp browning are consistent with the results of Moncada *et al*. (2013), Miceli *et al*. (2014), Sabatino *et al.* (2018), and Sabatino *et al.* (2019), who found no effects by grafting *S. torvum* rootstock.

The presence of seeds in the fruit is an undesirable trait by consumers especially in eggplant whose seeds cause bitterness and darkening of the flesh color (Du *et al.* 2016). Moreover, seedless fruits have a larger consumable flesh than seeded ones, so they are more attractive for consumers (Daunay 2008). However, the utility of natural parthenocarpic cultivars in cultivation in temperate climate needs further investigation (Caruso *et al.* 2017). Furthermore Radicetti *et al.* (2016) noted a positive correlation between the presence of seed and fruit browning index. In the present study, grafting did not significantly affect the seedness of flesh. The presence of seed could bring about different color and oxidization flesh color in fruits after cutting (Mozafarian *et al*. 2020). Fruit firmness is significant for postharvest storage and shelf life (Portis *et al.* 2015) and is closely linked with skin and pulp structure and fruit ripeness (Miceli *et al.* 2014). If fruits matured, hemicelluloses and pectin are dissolved, which leads to loosening and destruction of the cell walls (Arvanitoyannis *et al*. 2005). The present study showed that firmness of fruits both at harvest maturity and physiological ripeness was not affected by grafting, which is like the observations found by Cassaniti et al. (2011), Miceli *et al.* (2014), Sabatino *et al.* (2019), Sarıbaş (2019), and Kumbar *et al.* 2021). Our results showed that grafting eggplant onto *S. torvum* and interspecific hybrid rootstock had no influence SSC. The findings are consistent with those of Khah (2011), Sabatino *et al*. (2013), Miceli *et al.* (2014), and Mancak (2019).

As earliness provides better prices for producers, enhancement of earliness is a desirable trait (Krommydas *et al.* 2018). Our research found that grafting had a negative effect on fruit earliness, and earliness was observed in ungrafted plants. However, “Anafor” rootstock yielded earlier than *S. torvum* among grafted plants. Similar to our results, İbrahim et al. (2001) and Rahman *et al.* (2002) determined that fruit maturity was delayed due to grafting, which may be due to stress exposure by these plants during grafting (Khah *et al.* 2006, Musa *et al.* 2020). Grafting delayed the time of physiological ripeness, and the degree of delay varied depending on the scion variety and rootstock type. As a result, ungrafted varieties reached physiological ripeness earlier, but the physiological ripeness time of the scion was delayed because of grafting and the rootstock type. This has shown that in grafted plants, the fruits reach physiological ripeness at a later stage than the ungrafted plants. Among the rootstocks, *S. torvum* brings the fruit to physiological ripeness a little later than the other rootstock. In this case, Klinkong (2021) reported that it causes the harvest period to be prolonged.

CONCLUSIONS

Since the number of new rootstocks and eggplant varieties entering the market is increasing daily, this may cause scion/rootstock incompatibility and some changes in fruit morphology traits. This study showed that depending on the scion/rootstock combination, the grafting increased to peduncle length and delayed the physiological ripeness time. However, grafting also negatively affected fruit earliness and browning of pulp tissue. In addition, this study confirmed that the right rootstock selection is effective in grafting and that grafting provides a positive effect even in non-infested soil.

To date, no detailed research has been conducted on the grafting effects on pistil scar size, pistil scar depth, fruit apex, fruit patches, fruit stripes (stripes, prominence, density), fruit ribs, anthocyanin coloration underneath the calyx, and anthocyanin coloration of the eggplant calyx. Therefore, this could be an interesting topic for further research.

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