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Effect of grafting on growth and yield of tomato (*Lycopersicon esculentum* Mill.) in greenhouse and open-field

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Abstract

Seedlings of tomato (*Lycopersicon esculentum* Mill.) cv. 'Big Red' were used as scion and rootstock (self-grafted) and non-grafted control, while two hybrid tomatoes 'Heman' and 'Primavera' were used as rootstocks. Grafted and non-grafted plants were grown in the greenhouse and in the open-field. Grafted plants (BH and BP) were more vigorous than the non-grafted ones in the greenhouse as well as in the open-field. Plants grafted onto 'Heman' and 'Primavera' produced 32.5, 12.8% and 11.0 and 11.1% more fruit than the control (B) in the greenhouse and the open-field, respectively, whereas self-grafted plants BB had a lower yield in both cultivation conditions. However, the self-rooted plants B presented earliness in their performance, probably due to the lack of stress that followed the grafting operation. Quality and qualitative fruit characteristics were not affected by grafting.

Key words: *Lycopersicon esculentum*, *Lycopersicon hirsutum*, grafting, rootstock, scion, tomato, yield.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is a crop of high importance in many countries; according to FAO (1998), in Greece, 1.8 millions MT were produced. In the Mediterranean area, where land use is very intensive and continuous cropping is in common practice, vegetable grafting is considered an innovative technique with an increasing demand by farmers. Viewing recent data concerning the Mediterranean area by Leonardi and Romano (2004) it was reported that Spain is the most important country for the spreading of vegetable grafting with mainly tomato and watermelon, with 40 and 52% of the total of 154 million plants in 2004, respectively. They also indicated that in Italy an increasing dissemination of the grafting technique increased the number of the vegetable grafted plants from 4 million in 1997 to 14 million in 2000.

In Greece, grafting is becoming highly popular, especially in southern areas, where the ratio of the production area using grafted plants to the total production area, amounts to almost 90-100% for early cropping watermelons, 40-50% for melons under low tunnels, 5-10% for cucumbers and 2-3% for tomato and eggplant. In contrast, in northern Greece, the cultivation of grafted fruit-bearing vegetables is rare (Traka-Mavrona *et al.*, 2000).

Although in the beginning, tomato grafting was adopted to limit the effects of Fusarium wilt (Lee, 1994; Scheffer, 1957), the reasons for grafting have increased dramatically over the years. For example, grafts have been used to induce resistance against low (Bulder *et al.,* 1990) and high (Rivero *et al.,* 2003) temperatures; to enhance nutrient uptake (Ruiz *et al.,* 1997); to improve yield when plants are cultivated in infected soils (Bersi, 2002; Kacjan-Marsic and Osvald, 2004); to increase the synthesis of endogenous hormones (Proebsting *et al.* 1992); to improve water use (Cohen and Naor, 2002); to increase flower and seed production (Lardizabal and Thompson, 1990); to enhance vegetable tolerance to drought, salinity and flooding (AVRDC, 2000; Estan *et al.,* 2005). Moreover, many researchers reported that an interaction between rootstocks and scions exists resulting in high vigor of the root system and greater water and mineral uptake leading to increased yield and fruit enhancement (Lee, 1994; Oda, 1995; Bersi, 2002; White, 1963; Leoni *et al.,* 1990; Ioannou, *et al.,* 2002; Kacjan-Marsic and Osvald, 2004). On the contrary, Romano and Paratore (2001) stated that vegetable grafting does not improve the yield when the selection of the rootstock is not suitable, for example the self-grafted plant 'Rita x Rita' had a lower yield than the non-grafted plants. Also there are some contradictory results about the fruit quality traits and how grafting affects them. For example Traka-Mavrona *et al.* (2000) report that the solutes associated with fruit quality are translocated in the scion through the xylem, whereas Lee (1994) states that quality traits *e.g.* fruit shape, skin colour, skin or rind smoothness, flesh texture and colour, soluble solids concentration *etc*. are influenced by the rootstock. However, other researchers showed that grafting did not affect fruit quality (Leoni *et al.,* 1990; Romano and Paratore, 2001).

