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The effects of double-stemmed grafted tomato plants on yield and quality of tomato cultivation

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ABSTRACT

In this study, the effect of the production of double-stemmed grafted and non-grafted tomato plants on yield and quality was investigated. Android F_1 and Torry F_1 tomato (*S. lycopersicum* L.) cultivars were grafted on "Classmate" tomato rootstock, and grafting was doneaccording to one or two stems for treatments. There were 12 plants in each treatment over 4 grafting and 2 varieties and the plants were provided seedling nursery. The number of stems left in tomato seedlings as grafted and non-grafted was taken as the basis. The plants which are consisting of two stems are formed from the cotyledon axillary buds. The grafting in the experiment were created as follows;.1- grafted-double stem: Shoots were formed with the development of cotyledon axillary buds, 2- Non-grafted-double stem: Shoots were formed with the development of cotyledon axillary buds on cultivars, 3- Grafted-single stem and 4- non-grafted-single stem (control) were formed. In the experiment conducted, the highest plant height (167.25 cm) was obtained from the control treatment and the highest stem diameter (16.58 mm) was obtained from the grafted double stem treatment. *L* and Hue angel values measured in fruit color of treatments were not statistically significant. The highest total soluble solids (4.46%) was obtained from the non-grafted double stem treatment. In terms of total yield, the highest value (12.27 kg m^{-2}) was obtained in the control plants. The effect of double stem in cotyledon axillary buds on grafted tomato cultivation was found statistically significant on yield, and grafting with double stem decreased the yield, as compare to the control treatment.

1. Introduction

Grafted vegetable cultivation has been successfully applied in many Asian countries for years, and its use is increasing throughout the world. Watermelon and tomato are the two most commonly grafted vegetables worldwide. However, as stated by Lee and Oda (2003); grafting of herbaceous vegetables is an ancient practice. Grafting in Cucurbitaceae was briefly described in Korea in the seventeenth century by Hong (1643-1715), and then later adopted as a commercial production technology by many countries in Europe, the Middle East, North Africa, Central America and other Asian regions (Kumar et al. 2015). Grafting and budding are horticultural techniques used to join parts from two or more plants so that they appear to grow as a single plant. In grafting, the upper part (scion) of one plant grows on the root system (rootstock) of another plant (Anonymous 2023). One of the first reasons for using grafted seedlings is to prevent soil-borne diseases under the intensive production system. Grafting on suitable rootstocks can reduce the side effects of abiotic and biotic stresses such as salt, water, temperature, and heavy metals. Moreover, it has been observed that grafting increases water and nutrient usage values in tomato plants (Singh et al. 2017). The use of grafted seedlings in open field vegetable production exceeded 54% in Japan, 81% in Korea, 69% of greenhouse vegetable growing in Japan, and 81% in Korea (Kurata 1994). In Turkey, as stated by Tüzel et al. (2015); grafted seedling production increased 230 times between 1998-2013, while the number of firms producing grafted seedlings was 4 and the production amount was 500000 in 1998, the number of companies making grafted seedlings by the end of 2013 increased to 36 and the production amount increased to approximately 115 million. However, although growing hybrid tomato varieties in the greenhouse has gained worldwide popularity, the costs of producing grafted plants continues to be a deterrent for small-scale producers (Hanna 2012). Grafting techniques in vegetables have developed in the last decade due to the emergence of new techniques and materials. Grafted seedlings for plant growth is becoming an increasingly popular method in the vegetable industry. Despite these recent developments, the percentage of grafted vegetable plants is still relatively low. The most important reasons for this are; high cost of grafting, problems with the control of soil-borne pests and diseases, and the adaptation of grafted seedlings to abiotic stresses. The aim of this study was to investigate the effect of grafted and non-grafted double stems in cotyledon axillary buds on yield, quality, and plant growth on tomato cultivation.

2. Material and Methods

2.1. Materials

This study was conducted in a glass greenhouse in Akdeniz University Faculty of Agriculture Research and Treatment Field in the Fall season of 2018-2019. In the study, Android F_1 and Torry F_1 tomato cultivars were used on "Classmate" tomato rootstock.

