Effects of grafting on different rootstocks on tomato fruit yield and quality

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Abstract

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The aim of the study was to find effects of tomato grafting on another cultivar. The tomato cultivars used as scions were Yeni Talya, Swanson and Beril. Cultivars used as rootstocks were Beaufort and Arnold. Cleft grafting methods were applied. The following characteristics of grafted and nongrafted plants were recorded: fruit index, number of fruits/truss, fruit weight, fruit yield, dry matter, pH, concentration of soluble solids, titratable acidity, total sugar and lycopene and vitamin C. The results showed that fruit yield and fruit index, number of fruits/truss and fruit weights were improved by grafting. Fruit quality, measured in terms of dry matter, concentration of soluble solids, total sugar, and vitamin C content, was lower in the fruits of grafted plants than in nongrafted ones. No significant difference in lycopene and pH content was found. Titratable acid content was improved by grafting. A positive effect of grafting was recorded when Beaufort was used as rootstock. These results showed that grafting could be an advantageous alternative in tomato production.

Keywords: tomato; cultivars; grafting; yield; fruit index; fruit weight; titratable acids

Use of grafted seedlings became a widespread agricultural practice in many parts of the world (Pogonyi et al. 2005). Grafting is an important technique for vegetable production (Lee 2003). In the Mediterranean, where land use is very intensive and continuous cropping is a common practice, vegetable grafting is considered an innovative technique and is in increasing demand by farmers (Khah et al. 2006). Turkey, located in the East of the Mediterranean, is one of the area's dominant tomato producers. Production in 2007 was 9.95 million tons (FAO 2007). In Turkey, vegetable grafting, primarily for tomatoes and watermelon, recently increased (Atasayar 2006).

Khah et al. (2006) showed that tomato grafting on suitable rootstocks has positive effects on cultivation performance, especially in greenhouse conditions. These researchers consider that grafted plants, which provide increased yield and, consequently, higher profit, can be of value to farmers. Furthermore, in many of the most economically important vegetable crops such as tomato, increases in fruit yield are typically a result of increased fruit size (Pogonyi et al. 2005). Owing to their utilization of the vigorous root system of the rootstocks, grafted plants usually show increased uptake of water and minerals when compared with self-rooted plants (Lee, Oda 2003). Research has shown that possible mechanisms for increased yield are likely the result of increased water and nutrient uptake by vigorous rootstock genotypes. Uptake of macronutrients such as phosphorus and nitrogen was enhanced by grafting (Ruiz, Romero 1999, Leonardi, Giuffrida 2006). Lee (1994) reported that quality traits (fruit shape, skin color, skin or rind smoothness, flesh texture and color and soluble solid concentration) are influenced by the rootstock. High soluble solid concentration and titratable acidity are highly desirable, not only in processing tomato cultivars but also in fresh-market cultivars, owing to the important contribution of sugars and acids to the overall flavor and nutritional value of tomatoes (Cuartero, Fernández-Muñoz 1998). Rootstock (Radja) was able to induce increases in both fruit yield and fruit quality traits of the scion. The cultivated tomato and wild tomato (*Solanum cheesmaniae*) were tested as rootstocks, using the commercial hybrid Boludo as scion; the rootstock also improved soluble solid concentration and titratable acidity when grafted plants were grown under nonsaline conditions (Flores et al. 2010). Pogonyi et al. (2005) examined the effect of grafting on the yield and fruit characteristics of tomato cultivar Lemance F1 used as scion with Beaufort as rootstock. That study reported higher yield from the grafted plants than nongrafted. The increase of yield was caused mainly by higher average fruit weight. Soluble solid concentration and titratable acidity and carbohydrate content were lower in the fruits on grafted plants than on nongrafted ones, but no significant difference in acid content was found. In contrast, Khah et al. (2006) found that soluble solid concentration and titratable acidity, lycopene and pH concentrations in hybrid tomato fruits were not affected by grafting. On the whole, these results show the effectiveness of grafting for improvement of fruit quality in tomato. These findings are of great importance because they show that grafting is a rapid and efficient means to improve fruit quality.

Grafting methods and the influence of grafting on the yield of fruit-bearing vegetables in Turkey have not yet been studied in detail. The purpose of this study was to investigate possible positive effects of grafting and use of different rootstocks on the fruit yield, characteristics and quality attributes of tomato plants.

MATERIAL AND METHODS

Experiments were conducted for two consecutive summer seasons (2009 and 2010) in a greenhouse in the Mustafakemalpaşa Vocational School, Uludag University, Turkey (40°01'N, 28°22'E, 25 m a.s.l.).