The aim of this study was to evaluate a popular Greek commercial hybrid tomato, self-grafted and grafted on two new improved tomato rootstocks, for agronomic performance, yield and fruit quality attributes.

Materials and methods

Plant material: The commercial tomato (*L. esculentum* Mill.) hybrid cv. 'Big Red' was used as self-grafted and non-grafted control, while two hybrid tomatoes 'Heman' (*L. hirsutum*) and 'Primavera' (*L. esculentum* Mill.) were used as rootstocks.

'Heman' possesses resistance to *Pyrenochaeta lycopersici* and nematodes, whereas 'Primavera' is resistant to *Verticillium* and nematodes. Grafting combinations were as follows: BB (scion and rootstock 'Big Red'), BP (scion 'Big Red' and rootstock 'Primavera'), BH (scion 'Big Red' and rootstock 'Heman') and B (non-grafted, control).

The seeds of the scion cultivars were sown 5 days earlier than the seeds of the 2 rootstocks to ensure similar stem diameters at the grafting time because of the differences in growth vigour. Seedlings were grafted by hand, applying the splice grafting method when the scion had 2 real leaves and the rootstock 2.5-3 real leaves. Then the grafted plants were kept for 7 days under controlled conditions (90-95% RH, 24-26^{o}C and 45% shading). Plants were transplanted to the soil in a greenhouse on 4/3/2004 and to the open-field on 13/5/2004 at the Velestino Farm (Magnesia, Greece) of the University of Thessaly, at a density of 12800 plants ha^{-1}. Normal cultural practices were followed for irrigation, fertilizer and pesticide application. A randomised complete block design was adopted with 4 replications, each consisting of 8 plants. Plants were cultivated in 4 replicated plots each of which contained 8 plants spaced at 0.6x1.0m. Four plants from each replicate were evaluated for height, flowering and yield, one was used for dry and wet weight measurements, while the others remained as guard plants and were not included in the evaluations.

Measurements: Mean maximum and minimum air temperature, relative humidity and the amount of rainfall were recorded daily throughout the two cultivations. Plant height was recorded between 8-96 DAT (Days After Transplantation) in the greenhouse cultivation and between 34-130 DAT in the open-field cultivation. In order to obtain flowering data, flowers of 5 clusters was considered. The fresh weight was determined for plants that were harvested at ground level and separated into leaves, stem, flowers and fruits. For the dry weight determination the plant tissues were dried in a ventilated oven at 90^o C for 48h. Due to the different environmental condition in field and greenhouse, plants from both conditions were harvested almost in the same optical size and assessment was made at 107 DAT and 121 DAT for greenhouse and open-field, respectively. Total leaf area was measured by a Portable Area Meter (model LI3000A, LI-COR). Yield measurements were recorded on ripe fruits, which were hand-harvested, counted and weighed. For the greenhouse cultivation, 16 harvests were carried out between 75-192 DAT, while for the open-field cultivation 8 harvests were carried out between 68-130 DAT.

Finally 6 fruits were randomly harvested from each replication and were used for qualitative measurements *i.e.,* firmness (penetrometer FT327-8mm), soluble solids (refractometer), pH, titratable acidity, lycopene concentration (spectrophotometer at 600 nm) and concentration of Zn, Cu, Mn, Fe and Ca (atomic absorption spectrophotometer).

Data analysis: Statistical analysis was performed using 'SPSS 11.0 for Windows' and the differences between the means were compared using the criterion of the Duncan's multiple range test and LSD (*P*=0.05).

