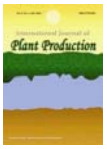

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Effect of grafting on growth, performance and yield of aubergine (S*olanum melongena* L.) in greenhouse and open-field

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Abstract

Seedlings of aubergine (S*olanum melongena* L.) cv. 'Rima' were used as scion (R) and control (non-grafted) and rootstock (self-grafted) (RR), while two hybrid tomatoes 'Heman' (*Lycopersicon hirsutm*) and 'Primavera' (*Lycopersicon esculentum*) were used as rootstocks. Grafted and non-grafted plants were grown in the greenhouse and in the open-field. Grafted plants Rima and Heman (RH) were more vigorous than the non-grafted ones in the greenhouse as well as in the open-field and produced 34.1 and 43.3% more fruits than the control whereas, plants which grafted onto Primavera (RP) produced 21.2% more fruits in greenhouse and 5.18% less fruit compare to the control in open field cultivation. The self-grafted plants RR had no significant yield differences with control in both cultivation conditions. Moreover, in greenhouse condition, the grafted plants RH and RP presented earliness in their productivity and produced less seeds number per fruit than control. Finally, quality and qualitative fruit characteristics were not affected by grafting.

Keywords: Grafting; Rootstock; Scion; Aubergine; Yield; Seed.

Introduction

aubergine (S*olanum melongena* L.) is a crop of high importance in many countries; (FAO, 1998). According to FAOSTAT in 2007, the world cultivation area of aubergine was 2.0437.000 ha with the total production of 32.072 millions metric tons. In Greece, aubergine was cultivated in open field and greenhouse 2.668 ha and 267 ha respectively and were produced 80.000 metric tons during 2008. Grafting vegetables on to compatible rootstocks offers a number of advantages the most important of which are: (a) resistance to soil pathogens, in particular *Verticillum* and *Fusarium* (Lockwood et al., 1970; Bletsos et al., 2003), (b) improved yield, particularly in infested soils (Bletsos et al., 2003) and reported up to 79.3% increase in grafted aubergine plants compared with the non-grafted

control. Also, Khah et al. (2005). reported that seedling of aubergine 'Rima' were grafted on to two tomato rootstocks, in the field and greenhouse, found that grafted plants produced 53% and 60% more fruits than non grafted plants respectively. Similar increases in aubergine yield as a result of grafting have also been observed (O' Brien, 1983; Bletsos et al., 1997; Lee, 1994), (c) greater tolerance to thermal and salt (Ahn et al., 1999; Rivero et al., 2003). (d) to increase the synthesis of endogenous hormones (Proebsting et al., 1992); (e) to improve water use (Cohen and Naor, 2002); (f) to increase flower and seed production (Lardizabal and Thompson, 1990); (g) to enhance vegetable tolerance to drought, salinity and flooding (AVRDC, 2000; Estan et al., 2005). Moreover, many researchers report that an interaction between rootstocks and scions exists resulting in high vigor of the root system and greater water and mineral uptake leading to increase 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) state that vegetable grafting does not improve the yield of the cultivation 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 agents associated with fruit quality are translocated in the scion through the xylem, whereas Lee (1994) states that quality traits e.g. fruit shape, skin color, skin or rind smoothness, flesh texture and color, soluble solids concentration etc- are influenced by the rootstock. However, other researchers showed that grafting does not affect fruit quality (Leoni et al., 1990; Romano and Paratore, 2001; Parousi and Bletsos, 2003). In a recent report by (Khah et al., 2011) investigating the changes in leaf photosynthetic capacity of aubergine plants, grafted on two tomato rootstocks, found that the leaf respiration per unit area was not altered by the scion/rootstock combination and point out that scion controlled respiration was independent of the rootstock. They concluded that leaf stomatal conductance and transpiration were not modified by the grafting, so that the water use efficiency was only altered by the modification of the net assimilation.