Plant material and grafting

The commercial tomato (*L. esculentum* Mill.) cultivars Yeni Talya, Swanson and Beril were used as scions. Beaufort and Arnold were used as rootstocks. Cleft grafting was applied as indicated by Oda (1995). Grafting was carried out in a greenhouse, in a shady place sheltered from the wind, to avoid wilting of the grafted plants. After the grafting, as indicated by Marsic and Osvald (2004), the grafted plants were maintained at 28–30°C and at more than 95% relative humidity for three days of healing to enhance the survival rate. The relative humidity was then gradually lowered, and the light intensity was increased. When wilting was observed, foliar spraying of grafted plants with water was effective in improving survival.

Plant growth experiment

The soil used in the greenhouse was clay loam (23.9% sand, 47.4% silt and 28.7% clay content). Organic matter content and pH of the soil were 2.2% and 7.8%, respectively. The average temperatures during the growing seasons were around 30°C. The experiments were laid out separately according to a completely randomized block design with three replications each consisting of 15 plants. Nitrogenous, phosphate and potassium fertilizers were applied as recommended by the Laben Agricultural Analysis Laboratory, Antalya, Turkey. Plots were fertilized with 128 kg/ha P_2O_5 as triple super phosphate and 145 kg/ha K_2O in the form of potassium sulphate each year before sowing. Nitrogenous fertilizer was applied manually at the rate of 124 kg/ha N (ammonium sulphate) three times; before planting, when flowering started and fruit began to ripen. The grafted and nongrafted seedlings were then hand planted (15th of May) at 1.00 m row spacing, spaced 0.40 m apart, and grown vertically in the greenhouse. The experiment used normal culture practices for irrigation (drip), fertilization and pesticide application. The experiment was terminated in middle of September.

Measurements and quality analysis

Fruits were harvested from the third week of July to the middle of September. Fruits were harvested at two-day intervals at the ripening stage. Ten ripe fruits (judged by appearance) from all plants were selected to determine the yield and quality. The following measurements were recorded for each plant: fruit index (fruit diameter/fruit length) (Alan et al. 2007) and fruit weight (g/fruit). Number of fruits/truss and fruit yield (kg/plant) were calculated by using all fruits on each plant.

For the quality analyses, juice of each fruit was extracted by dividing the fruit into halves and pressing the halves through a 1 mm metallic sieve, thereby facilitating removal of the fruit coat and the seeds. The fruit juice extracts were used for estimation of soluble solids concentration (SSC, %), pH value, titratable acidity (TA, %) and total sugar (TS, %). Determination of SSC was done with a refractometer Abbe-type refractometer, model 60/DR (Bellingham and Stanley, Ltd., Kent, UK) using the following procedure described by Tigchelaar (1986). Fruit juices pH levels were measured with a pH meter. Titratable acidity was determined by titration with using fruit juice. Results were expressed as percentage of citric acid (Anonymous 1968). For the analysis of total sugar content (%), the Luff-Schoorl method was used (Gormley, Maher 1990). Spectrophotometer quantification of lycopene was performed as described by Adsule, Dan (1979). The lycopene content was measured in the supernatant using a spectrophotometer Shimadzu UV-1208 (Shimadzu Co., Kyoto, Japan) at a wavelength of 505 nm. The lycopene concentration in fresh matter was expressed as mg/100 g. Vitamin C (ascorbic acid) content in fresh tomato samples was determined by the titration method (AOAC 1980). The results were expressed as mg/100 g fresh matter. Dry matter (DM) content of fruit was calculated as % of fresh weight (following drying at 80°C for 48 h) of samples.

Statistical analysis

Data were analyzed using MSTAT-C v. 2.1 (Michigan State University, Michigan, USA) and Minitab 14.0 software (University of Texas at Austin, Texas, USA). Analysis of variance (ANOVA) was performed. Significance of differences among treatments was tested using the least significant difference (LSD) method. Differences were judged significant at $P < 0.05$ according to the F-test. The F-protected LSD values were calculated at 0.05 probability levels.