Results and discussion

Plant height was not significantly affected by grafting under greenhouse conditions, whereas in the open-field cultivation at 130 DAT the height of BH was significantly greater than the control and BP (Table 1). This result agrees with the results of Lee (1994) and Ioannou *et al.* (2002) who found that grafted plants were taller and more vigorous than self-rooted ones and had a larger central stem diameter.

Table 1. Plant height of non-grafted (B) and 3 grafted tomato plants (BH, BP, BB) over different growth periods in greenhouse and open-field conditions

	DAT	Plant height (cm)			
		BH	BP	BB	B
Greenhouse	30	42.70b	48.44c	36.80a	38.00b
	70	83.06a	91.88a	82.75a	80.31a
	96	95.88a	106.38a	100.75a	94.19a
Open-field	34	53.75bc	46.44a	51.06ab	56.81c
	89	67.75b	62.50a	64.38ab	63.13a
	130	75.31b	69.31a	72.00ab	70.32a

Means followed by the same letter are statistically not significant according Duncan's multiple range test (*P*=0.05). DAT: Days After Transplanting, BH: 'Big Red' x 'Heman', BP: 'Big Red' x'Primavera', BB: 'Big Red' x 'Big Red', B: 'Big Red'.

It was observed that in both greenhouse and open field cultivations flowering began earlier in the self-rooted plant, probably due to the fact that grafting caused stress and delayed flower formation. However, by the 5th cluster, grafted plants generally appeared to have a larger number of flowers but no significant differences between all the treatments with respect to the total number of flowers per plant were found. Also, it is worth mentioning that the number of flowers in the open field were almost 50 % less than in the greenhouse in all the treatments (Table 2).

Table 2. The mean number of flowers per cluster and total number of flowers per plant of non-grafted (B) and 3 grafted tomato plants (BH, BP, BB) at different growth periods under greenhouse and open-field conditions

	Cluster number	DAT	Number of flowers/cluster			
			BH	BP	BB	B
Greenhouse	1st	96	4.31a	4.13a	4.19a	4.56a
	2nd	96	5.19b	4.38a	4.25a	4.81ab
	3rd	96	3.81a	4.81a	5.25a	4.75a
	4th	96	5.13b	4.88ab	3.75a	5.38b
	5th	96	3.69a	4.81a	4.06a	4.94a
Total	5th	96	22.13a	23.01a	21.50a	24.44a
Open-field	1st	68	3.44a	3.25a	3.81a	3.69a
	2nd	68	0.69a	1.19a	1.0a	0.63a
	3rd	89	2.5a	3.06a	2.69a	2.44a
	4th	89	3.31a	3.31a	2.19a	2.38a
	5th	97	2.88a	2.56a	2.63a	2.25a
Total lowers	5th	97	12.82	13.37a	12.32a	11.39a

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

From the data presented in Table 3, it is seen that there were no significant differences between the fresh and dry weights of stems, leaves and fruits both in the greenhouse and in the open-field after 107 and 121 DAT respectively, with the exception of the BH plants, which had a significantly lower fresh and

Table 3. Fresh and dry weight, plant height and total leaf area of non-grafted (B) and 3 grafted tomato plants (BH, BP, BB) at 107 DAT and 121 DAT under greenhouse and open-field conditions, respectively

Characterstics/ part		Greenhouse				Open-field			
		BH	BP	BB	B	BH	BP	BB	B
Stem	FW	204.30a	283.78a	242.38a	226.10a	185.00a	175.00a	208.33a	163.75a
	DW	36.30a	60.69a	45.10a	40.28a	26.73a	25.65a	31.90a	25.70a
Leaves	FW	884.08a	980.28a	775.60a	766,33a	351.25a	300.00a	310.00a	312.50a
	DW	139.84a	153.54a	126.69a	133.48a	33.34a	27.82a	30.27a	31.55a
Flowers	FW	13.35a	26.98b	20.40ab	14.93ab	5.00a	5.00a	5.00a	5.00a
	DW	2.23a	4.70b	3.73ab	3.03ab	0.73a	0.38a	0.73a	0.95a
Fruits*	FW	1776.63a	2787.78a	2241.38a	2531.38a	1955.00a	1873.33a	2840.00a	1740.00a
	DW	59.38a	55.80a	40.23a	71.19a	33.36a	27.09a	39.58a	26.42a
Total DW/FW %		8.86a	9.15a	7.49a	7.68a	4.38a	3.57a	3.81a	3.90a
Total leaf area (cm^2)		10923.10a	8646.20a	7598.10a	8693.20a	4949.0a	4087.80a	3997.0a	4296.50a
Plant height (cm)		127.75a	135.00a	144.50a	139.00a	74.00a	69.25a	71.33a	65.25a