In Greece, 90-95% of watermelon, 40-50% melon and tomato 5-8% and 2-4% cucumber and aubergine are grafted (Traka-Mavrona et al., 2000). Intensive use of the soil for greenhouse crops in Greece has resulted in serious soil contamination by pests and pathogens, which are usually controlled by soil fumigation with methyl bromide. Because methyl bromide is highly toxic to humans and the environment (Ristanino and Tomas, 1997), its use is being phased out. Hence alternative methods of confronting soil pathogens are required, one of which is grafting on to resistant rootstocks. For grafting to be adopted for vegetable species, improved knowledge of rootstock-scion compatibility is required and the cost of grafting, which is highly labour-intensive, must be reduced, for example by the introduction of robots (Oda et al., 1997).

The aim of this study was to investigate and evaluate the agronomic performance, fruit and seed yield as well as to examine some fruit quality. For this a popular Greek commercial hybrid aubergine which is commonly cultivated, was used both in the field and in the greenhouse conditions. Aubergine plants were evaluated both as a self-grafted and as a grafted on two new improved tomato rootstocks.

Materials and Methods

The commercial aubergine hybrid (*Solanum melongena* L.) 'Rima' was used as self-grafted and non-grafted control, while two hybrid tomatoes 'Heman' (*Lycopersicum hirsutum*) and 'Primavera' (*Lycopersicum 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: 'RR' (scion and rootstock 'Rima'), 'RH' (scion 'Rima' and rootstock 'Heman') RP (scion 'Rima' and rootstock 'Primavera') and R (non-grafted, control).

The seeds of the scion were sown 5 days earlier than the seeds of the 2 rootstocks, because of the differences in growth vigour, in order to ensure similar stem diameters at the grafting time. 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, 25-30 ^{o}C and 45% shading). Plants were transplanted to the soil of a greenhouse on 13/3/2004 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 randomized 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 0.6 x 1.0 m. 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.

Mean air temperature and relative humidity and the amount of rainfall were recorded daily throughout the two cultivations. Plant height was recorded between 32-108 DAT (Days After Transplanting) in the greenhouse cultivation and between 46-115 DAT in the open-field cultivation. In order to obtain the rate of flowering and plant development, the number of flowers of the first 4 sets flowers was recorded. 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. Assessment was made at 137 DAT and 120 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 gently hand-harvested, counted and weighed. For the greenhouse cultivation, 10 harvests were carried out between 76-193 DAT, while for the open-field cultivation 9 harvests were carried out between 56-132 DAT. The total harvesting periods of Greenhouse and open field were 117 and 76 days respectively. In order to evaluate the rate of fruit production, total harvesting periods were divided in three periods: early, middle and late production which were 27, 70 and 20 days for greenhouse and 21, 45 and 10 days for open field.

Finally 6 fruits from each replication were used randomly in order to collect some qualitative data. The measurements that took place were: physicochemical analysis and soluble solids were done with the refract meter (Merck RQflex 2, Darmstadt, Germany), pH, titratable acidity (with 0.01 n NaOH solution and phenolphthalein as indicator) and concentration of Zn, Cu, Mn, Fe and Ca (Atomic Absorption Spectrometer, model: Perkin Elmer 3300, CA, USA).

Statistical analysis was performed using the 'SPSS 11.0 for Windows' and the differences between the means were compared using the criterion of the Duncan-test and LSD-test at P=0.05.

Results and Discussion

Plant height of the grafted plants were significantly taller than non-grafted on the early growth periods until 93 and 85 DAT on greenhouse and open field conditions respectively. However, these differences were not significant later on (Figure 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. Bletios (2006) reported that grafted aubergine plants on S. *torvum* were significantly more vigorous, as measured by plant height, stem diameter and root biomass than the control plants. Measuring the first four sets of flowers it was found that the grafted plants had earlier flowering than control and RR, which this lead to higher proportion (% flower/fruit) of fruit setting and bigger production during the primary period, in both greenhouse and in the open field cultivations (Table 1). It is worth to mention that in order to record the rate of fruit production, harvesting period was divided in three period's early, middle and late. The results indicate that grafted plants produced significantly earlier fruits than control and RR particularly in greenhouse condition (Table 1).