RESULTS AND DISCUSSION

The fruit characteristics of grafted plants were compared with those of nongrafted plants. The results showed that the fruit index (diameter/length), number of fruits/truss, and fruit weight were significantly influenced by grafting (Table 1). The results agree with those reported by Lee (1994), who

Table 1. Fruit index, fruit number, fruit weight, fruit yield of nongrafted and grafted tomato plants

Treatments	Fruit index (diameter/length)	Fruit number (number of fruits/truss)	Fruit weight (g/fruit)	Fruit yield (kg/plant)
Yeni Talya	1.21^{b}	4.84^{b}	146.61^{b}	4.49^{c}
Yeni Talya/Beaufort	1.34^{a}	5.47^{a}	202.09^{a}	6.77^{a}
Yeni Talya/Arnold	1.33^{a}	5.28^{ab}	174.1^{ab}	5.63^{b}
LSD (5%)*	0.03	0.53	42.69	0.08
Swanson	1.25^{b}	4.64^{b}	151.05^{b}	5.07^{b}
Swanson/Beaufort	1.35^{a}	5.57^{a}	189.05^{a}	5.74^{a}
Swanson/Arnold	1.31^{ab}	5.32^{a}	170.4^{ab}	5.65^{a}
LSD (5%)*	0.08	0.35	34.14	0.36
Beril	1.19^{b}	4.85^{c}	132.79^{b}	4.46^{c}
Beril/Beaufort	1.30^{a}	6.02^{a}	181.89^{a}	5.36^{a}
Beril/Arnold	1.26^{ab}	5.14^{b}	179.19^{a}	5.14^{b}
LSD (5%)*	0.08	0.12	44.93	0.06

*Means followed by the same letter are statistically not significant (Duncan's multiple range test, $P = 0.05$)

concluded that fruit shapes are influenced by rootstocks. Pogonyi et al. (2005) reported that when Lemance F1 was grafted onto Beaufort rootstock, increased yield was caused mainly by higher average fruit weight. Ibrahim et al. (2001) found that the total number of fruits per truss in nongrafted plants was statistically different from the total for grafted plants. In a similar study (Khah et al. 2006), fruit weight of grafted plants was found to be higher than in nongrafted plants, and plants grafted onto Heman and Primavera produced more fruit than the nongrafted, both in the greenhouse and in the open field. In our study, the fruit index, number of fruits/truss, and fruit weights of nongrafted plants were significantly lower than the corresponding values for plants grafted onto both rootstock cultivars. That is, the effect of grafting was positive when Yeni Talya, Swanson and Beril were used as scion and Beaufort, Arnold as rootstock. Comparisons of the responses of the grafted plants when Yeni Talya and Swanson were grafted onto Beaufort and Arnold showed that different rootstocks had no effect on fruit characteristics. In general, no significant differences were found among the fruit indexes, numbers of fruit/trusses, or fruit weights of the graft combinations (Yeni Talya/Beaufort and Yeni Talya/Arnold, Swanson/Beaufort and Swanson/Arnold). However, number of fruits/truss of Beril/Beaufort plants was significantly higher than the corresponding values for Beril/Arnold grafted plants.

The results of the study showed that tomato grafting on suitable rootstocks had positive effects on the yield. In grafted combinations, the total fruit yield per plant increased significantly in comparison with that of the nongrafted plants. Ibrahim et al. (2001) and Marsic, Osvald (2004) observed similar results in grafted and nongrafted tomato plants. These investigators suggested that the higher yield of fruit from grafted tomato plants was most likely an effect of the vigorous root system of the rootstock. According to Lee (1994), the increased yield of grafted plants is also believed to be due to enhanced water and mineral uptake. In this study, the highest fruit yield was found in the Yeni Talya/Beaufort grafted combination (6.77 kg/plant), and the lowest fruit yield was recorded in the Beril cultivar (4.46 kg/plant). Fruit yield of Swanson tomato cultivar was not significantly affected by grafting onto Beaufort or Arnold rootstock (Table 1). However, fruit yield of Yeni Talya and Beril was significantly affected by grafting onto Beaufort or Arnold rootstock. The use of Beaufort rootstock caused a significant increase in yield per plant of Yeni Talya and Beril grown under greenhouse conditions. Likewise, Marsic, Osvald (2004) reported that tomato grafting on suitable rootstocks has positive effects on cultivation performance, especially under greenhouse conditions.

Fruit DM content of grafted and nongrafted plants varied between 4.75% and 5.42%, as presented in Table 2. The results are similar to those reported by Kolota and Winiarska (2005) and Majkowska-Godomska et al. (2008). Fruit DM of nongrafted plants was significantly higher than that of the plants grafted onto both rootstock cultivars. Fruit DM of cultivars grafted onto Beaufort rootstock (Yeni Talya/Beaufort, Swanson/Beaufort and Beril/Beaufort) was significantly higher than the corresponding values for other cultivars grafted onto Arnold rootstock (Yeni Talya/Arnold, Swanson/Arnold and Beril/Arnold).