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

dry weight of flowers than BP in the greenhouse cultivation. However, the ratio of total dry weight to total fresh weight was not significantly different between grafted plants and the control in both cultivations (Table 3). Moreover, in the greenhouse, grafted plants of BH and BP had a heavier fresh and dry weight than the open field cultivation. Table 3 shows that although the distribution of dry matter in the various parts of the plant was even in greenhouse cultivation, grafted plants had a higher accumulation of dry matter. It is worth mentioning that Romano and Paratore (2001) also reported that the dry weight of the aerial organs of grafted tomato plants ('Rita x Beaufort') was greater than that of the self-rooted plants.

Leaf area measurements at 107 DAT and 121 DAT in the greenhouse and in the open-field, respectively (Table 3) revealed that the plants of BH grafting had a larger leaf area than the other treatments. However, there was no significant difference. Also Pulgar *et al.* (1998) observed increased production of leaves in grafted plants as a result of an increased uptake of water and nutrients.

In the greenhouse as well as in the open-field during the harvest period 0-84 DAT, the self-rooted plants B had a greater yield than the grafted plants. This could be due to the fact that grafted plants were initially subjected to stress following the grafting operation. This early negative effect of grafting has also been reported by other authors (Ginoux, 1974; Tsouvaltzis *et al.,* 2004). However, during the 2nd harvest period the grafted plants BH and BP had a greater yield than the self-rooted B, while during the 3rd harvest period the three types of grafted plants had a greater yield than the self-rooted control (Table 4). It seems that the 4 treatments produced a higher quantity of fruits per plant at the 2nd harvest period when the plants had more favourable environmental conditions for growth. Mean daily temperatures for the first, second and third harvesting periods were 22.3, 27.8, 3 and 33.1°C for the greenhouse and 20.3, 26.8 and 23.5°C for the open field cultivations respectively. Finally, these increases in the total fruit yield of the BH and BP plants of the greenhouse cultivation, at 192 DAT resulted into 32.5% and 10% more fruit weight per plant than the control B, respectively, whereas self-grafted plants gave almost the same yield as the control. Similar results were found for the open-field cultivation where a higher total fruit weight of BH and BP at 130 DAT were obtained (12.8 and 11.1% higher than in the control, respectively) (Table 4).

Regarding fruit qualitative characteristics (Table 5) there were no significant differences between the 4 treatments in pH, Brix (%), concentration of lycopene or firmness. However, fruit acidity in grafted plants of BH cultivated in the open field was higher than in BB and B plants. The above results in general agree with other researchers who found that fruit descriptive and qualitative characteristics were not affected by grafting. (Leoni *et al.,* 1990; Romano and Paratore, 2001).