Table 1. Qualitative fruit parameters of non-grafted (R) and 3 grafted aubergine plants (RR, RH, RP) under greenhouse and open-field conditions.

	Greenhouse (G)				Open field (O)			
	RxR	RxH	RxP	R	RxR	RxH	RxP	R
Height (cm) $_1$	146.06^{a}	148.22^{a}	146.78^{a}	140.59^{a}	76.11^{ab}	83.43^{b}	78.22^{ab}	74.00^{a}
Flowering (%) $_2$	100	100	100	100	92.19	95.31	96.88	89.06
Fruit set (%) $_3$	45.31	93.75	98.44	65.63	67.73	69.93	62.90	57.82
Early production periods (kg) $_4$	0.60^{a}	1.49^{b}	1.63^{b}	0.71^{a}	1.38^{a}	2.75^{a}	2.42^{a}	2.12^{a}
Normal production periods (kg) $_5$	3.72^{a}	4.95^{a}	4.56^{a}	4.24^{a}	10.26^{a}	11.00^{a}	6.87^{a}	7.10^{a}
Late production periods (kg) $_6$	0.91^{a}	1.89^{a}	1.39^{a}	1.28^{a}	2.10^{a}	1.76^{a}	1.12^{a}	1.72^{a}
Total production (kg) $_7$	5.27^{a}	8.36^{c}	7.59^{bc}	6.23^{ab}	3.44^{a}	3.90^{a}	2.60^{a}	2.74^{a}
Zn (ppm) $_8$	0.53^{b}	0.40^{ab}	0.35^{a}	0.49^{ab}	0.44^{ab}	0.47^{b}	0.41^{a}	0.42^{ab}
Fe (ppm) $_8$	0.71^{a}	0.68^{a}	0.67^{a}	0.78^{a}	0.65^{ab}	0.74^{b}	0.58^{a}	0.70^{b}
Mn (ppm) $_8$	0.28^{a}	029^{a}	024^{a}	0.27^{a}	0.25^{a}	0.27^{a}	0.25^{a}	0.25^{a}
Cu (ppm) $_8$	0.34^{a}	0.35^{a}	0.30^{a}	0.34^{a}	0.35^{a}	0.37^{a}	0.35^{a}	0.35^{a}
Ca (ppm) $_8$	30.22^{a}	33.24^{a}	41.70^{a}	37.66^{a}	50.70^{a}	53.54^{a}	40.17^{a}	36.48^{a}
Number seeds/fruit $_9$	847.82^{b}	378.75^{a}	670.42^{b}	842.53^{b}	1691.86^{b}	1368.44^{a}	1291.09^{a}	1326.9^{a}
Seeds 1000 wt.(g)	1.44^{a}	1.44^{a}	1.29^{a}	1.12^{a}	1.33^{a}	1.16^{a}	1.67^{a}	1.40^{a}
fresh/dry Weight$_{10}$	7.24	5.79	6.03	6.67	8.01	8.35	8.19	10.27
pH	5.26^{a}	5.23^{a}	5.27^{a}	5.31^{a}	5.33^{a}	5.49^{a}	5.55^{a}	5.46^{a}
Brix (%)	4.62^{a}	3.64^{a}	3.12^{a}	3.65^{a}	4.43^{a}	4.82^{a}	4.05^{a}	4.75^{a}
Acidity (%)	0.12a	0.11^{a}	0.11^{a}	0.11^{a}	0.21^{a}	0.20^{a}	0.19^{a}	0.24^{a}
LAI (cm^2) $_{11}$	9661.4^{ab}	13747.8^{b}	8706.5^{a}	10179.0^{ab}	8881.56^{a}	8899.8^{a}	5305.3^{a}	8890.7^{a}