The pH value also plays an important role in determining fruit quality characteristics. Many studies focused on pH as a key element in tomato selection (Hong, Tsou 1998). Analysis results showed that the pH values of tomato fruit ranged between 4.35–4.12 (Table 2). Kuzucu et al. (2004) also reported that Koral, Mobil and H-2274 (fresh tomato) have a pH value of 4.31, 4.33 and 4.33, respectively. In this study, pH values differed slightly among tomato plants. Moreover, pH values did not differ significantly between the grafted and nongrafted plants. In addition, different rootstocks had no positive effects on fruit pH values. Our findings in generally agree with other researchers who found that fruit pH values were not affected by grafting (Khah et al. 2006).

SSC is the most important quality criterion for tomato (Cuartero, Fernádez-Muñoz 1998). In this study, the highest SSC value was found in the Swanson cultivar (4.86%). The lowest values were found in Beril grafted onto Arnold (4.17%) (Table 2). Our results also agree with the finding by Turhan and Seniz (2009) that the SSC of ripe tomato genotypes was between 3.4% and 5.5%. According to Campos et al. (2006), the SSC of fresh tomato fruit is approximately 4.5. In greenhouse culture, fruit SSC values differed significantly between grafted and nongrafted plants. These results are similar to those reported by Lee (1994), who found that fruit SSC was influenced by the rootstock. SSC values of nongrafted plants were higher than those of grafted ones. In agreement with the results of the current study, several authors reported that grafting onto

Table 2. Qualitative fruit parameters of nongrafted and grafted tomato plants

Treatments	DM	pH	SSC	TA	TS	Lycopene	Vitamin C
Yeni Talya	5.35[a]	4.15	4.8[a]	0.30[b]	4.11[a]	7.73	17.81[a]
Yeni Talya/Beaufort	4.91[b]	4.12	4.34[b]	0.38[a]	3.22[b]	7.7	13.36[b]
Yeni Talya/Arnold	4.85[c]	4.14	4.35[b]	0.38[a]	2.51[c]	7.77	12.31[c]
LSD (5%)*	0.03	NS	0.07	0.02	0.05	NS	0.32
Swanson	5.33[a]	4.33	4.86[a]	0.33[b]	4.34[a]	7.15	12.9[a]
Swanson/Beaufort	4.91[b]	4.35	4.38[b]	0.39[a]	2.09[b]	7.09	9.20[b]
Swanson/Arnold	4.75[c]	4.35	4.32[b]	0.38[a]	2.03[c]	7.09	8.82[c]
LSD (5%)	0.05	NS	0.13	0.03	0.04	NS	0.39
Beril	5.42[a]	4.21	4.72[a]	0.34[b]	4.14[a]	6.32	15.62[a]
Beril/Beaufort	4.97[b]	4.23	4.31[b]	0.38[a]	2.72[b]	6.3	9.24[b]
Beril/Arnold	4.88[c]	4.22	4.17[c]	0.37[a]	2.35[c]	6.24	7.84[c]
LSD (5%)*	0.03	NS	0.13	0.02	0.07	NS	0.06

*means followed by the same letter are statistically not significant (Duncan's multiple range test, $P = 0.05$), NS – nonsignificant; DM – dry matter (%), SSC – soluble solid concentration (%), TA – titratable acidity 'citric acid' (%), TS – total sugar (%), lycopene (mg/100 g fresh matter), vitamin C (mg/100 g fresh matter)

various rootstocks decreased soluble solids in fruit (Lopez-Galarza et al. 2004; Alexopoulos et al. 2007). Additionally, a previous study reported that SSC was reduced by grafting (Pogonyi et al. 2005; Qaryouti et al. 2007). However, Mohammed et al. (2009) found that grafting also increased soluble solids in Cecilia grafted onto Beaufort rootstocks. Fruit SSC of Swanson and Yeni Talya tomato cultivars were not significantly affected by grafting onto Beaufort or Arnold rootstock. In contrast, the SSC of Beril grafted onto Beaufort plants was higher than that for Beril grafted onto Arnold plants.

Consumers often complain about the overall flavor of fresh-market tomatoes. Flavor quality of tomatoes is largely determined by the sugar and acid composition of the fruit (Moretti et al. 1998). In fresh-market cultivars, sugars and acids contribute significantly to the overall flavor and nutritional value of tomatoes (Cuartero, Fernández-Muñoz 1999). The high contents of sugar and acid are signs of good taste and flavor (Kamis et al. 2004). Total sugar content in grafted and nongrafted tomato plants is presented in Table 2. The results show that fruit TS content was significantly influenced by grafting. TS content of nongrafted plants was significantly higher than that of grafted ones. This result agrees with the findings of Pogonyi et al. (2005), who noted that the increase of carbohydrate content was lower in the fruits of grafted plants (Beaufort was used as rootstock) than nongrafted ones (Lemance F1 was used as scion). The highest and lowest sugar contents were found as 4.34% and 2.03% in Swanson and Swanson/Arnold, respectively. Our results also agree with Petro-Turzo (1987), who found that the total sugar content of ripe tomato was between 1.7% and 4.7%. Our results showed that fruit TS values were influenced significantly by rootstocks. In our study of the comparative responses of the grafted plants of rootstocks (Beaufort and Arnold), a positive effect of grafting was found when Yeni Talya, Swanson and Beril cultivars were used as scion and Beaufort as rootstock, whereas a negative effect of grafting was found when Arnold was used as rootstock.