2.2. Methods

There were 12 plants in each treatment over 4 grafting methods and 2 varieties, the plants were provided by the Ad-Rossen company and the number of stems left in tomato seedlings as grafted and non-grafted was taken as the basis. In plants consisting of two stems, shoots are formed from the axillary bud of cotyledon leaves. The grafting in the experiment was created as follows; 1. Grafted double stem: Shoots were formed with axillary bud development in cotyledon leaves. Non-grafted double stem: Shoots were formed with the development of the axillary bud in cotyledon leaves. Grafted-single stem and non-grafted single stem (control) were obtained on seedlings. The plants were spaced according to the double row planting systemon 25.09.2018, the planting distances were a wide row of 100 cm, a narrow row of 50 cm and 50 cm between plants within the row. Plants with double stems were planted in the middle of the double row as a single row and at a distance of 50 cm between plants within the row. Both shoots left to develop in plants were planted according to the double-row arrangement and the plants were supported by attaching them to the hanger rope. Apical bud removal was performed in plants after the 6^{th} cluster, and the last harvest was carried out on 08.04.2019. In the seedlings planted according to the double-row and single-row planting system, the irrigation system was a single line for each plant with double stemmed and single-stemmed plants. The amount of fertilizer required for one ton of tomato yield in fertilization was calculated as 3.5 kg N, 1 kg P_2O_5 and 6 kg K_2O over the pure substance (Gianquinto et al. 2013). In the study; plant height, plant stem diameter, *L* and Hue angle (h°) for fruit color (Minolta Chroma Meter CR-400), total soluble solids (Brix°), pH, number of fruit in clusters and yield values were investigated.

2.3. Statistical analysis

The study had 4 replications according to the randomised block design pattern. After the ANOVA, the means of the treatments were compared according to the LSD test at the significance level of $P \leq 0.05$.

3. Results and Discussion

The effect of double-stem growing on cotyledon axillary buds in grafted and non-grafted tomatoes on plant growth development is given in Table 1. As can be seen in Table 1, the effects of grafting on plant height was found to be statistically significant. The highest plant length was in the control plants (167.25 cm) and the lowest value was obtained from grafted double stem plants (147.63 cm). The effects of grafting on plant stem diameter in grafted tomatoes were found to besignificant (Table 2).

In grafted double stem plants, the stem diameter of the plant was 16.58 mm, which is higher than other grafting. Findings obtained from Rahmatian et al. (2014) and Soare et al. (2018) showed similarity with the results. The effects of grafting and varieties on color values related to *L* and h° in tomato fruits were found to be statistically insignificant. The values are given in Table 3. The effect of the grafting on the total soluble solids in fruit juice was found to be statistically significant but no difference was found between the varieties. While the highest

Table 1. The effect of the different stem numbers on the plant height in grafted and non-grafted tomatoes (cm)

Varieties	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem	Average (Variety)
Android F_1	141.75 d*	152.50 c	160.75 b	165.50 ab	155.13 B**
Torry F_1	153.50 c	165.00 ab	161.00 b	169.00 a	162.13 A
Average (Grafting)	147.63 C	158.75 B	160.88 B	167.25 A***	
LSD %5	(Graft.): 4.67	(Var.): 3.3	(Graft. x Var.): 6.6		

*Means in the interaction by the same letter are not significantly different ($P \leq 0.05$), **Means in the same column by the same letter are not significantly different ($P \leq 0.05$), ***Means in the same line by the same letter are not significantly different ($P \leq 0.05$).

Table 2. The effect of the different stem numbers on the diameter of the plant in grafted and non-grafted tomatoes (mm)

Varieties	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem	Average (Variety)
Android F_1	17.00	15.35	15.48	15.80	15.91 A**
Torry F_1	16.15	15.35	15.28	14.18	15.24 B
Average (Grafting)	16.58 A*	15.35 B	15.36 B	14.99 B	
LSD %5	(Graft): 0.74	(Var.): 0.52	(Graft x Var.): ns		

*Means in the same line by the same letter are not significantly different ($P \leq 0.05$), ns: Non-significant, **Means in the same column by the same letter are not significantly different ($P \leq 0.05$).

Table 3. The effect of the different stem numbers on *L* color and h° value of fruits in grafted and non-grafted tomatoes

Varieties	Grafted double stem		Non-grafted double stem		Grafted single stem		Non-grafted single stem		Average (Variety)	
	L	h°	*L*	h°	*L*	h°	*L*	h°	*L*	h°
Android F_1	43.45	50.90	43.25	51.18	44.25	51.13	43.93	51.35	43.72	51.14
Torry F_1	44.23	51.43	43.70	51.68	44.18	53.43	43.23	50.45	43.83	51.74
Average (Grafting)	43.84	51.16	43.48	51.43	44.21	52.28	43.58	50.90		
LSD %5 (*L*)	(Graft): ns		(Var.): ns		(Graft x Var.): ns					
LSD %5 (h°)	(Graft): ns		(Var.): ns		(Graft x Var.): ns					

ns: Non-significant.