1: 108 DAT (G), 85 DAT (O), 2: 95 DAT (G), 85 DAT (Y), 3: 104 DAT (G), 98 DAT (O), 4: 27 DHP (G), 21 DHP (O), 5: 70 DHP (G), 45 DHP (O), 6: 20 DHP (G), 10 DHP (O), 7: 193 DAT(G), 132 DAT (O), 8: 1g dry weight of matured fruit, 9: Matured fruit, 10: 137 DAT (G), 120 DAT (O), 11: 137 DAT (G), 120 DAT (O).
DAT: Days After Transplanting.
a, b, c: Duncan test (SPSS 11.0), DHP: Days Harvesting Period Means of each cultivation conditions followed by the same letter are not statistically significant according Duncan's multiple range test (P=0.05).

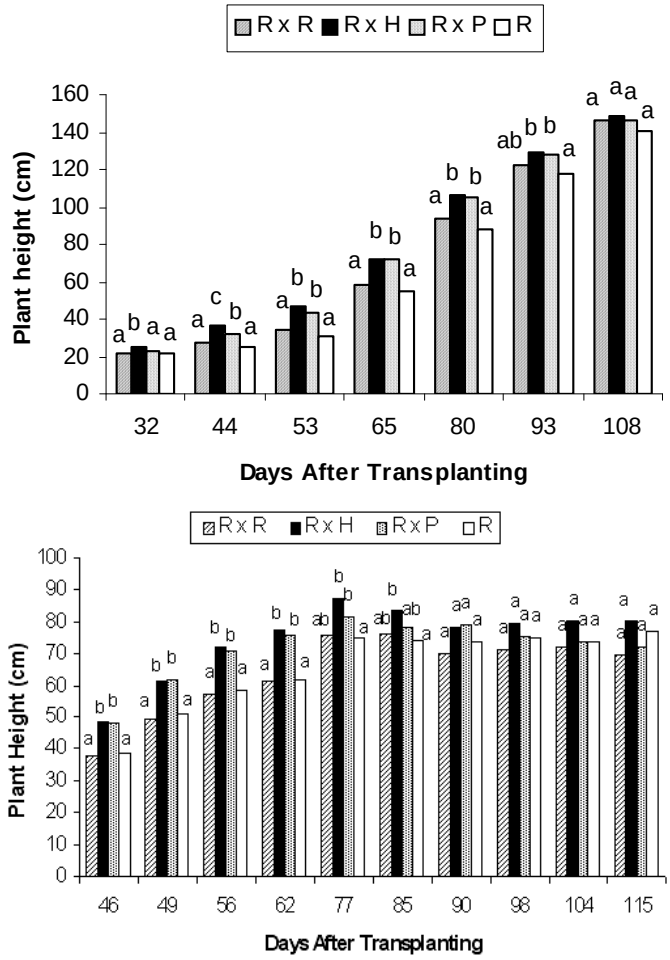

Figure 1. Plant height o non grafted (R) and 3 grafted aubergine plants (RxR, RxH and RxP) over different growth periods in greenhouse (above Figure) and open field (below Figure). Means followed by the same letter are not statistically significant according Duncan's multiple range test (P=0.05).

Figure 2 show that fruit weights per plant of RH and RP were significantly higher than R and RR in all 10 fruit harvestings in greenhouse condition However; these differences were not significant in open field. Also, from growth analysis which was done on 137 and 120 DAT in both in greenhouse and in the open-field respectively, results shown that the ratio of total fresh weight to total dry weight as well as the Leaf area measurements were not significantly different between grafted plants and control (Table 1). Instead in the greenhouse condition, during the harvest period 76 up to 193 DAT, the grafted plants had a greater yield than self-rooted and control plants. However, in the open field condition these differences were not significant (figure 2). Finally, these increases in the total fruit yield of

the RH and RP plants of the greenhouse cultivation, at 193 DAT gave 34.1% and 21.8% more fruit weight per plant than the control (R) respectively, whereas self-grafted plants (RR) gave 15.4% less yield than control. Similar results were found for the open-field cultivation where a higher total fruit weight of RH and RR at 132 DAT were obtained 42.3% and 25.5% higher than in the control respectively, whereas RP gave 5.1% less fruit than control. It is worth to mention that, during whole growth period, the mean weekly temperature and relative humidity were 26.8 ^{o}C and 48% for greenhouse respectively and mean temperature and mean rainfall were 21 ^{o}C and 16.13 mm for open field cultivation condition reactively.