The fruit Cu, Mn and Fe contents were not significantly different

Table 4. Yield at different harvest periods and total of non-grafted (B) and 3 grafted tomato plant types (BH, BP, BB) under greenhouse and open-field conditions

	DAT	Fruit weight (g) $plant^{-1}$			
		BH	BP	BB	B
		Greenhouse			
1st	0-84	628.76ab	376.40a	738.62ab	786.52b
2nd	85-155	5066.90a	4267.76a	3411.79a	3483.59a
3rd	156-192	1872.50a	1042.31a	844.75a	836.25a
Total		7568.16b	5671.47ab	4995.16a	5106.36ab
		Open-field			
1st	0-84	420.94a	379.06a	388.44a	549.69a
2nd	85-121	1137.81a	1355.63a	1064.69a	1122.81a
3rd	122-130	537.50b	321.25b	318.75ab	154.94a
Total		2096.25a	2055.94a	1771.88a	1827.44a

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

Table 5. Qualitative fruit parameters of non-grafted (B) and 3 grafted tomato plants (BH, BP, BB) under greenhouse and open-field conditions

Cultivars	pH	BRIX (%)	Acidity (% citric acid)	Lycopene (mg/ 100gDW)	Firmness (kg)	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)	Ca (ppm)
Greenhouse										
BH	3.42a	4.4a	0.35a	2.83a	2.58a	0.35a	0.52a	0.13a	0.44a	25.25b
BP	3.72a	4.5a	0.25a	3.41a	2.58a	0.27a	0.44a	0.09a	0.45a	19.72ab
BB	3.30a	5.1a	0.31a	3.23a	2.49a	0.33a	0.42a	0.10a	0.56a	16.70a
B	3.48a	4.8a	0.33a	3.87a	3.15a	0.33a	0.40a	0.14a	0.61a	16.83a
Open-field										
BH	4.41a	4.04a	0.35b	6.00a	2.28a	0.36ab	0.31a	0.11a	0.51a	17.24a
BP	4.33a	3.90a	0.28ab	4.86a	2.15a	0.36ab	0.30a	0.11a	1.28a	18.99a
BB	4.30a	3.15a	0.25a	6.63a	2.10a	0.35a	0.32a	0.07a	0.52a	13.68a
B	4.34a	3.68a	0.25a	4.37a	2.37a	0.48b	0.39a	0.10a	0.62a	19.11a

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

between the grafted plants and the control plants, either in the greenhouse or in the open-field. However, analyses showed that the fruit concentration of Ca in grafted plants BH was greater than in the fruits of the grafted plants BB and B in the greenhouse cultivation. The absorption of Ca could be associated strongly with the higher rate of absorption of water and minerals from the soil by roots of the rootstock Heman and therefore this could improve the absorption of Ca. Tsouvaltzis *et al.* (2004) recorded similar results, when tomato cv. 'Sacos F1' was grafted on 'Primavera' rootstock and fruit yield and mineral concentration increased. Also Lee (1994) found an increase in yield which was attributed to the vigour of the rootstock and the higher uptake of water and nutrients. Passam *et al.* (2005) found that eggplants grafted on to two tomato rootstocks gave a higher yield and bigger fruit size than those grafted on to two eggplant rootstocks, but the mineral composition of fruits from grafted plants did not differ from that of non grafted plants.

This study showed that in both the greenhouse and the open-field, tomato cv. 'Big Red' grafted on tomato rootstock 'Heman' gave a higher total yield without having significant effects on the quality of the fruits produced.

The results showed that tomato grafting on suitable rootstocks has positive effects on the cultivation performance, especially in the greenhouse conditions. The use of improved genotypes for rootstocks is required so as to improve yields under a variety of climatic and soil conditions. It is well known that the root system of the plants affects vegetative growth and yield. So, the effects of grafting recorded in most research papers are obviously related to the differences in the root system between grafted and non-grafted plants, *i.e.* to the efficiency of water and nutrient uptake by the roots, or even to the distribution of growth regulators.

In Greece, where the vegetable cultivation is still carried out mostly by traditional methods and modern cultivated techniques are adopted slowly, the grafting technique could help in the solution of many problems. Therefore, we consider the advantages of grafted plants, which offer increased yield and consequently higher profit, to be of value for farmers. Finally, the use of grafting is a simple step for more developed cultivation forms, like hydroponics.

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