values of Brix were observed in non-grafted and grafted-double stem plants (4.46% and 4.35%), low values were obtained in control and grafted single stem grafting respectively (14.14% and 3.98%) (Table 4). These results are thought to be related to the high-water consumption coefficient due to mineral intake in double-stem plants. At the same time, a study by Rahmatian et al. (2014) showed that the number of stems does not affect the amount of total soluble solids in tomato. Colla et al. (2015) investigated the effect of grafted melons grown in salty conditions on yield, fruit quality and mineral composition and reported that the amount of Brix is higher in non-grafted plants compared to grafted plants. In a study by Qaryouti et al. (2007) with grafted and non-grafted tomato plants grown in a soil and soilless culture medium, it was noted that the value of Brix is lower in grafted tomato fruits grown in a soilless culture. In the results obtained by Neocleous (2010), who worked on the cultivation of grafted and non-grafted tomatoes in different environments, the Brix value was expressed as 4.9% in fruits taken from grafted plants and 5.5% in non-grafted plants. Abdulaziz et al. (2017) and Turkmen et al. (2010) reported that grafted tomatoes had increased amounts of Brix on different rootstocks. In grafted tomato cultivation, the effect of different stem grafting on the pH value of tomato juice was not found to be statistically significant. The acidity values of tomato juice varied between pH 4.51-4.68. Khah et al. (2006) and Yarsi (2011) obtained similar results and reported that the grafting on pH value of tomato fruit juice did not make any difference in grafted and non-grafted tomato cultivation. The effect of double stem formed in cotyledon axillary buds in grafted tomato cultivation on the number of fruits in the cluster was found to be statistically significant among the grafting in the "Android" tomato variety (Table 5). While the highest (4.15) values were obtained in the control and grafted single stem plants, the number of fruits was 3.98 in grafted double stem plants. The lowest number of fruits was obtained from grafted double stem plants (3.70 fruit number). In the Android tomato variety, the effect of fruit number between clusters in different grafting was found to be statistically significant. According to the values obtained, the highest number of fruits was determined in the first and second cluster (5.49, 5.21) and the least number of fruits (1.54) in the sixth cluster. Depending on the cluster, the effect of the grafting on the number of fruits in the cluster was found to be statistically significant (Table 5). According to the values obtained for "Torry" cultivar (Table 6), the highest number of fruits was obtained from the first and second cluster (5.16, 5.04) and the least number of fruits was obtained from the sixth cluster (1.56). The effect of double stem in cotyledon axillary buds in grafted tomato cultivation on average fruit weight was not found to be statistically different between grafting and varieties (Table 7).

The results show compatibility with the findings of Oda et al. (1996), Qaryouti et al. (2007) and Soare et al. (2018). The effects of grafting on the total yield of tomatoes were found to be statistically significant and the highest yield values (12.27 kg m^{-2}) were obtained from the control plants (Table 8). These values were determined as 11.46 kg m^{-2}, 10.49 kg m^{-2} and 10.10 kg m^{-2} in single stem, grafted and non-grafted double stem grafting, respectively. There was no difference in total yield between varieties, but differences in treatment variety interactions were found to be significant. The highest yield was obtained from the control (12.67 kg m^{-2}) and single grafted (12.11 kg m^{-2}) treatments in Android F_1. The highest yield was also obtained from the control (11.86 kg m^{-2}) and grafted double (11.88 kg m^{-2}) treatments in Torry F_1. The grafted double stem plants had a low yield compared to the control plants, due to the stress caused by grafting. It is believed that grafted plants have a slow development and a partial delay in flowering and fruit set. The rootstock-scion compatibility in the vascular system can affect the yield negatively (Arpacı 2016). Traka-Mavrona et al. (2000) showed that it does not make a difference from the control plants on the yield of some pumpkin rootstock varieties in melon, and even revealed that it caused a significant decrease in the yield of some rootstocks. Kacjan-Marsic and Osvald (2004) investigated the effect of buds on tomato yield in a study where "Monro" and "Belle" cultivars used as a scion, "PG-3" and "Beaufort" cultivars. The combination of "Monro" / "Beaufort" from the rootstock scion treatment created a positive difference. In all grafting where the "Belle" variety was used as a scion, tomato yield decreased and they obtained higher yields than tomato plants without vaccine. However, Neocleous (2010) reported in his study that there was no difference in the total yield of grafted tomato plants.

Table 4. The effect of the number of different stems in grafted and non-grafted tomato on the amount of Brix^0 of the fruit juice (%)

Varieties	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem	Average (Variety)
Android F_1	4.33	4.53	4.02	4.02	4.25
Torry F_1	4.38	4.40	3.93	4.25	4.24
Average (Grafting)	4.35 AB*	4.46 A	3.98 C	4.14 BC	
LSD %5	(Graft.): 0.24	(Var.): ns	(Graft. x Var.): ns		

*Means in the same line by the same letter are not significantly different ($P \leq 0.05$), ns: Non-significant.