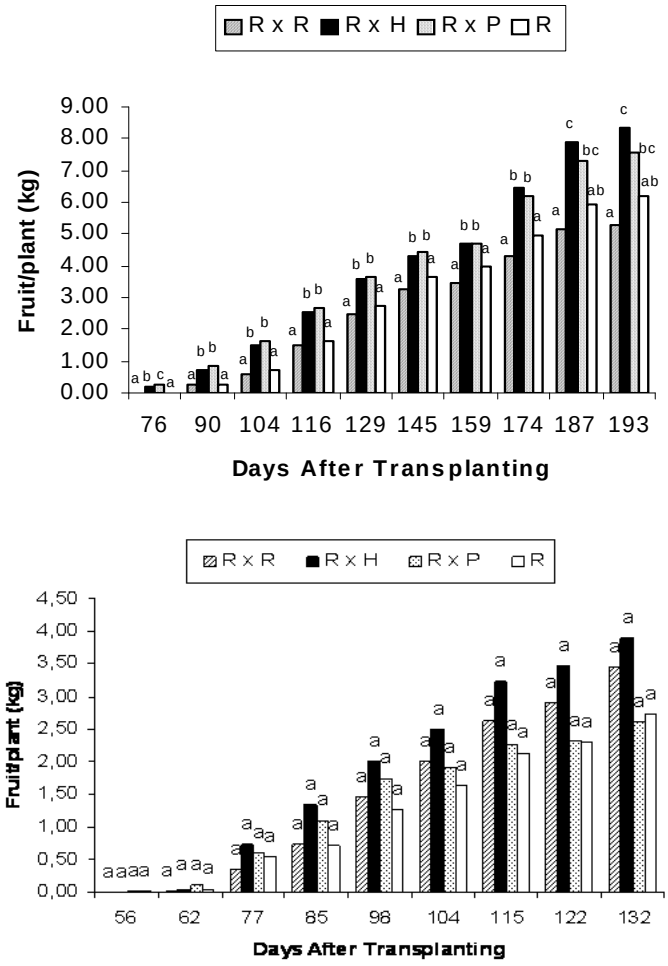

Figure 2. Plant yield of non grafted (R) and 3 grafted aubergine plants (RxR, RxH and RxP) over different growth periods in greenhouse (above Figure) and open field (below Figure Means followed by the same letter are not statistically significant according Duncan's multiple range test (P=0.05).

Regarding fruit qualitative characteristics there were no significant differences between the 4 treatments in pH, BRIX (%), acidity (%). 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; Parousi and Bletsos, 2003).

The fruit Cu, Mn, Ca, Zn and Fe (ppm) contents were not significantly different between the grafted plants and the control plants, either in the greenhouse or in the open-field. The similar results was reported by Passam et al. (2005) which found that eggplants grafted on to two tomato rootstocks gave a higher yield and bigger fruit size than those non grafted plants, but the mineral composition of fruits from grafted plants did not different from that of non grafted plants. However, Tsouvaltzis et al. (2004) recorded 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 vigor of the rootstock and the greater uptake of water and nutrients.

Furthermore, the results of the seeds number per fruit show that the grafted plants of RH had significant less seeds than the other plants in the greenhouse cultivation whereas, this difference was not observed in the open field cultivation. However, in both cultivations conditions as well as in all the treatments the seed size (1000 seeds weight) was not significantly affected by grafting.

Conclusion

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

The results showed that aubergine 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 significant increase 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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