TA content in grafted and nongrafted tomato plants is presented in Table 2. Our investigations showed that the TA values of tomato fruit ranged between 0.30–0.39. George et al. (2004) reported that TA in fruits of 12 different tomato genotypes varied from 0.25–0.70. The highest acid values were found in grafted tomato plants, whereas the lowest were found in nongrafted tomato plants. Grafting may have positive effects on the acidity of the tomato fruit produced. These results were similar to those reported by others (Flores et al. 2010). That study reported that rootstock improved the TA value of grafted tomato plants. In contrast, (Fernández-Garcia et al. 2004) stated that TA values were the most important chemical quality parameters for tomato and were not affected by grafting. In our study, the TA values were not significantly affected by different rootstocks. No significant differences in TA values were found between the Yeni Talya/Beaufort and Yeni Talya/Arnold, Swanson/Beaufort and Swanson/Arnold, and Beril/Beaufort and Beril/Arnold grafted combinations.

Tomato color is another important factor affecting consumers' tomato preferences. The color of a ripe tomato is determined by the ratio of two pigments, lycopene and β-carotene (Hobson, Grierson 1993). Lycopene, a carotenoid, is formed during fruit ripening and determines the degree of fruit redness. The red color of the fruit originates from lycopene (Tepic et al. 2006). Tomato contains significant amounts of this compound. In this study, the highest lycopene content was found in grafted Yeni Talya/Arnold (7.77 mg/100 g). However, Beril/Arnold (6.24 mg/100 g) grafted combinations had the lowest values of lycopene content (Table 2). As found by Diana et al. (2007), lycopene content for Campbell tomato varieties varied from 2.09 to 5.05 mg/100 g. As shown in Table 2, lycopene content did not differ significantly between the grafted and nongrafted plants. Moreover, different rootstocks had no positive effects on fruit lycopene content. The results reported above generally agree with reports from other researchers who found that fruit qualitative characteristics were not affected by grafting (Romano, Paratore 2001; Khah et al. 2006). In contrast, Mohammed et al. (2009) found a decrease for lycopene in grafted tomato plants.

Vitamin C (ascorbic acid) is an oxidant. Tomato is very rich in vitamin C and contains significant amounts of this vitamin (Sablani et al. 2006). Stevens (1974) found that the vitamin C concentration of 98 tomato varieties ranged from 13 to 44 mg/100 g. The authors Valšíková et al. (2010) investigated the vitamin C content in 28 varieties of tomatoes. In this research they found a range from 202.6 to 404.1 mg/kg in vitamin C. With 16 varieties of green peppers the average vitamin C was from 1,474 to 2,092 mg/kg (Valšíková et al. 2006). In this study, the highest vitamin C content was found in the Yeni Talya cultivar (17.81 mg/100 g), and the lowest values were found in Beril grafted onto Arnold (7.84 mg/100 g) (Table 1). The fruit vitamin C content was strongly reduced by grafting. Compared with the non-grafted plants, the grafted plants accumulated less vitamin C in their fruit tissue. This finding agrees with those reported by Qaryouti et al. (2007), who found that vitamin C content was reduced in soil cultivation in Cecilia grafted on He-Man and Spirit. However, the effects on vitamin C content of grafting onto various rootstocks may be either positive or negative. For example, vitamin C content differed significantly between plants grafted onto Beaufort and Arnold rootstocks. Beaufort exhibited better vitamin C content performance than did Arnold.

CONCLUSIONS

In tomato plants, yield is positively affected by grafting due to the increase in fruit index, number of fruits/truss and fruit weight. Thus, grafted plants offer increased yield and consequently higher profits. We consider these benefits to be of value to farmers. Although fruit quality values, such as dry matter, total soluble solids, total sugar and vitamin C content were lower in grafted plants, these values were still satisfactory and lied within the adequate ranges. However, lycopene content and pH values remained unchanged, and titratable acid content was slightly increased by grafting. Therefore, grafting had no harmful effects on fruit quality, but additional research is needed to determine whether grafting is economically feasible to the producer.

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