Table 5. The effect of the different stem numbers in grafted and non-grafted tomatoes on the number of fruits in the cluster in the Android F_1 tomato variety (number of fruit cluster^{-1})

Cluster	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem	Average (Cluster)
1	5.10	5.63	5.50	5.73	5.49 A*
2	5.18	5.08	5.13	5.48	5.21 A
3	4.13	3.90	4.55	3.78	4.09 B
4	3.88	3.73	4.60	3.75	3.99 B
5	3.13	4.10	3.55	3.93	3.68 B
6	0.80	1.48	1.60	2.28	1.54 C
Average (Grafting)	3.70 B**	3.98 AB	4.15 A	4.15 A	
LSD %5	(Graft.): 0.34	(Cluster): 0.42	(Graft x Cluster): ns		

*Means in the same column by the same letter are not significantly different ($P \leq 0.05$), ns:Non-significant, **Means in the same line by the same letter are not significantly different.

Table 6. The effect of the different stem numbers in grafted and non-grafted tomatoes on the number of fruits in the cluster in the Torry F_1 tomato variety (number of fruit cluster^{-1})

Cluster	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem	Average (Cluster)
1	5.05	4.63	5.18	5.80	5.16 A*
2	5.13	5.00	4.95	5.10	5.04 A
3	3.78	3.80	3.70	3.95	4.10 B
4	4.03	4.28	3.90	4.18	3.80 BC
5	3.43	3.63	3.45	3.95	3.61 C
6	1.02	1.63	1.78	1.80	1.56 D
Average (Grafting)	3.74	3.83	3.83	4.13	
LSD %5	(Graft): ns	(Cluster): 0.37	(Graft. x Cluster): ns		

*Means in the same column by the same letter are not significantly different ($P \leq 0.05$), ns: Non-significant.

Table 7. The effect of different number of stems in grafted and non-grafted tomato on average fruit weight (g)

Varieties	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem (control)	Average (Variety)
Android F_1	173.60	188.00	185.00	184.80	182.70
Torry F_1	182.30	163.10	190.00	174.30	177.40
Average (Grafting)	177.90	175.60	187.50	179.50	
LSD %5	(Graft): ns	(Var.): ns	(Graft. x Var.): ns		

ns: Non-significant.

Table 8. The effect of the different number of stems in grafted and non-grafted tomato on total yield (kg m^{-2})

Varieties	Grafted double stem	Non-grafted double stem	Grafted single stem	Non-grafted single stem	Average (Variety)
Android F_1	9.10 d	10.49 bc	12.11 a	12.67 a	11.10
Torry F_1	11.88 a*	9.72 cd	10.80 b	11.86 a	11.06
Average (Grafting)	10.49 C**	10.10 C	11.46 B	12.27 A	
LSD %5	(Graft): 0.67	(Var.): ns	(Graft x Var.): 0.95		

*Means in the interaction by the same letter are not significantly different ($P \leq 0.05$), ns: Non-significant, **Means in the same line by the same letter are not significantly different.

4. Conclusion

The effect of double stem in cotyledon axillary buds on yield in grafted tomato cultivation was found to be statistically significant, and different treatments decreased the yield. The highest yield was obtained from the control plants (12.27 kg m^{-2}), the lowest values in grafted and non-grafted double stem treatment were 10.49 kg m^{-2} and 10.10 kg m^{-2} respectively. According to the control, a decrease in the yield was determined to be 6.6% in grafted single-stem plants and 14.5% in grafted double-stem plants. By comparison, in double-stemmedtomatoes it is seen that the rootstock provides a 3.7% increase in yield. This decrease is due to the same amount of fertilizer value given to the unit area in grafted double stem plants.The small difference between grafted and non-grafted plants is related to the rootstock-scion compatibility, rootstock power and the amount of water and fertilizer given per unit area. Acomparision of “Android” and “Torry” varieties used in the study showed no difference between them in terms of yield. the double stems created by cotyledon axillary buds did not shown a homogeneous development in the greenhouse as expected, and a slight difference was observed in development between both branches. Differences of development in double branches has been seen not only in the grafted plants but also in non-grafted double stem plants. It is thought that the unbalanced development of double-stem plants is caused by the stress of pruning in seedlings to eliminate apical domination. In other words, it is predicted that the angle given to the top shoot in the seedlings and the height of the terminal shoot may make a difference in the development of the stems. In addition to the fact that rootstock and variety are important criteria in grafted tomato cultivation, the use of double laterals in fertilization and irrigation in double stem tomato cultivation is important and necessary in terms of irrigation and water demand, and the fertilization should remain higher in grafted plants with double stem for adequate yield. If the same fertilizer is given, compared to traditional planting in double stem cultivation, two drip lines should be drawn on both sides of the root collar of the plant, and in case of a single drip line, the fertilizer dose should be increased. According to the findings of this study, a double drip line without increasing the fertilizer dose would be a more appropriate choice.

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